

## Chapter 2

# Properties and Environments of Life

In this chapter, we try to answer two basic questions: (i) how can life be characterized; what is the difference between nonliving and living substances? and (ii) how did life originate on Earth? Up to now, the Earth is the only planet where we can study life. We assume that life can only arise under similar circumstances that were found on early Earth. All objects (planets but maybe also large satellites of planets) that fulfill this criterion are called habitable.

The chemical background that is needed to understand basic mechanisms that are found in living cells is presented in the appendix, as well as a short introduction to the nomenclature of organic chemistry. Here, we discuss the occurrence of organic compounds in space, how life might have evolved from nonliving, and the structure of the cells and primitive living forms from the biological point of view. Finally, we briefly describe how primitive life forms on Earth have evolved. Bacteria, viruses, and cyanobacteria are discussed in more detail because these are the simplest form of life and they could probably be found elsewhere in the solar system as it will be discussed later. For the description of the biological processes, we followed [179, 136] and more details can be found there.

## 2.1 Organic Compounds in Space

Basic elements of organic chemistry are given in the appendix. In this section, we concentrate on organic compounds that can be found in space.

### 2.1.1 *Interstellar Medium*

The space between stars is not empty but it is filled with atoms and molecules and this mixture is called the *interstellar medium*. The physics of this mixture is quite different from that we know under laboratory conditions on Earth. In general, the interstellar medium is very dilute with densities from a few hundred up to about  $10^8$  particles  $\text{cm}^{-3}$ . The interstellar medium can be cool (temperatures below 100 K)

or hot (temperatures up to  $10^6$  K). The interstellar medium consists of a gas component (mostly hydrogen) and about 1% of the interstellar medium is dust (micron sized particles, this can be inferred from polarization measurements). In total the interstellar medium contributes few percent to the total mass of a typical galaxy.

Interstellar molecules [27] can be observed at radio-, millimeter-, submillimeter- and IR-wavelengths. From these observations, many organic molecules were detected. It must be stressed that their abundance, relative to hydrogen (molecular), is less than  $10^{-4}$  and in many cases even less. However, even very complex molecules like  $\text{HC}_{11}\text{N}$  and diethyl ether,  $\text{CH}_3 - \text{CH}_2 - \text{O} - \text{CH}_2 - \text{CH}_3$ , have been detected.

In the cold phases of the interstellar medium, there are icy dust grains.<sup>1</sup> These particles are important because they may act as catalysts.

The interstellar medium may also appear as dark clouds that absorb starlight. The densities are several  $10^2$  particles  $\text{cm}^{-3}$ . In such clouds, polycyclic aromatic hydrocarbons (PAHs), fullerenes, carbon-chains, diamonds, etc., are found.

Some of the molecules that have been detected in the interstellar medium are listed in Table 2.1.

Note that this table is only a sample of the list of molecules that have been detected. The detection of Glycine,  $\text{H}_2\text{NH}_2\text{CCOOH}$ , which is one of the 20 amino acids found in proteins was claimed by Kuan et al. [131] in the hot molecular cores Sgr B2(N-LMH), Orion KL, and W51 e1/e2 and later critically reviewed by Snyder et al. [230]. Cunningham et al. [49] used the Mopra Telescope<sup>2</sup> to search for glycine and the simple chiral molecule propylene oxide in the molecular clouds Sgr B2

**Table 2.1** Some important molecules detected in the interstellar medium

CO	Carbon monoxide
FeO	Iron (I) oxide
H <sub>2</sub>	Molecular hydrogen
HO	Hydroxyl radical
NO	Nitric oxide
NaCl	Sodium chloride
C <sub>2</sub> H	Ethynyl radical
CO <sub>2</sub>	Carbon dioxide
H <sub>2</sub> C	Methylene
H <sub>2</sub> O	Water
H <sub>2</sub> S	Hydrogen sulfide
NH <sub>2</sub>	Amino radical
SO <sub>2</sub>	Sulfur dioxide
C <sub>2</sub> H <sub>2</sub>	Acetylene
H <sub>2</sub> CO	Formaldehyde
NH <sub>3</sub>	Ammonia
CH <sub>4</sub>	Methane
HCOOH	Formic acid
CH <sub>3</sub> OH	Methanol

<sup>1</sup> This has been investigated with the ISO satellite, Infrared Space Observatory.

<sup>2</sup> Mopra is a 22-m single-dish radio telescope located at the edge of the Warrumbungle Mountains near Coonabarabran, about 450 km north-west of Sydney.

(LMH) and Orion KL in the 3-mm band, but they were not successful and gave only some upper limits arguing that the detection of Kuan et al. was not real.

In 2004, a team detected traces of PAHs in an interstellar cloud, the most complex molecule, to that date, found in space. The use of PAHs has also been proposed as a precursor to the RNA world.

### ***2.1.2 Organic Material Around Stars***

The solar system is surrounded by a spherical shell that ranges from a distance of 50,000 AU to about 1 light year and contains billions of cometary like objects composed of ices like water, ammonia, and methane. The estimated mass of all objects in this Oort cloud is about  $3 \times 10^{25}$  kg. Such clouds are believed to occur also around other extrasolar planetary systems.

As we will discuss later, in comets and outer solar system bodies, organic molecules formed in the presolar nebula may have survived the solar system formation. Because of the low temperatures there, the molecules in the outer solar system have not been changed later. In the inner solar nebula, heating and thermochemical reactions were important and the molecules changed. Therefore, the outer solar system reflects the primordial state of the presolar nebula.

In comets and meteorites, many organic compounds are found. The Murchison meteorite fell in Australia on 28 September 1969. Seventy different amino acids were detected in this material. Initial analyses showed that the amino acids found there were racemic. A racemic mixture is one that contains equal amounts of left- and right-handed enantiomers (nonsuperimposable complete mirror images of each other) of a chiral molecule. A chiral substance is enantiopure or homochiral when only one of the two possible enantiomers is present. Biological homochirality evolved on a presumably racemic primordial early earth. Homochirality can, therefore, be regarded as a sign for biologic activity.

We will discuss the formation of planets from so-called protoplanetary disks in more detail later. Let us mention here that planetary systems form out from the gravitational collapse of a protoplanetary disk. Many organic compounds were found in such disks. Water is an essential component for life. Today, it is assumed that impacts provided a substantial fraction of organic compounds and even water, which is necessary for life to form on Earth.

## **2.2 Life**

Some basics of organic chemistry are outlined in the appendix. Now, we want to discuss the question, what is life and offer some ideas of how life could have originated.

### 2.2.1 What Is Life?

This question is not a trivial one. Growth is not a criterion, crystals can also grow. Movement alone is not a valid criterion, e.g., when a pellet of dry ice (frozen carbon dioxide) is dropped into water, the pellet will move randomly across the surface.

Living organisms consist of *cells*, which are mainly composed of *cytoplasm* bound by a very thin *membrane*. All living cells contain genetic material. This controls their development and activities. In many cells, the genetic material, DNA, is found in the nucleus, a spherical structure suspended in the cytoplasm. In simpler forms of life such as bacteria, the DNA is distributed in the cytoplasm.

Besides consisting of cells, life has other “properties”:

*Growth*: new cells are produced.

*Reproduction*: when organisms reproduce, the offspring resemble the parents.

*Response to stimuli*: a major characteristic of all living things. Plant responses to stimuli are generally much slower than those of animals.

*Metabolism*: collective product of all the biochemical reactions taking place within an organism. New cytoplasm is produced, damage repaired, and normal cells are maintained. Metabolism includes photosynthesis, respiration, digestion, and assimilation.

*Movement*: plants can also move. Leaves of sensitive plants (e.g., *Mimosa pudica*) fold within a few seconds after being disturbed or subjected to sudden environmental changes.

*Complexity of organization*: cells are composed of large numbers of molecules (typically more than 1 trillion in a typical cell). The molecules are organized into compartments, membranes, and other structures in the cell. Bacteria are considered to have the simplest cells known, yet this cell contains at least 600 different kinds of protein and 100 other substances. Other organisms are more complex.

*Adaption to the environment*: living organisms respond to their environment – to air, light, water, soil, etc. Natural selection leads to adaption to their environment. Today, many species are threatened with extinction because they are not able to adapt fast enough to the changing environment.

### 2.2.2 From Nonliving to Living

The key questions for the emergence of life can be summarized as follows:

- What are the basic building blocks and how were they synthesized first?
- Does there exist a type of primordial synthetic chemistry that leads to the above process?
- Where did self-assembly occur (e.g., areas of geothermal activity)?

#### 2.2.2.1 Life on Early Earth

In 1903, S. Arrhenius [5] (1859–1927) suggested an extraterrestrial origin of life on Earth. He argued that life might have reached the Earth in the form of microscopic

spores that have been transported through space by the radiation pressure of stars. This is also called the *panspermia hypothesis*. At that time, Lowell discussed the Martian channels that were described first, when Mars was near to Earth (Opposition) in 1877, by Schiaparelli (he claimed to have seen linear structures on Mars which he named by the Italian word *canali*). Lowell and Flammarion suggested that these *canali* were constructed by intelligent Martians to distribute water on the dry planet but Arrhenius did not believe that. However, Arrhenius produced a map in which huge carboniferous swamps were assumed on Venus.

In 1920, A. Oparin and J.B.S. Haldane proposed that life on Earth might have originated from a reducing, primitive atmosphere composed of methane, ammonia, and water. The source of carbon for life was believed to be methane (Oparin) or carbon dioxide (Haldane). Both supposed that life first began in the atmosphere and then in the oceans. In 1982, A.G. Cairns-Smith proposed that mineral life-forms evolved from complex prebiotic clay crystals. Thus, there is no need for a reducing atmosphere or a primordial soup [31].

In the 1950s, it was assumed that the primitive Earth atmosphere consisted of methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>), hydrogen (H<sub>2</sub>), and water (H<sub>2</sub>O) and S.L. Miller and H.C. Urey [166, 167] carried out a famous experiment at the University of Chicago. They modeled the primitive Earth atmosphere and ran continuous electric currents simulating lightning storms, which were very common on the early Earth to this environment. After 1 week, 10–15 amino acids were found in the primordial soup.

Another experiment was conducted later in 1961 by J. Oro and he was able to produce amino acids from hydrogen cyanide (HCN) and ammonia in an aqueous solution.

However, today, there are strong objections against these experiments. The primitive Earth atmosphere contained much less reducing molecules. It did not consist mainly of NH<sub>3</sub> and CH<sub>4</sub> but most probably of CO<sub>2</sub>, CO, and N<sub>2</sub>. There are two reasons to support this idea: first, volcanic eruptions contain these gases and second, solar UV radiation destroys NH<sub>3</sub> and CH<sub>4</sub>. These molecules would have been short-lived. Solar UV photolyzes H<sub>2</sub>O:



The OH radicals attack methane, which results in CO<sub>2</sub> and release H<sub>2</sub>. The hydrogen will be lost into space.

It was found that gas mixtures of CO, CO<sub>2</sub>, and N<sub>2</sub> in the absence of O<sub>2</sub> give similar results as those used by Miller and Urey. It was possible to produce most of the natural amino acids, purines<sup>3</sup>, and sugars using such mixtures. When oxygen was added, however, no organic molecules formed.

Sagan and Chyba [215] proposed that the early Earth had an organic haze layer in its atmosphere. Such a layer can be found in the atmosphere of Titan, the largest

---

<sup>3</sup> Purines are heterocyclic aromatic organic compounds. They consist of a pyrimidine ring fused to an imidazole ring. Purines and Pyrimidines make up the two groups of nitrogenous bases which are a crucial part of both deoxyribonucleotides and ribonucleotides, and the basis for the universal genetic code.

satellite of Saturn and is produced by methane photolysis in the presence of nitrogen. An organic haze layer would preferentially absorb ultraviolet light, thereby allowing ammonia and methane to persist in the atmosphere. However, as in the case of Titan, such a layer would also have an antigreenhouse effect [162], which could oppose or even cancel any greenhouse effect generated by the shielded methane and ammonia. The question of whether a combination of an organic haze layer and methane and ammonia gases can combine to produce a net greenhouse effect on the early Earth depends on the optical properties of the organic haze layer (cited from Imanaka, Khare and McKay [114]).

#### 2.2.2.2 Hydrothermal Vents

Hydrothermal vents are openings, in the ocean floor. From these openings, hot, mineral-rich water escapes or erupts. In the 1970s, black smokers (Fig. 2.1) were detected. These are chimney-like structure above hydrothermal vents.<sup>4</sup> In these smoker chimneys, sulfides of iron, copper, and zinc are found. At the mixture of the hot mineral-rich water with cold water, these sulfides are precipitated and the vent water, therefore, appears black in color.<sup>5</sup> The most striking discovery was that these warm chemical rich environments are the living space for many species. Strange animals, like a 1-m-long reddish worm (*vestimentiferan*), which builds and lives in a tube up to 7 m long, were found. The chemoautotrophic archaea use chemical energy derived from the breakdown of hydrogen sulfide to build organic compounds. Chemoautotrophs are microorganisms (many archaea and bacteria) that synthesize organic compounds they need from inorganic raw materials in the absence of sunlight (i.e., no photosynthesis).

In the 1980s, G. Wächtershäuser [255] proposed his iron-sulfur theory. In contrast to the classical Miller experiments, which depend on external sources of energy (such as stimulated lightning or UV irradiation), the energy is released from redox reaction of sulfides of iron and other minerals. This energy permits the synthesis of organic molecules and also the formation of oligomers<sup>6</sup> and polymers. Huber and Wächtershäuser [111] modelled volcanic or hydrothermal settings. They showed that amino acids were converted into their peptides by use of precipitated (Ni,Fe)S and CO in conjunction with H<sub>2</sub>S (or CH<sub>3</sub>SH) as a catalyst and condensation agent at 100°C and pH 7–10 under anaerobic, aqueous conditions. Thus, a thermophilic origin of life seems plausible.

#### 2.2.2.3 Extremophiles

Organisms that live under extreme physical or geochemical conditions are classified as extremophiles. Most of them are microbes. Some types of extremophiles are listed in Table 2.2.

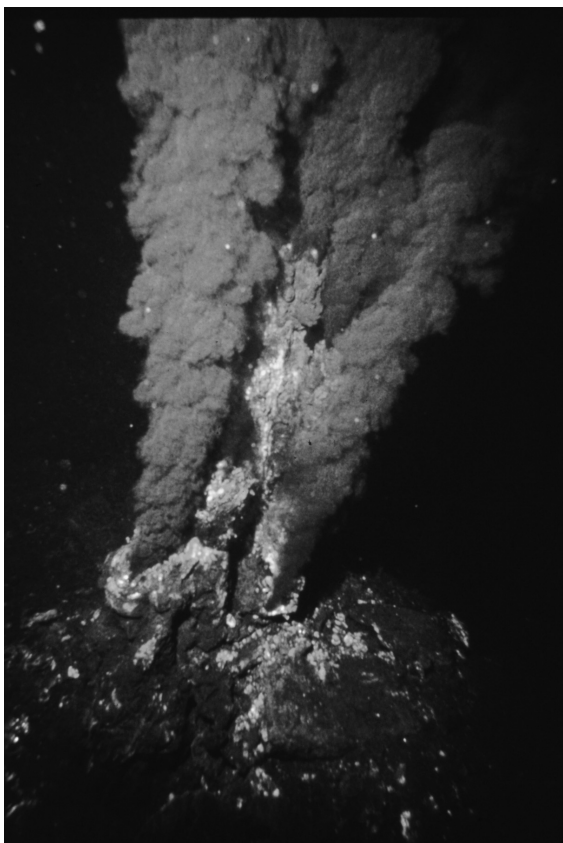
---

<sup>4</sup> Sometimes also called underwater geyser.

<sup>5</sup> Hydrogen sulfide H<sub>2</sub>S is the closest chemical analogue of water.

<sup>6</sup> Conversion of monomers to a finite degree of polymerization.

**Fig. 2.1** Black smoker at a mid-ocean ridge hydrothermal vent. Credit: OAR/National Undersea Research Program (NURP); NOAA



The hyperthermophiles were discovered in the 1960s in hot springs in Yellowstone National Park. The hyperthermophile *Strain 121* is able to survive a temperature of  $121^{\circ}\text{C}$  and even to double its population within 24 hours in such an environment. It consists of hyperthermostable proteins. Another example is *Pyrololobus fumarii*, an Archaea living at  $113^{\circ}\text{C}$  in Atlantic hydrothermal vents.

The new findings about extremophiles are of particular interest for our study. If an asteroid impact on Earth caused the global temperature to decrease or rise considerably and most of the highly advanced species died in a mass extinction, then it is plausible that at least such extremophiles survived a cosmic catastrophe.

Extremophiles and extreme environments in the context of astrobiology and the search for extraterrestrial life were investigated by Cavicchioli [35].

#### 2.2.2.4 Molecular Self-Assembly

There exist many examples of self-organization in biology: spontaneous folding of proteins and other biomacromolecules, formation of lipid bilayer membranes

**Table 2.2** Some types of extremophiles

Name	Environment
Acidophiles	Live in $\text{pH} \leq 3$
Alkaliphiles	Live in $\text{pH} \geq 9$
Barophiles	Live under high pressure
Piezophiles	—
Endoliths	Live in microscopic spaces within rocks
Cryptoendoliths	Live in fissures, faults in deep subsurface
Halophiles	Need salt to grow
Hyperthermophiles	Live at $T = 80 - 120^\circ$ , hydrothermal vents
Hypoliths	Live inside rocks in cold deserts
Litoautotrophs	Source of carbon is $\text{CO}_2$
Metatolerants	Capable of tolerating high levels of metals like copper, cadmium, zinc.
Oligotrophs	Grow in nutritionally limited environment
Osmophiles	Grow in sugar concentration
Psychrophiles, cryophiles	Grow at $T < -15^\circ$ ; permafrost, polar ice..
Radioresistants	Tolerate high levels of ionizing radiation
Thermophiles	Live at temperature up to $80^\circ\text{C}$
Xerophiles	Grow in extremely dry conditions

and also social animals like social insects (bees, ants, and termites), formation of flocks by birds, etc. Molecular self-assembly is crucial to the function of cells: self-assembly of lipids to form the membrane, the formation of double helical DNA through hydrogen bonding of the individual strands, etc.

Moreover, the transition to life from nonliving matter is strongly connected with molecular self-assembly. Nature has always worked bottom up, from the simplest assemblies to more complex structures. Molecular self-assembly can be defined as *spontaneous emergence of highly organized functional supramolecular architectures from single components of a system under certain external condition*.<sup>7</sup> To study the origin of life, molecular self-assembly<sup>8</sup> seems a crucial starting point. Hazen and Deamer [98] studied reactions of pyruvic acid under hydrothermal conditions. A complex mixture of larger organic molecules resulted, some of which are amphiphiles<sup>9</sup> that readily self-assemble into cell-sized vesicular structures.

An unsolved question is the obvious homochirality, which is a symmetry break in nature. A molecule is chiral if it cannot be superimposed on its mirror image. Homochirality means that molecules possess the same sense of chirality. All of the 20 biologically active amino acids are left handed. Amino acids that are produced in the laboratory are 50% left handed and 50% right handed. It is an interesting fact that life on Earth is based on left handed (L) amino acids and right handed (D) sugars.<sup>10</sup> It is even assumed that homochirality is a characteristic signature of life.

<sup>7</sup> After [140].

<sup>8</sup> See as a review: [274].

<sup>9</sup> A chemical compound possessing both hydrophilic and hydrophobic properties.

<sup>10</sup> The explanation maybe parity-violating energy difference.



Finding molecules of one chirality on a planet could be used as a signature for life or at least prebiotic chemistry (see also [47]).

In recent years, this fundamental problem for the origin of life was tested experimentally by direct microscopic verification of self-assembled DNA bases on mineral template surfaces. A sizzling technique was applied to simulate possible spontaneous self-assembly of two-dimensional molecular crystalline layers onto mineral surfaces with a primordial soup scenario. The free parameters of such experiments are the concentration of the solution, the substrate temperature (was tested up to 130°C), the quantity of the solution, and temperature+time tempering. The scenario gives a model for the assembly of polypeptides based on a 2d-DNA-base at the solid-liquid interface: inorganic template → organic template → chiral symmetry break → enzyme, protein, etc.<sup>11</sup>

It must be stressed that simple organic molecules are of course a long way from a fully functional self-replicating life form. The spontaneous formation of complex polymers from abiotically generated monomers is not straightforward. According to the “soup theory,” these simple organic molecules played an important role and were accumulated by various processes.

A source for the complex molecules might have been impacts that were quite numerous on early Earth.

M. Eigen (1970s) [54] tried to examine the transient stages between the molecular chaos in a prebiotic soup and the transient stages of a self-replicating hypercycle, between the molecular chaos in a prebiotic soup and simple macromolecular self-reproducing systems. The hypercycle consists of a cyclic sequence of individual self-reproducing cycles. These cycles consist of RNA and peptide molecules and there are interactions and back reactions between them. In this context, the term *self-organization* again becomes important.

Polymers in the range of 30–60 monomers are needed for a genetic system. The problem is how these can be formed because in aqueous solution hydrolysis competes with polymerization. Mineral surfaces to facilitate prebiotic polymerization [59].

### 2.2.3 Cells

Cells are the structural and functional unit of all known living organisms; some organisms are unicellular, they consist of a single cell (most bacteria); humans consist of about  $10^{14}$  cells.

Cells consist of cytoplasm and the structures within.

About 96% of the cytoplasm are composed of C, H, O, and N. Three percent consist of P, K, and S. The remaining 1% includes Ca, Fe, Mg, Na, Cl, Cu, Mn, Co, Zn, and minute quantities of other elements.

---

<sup>11</sup> Review given by Ref. [101]

### 2.2.3.1 Prokaryotic, Eukaryotic Cells

There are two basic types of cells:

- Cells without nuclei and some other features: *prokaryotic* cells.<sup>12</sup>
- *Eukaryotic* cells<sup>13</sup> possess a nucleus.

Most plant cells and animal cells are tiny and they are invisible to the unaided eye. Prokaryotic and eukaryotic cells have in common the cell membranes, cytoplasm, genetic material, and energy currency enzymes and coenzymes. All these are necessary to maintain a cell alive.

In biology, all organisms are classified into large categories called *domains*.

Most single-celled organisms are *prokaryotic bacteria*. There is another class called *archaeobacteria*. Bacteria are a few micrometers long have many different shapes such as spheres, rods, or even spirals and they are found on quite different habitats on Earth: in soil, acidic hot springs, or even in radioactive waste and they can survive outer space (that means extreme cold and vacuum). In a gram of soil, there are typically  $40 \times 10^6$  bacteria and in a milliliter of water, about  $10^6$ . The ancestors of modern bacteria were single celled organisms that developed as first forms of life about  $4 \times 10^9$  years ago. *Stromatolites* are fossils. They have been formed by sedimentation and cementation of microorganisms such as the cyanobacteria.<sup>14</sup>

The *archaea* are more closely related to eukaryotes than the bacteria. Their genetic transcription and translation is similar to those of eukaryotes. Most bacteria and eukaryotes have membranes that are composed of glycerol-ester lipids. The membrane of the archaea is composed of glycerol-ether lipids. Archaea are found in extremely hot environments (hyperthermophiles) but they can be also found in all habitats.

### 2.2.3.2 Cell Membranes

Membranes confine and protect a cell from the environment, and also the organelles inside the cell have membranes. The cell membranes are thin sheets and are composed of phospholipids and proteins. The phospholipid molecules are polar molecules- one end (the glycerol portion) is soluble in water (hydrophilic), the other end is not water soluble (hydrophobic) and is comprised of fatty acids. Phospholipid molecules form a double-layered sheet with the hydrophilic portions of the molecules facing away from each other.

Thus, in water, the lipophilic tails line up against one another forming a membrane with hydrophilic heads on both sides facing water. *Liposomes* are formed spontaneously. These are small lipid vesicles used for transport of materials into the cells and allow for diffusion.

---

<sup>12</sup> pro means before, karyon means nucleus.

<sup>13</sup> eu means well or good.

<sup>14</sup> An old term no longer used now is blue green algae.

The protein component of a cellular membrane can be found located either on the surface of the membrane or inside it. They help to transport molecules and also allow organisms to recognize differences between types of cells – disease causing organisms are recognized because their surface proteins are different from those of the organism's own cellular membranes. Cell membranes have molecules on their surface known as cluster of differentiation or CD markers and they are designated as CD1, CD2, ...CD4 cells and are found inside the human body (blood cells).<sup>15</sup>

In the membrane, cholesterol is also found, which helps in stabilizing the membrane and keeps it flexible.

### 2.2.3.3 Diffusion and Osmosis

One of the main activities of cells is the exchange of nutrients and wastes with the environment by diffusion, osmosis, facilitated diffusion, active transport, and phagocytosis.

The process of *diffusion* is well known from molecular kinetics. The motion of molecules is completely random. But when considering two types of molecules there is a trend to form a mixture (e.g., sugar in water). That is called the net movement and it depends on the relative concentration of the molecules, the concentration gradient (diffusion gradient). When the molecules are equally distributed, there is no net gradient. The permeability of molecules through the plasma membrane depends on the size and ionic charge as well as on the solubility of the molecules. The cell has little control and, therefore, diffusion is considered a passive process. The direction of diffusion is always from high to low concentration.

*Osmosis* denotes a selectively permeable membrane and the diffusion associated with it. The membrane allows, for example, the diffusion of molecules that are small (e.g., water) and are able to dissolve in phospholipids (e.g., vitamins A and D), but the passage of larger molecules is prevented. Osmosis is essential for the plants. If the water concentration outside the plant cells is higher than that inside, more water molecules enter the cell, which creates an internal pressure. Osmosis, like diffusion, is a passive mechanism because the cell does not control it.

One example of *facilitated diffusion* is the movement of glucose molecules throughout the cell. This is accomplished by specific proteins – active carrier proteins.

For a cell to function, a certain amount of water is necessary, but too much water may interfere with the chemical reactions, water is necessary to dissolve poisonous products in the cell.

*Endocytosis* (or phagocytosis) occurs when the cell wraps around a particle and engulfs it.<sup>16</sup> The material is brought into the cell in a vacuole and inside the cell, the vacuole breaks up; the contents are released and, e.g., destructive enzymes start to work.

---

<sup>15</sup> The CD4 acts as the attachment site for human immunodeficiency virus (HIV). The virus enters the CD4 cell and commands its metabolism but HIV cannot attach to cells that do not have the CD4 surface markers (e.g. skin cells).

<sup>16</sup> For example Leukocytes, white blood cells, they surround invading bacteria, viruses.

#### 2.2.3.4 Organelles and Membranes

The *endoplasmic reticulum* (ER) consists of folded membranes and tubes throughout the cell. These membranes form a large surface enabling chemical reactions to take place there.

In the *Golgi apparatus*, certain molecules are synthesized and chemical reactions are concentrated. The active or inactive forms of enzymes are controlled; lysosomes can decompose dead or dying cells, selectively destroy cells, digest macromolecules, and kill dangerous microorganisms.

The *nuclear membrane* separates the nucleus (nucleoplasm) from the cytoplasm. The nuclear membrane is formed like a sphere around the DNA.

The *mitochondrion* resembles a small bag. On the inner surface, there are particular proteins and enzymes, which enable aerobic cellular respiration. Aerobic cell respiration means that energy is produced from food molecules using oxygen. A typical human cell contains up to  $10^4$  mitochondria. Muscle cells contain even more. When there is activity in the cells, the mitochondria swell; when there is low activity, they shrink.

*Chloroplasts* are found only in plants and algae. There are cells that contain only one large chloroplast; others contain hundreds of smaller chloroplasts. In the chloroplasts, by *photosynthesis* light energy is converted to chemical-bond energy.

Other nonmembranous organelles in the cytoplasm include the *ribosomes*. They are composed of RNA and protein. The ribosomes manufacture protein. Liver cells, e.g., actively produce protein and they contain great numbers of free and attached ribosomes. Other nonmembranous organelles are the microtubules, microfilaments, and intermediate filaments. These provide the cell shape and support.

*Chromatin* is loosely organized DNA/protein strands in the nucleus. When the chromatin is tightly coiled into shorter, denser structures, we call them *chromosomes*. Besides chromosomes, the nucleus contains one to several nucleoli. The liquid matrix in the nucleus is called the nucleoplasm.

Finally, we mention that many cells have cilia or flagella. These are hairlike structures from their surfaces and the cell is able to control the action of these microtubular structures.

#### 2.2.3.5 Cell Types

The prokaryotic cells (bacteria and archaea) do not have a typical nucleus bound by a nuclear membrane and they do not contain mitochondria, chloroplasts, Golgi, or extensive ER. On the other hand, prokaryotic cells contain DNA and enzymes. They are able to reproduce and show metabolism and perform all the basic functions of life. The archaea make up to 20% of the biomass. The first archaea were detected in hostile environments but later it became clear that they occur also in soil and in the oceans. There are no known members of archaea that cause diseases.

Only 5% of prokaryotic bacteria cause diseases (tuberculosis, gonorrhea, etc.). Bacteria are also involved in the decay and decomposition of dead organisms. Many

bacteria are surrounded by a capsule enabling them to stick to surfaces and resist phagocytosis. Most bacteria are rods (bacilli), spherical (cocci), or curved (spirilla).

The eukaryotic cells contain a nucleus and most of the other organelles described above. Cells of plants, fungi, protozoa, and animals are prokaryotic; the cells of plants and algae contain chlorophyll, thus they contain chloroplasts in their cytoplasm.

Fungi (yeasts, molds, and mushrooms) cells lack chlorophyll. They are not able to produce their own food (like the plants) and they have no cell walls like the animals. The protozoans (Amoeba, Paramecium) have all the organelles described above and must consume food as do the fungi and the multicellular animals.

### 2.2.3.6 Cell Division

By cell Division, dead cells are replaced, damaged tissues are repaired, and the growth of the organism is enabled. The human body loses about 50 million cells per second that must be replaced. In the process called *mitosis* (Fig. 2.2), the genetic information is equally distributed to two daughter nuclei. The stages of mitosis are the interphase, the prophase (replicated chromatin strands become recognizable as chromosomes, nuclear membrane fragments, and centrioles move to the cell poles), metaphase (chromosomes move to the equator of the cell – in a human cell there are 46 chromosomes aligned at the cell's equatorial plane), anaphase (DNA replication completed, daughter chromosomes contain identical information), and telophase (division begins, cytokinesis). Cancer refers to any abnormal growth of cells that has a malignant potential.

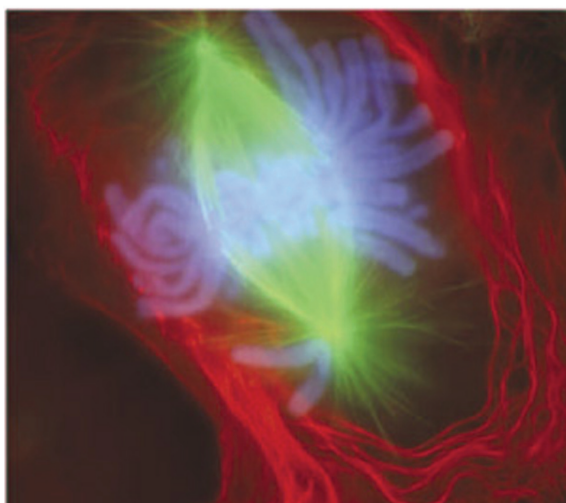
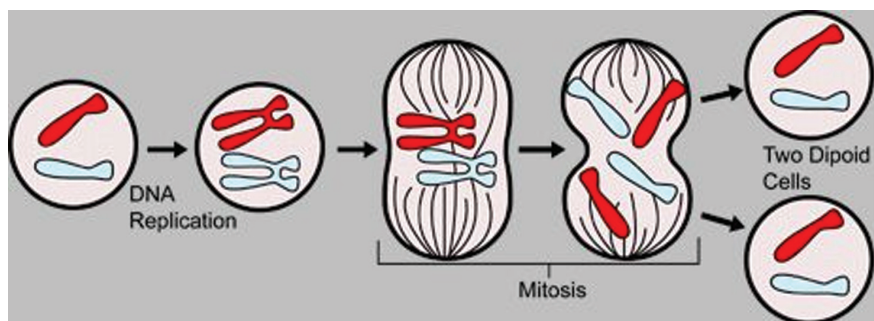
Each new cell gets one of the two daughter nuclei, both have a complete set of genetic information.

There are five stages in the life of a eukaryotic cell:

1.  $G_1$  gap (growth),
2. S synthesis,
3.  $G_2$  gap, growth – phase two,
4. Cell division (mitosis, cytokinesis),
5.  $G_0$  gap (growth), dormancy or differentiation.

The first three phases –  $G_1$ , S, and  $G_2$  are also known as interphase. The cell is not dividing but engaged in metabolic activities (e.g., muscle cell contractions and photosynthesis). The individual chromosomes are not visible. The DNA strands of the chromosomes contain different information on enzymes required for digestion, how to produce enzymes that will enable metabolism and eliminate harmful wastes, how to repair cell parts, production of a healthy offspring, how to react to changes of the environment, and coordination and regulation of essential life functions.

Another important form of cell division is *meiosis*. Here, there are, in principle, two cell divisions. This results in cells with haploid number of chromosomes (haploid means one set of chromosomes). Germ cells (eggs and sperms) are produced



**Fig. 2.2** Basic processes during mitosis (Wikimedia Cosmos). Below: an image of a newt lung cell stained with fluorescent dyes undergoing mitosis. The scientists use newt lung cells in their studies because these cells are large, easy to see into, and are biochemically similar to human lung cells (from <http://www.nigms.nih.gov/moleculestomeds/images>)

and the amount of genetic material is reduced. One parent cell produces four daughter cells. Daughter cells have half the number of chromosomes found in the original parent cell and, with crossing over, are genetically different.

### 2.2.3.7 Cell Division and Cosmic Catastrophes

Ionizing radiation can damage the DNA and that damage leads to cancer. Radiation produces free OH radicals that can easily break up chemical bonds. Single-strand breaks occur in the DNA. Such free radicals are also produced during normal metabolism and the cell possesses mechanisms to repair such single-strand breaks. The repair makes use of the information redundancy built into the double-stranded DNA molecule and uses the undamaged strand to restore the DNA to its original state. When an entire base becomes separated from the sugar, this is called abasic

site. Furthermore, base alteration can also occur. A double-strand break where two backbones are broken is more severe and cause mutations and cancer.

Cosmic catastrophes that can cause strongly enhanced radiation are as follows:

- Violent solar eruptions (flares, CMEs); they occurred more frequently and with larger intensity during the early phase of the Sun, more than 4 billion years ago.
- Nearby supernova explosions; the probability is not very large but they might cause severe effects (see the relevant chapter).
- Variation of the infalling cosmic ray particle flux due to a weakening of the Earth's magnetic field or the heliosphere. This occurred several times in the evolution of life on Earth.

### 2.2.4 RNA-Based Life

Ribonucleic acid (RNA) is made from long chains of nucleotides; each of these nucleotides consists of a nitrogenous base, a ribose sugar, and a phosphate. Therefore, RNA is similar to DNA, however, there are several differences: RNA is usually single stranded, RNA contains ribose (DNA contains deoxyribose), RNA contains uracil instead of thymine which is found in DNA, and the chain of RNA is shorter than that of DNA.

The RNA world hypothesis states that RNA-based life could have been a precursor to DNA-based life. The chemical stability of the DNA is greater, however, RNA can still be found, e.g., as rRNA (in ribosomes; catalyzes protein production) in modern cells. Several properties of RNA are important for the beginning of life: ability to self-duplicate, ability to catalyze chemical reactions, and ability to form peptide bonds (e.g., rRNA). RNA has the ability to act as both genes and enzymes.

In chemistry, an enantiomer is one of two stereoisomers that are nonsuperimposable complete mirror images of each other.<sup>17</sup> The term enantiopure means a substance of which only one of two possible enantiomers is present. A theoretical mechanism resulting in the prebiotic appearance of enantiopure ribose, which would be needed for the origin of RNA and the “RNA world” is proposed by Bielski and Tencer [17].

## 2.3 How Do Organisms Produce Energy?

### 2.3.1 Oxidation–Reduction

There are two basic processes of energy generation for organisms:

- Photosynthesis,
- Respiration.

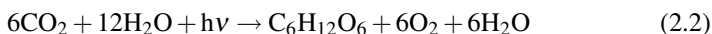
---

<sup>17</sup> For example as one's left and right hands are “the same” but opposite.

Chemically, in both reactions oxidation–reduction reactions are involved. *Oxidation* is the loss of one or more electrons; *reduction* is the gain of one or more electrons, which are added to a compound. In most organic oxidation–reduction reactions, the oxidation of one compound is coupled with the reduction of another compound, catalyzed by an enzyme.

### 2.3.2 Photosynthesis

Photosynthesis, the transformation of light energy (from the Sun) into chemical energy (sugar), is the principal means of sustaining life at any level. There are only few bacteria that derive their energy from sulfur salts and other inorganic compounds. As a byproduct, oxygen is released. The basic reaction is



Photosynthesis takes place in chloroplasts or in cells with membranes in which chlorophyll is embedded. All the world's plant organisms (in land and in the oceans) produce up to  $220 \times 10^9$  t of sugar each year. Ninety-four percent of the dry weight substances of green organisms is produced by photosynthesis (amino acids for proteins, etc.). Between 40% and 50% of the oxygen released in the atmosphere originates from photosynthesis of organisms living in the oceans. There are well-known pollutants that can stop the photosynthesis. One example is the PCBs (polychlorinated biphenyls). They are used in electrical insulators and may stop photosynthesis in concentrations as low as 20 ppb. The total amount of sugar produced by photosynthesis in plants determines, finally, how big the population could grow on the Earth.

The principal elements involved in photosynthesis are carbon dioxide, water, light, chlorophyll.

#### 2.3.2.1 Carbon Dioxide

Our atmosphere consists of approximately 78 % nitrogen and about 21% oxygen. Among the remaining gases there is (at present) about 0.036% (360 ppm) carbon dioxide. One acre<sup>18</sup> accumulates more than 2,500 kg of carbon from the atmosphere during a growing season which corresponds to 11 tons of CO<sub>2</sub>. The total present atmospheric supply of CO<sub>2</sub> would be completely used up in about 22 years if it were not constantly being replenished. Plant and animal respiration, decomposition, natural fires, and volcanoes replace the CO<sub>2</sub> at roughly the same rate at which it is removed during photosynthesis but human activities (use of fossil fuels, pollution, and deforestation) disrupted this equilibrium. The increase of this greenhouse gas leads to global warming (the global warming since the 1980s cannot be explained only by an increase of the solar luminosity) and by the year 2100, the global temperature will increase between 1.0°C and 3.5°C. An increase in carbon dioxide levels

---

<sup>18</sup> 1 acre = 4046.85 m<sup>2</sup>.



(in 1800, the  $\text{CO}_2$  content was 280 ppm<sup>19</sup>; in 2001, it was 360 ppm; the yearly increase is nearly 2 ppm) enhances photosynthesis and increases food production. On the other hand, however, insects, bacteria, and viruses proliferate with warmer temperatures. Fertilizing plants with carbon dioxide in commercial greenhouses has increased yields by more than 20%. Thus, plants have the potential to limit temporarily elevated carbon dioxide levels in the atmosphere. A global temperature increase would perhaps accelerate both plant photosynthesis and animal respiration.

### 2.3.2.2 Water

Less than 1% of all the water absorbed by plants is used in photosynthesis, the remainder is transpired, incorporated into cytoplasm, etc. Water is used as the source of electrons and the oxygen released is a byproduct and does not come from the carbon dioxide. In case of short supply, photosynthesis becomes limited and the stomata close and the carbon supply is reduced.

### 2.3.2.3 Light

Forty percent of the radiant energy we receive is in the form of visible light. Leaves absorb about 80% of the visible light. There is a complex connection between light intensities and photosynthesis for different plants. In some plants, photosynthesis will not increase when they receive more than  $670 \mu\text{mol m}^{-2}$ .<sup>20</sup> Plants on a forest floor can survive with less than 2% of full day sunlight, some mosses as low as 0.05%. Most land plants grow naturally at 30% of full day sunlight.

In case of too much sunlight, two processes may occur: photorespiration (uses oxygen and releases  $\text{CO}_2$ ) and photooxidation (bleaching, destruction of chlorophyll). Photooxidation occurs in autumn, a breakdown of the chlorophyll in leaves.

### 2.3.2.4 Chlorophyll

All the different types of chlorophyll molecules contain one atom of Mg. They are similar in structure to the heme in hemoglobin.<sup>21</sup> Each molecule has a long lipid tail, which anchors the chlorophyll molecule in the lipid layers of the membranes of cells. *Chlorophyll a* is blue-green in color ( $\text{C}_{55}\text{H}_{72}\text{MgN}_4\text{O}_5$ ); *Chlorophyll b* is yellow-green in color ( $\text{C}_{55}\text{H}_{70}\text{MgN}_4\text{O}_6$ ). Usually chloroplasts contain three times more chlorophyll a than b. The more the chlorophyll a in the cell, the brighter green the cell. There are also other pigments such as the carotenoids (yellow-orange), phycobilins (blue or red, found in cyanobacteria and red algae), and chlorophyll c, d, and e.

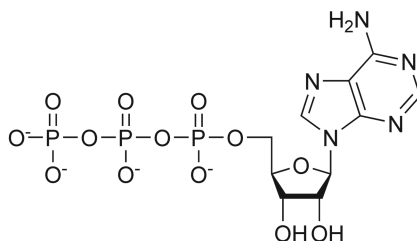
---

<sup>19</sup> Parts per million.

<sup>20</sup> On a clear summery day at noon the intensity of sunlight is  $2000 \mu\text{mol m}^{-2}$ .

<sup>21</sup> Iron containing red pigment that transports oxygen in the blood.

**Fig. 2.3** Structure of adenosine-triphosphate (ATP)



Chlorophylls absorb light primarily in the violet to blue and in the red wavelengths. They reflect green wavelengths – therefore, they appear green. Each of the above mentioned pigments has a distinctive pattern of light absorption. In the process of absorption, the energy levels of some of the pigment's electrons are raised.

There are two types of photosynthetic units in most chloroplasts, called photosystem I and photosystem II. Photosystem II was discovered after photosystem I but today we know that the reactions that take place in photosystem II come before those of photosystem I. Both photosystems produce ATP (adenosine triphosphate) (Fig. 2.3) but only organisms that have both can produce NADPH (nicotinamide adenine dinucleotide phosphate) and oxygen as a byproduct. 2.8 billion years ago the cyanobacteria evolved from primitive bacteria and chlorophyll a and photosystem II developed.

The photosystem I consists of more than 200 molecules of chlorophyll a, small amounts of chlorophyll b, carotenoid, and a  $P_{700}$  reaction center molecule. Only this molecule can use the energy of the infalling photons; the other molecules act as antenna pigments – they function like an antenna in gathering and passing light energy. The letter *P* stands for pigment and the number for the peak in the absorption spectra of light (photosystem I 700 nm, photosystem II 680 nm).

The photosystem II consists of chlorophyll a,  $\beta$ -carotene,<sup>22</sup> and the reaction center is  $P_{680}$ .

These complex mechanisms were invented by the cyanobacteria 2.8 billion years ago when water was already abundant, thus, the process to generate oxygen was facilitated. The oxygen in the Earth's atmosphere increased, therefore, energy-efficient aerobic-respiration-based life could evolve.

Photorespiration occurs when the weather is hot and dry. The stomata are closed and, thus, carbon dioxide is prevented from entering the leaf. Therefore, the concentration of carbon dioxide drops and the concentration of oxygen increases. When the carbon dioxide concentration drops below 50 ppm, rubisco fixes oxygen and photorespiration starts; light is still needed to generate ATP and NADPH. Carbon dioxide is then released.

### 2.3.2.5 Photosynthesis and Cosmic Catastrophes

Photosynthesis on Earth produced the first signatures of life that can be detected astronomically. Photosynthetic-relevant radiation occurs in the near infrared at bands

<sup>22</sup> Precursor of vitamin A.

0.93–1.1  $\mu\text{m}$ , 1.1–1.4  $\mu\text{m}$ , 1.5–1.8  $\mu\text{m}$ , and 1.8–2.5  $\mu\text{m}$  and plays an important role in the search for extraterrestrial life [122].

As it was shown, photosynthesis is a very complex process depending on many factors; to start the process, the infalling electromagnetic radiation is critical. A change of the infalling light spectrum, therefore, strongly influences the photosynthetic processes. Such a shift in the infalling electromagnetic spectrum can occur by

- The solar output slightly shifted both in luminosity and also in the spectral energy distribution. The early Sun emitted only about 70% of its present output.
- Nearby supernova explosion, an increase of the shortwave energy flux will occur.
- The consequences of an impact are that dust and aerosols will change the transparency of the atmosphere.

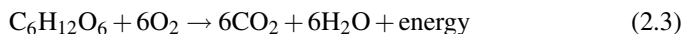
The carbon dioxide content is also critical and can be strongly influenced by an impact of an asteroid or by large volcanic eruptions on earth. All these topics will be discussed in more detail.

### 2.3.3 *Respiration*

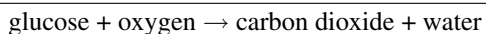
Basically, respiration is the release of energy from glucose molecules that are broken down to individual carbon dioxide molecules. This process takes place in all active cells, regardless of whether or not photosynthesis occurs simultaneously in the cells.

Respiration is initiated in the cytoplasm and completed in the mitochondria. No oxygen is needed to initiate the process, but in aerobic respiration, the process cannot be completed without  $\text{O}_2$ .

The simplified reaction is as follows:

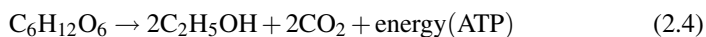


That means



This aerobic respiration is the most widespread type of respiration. The energy released for this process is 2,880 kJ/mole or 36 ATP.

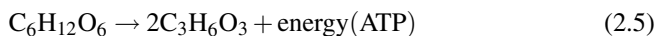
Anaerobic respiration and fermentation were important when there was no oxygen in the atmosphere (at the early phase of the Earth's evolution). The release of energy is only 6% of the amount that is released by aerobic respiration. Two well-known forms of fermentation are



Thus, on the right hand side, ethyl alcohol and carbon dioxide are produced. Cells can only survive if the concentration of alcohol is less than 12%. This is well

known from yeasts that ferment sugars. As soon as the alcohol concentration builds up beyond 12%, these cells die and fermentation is stopped.

Another well-known reaction is



On the right hand side, there occurs lactic acid and energy. The actual amount of energy stored is only 29% of the 200 kJ/mole of energy released approximately in aerobic respiration.<sup>23</sup> The energy released during that anaerobic process is 120 kJ/mole or 2 ATP.

For the strict anaerobes, the presence of oxygen is lethal. An example is *C. tetani* that causes tetanus.

Note also that the terms anaerobic respiration and fermentation are used interchangeably, meaning respiration in an environment of little or no oxygen.

Three factors affect respiration: temperature, water, and oxygen.

**Temperature:** when temperatures rise from 20°C to 30°C, the respiration rate of plants doubles or even triples. The faster the respiration, the faster energy is released from sugar molecules. In harvested fruits, respiration continues, and, therefore, most fresh fruits are kept under refrigeration to lower respiration rate and water loss and dissipate the heat that is generated by this process. Heating to temperatures > 40°C inactivates most enzymes. Only cyanobacteria (for example) have adapted to hot places above 60°C.

**Water:** the water content in living cells is more than 90%. In seeds, the water content is reduced to less than 10 % and, also, respiration occurs at extremely low values.

**Oxygen:** when foods are stored, a reduced oxygen environment helps to lower the respiration rates. In warehouse, where crops are stored, the oxygen content is lowered to 1...3% by replacing it with N. If the oxygen content becomes too low, however, uncontrolled fermentation could start.

### 2.3.3.1 Respiration and Cosmic Catastrophes

Since respiration depends mainly on temperature, water, and oxygen, we shortly mention possible catastrophes that can influence these factors. The temperature depends on the amount of infalling solar radiation, which, as we have mentioned already, slowly changed during the solar evolution. Besides this slowly varying solar luminosity over the course of billion years, there are also short-term variations due to solar activity. Today these variations are low in amplitude but were by a factor of 100 larger in the case of early Sun. The strongest temperature variations could have been caused by impacts of asteroids. Dust in the atmosphere lead to a global

---

<sup>23</sup> 1 kcal = 4.184 kJ is the energy required to raise the temperature of 1 kg of water from 14.5 to 15.5°C.

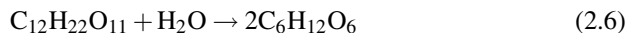
temperature decrease, if the impact occurred in ocean, the amount of additional water vapor, which is an effective greenhouse gas, lead to an increase in temperature.

Also, anaerobic respiration strongly depends on temperature. Anaerobic respiration derived from the period when there was no oxygen in the earth's atmosphere and is also important as adaption in habitats where there is no oxygen. Therefore, in the case of strong reduction of oxygen in an atmosphere, organisms are able to survive a hostile environment. The end-Permian mass extinction occurred during an interval characterized by global warmth and falling atmospheric oxygen levels [165].

The dissolved oxygen content in the world ocean is variable on the decadal time-scale [68].

### 2.3.4 Digestion and Assimilation

As we have shown, sugars are produced by photosynthesis. These undergo many transformations. Some are used directly in respiration; others are transformed into substances like lipids, proteins, and other carbohydrates. Some important carbohydrates are sucrose, starch, and cellulose. By the process of assimilation, these products are used in building the protoplasm and cell walls. The conversion of starch and other carbohydrates to soluble forms is called *digestion*. Let us look at one example—conversion of the disaccharide maltose (malt sugar) in two molecules of glucose with the aid of enzymes:



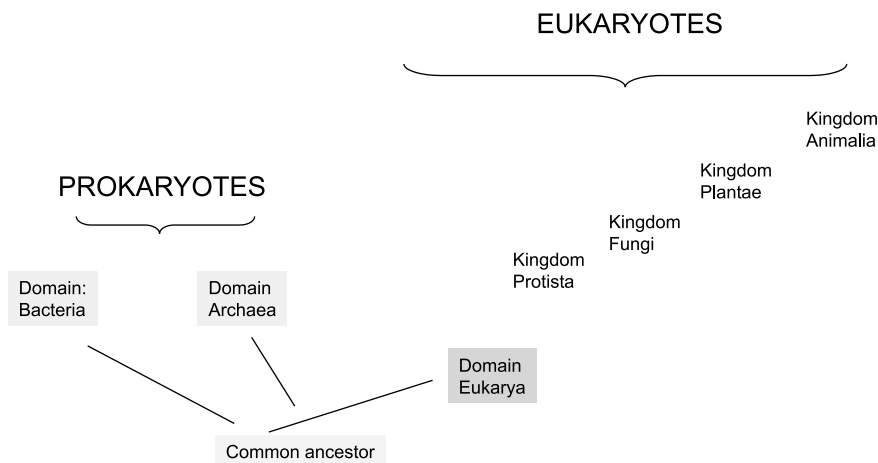
The enzyme involved here is maltase.

Similar to this process, fats are broken down to their component fatty acids and glycerol, and proteins are digested to amino acid building blocks. In animals, special digestive organs were developed. Digestion is similar in both plant cells and animal cells.

## 2.4 Biological Classification

The goals of biological classification are as follows: assign names to organisms and group them according to their relatedness. If two organisms are related, this means that they share a common evolutionary history or phylogeny, and it follows that both groups evolved from common ancestors. The study of evolutionary relationships is also called *phylogenetics*.

First, organisms were classified into plants (kingdom Plantae) and animals (kingdom Animalia). Today, a system of five kingdoms is accepted (Fig. 2.4). The Kingdom monera: includes the prokaryotes and is divided into Eubacteria (true bacteria) and the Archaea. Just for an illustration, let us give the biological classification of the *Homo sapiens*: Domain: Eukaryota, Kingdom Animalia, Phylum Chordata, Class Mammalia, Order: Primates, Family: Hominidae, Genus: *Homo*, Species: *sapiens*.



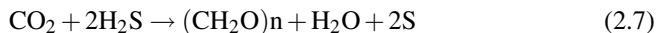
**Fig. 2.4** The major groups of living organisms on Earth

### 2.4.1 *Bacteria*

The cells are very small, much smaller than single-celled eukaryotes. Under ideal conditions they undergo fission every 10–20 minutes. This leads to an enormous mass: within 36 hours, the number becomes  $\sim 2^{100}$ . Of course, this is only theoretical and their number is limited by exhaustion of food supplies and accumulation of toxic wastes. Some bacteria have flagella 5–10 micrometers in length. They are used for movement through fluid media.

Bacteria can be divided into heterotrophic and autotrophic. Heterotrophic bacteria cannot synthesize their own food and depend on other organisms. The majority of heterotrophic bacteria are saprobic<sup>24</sup> bacteria. These (as the fungi) are responsible for decay and recycling of organic matter in the soil. Another class of heterotrophic bacteria are parasites — they depend on other living organism for their food.

The autotrophic bacteria are capable of synthesizing organic compounds from simple organic substances. Some autotrophic bacteria like cyanobacterio and chloroxybacteria carry out photosynthesis and oxygen, as a byproduct of these reactions, is set free. The purple sulfur bacteria, the purple nonsulfur bacteria, and the green sulfur bacteria also live from photosynthesis but no oxygen is released. The general reactions here are



The chemoautotrophic bacteria obtain their energy through chemical reactions involving the oxidation of reduced organic groups such as  $\text{NH}_3$ ,  $\text{H}_2\text{S}$ , and  $\text{Fe}^{++}$ .

Another group of chemoautotrophic bacteria are the iron bacteria. They transform soluble compounds of Fe into insoluble substances that accumulate as deposits,

<sup>24</sup> An organism that derives its nourishment from nonliving or decaying organic matter.

for example, in water pipes. The sulfur bacteria convert hydrogen sulfide gas to elemental sulfur and sulfur to sulfate.

Since bacteria are ubiquitous, any accumulation of household garbage, leaves, weeds, etc., heaped together will become decomposed and heat is generated (up to 70°C). Due to the increase of heat, organisms that are adapted to higher temperatures replace the others. Also, many weed seeds and most disease organisms are killed during this process.

The Bubonic plague (Black Death) are bacteria transmitted by fleas, deerflies, and ticks of lice that have been parasitizing infected animals (particularly rodents). In 1665, in London, hundreds of thousands perished from the Black Death. Between 1347 and 1349, 1/4 of the entire population of Europe (25 million persons) were killed. It is still present in some parts of Asia, and even in Europe and South America. It is possible to control this plague by controlling rats and fleas and the use of vaccines.<sup>25</sup>

Many harmful pests and weeds can be significantly limited through the use of biological controls. The *Bacillus thuringiensis* (often referred to as Bt) is effective against a wide range of caterpillars and worms, like the peach tree borers, European corn borers, cabbage worms, etc.

#### 2.4.1.1 Cyanobacteria and Prochlorobacteria

There is a difference between true algae and blue-green algae, the cyanobacteria. The cyanobacteria have prokaryotic cells and are much more like true bacteria. The main differences between the cyanobacteria and bacteria are

- Cyanobacteria have chlorophyll which is found in higher plants,
- Cyanobacteria have blue green phycocyanin and red phycoerythrin pigments,
- Cyanobacteria can both fix nitrogen and produce oxygen (normally nitrogen-fixation is essentially an anaerobic process).
- Also, the prochlorobacteria are capable to carry out photosynthesis, however, they do not produce oxygen.

The cyanobacteria are found in pools, particularly if the water is polluted, in fresh and marine waters, and even in ice-covered lakes of the Antarctic. In the oceans, cyanobacteria are the principal photosynthetic organisms in plankton (the cyanobacterium *Synechococcus* at a size of 0.8–1.5 µm occurs in concentrations 10,000 cells per milliliter). A species is also found in the different temperature ranges of Yellowstone National Park at water temperatures up to 85°C. There, the bacteria precipitate carbonate deposits – a rocklike substance called travertine (2 to 4 mm/week).

After volcanic eruptions, cyanobacteria are often found to be the first photosynthetic organisms on bare lava. They are even found on the shells of turtles and snails. Others live symbiotically. Cells of cyanobacteria occur in colonies- often in chains or filaments, sometimes branched. The individual cells are held together by

---

<sup>25</sup> Immunity lasts for about 6 to 12 months.

gelatinous sheaths, which can be colored red, brown, green blue, and even violet. There are cyanobacteria that occur symbiotically – they lack cell walls and function as chloroplasts. There is a speculation that chloroplasts originated as cyanobacteria or prochlorobacteria that live within other cells. That assumption is also supported by the fact that when eukaryotic cell containing chloroplasts divide, the chloroplasts divide at the same time.

Microorganisms 3 billion years old from the Precambrian of South Africa were found by Barghoorn and Schopf [10]. In 1993, Schopf [218] described fossils that resemble cyanobacterium-like microorganisms and the fossils are about 3.5 billion years old. However, these fossils are no longer considered to be morphologically similar to cyanobacteria. It is assumed that about 3 billion years ago, these organisms began producing oxygen, which started to accumulate in the earth's atmosphere. It lasted, however, 2 billion years before oxygen became a substantial part of our atmosphere. The ozone layer became an effective shield against shortwave harmful solar UV radiation 1 billion years ago. Before that time, the organisms were only protected by their watery environment. Again, the important role of the cyanobacteria for the entire history of the evolution of life on Earth is seen. In water, they are often at the bottom of the food chains.

The Prochlorobacteria were detected in 1976<sup>26</sup> They have chlorophylls a and b like the plants but no phycobilin pigments that are typical for the cyanobacteria.

### 2.4.1.2 Archaeobacteria

There are three distinct groups of archaeobacteria.

1. Methane Bacteria: they are killed by oxygen and survive only under anaerobic conditions found in swamps, oceans, lake sediments, hot springs, animal intestine tracts, and other environments. Methane bacteria generate energy through formation of methane gas ( $\text{CH}_4$ ) from carbon dioxide and hydrogen. Methane will burn when it constitutes only 5% to 6% of the air (dancing light over swamps seen at night). To our civilization, methane could be extremely useful. It is the principal component of natural gas. It can be estimated that 9 kg of horse manure (or 4.5 kg of pig manure) fed daily into a methane digester will produce all the gas needed for the average adult's cooking needs in northern latitudes. Methane is clean, practically nonpolluting, safe and nontoxic and can be used as a motor fuel.
2. Salt Bacteria: observed from above, salt evaporation ponds and other salt containing shallow bodies of water often have a red appearance. This is caused by the salt bacteria. They carry out photosynthesis with the aid of the red pigment rhodopsin.
3. Sulfolobus Bacteria: they occur in sulfur hot springs and are thermophilic bacteria. Their environment is unusually hot (up to  $110^\circ\text{C}$ ) and exceptionally acidic ( $\text{pH} = 2$ ).

---

<sup>26</sup> R.A. Lewin.



## 2.4.2 Viruses, Viroids, and Prions

### 2.4.2.1 Viruses

During the time of L. Pasteur,<sup>27</sup> all infectious agents including bacteria, protozoans, and yeast were called viruses. One of Pasteur's collaborators discovered that porcelain filters would block out bacteria but not smaller elements. Agents that penetrated such porcelain filter were called filterable viruses or just viruses. Viruses cause many well known diseases like smallpox, measles, mumps, chicken pox, polio, yellow fever, influenza, fever blisters, and the common cold.

How are viruses defined? First, they have no cellular structure. In 1946, W. Stanley got a Nobel Prize because he demonstrated that a virus causing tobacco mosaic (plant disease) could be isolated, purified, and crystalized. These crystals can be stored and always still produce the disease in the plants. The second property of viruses is that they do not grow by increasing their size or dividing. Furthermore, they do not respond to external stimuli, cannot move, and there is no independent metabolism. They are about the size of large molecules (15–300 nm). A typical teaspoon of sea water contains more than  $10^9$  viruses.

Viruses consist of a nucleic acid core surrounded by a protein coat. The nucleic acid core contains either of DNA or RNA—never both. The protein coats are complex (many have 20 sides), some have a distinguishable head and tail. Viruses that attack bacteria are called *bacteriophages* (sometimes only the word phage is used).

Typical for viruses is their reproduction. They attach to a host cell. Then, they penetrate to the interior. Their DNA or RNA directs the synthesis of new virus molecules, which are then released from the host cell. Usually, the host cell dies. Some viruses can mutate very rapidly, e.g., influenza. They are able to attack organisms that previously had been immune to them. New vaccines must be developed. Many forms of cancer (abnormal cell growth) are caused by viruses. Cells of higher animals that are invaded by viruses produce a protein—*interferon*. This cause the cells to produce a protective protein, which prevents the propagation of many types of viruses. It also inhibits viruses from causing tumors. Thus, interferon can be used for controlling many forms of cancer.

### 2.4.2.2 Viroids and Prions

Many plant diseases are caused by viroids (e.g., potato spindle-tuber disease). Viroids consist of circular strands of RNA and occur in the nuclei of infected plant cells. They may remain latent in some plants and cause severe symptoms in others. Viroids are transmitted from plant to plant via pollen.

Prions are also smaller than viruses. They are particles of protein that cause diseases of animals and humans.

---

<sup>27</sup> 1822–1895.

### 2.4.3 *The Kingdom Protista*

As it was pointed out, less than 1 billion years ago, all living organisms on Earth lived in the oceans. Such an environment was necessary because of the following reasons:

- Protection from drying out.
- Protection from intense solar UV radiation.
- Protection from large temperature fluctuations.

About 400 million years ago, green algae — members of the kingdom protista — started to make the transition from water to land. Thus, plants evolved. An ancestor of today's land plants could be *Coleochaete* — a green freshwater alga that grows epiphyte (i.e., it attaches itself in a nonparasitic manner to another living organism). We find, for example, the production of lignin-like compounds that are important to strengthen the cell walls.

All members of the Kingdom Protista have eukaryotic cells. Algae can be found in Seaweeds, fish-tank films, in swimming pools, etc. The green algae are an important part of the plankton (free floating microscopic organisms). Like the higher plants, green algae store their energy in the form of starch within the chloroplasts. The *Chlamydomonas* is unicellular and has a pair of whip-like flagella. The *volvox* forms a hollow spherical colony of cells that spin on their axes as the flagella of each cell beats in a coordinated way.

### 2.4.4 *The Evolution of Complex Life, Cosmic Catastrophes*

Complex organisms evolved from simple unicellular organisms, some cells became specialized to specific tasks. Complex organisms need more energy to maintain their function, therefore, a transition from photosynthesis to aerobic respiration was necessary. The prize for these evolutionary quantum leaps was a greater vulnerability to changing environmental conditions that result from cosmic catastrophes.

We can state that

- primitive life (bacteria, archaea): less vulnerable to cosmic catastrophes; once having formed on a planet, it is highly probable to survive a cosmic catastrophe.
- complex life: multicellular; more vulnerable to catastrophes; chances to survive cosmic catastrophes are smaller. Needs a stable continuous habitable zone for a long time; cosmic catastrophes led to mass extinction and provided the chance to mutations that evolved to more complexity.



<http://www.springer.com/978-3-540-76944-6>

Habitability and Cosmic Catastrophes

Hanslmeier, A.

2009, XIV, 248 p., Hardcover

ISBN: 978-3-540-76944-6