The origin of life

Life began so long ago that many people believe it is impossible to reconstruct the events that led to the appearance of the first cell. The skepticism is understandable, since there are no fossils from that period to study and our knowledge of the Earth's formative years is still rudimentary. Nevertheless, some progress has been made by studying the most primitive cells on Earth today and by conducting laboratory experiments that attempt to reconstruct, in a test tube, the conditions of ancient Earth.

The Big Bang

Fifteen billion years ago, everything in the universe was a soupy concoction of plasma compressed into an area smaller than the head of a pin. There was no matter as we think of it now: no iron, no copper, no carbon, and no oxygen. Just subatomic particles brought together by a crushing force of gravity. No one knows how long the universe remained in this state or even if time, as we know it, existed. We do know that it was extremely hot, with temperatures exceeding 10 billion degrees, 1,000 times hotter than the center of the Sun. Eventually, something happened (no one knows what), and that pinhead of unimaginable heat and density suddenly exploded. Within seconds, the temperature dropped enough for atomic nuclei to form; after a million years, the temperature was low enough for the first elements to appear. The first of these was hydrogen, the simplest of all elements, and the one that gave rise to all the rest. Although the universe was cooling down, it was still hot enough to fuse hydrogen atoms to produce helium. Enough hydrogen and helium were formed in this way to produce all the stars and galaxies. Heat within the stars was sufficient to fuse hydrogen and helium atoms to form all the other elements that we now find in nature, such as carbon, iron, copper, and nitrogen.

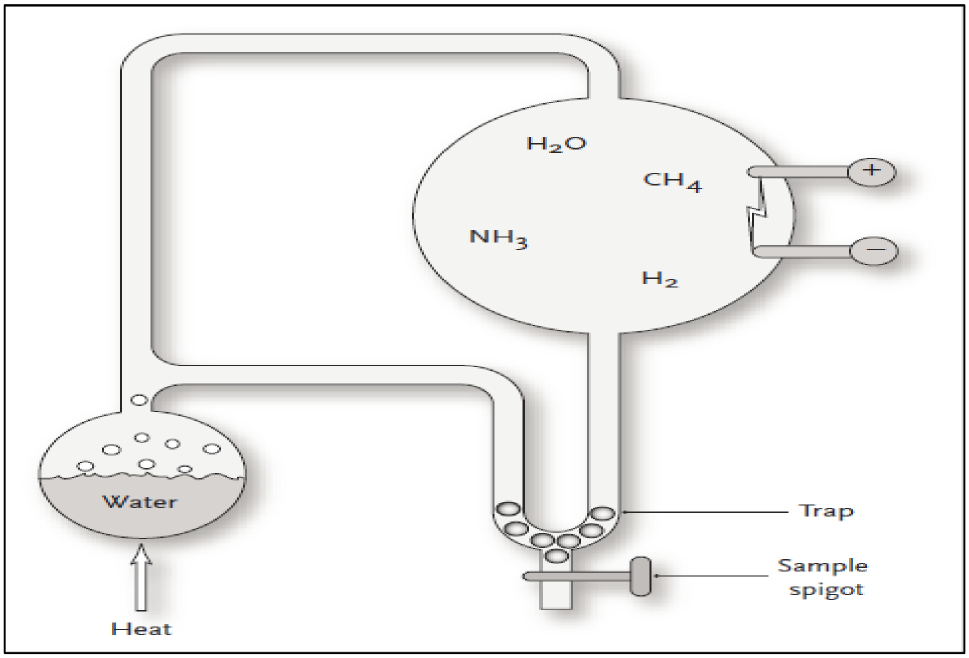
The Importance of Violent Storms

Ten billion years after the big bang, our Earth was created as a molten ball of metal and stone thrown off by the sun during the formation of the solar system. Additional material was added to our planet as it collided with asteroids and meteors. The high surface temperature liberated an enormous amount of water vapor from the nearly molten rocks. The vapor rose into the atmosphere, forming a heavy cloud layer that completely enshrouded the planet, effectively blocking the sun's rays. During the subsequent half-billion years, the Earth cooled down, and when it did, the rains began to fall. a pelting rain that lasted hundreds of years and led to the formation of the oceans, which covered most of the Earth's surface just as they do today. The land was barren and wracked with volcanic eruptions that spewed noxious gases such as methane (CH_4) and ammonia (NH_3) into the atmosphere. The air contained very little, if any, free oxygen.

A planet with an atmosphere of methane and ammonia does not, at first glance, appear a likely candidate for the origin of life. Modern cells need oxygen to breathe and require four kinds of organic molecules: amino acids (building blocks for proteins), nucleic acids (building blocks for DNA and RNA), fats, and sugars. This is a short list, but a long way from methane and ammonia. Nevertheless, in 1953, Harold Urey, a professor at the University of Chicago, and his graduate student, Stanley Miller, decided to test the hypothesis that Earth's ancient atmosphere, combined with fierce electric storms, was essential for the production of the molecules that cells need to live.

To conduct the experiment, Miller constructed a simple test-tube apparatus consisting of two round flasks connected by glass tubing. One of the flasks, containing water, simulated the ocean; a second flask, filled with hydrogen, methane, and ammonia gases, served as the atmosphere. They passed an electric discharge through the flask containing the atmosphere to simulate lightning and heated the water flask to produce the high temperature of the young earth. After a week, Urey and Miller tested the contents of the flask and to their great surprise found that the water contained large amounts of amino acids. By varying the conditions of their experiment they were able to produce a wide variety of organic compounds, including nucleic acids, sugars, and fats.

An artist's conception of prebiotic Earth showing a volcano and the hot, stormy environment. (*Courtesy of Steve Munsinger/Photo Researchers, Inc.)*



Urey-Miller experiment to simulate conditions on prebiotic Earth. Water is heated in a closed system containing methane (CH_4), ammonia (NH_3), and hydrogen (H_2) gases. An electric discharge is passed through the vaporized mixture to simulate lightning in the atmosphere. Synthesized compounds collect in the trap and are sampled by opening the spigot. The original experiment was run for a week or more before samples were collected.

Cells

Cells are basic membrane-bound units that contain the fundamental molecules of life, the substances of which all living things are composed. A single cell is often a complete organism in itself, such as a bacterium or yeast. Other cells acquire specialized functions as they mature. These cells cooperate with other specialized cells and become the building blocks of large multicellular organisms—such as animals, including humans. Although cells are much larger than atoms, they are still very small. The smallest known cells are a group of tiny bacteria called mycoplasmas. Some of these single celled organisms are spheres about 0.3 micrometre in diameter, with a total mass of 10^{-14} gram—equal to that of 8 billion hydrogen atoms. Cells of humans typically have a mass 400,000 times larger than the mass of a single mycoplasma bacterium, but even human cells are only about 20 micrometres across. It would require a sheet of about 10,000 human cells to cover the head of a pin, and each human organism is composed of more than 75 trillion cells. A cell functions both as an individual unit and as a contributing part of a larger organism. As an individual unit, the cell is capable of metabolizing its own nutrients, synthesizing many types of molecules, providing its own energy, and replicating itself to produce succeeding generations. It can be viewed as an enclosed vessel, within which innumerable chemical reactions take place simultaneously. These reactions are under precise control so that they contribute to the life and procreation of the cell. In a multicellular organism, cells become specialized to perform different functions through the process of differentiation. To do this, each cell keeps in constant communication with its neighbours. As it receives nutrients from and expels wastes into its surroundings, it adheres to and cooperates with other cells. Cooperative assemblies of similar cells form tissues, and a cooperation between tissues in turn forms organs, which carry out the functions necessary to sustain the life of an organism.

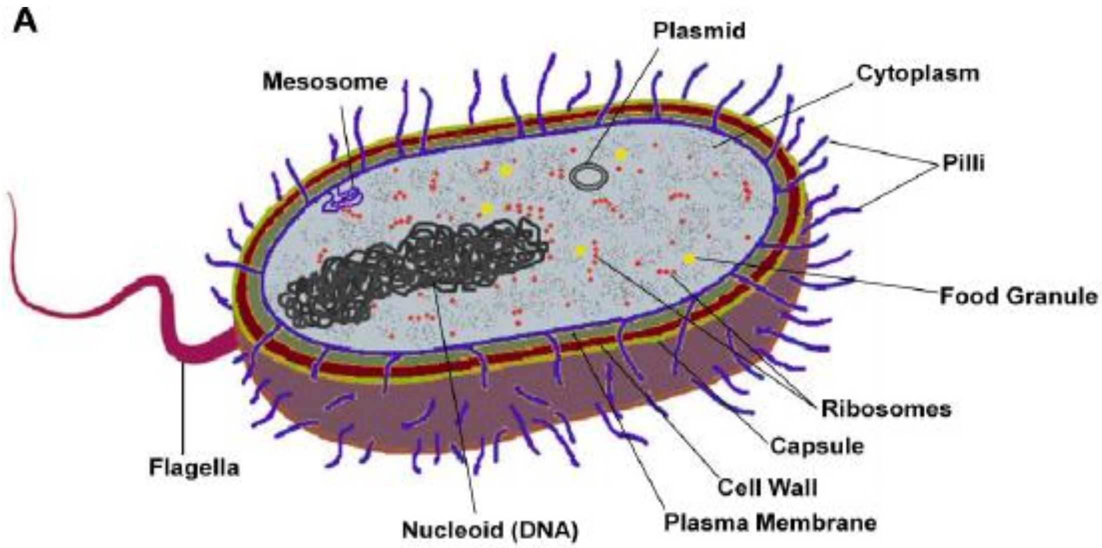
Eukaryotes and prokaryotes

Eukaryotes and prokaryotes are groups of organisms that are distinguished by fundamental differences in their cell plans. A eukaryote is any cell or organism that possesses a clearly defined nucleus. The eukaryotic cell has a nuclear membrane that surrounds the nucleus, in which the well-defined chromosomes (bodies containing the hereditary material) are located. Eukaryotic cells also contain organelles, including mitochondria (cellular energy exchangers), a Golgi apparatus (secretory device), an endoplasmic reticulum (a canal-like system of membranes within the cell), and lysosomes (digestive apparatus within many cell types).

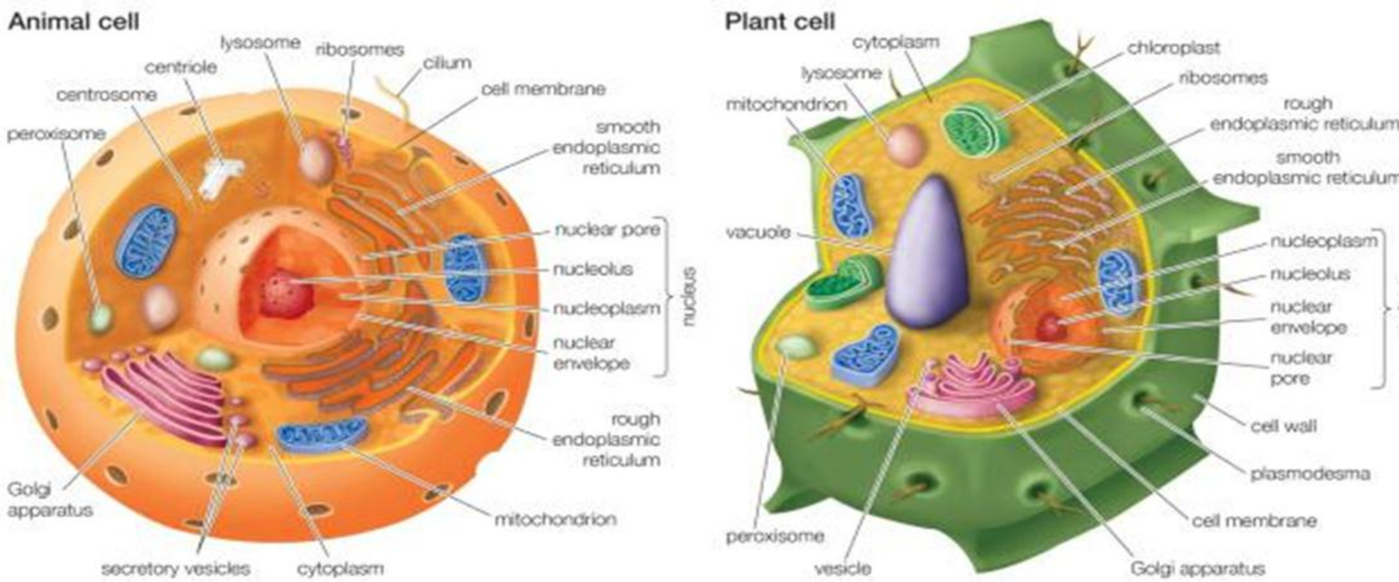
A prokaryote is any organism that lacks a distinct nucleus and other organelles because of the absence of internal membranes. Bacteria are among the best-known prokaryotic organisms. The lack of internal membranes in prokaryotes distinguishes them from eukaryotes. The prokaryotic cell membrane is made up of phospholipids and constitutes the cell's primary osmotic barrier. The cytoplasm contains ribosomes, which carry out protein synthesis, and a double-stranded deoxyribonucleic acid (DNA) chromosome, which is usually circular. Many prokaryotes also contain additional circular DNA molecules called plasmids, with additional dispensable cell functions, such as encoding proteins to inactivate antibiotics. Some prokaryotes have flagella. Prokaryotic flagella are distinct in design and movement from the flagella found on some eukaryotes.

The organization of cells

A cell is enclosed by a plasma membrane, which forms a selective barrier that allows nutrients to enter and waste products to leave. The genetic material of cells contains the information necessary for cell growth and reproduction. Each eukaryotic cell contains only one nucleus, whereas other types of organelles are present in multiple copies in the cellular contents, or cytoplasm. These other organelles perform specific functions. For example, mitochondria are responsible for the energy transactions necessary for cell survival, lysosomes digest unwanted materials within the cell, and the endoplasmic reticulum and the Golgi apparatus play important roles in the internal organization of the cell by synthesizing selected molecules and then processing, sorting, and directing them to their proper locations. In addition, plant cells contain chloroplasts, which are responsible for photosynthesis, whereby the energy of sunlight is used to convert molecules of carbon dioxide (CO_2) and water (H_2O) into carbohydrates.



Generalized structure of a bacterial cell



Generalized structure of animal and plant cell

Between all these organelles is the space in the cytoplasm called the cytosol. The cytosol contains an organized framework of fibrous molecules that constitute the cytoskeleton, which gives a cell its shape, enables organelles to move within the cell, and provides a mechanism by which the cell itself can move.

The molecules of cells

Cells contain a special collection of molecules that are enclosed by a membrane. These molecules give cells the ability to grow and reproduce. The overall process of cellular reproduction occurs in two steps: cell growth and cell division. During cell growth, the cell ingests certain molecules from its surroundings by selectively carrying them through its cell membrane. Once inside the cell, these molecules are subjected to the action of highly specialized, large, elaborately folded molecules called enzymes. Enzymes act as catalysts by binding to ingested molecules and regulating the rate at which they are chemically altered. These chemical alterations make the molecules more useful to the cell. Unlike the ingested molecules, catalysts are not chemically altered themselves during the reaction, allowing one catalyst to regulate a specific chemical reaction in many molecules.

Biological catalysts create chains of reactions. In other words, a molecule chemically transformed by one catalyst serves as the starting material, or substrate, of a second catalyst and so on. In this way, catalysts use the small molecules brought into the cell from the outside environment to create increasingly complex reaction products. These products are used for cell growth and the replication of genetic material. Once the genetic material has been copied and there are sufficient molecules to support cell division, the cell divides to create two daughter cells. Through many such cycles of cell growth and division, each parent cell can give rise to millions of daughter cells, in the process converting large amounts of inanimate matter into biologically active molecules.

The Structure of Biological Molecules

Cells are largely composed of compounds that contain carbon. The study of how carbon atoms interact with other atoms in molecular compounds forms the basis of the field of organic chemistry and plays a large role in understanding the basic functions of cells. Because carbon atoms can form stable bonds with four other atoms, they are uniquely suited for the construction of complex molecules. These complex molecules are typically made up of chains and rings that contain hydrogen, oxygen, and nitrogen atoms, as well as carbon atoms. These molecules may consist of anywhere from 10 to millions of atoms linked together in specific arrays.

Most, but not all, carbon-containing molecules in cells are built up from members of one of four different families of small organic molecules: sugars, amino acids, nucleotides, and fatty acids. Each of these families contains a group of molecules that resemble one another in both structure and function. In addition to other important functions, these molecules are used to build large macromolecules. For example, the sugars can be linked to form polysaccharides such as starch and glycogen, the amino acids can be linked to form proteins, the nucleotides can be linked to form the DNA and RNA (ribonucleic acid) of chromosomes, and the fatty acids can be linked to form the lipids of all cell membranes.

Most of the catalytic macromolecules in cells are enzymes, and most enzymes are proteins. Key to the catalytic property of an enzyme is its tendency to undergo a change in its shape when it binds to its substrate, thus bringing together reactive groups on substrate molecules. Some enzymes are macromolecules of RNA, called ribozymes. Ribozymes consist of linear chains of nucleotides that fold in specific ways to form unique surfaces, similar to the ways in which proteins fold. As with proteins, the specific sequence of nucleotide subunits in an

RNA chain gives each macromolecule a unique character. RNA molecules are much less frequently used as catalysts in cells than are protein molecules, presumably because proteins, with the greater variety of amino acid side chains, are more diverse and capable of complex shape changes. However, RNA molecules are thought to have preceded protein molecules during evolution and to have catalyzed most of the chemical reactions required before cells could evolve.

APPROXIMATE CHEMICAL COMPOSITION OF A TYPICAL MAMMALIAN CELL	
COMPONENT	PERCENTAGE OF TOTAL CELL WEIGHT
water	69.65
inorganic ions (sodium, potassium, magnesium, calcium, chloride, etc.)	1
miscellaneous small metabolites	3
proteins	18
RNA	1.1
DNA	0.25
phospholipids and other lipids	5
polysaccharides	2

References

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THE CELL 2011, Kara Rogers, Published by Britannica Educational Publishing 1st edition.