Chapter 6-1: The Origin of Organic Molecules

The modern theory that explains the origin of life on Earth is centered around the idea of the primordial cloud. According to this theory, the primordial cloud was actually many clouds of cosmic dust and gases that condensed into planets to form the solar system. A series of thermonuclear reactions caused the largest mass in the center to become the sun, and other areas of concentrated matter to become the planets. Over eons of time, organic molecules developed on primordial Earth, after which came the first living things. This plate considers one of the theories for the origin of organic molecules.

> This plate illustrates a theory first proposed in 1953 that accounts for the origin of organic molecules on Earth, and we use a laboratory setup to simulate primitive Earth conditions to demonstrate it.

Billions of years ago, as the primordial Earth traveled through space, its gases contracted to form a hot, dense core that had a temperature of several thousand degrees. When the planet began to cool four billion years ago, a primitive atmosphere formed from gases that escaped from the Earth's core through volcanic action. We see a **volcano (A)** in the plate; the lava should be colored dark red, and a lighter color should be used for its remainder.

In 1953, Stanley Miller and Howard Urey at the University of Chicago tackled the question of how these volcanic gases could transform into our present atmosphere. They poured water into a flask and placed a **flame (B)** under it. The heat caused the water to **boil (C)**. Soon **water vapor (D)** filled the area above the flask much as hot vapors probably filled the early atmosphere.

Earth's early atmosphere contained a number of different **atmospheric gases (E)**. A pale color should be used to shade the sky. Miller and Urey filled a chamber with the gases that were believed to exist at that time, which included **methane (F)**, **ammonia (G)**, and **hydrogen (H)**.

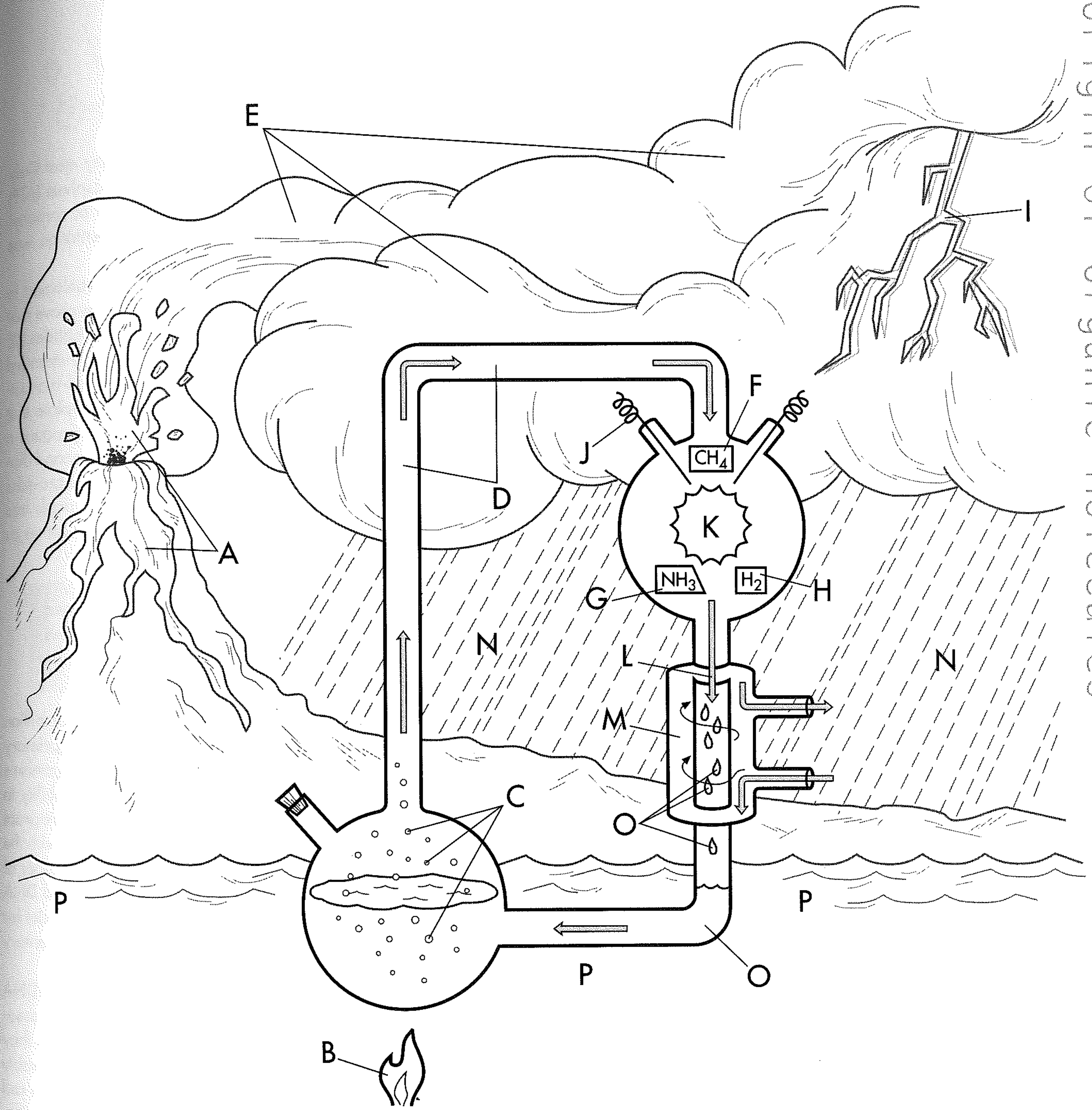
> Notice that there was no free oxygen on the Earth at this time, so that organic molecules could not have been created from diatomic oxygen. We will now continue describing the experiment that Miller and Urey performed. Continue your reading below as you color.

Miller and Urey asked themselves how methane, ammonia, and hydrogen could be transformed into organic molecules. They theorized that the energy source that drove chemical reactions might have been ultraviolet light that was bombarding the primitive Earth. The source of this ultraviolet light would have been **lightening (I)**. To simulate these conditions, Miller and Urey used electrical energy from **electrodes (J)**. A dark color should be used for the electrodes, which provided an **electrical spark (K)**.

> Miller and Urey questioned whether electrifying the primordial gases would indeed lead to the synthesis of organic molecules. They found their answer when they analyzed the products of the reaction.

Miller and Urey then passed the gaseous mixture through a **condenser tube (L)**. A **condenser coil (M)** carried cold water, which caused the vapors to condense. The scientists reasoned that early in the history of the earth, **rains (N)** were unrelenting for years at a time, and the effects of this rain were simulated by the condenser.

Droplets of water formed in the condenser, as Miller and Urey anticipated, and after analysis, they found that these drops of water contained a number of **organic molecules (O)**. For example, they found amino acids, which are the building blocks of protein. They also found acetic acid, which is a simple acid widely encountered in organic chemistry, and urea. These analyses indicated that organic molecules could indeed form from primitive Earth gases when charged with electricity. These droplets fell into the sea and accumulated in **seawater (P)**. The early oceans were probably full of organic molecules, and it was in them that living things first appeared.



The Origin of Organic Molecules

○ Volcano ....A
○ Flame ....B
○ Boiling Water C
○ Water Vapor ....D
○ Atmospheric Gases ......E

○ Methane ....F
○ Ammonia ....G
○ Hydrogen ....H
○ Lightening I
○ Electrodes ....J
○ Electrical Spark ......K

○ Condenser Tube L
○ Condenser Coil ....M
○ Rain ....N
○ Organic Molecules......O
○ Seawater ....P

Chapter 6-2: The Origin of Life

In the course of the evolution of life on Earth, gases in the atmosphere combined to form simple organic molecules. It is conceivable that these simple organic molecules joined to form more complex molecules in a process called polymerization, but in order for these molecules to polymerize, they first needed to be isolated from the atmosphere. The process of the polymerization of molecules eventually led to the creation of cells, and this plate demonstrates the most popular theory about how cells first came into existence.

This plate contains three sections, each of which diagrams a stage in the origin of life on Earth. Focus your attention on the first diagram, which is entitled Coacervate Activity, and begin your reading below.

One of the first steps in the formation of the cell was the isolation of molecules from the environment. This would have isolated and concentrated the molecules, which would have made it possible for them to combine more frequently in chemical reactions.

There are several theories that describe the first precells that might have occurred. These precells probably had water-repellent, membrane-like shells, that were semi-permeable and served to concentrate their organic molecules even further.

One of the first models of a precell was created by A. I. Oparin in 1938. Oparin proposed the early existence of microscopic droplets called **coacervates (A)**. He created these by shaking a solution of nucleic acids, polypeptides, and polysaccharides, and found that the droplets formed were similar to fat droplets. Since then it has been discovered that interesting things take place when enzymes are added to coacervates. For instance, the arrow represents the enzyme **phosphorylase (B)**. When **glucose-phosphate (C)** is added, the enzyme acts on its substrate, transforming it into **starch (E)** and, in the process, releasing a **phosphate group (D)**. Another enzyme, amylase, then breaks down the starch into **maltose (F)**.

Other types of droplets have been proposed; in 1959 Sidney Fox worked with small protein spheres called proteinoid microspheres. In recent years, some scientists have also proposed that microscopic lipid droplets called liposomes could have been precells.

We will next examine what are thought to be some of the first complex molecules on Earth. Your attention should be directed to the second diagram entitled RNA Formation.

When primitive cells first came into existence, they most likely used energy that was derived from adenosine triphosphate (ATP) to metabolize organic compounds. The breakdown of carbohydrates may have provided this energy, and fermentation was probably another way in which cells obtained ATP.

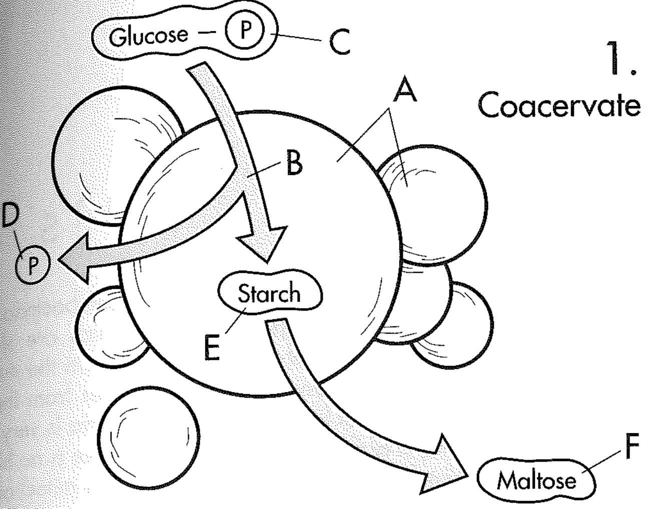
The hereditary information of the first cells was contained in nucleic acids. Recent experiments that are believed to prove that RNA was the first genetic material show that **RNA nucleotides (G)** spontaneously bond with one another to form a single-stranded **molecule of RNA (H)**. It is also known that RNA is self-replicating; a strand of RNA called a ribozyme acts as a template that dictates the order of addition of RNA nucleotides to produce a new, complementary RNA chain. This is shown in the second diagram. RNA is essential to the synthesis of protein since it provides the information necessary for the assembly of amino acids into proteins. Thus, RNA has some enzyme capabilities and serves as a carrier of genetic information.

We will now show how RNA could have been used to form DNA, which is the genetic information in the modern cell.

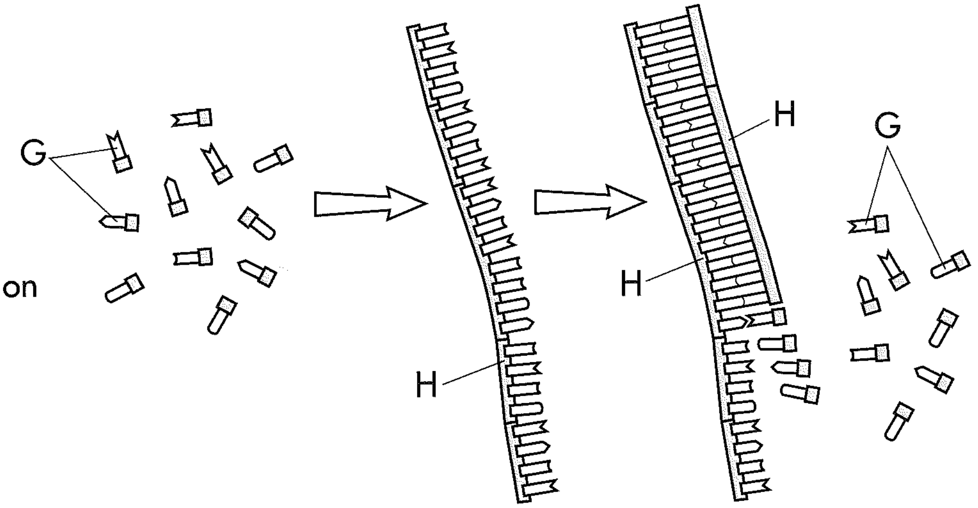
Scientists have theorized that it was not until about four billion years ago that DNA evolved from RNA to become the primary hereditary material. It was discovered that certain microorganisms contain the enzyme reverse transcriptase, which has the ability to use RNA as a template for the synthesis of DNA. Look at diagram 3. Here, a molecule of RNA (H) provides a template and, with the help of the enzyme reverse transcriptase (not shown), a number of **DNA nucleotides (I)** are combining to form **single-stranded DNA (J)**. The single-stranded DNA molecule then serves as a model for the synthesis of another strand of DNA. The two complementary strands then intertwine to form **double-stranded DNA (K)**.

Scientists know that the first true cell must have contained **DNA (K)** as well as **RNA (H)**. **Ribosomes (L)** are other structures associated with, and necessary for, the synthesis of protein, so they must also have been present. These materials were presumably suspended in some sort of **cytoplasm (M)** and enclosed by a **cell membrane (N)**. The cells we have just described are similar to the most primitive bacteria now found on Earth. These organisms are prokaryotes, and they contain little more than the parts just mentioned, but they are considered functionally complete cells.

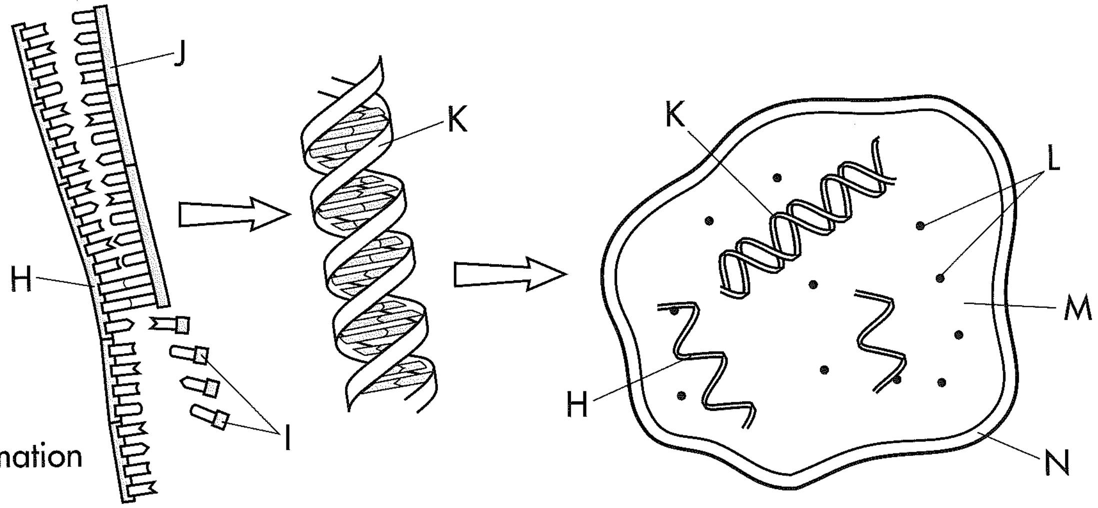
1. Coacervate Activity



2. RNA Formation



3. Cell Formation



The Origin of Life

○ Coacervate ....A
○ Phosphorylase ....B
○ Glucose-Phosphate C
○ Phosphate ....D
○ Starch ....E
○ Maltose ....F
○ RNA Nucleotides ....G
○ RNA ....H
○ DNA Nucleotides I
○ Single-Stranded DNA....J
○ Double-Stranded DNA....K
○ Ribosomes L
○ Cytoplasm ....M
○ Cell Membrane ....N

Chapter 6-3: The First Eukaryotic Cells

The first cells to exist on Earth were very simple prokaryotic cells that were similar to today's bacteria. They are thought to have existed for approximately three and a half billion years, and for about two billion years they were the only cells on Earth. These prokaryotic cells lived in an anaerobic environment and assimilated organic molecules from their surroundings. They had no nuclei or organelles, did not reproduce by mitosis, and each possessed only a single strand of DNA.

Eukaryotic cells, by contrast, are much more complex. They possess nuclei, nuclear membranes, organelles, multiple chromosomes (often occurring in pairs), and they reproduce by mitosis. Eukaryotic cells appeared in the fossil record about one and a half billion years ago; scientists believe that they arose from prokaryotic cells in a process described by the endosymbiont theory.

> This plate displays a multistep process in which a prokaryotic cell evolves into a eukaryotic cell. Focus on the first diagram.

Let's first take a look at a prokaryotic cell. A prokaryotic cell has **cytoplasm (A)**, which is enclosed in a **cell membrane (B)**. As the first diagram shows, the **DNA (C)** in the cell consists of a single, long molecule arranged in a ring. A light color should be used to trace this molecule. Scattered throughout the cytoplasm are molecules of **RNA (D)**.

The endosymbiont theory is one of a few theories that describe how eukaryotic cells may have arisen from prokaryotic cells. This theory proposes that **aerobic bacteria (E)** are taken into a prokaryotic cell by phagocytosis. In the second diagram, we see that the cell membrane **invaginates (F)**, and several aerobic bacteria are taken into the cell to become **symbiotic bacteria (G)**, which take up permanent residence within the cell. The DNA (C) moves to the center of the cell, and the cytoplasm (A) and cell membrane (B) are still clearly seen.

> Now take a look at diagram 3. Here we encounter the first organelles in the evolving cell. Continue your coloring as you read the text below.

In diagram 3, you can see that the symbiotic bacteria have evolved into **mitochondria (H)**, several of which are shown. Mitochondria are the sites of cellular respiration in the modern cell. Support for the endosymbiont theory comes from the fact that the genetic material found in the mitochondria is very similar to that found in prokaryotes. Furthermore, there is no histone protein associated with either prokaryotic DNA or mitochondrial DNA.

The emerging eukaryotic cell also shows two membranous organelles. The DNA (C) is grouped at the center of the cell and a **developing nuclear membrane (I)** encloses it. Also, at this point, the invaginating cell membrane begins to develop into **endoplasmic reticulum (ER) (J)**. The ER is a complex of interconnected membranes that's continuous with the nuclear envelope; its associated ribosomes are the sites of protein synthesis and the ER is responsible for the distribution of these new proteins.

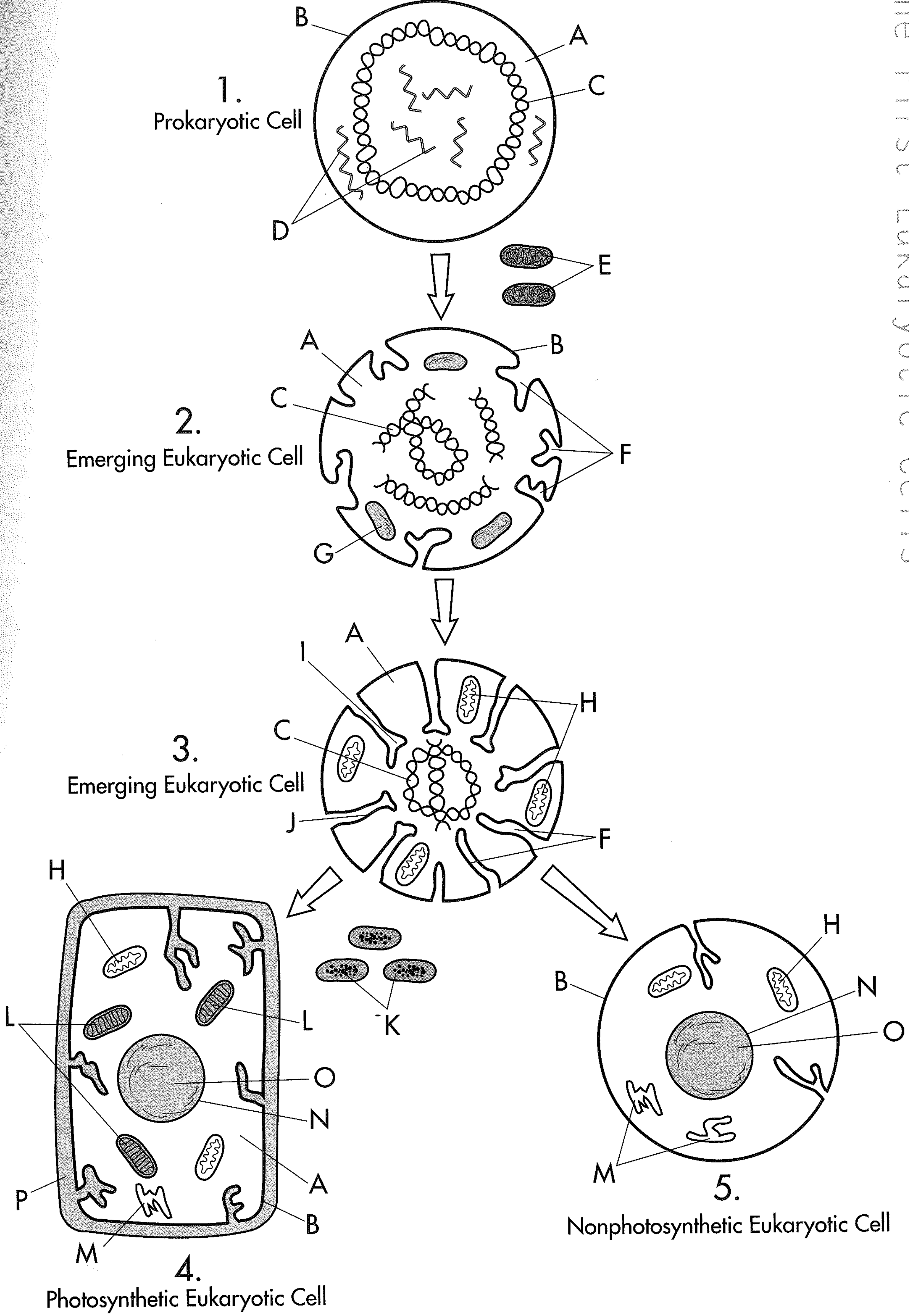
On the bottom right, we see the nonphotosynthetic, contemporary eukaryotic cell. The **nucleus (O)** contains DNA, and a **nuclear membrane (N)** encloses it. Mitochondria (H) and **endoplasmic reticulum (M)** are seen in the cell.

> Focusing on the cell on the bottom left, you can see that chloroplasts, which do not exist in animal cells, are present in plant cells. Now we will see how the endosymbiont theory accounts for their development.

Cyanobacteria (K) are bacteria that have photosynthetic pigments in their cytoplasm. Scientists propose that these bacteria were taken into the cytoplasm of eukaryotic cells, and that they remained in them to become what we now call **chloroplasts (L)**. This theory is supported by the fact that there are several similarities between chloroplast and prokaryotic DNA. Notice the other major features of the eukaryotic cell, including the nucleus (O), the nuclear membrane (N), mitochondria (H), and the endoplasmic reticulum (M). One notable structure of the photosynthetic plant cell is the **cell wall (P)**, which is found outside the cell membrane.

The First Eukaryotic Cells

○ Cytoplasm .... A
○ Cell Membrane .... B
○ DNA C
○ RNA .... D
○ Aerobic Bacteria ...... E
○ Invaginating Cell Membrane .... F
○ Symbiotic Bacterium .... G
○ Mitochondrion .... H
○ Developing Nuclear Membrane I
○ Developing Endoplasmic Reticulum .... J
○ Cyanobacteria .... K
○ Chloroplasts L
○ Endoplasmic Reticulum .... M
○ Nuclear Membrane ...... N
○ Nucleus .... O
○ Cell Wall .... P


1.
Prokaryotic Cell
A
B
C
D
E
2.
Emerging Eukaryotic Cell
A
B
C
F
G
3.
Emerging Eukaryotic Cell
A
I
C
H
J
F
4.
Photosynthetic Eukaryotic Cell
H
L
L
O
N
A
P
M
B
K
5.
Nonphotosynthetic Eukaryotic Cell
B
H
N
O
M