

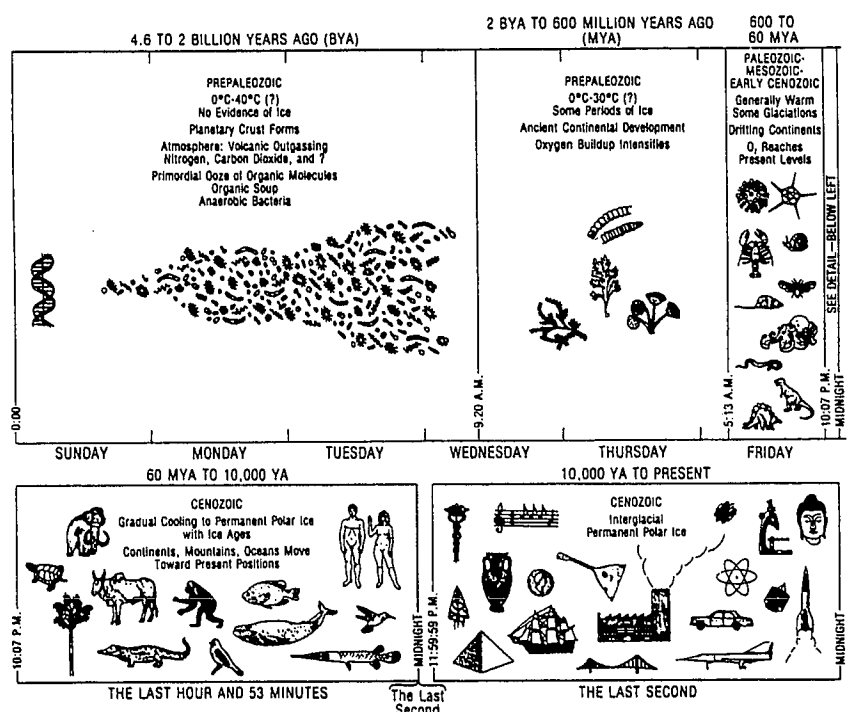
**Teaching Activity: LABORATORY INVESTIGATION:**

*How have the atmosphere and living things interacted over time?*

**Background:** Nowhere is the concept of an Earth system, intimately connecting all of the major spheres, better illustrated than in the formation and evolution of the Earth's atmosphere. Volcanic outgassing and other processes helped to create the primitive early atmosphere while surface features developed at the same time. These events determined the evolving albedo and greenhouse properties of the early Earth. In ways not yet well understood, the basic chemical constituents of life (carbon, hydrogen, oxygen and nitrogen) were somehow synthesized into primitive organic molecules from which early life began. This probably occurred in the first half billion years of Earth history in an atmosphere with practically no oxygen. The anaerobic bacteria developing at this time could not have survived in an oxygen-rich environment. They did thrive in the predominately water-vapor and CO<sub>2</sub> atmosphere - with trace amounts of ammonia, methane and other gases --- that appears to have prevailed.

Over the geologically long term, life contributed to the evolution of the environment, just as the changing environment shapes the formation or sustainability of organisms. For instance, green plants, when they use carbon dioxide to synthesize their tissues, release oxygen. Most biologists and atmospheric chemists who study the evolution of the atmosphere think that the large volume of oxygen present today is a the result of two processes occurring over eons. One is controlled by the rate at which oxygen is removed from the atmosphere and buried as oxide sediments such as iron oxide "red beds". The other is photosynthesis, a primary producer of oxygen. (Other processes, like the breakup of water vapor or other molecules of hydrogenated oxygen atoms, are also involved in the oxygen balance.) Despite debates over how life started and the precise mechanisms of evolution, it can generally be said that the Earth's atmosphere and the biosphere *coevolved* as a result of their interactions.

A schematic of the coevolution of the environment and life.



The philosophical - perhaps theological - significance of this close interrelation between life and its environment is known as the Gaia Hypothesis. This model considers the Earth's living matter, oceans, air and land surface as a complex system which can be seen as a single organism and which has the capacity to keep our planet a fit place for life. The implication is that somehow all of life is a directed organism that manages and evolves in its own environment while controlling its long term destiny. To bolster their case, the authors of the Gaia Hypothesis cite the faint-early-Sun paradox and the yet unexplained processes of how early anoxic life, which apparently survived in an ammonia / methane environment, converted to the oxygen - loving forms adapted to today's physical and chemical conditions:

"The first appearance of oxygen in the air heralded an almost fatal catastrophe for early life. To have avoided by blind chance death from freezing or boiling, from starvation, acidity or grave metabolic disturbance, and finally from poisoning, seems too much to ask; but if the early biosphere was already evolving into more than just a catalogue of species and was assuring the capacity for planetary control, our survival through these hazardous times is less difficult to comprehend."

Regardless of whether you believe in a collective biological purpose behind environmental and biological evolution, or further, take comfort from such a faith in "our survival through these hazardous times", it is a profound realization that the physical, chemical and biological subcomponents of the Earth all interact, and whether by accident or design, mutually alter their collective destiny.

**Goals:**

- To plot the percentages of various gases present in the Earth's atmosphere;
- To construct a cumulative line graph\*\* depicting changes in the atmosphere over time;
- To identify major geological events on the same graph;
- To interpret the graph relating the events to the changes in the atmosphere;
- To make a prediction about the outcome of the investigation;

**Materials (Per student):** Lab packet, pencil / pen, colored pencils, markers or crayons, ruler, calculator;

\*\* NOTE: A cumulative graph shows the total composition or, at the same time, the amounts of the different parts that make up that total. The amounts of all the parts are built upon the per cent of carbon dioxide. For any given year, the sum of the percentages of all the categories is always 100%. When you plot the points for each gas, add it to all the numbers above it.

Example: The amount in 4.5 Byr BP for carbon dioxide is 80% and that for nitrogen is 10%.

- Add  $80 + 10 = 90\%$ . Plot 90% on the graph.
- You should continue to do this for each gas:  
Hydrogen = 5%:  $80 + 10 + 5 = 95\%$ . Plot the 95% for hydrogen.

**Procedure:**

1. The first data table illustrates the composition of the Earth's atmosphere at different times in the planet's history.

- Students will use it to create a cumulative line graph of the composition of the atmosphere over time.
- Students should make their prediction about the outcome of this investigation and write it at the top of the **Investigation Report Sheet**.

2. Students should plot the percentages of carbon dioxide with a colored pencil.

- Students should be sure to place a dot in the correct place for each amount and related time period.

Ex: Carbon dioxide

4.5 Byr BP	=	80%
4.0 Byr BP	=	20%
3.5 Byr BP	=	10%
3.0 Byr BP	=	8%
2.5 Byr BP	=	5%
2.0 Byr BP	=	3%
1.5 Byr BP	=	1%
1.0 Byr BP	=	0.07%
0.5 Byr BP	=	0.04%
Present	=	0.025%

3. Using a different colored pencil, have students plot the data for nitrogen in the same way that they did for carbon dioxide.

- Students should proceed with the other gases in the same way, using a different color for each gas.

4. After all the points are plotted, students should connect the points for each gas, producing a curve for each.

- The curve represents the gradual change over time.

5. Students should then color in the entire area represented by each gas. The area beneath the line drawn for carbon dioxide represents the proportion of carbon dioxide in the air.

- Students should shade this area the color that they used when plotting the points for carbon dioxide.

6. The second data table lists some important events in Earth's history.

- Students should write the events beneath the graph next to the time that they occurred.

7. When students have completed the graphing part of the activity, they should complete all of the **Investigation Report Sheet**.

***Student Activity Sheet: LABORATORY INVESTIGATION:***

***"How have the atmosphere and living things interacted over time?"***

***Background:*** The formation and evolution of the Earth's atmosphere is a prime example of the concept of a interconnected Earth system. While the surface features of the Earth developed, volcanic activity and other processes injected large amounts of gaseous materials into the atmosphere. These events determined the reflectivity and the heat absorbing properties of the early Earth. Somehow, the basic components of life, carbon hydrogen, oxygen and nitrogen, were synthesized into simple organic molecules from which the first life forms emerged. Scientists think that this event occurred in the first half billion years of Earth history in an atmosphere with practically no oxygen. The bacteria living at that time were adapted to survive in a an oxygen-free environment. These primitive organisms apparently thrived in an atmosphere that was predominately water-vapor and carbon dioxide, with small amounts of methane, ammonia and other gases.

Over time, life contributed to the development and evolution of the environment in the same way that the changing environment determines the formation and ability to survive of organisms. For instance, green plants use carbon dioxide to create their tissue and in doing so release oxygen. Most biologists and atmospheric chemists who study the evolution of the atmosphere think that the amount of oxygen in our atmosphere today is the result of two processes: photosynthesis and the oxidation of iron in the crust which forms "red bed" deposits. It is generally safe to say that the Earth's atmosphere and the biosphere *coevolved* as a result of their interactions.

The Gaia Hypothesis is a philosophical model of the close interrelation between the environment and life. It sees Earth as a single organisms made up of a complex system of living matter, oceans, air, and land surface which has the ability to keep the Earth a fit place for life. It suggests that all of life manages and evolves within its own environment and at the same time controls its long term destiny. The authors of the Gaia Hypothesis use several events in Earth history to support their idea, including how anoxic life forms, which lived in an ammonia/methane environment, were able to change over to oxygen-loving life forms which could survive in an environment with very different physical and chemical conditions.

Whether or not you accept the Gaia Hypothesis as a possibility or are comforted by the Earth's ability to get us through "these hazardous times" , it is very obvious that the physical, chemical and biological components of the Earth system all interact and effect their collective form and function.

**Task:** You will be working with information about the Earth's early atmosphere as well as important events that took place over the course of Earth history. Using this information you will:

- make a prediction about the plot percentages of atmospheric gases;
- create a cumulative graph depicting changes in the atmosphere over time;
- identify the major geological events during the same time period;
- interpret the graph by relating events to the changes in the atmosphere;
- make a prediction about the outcome of the investigation;

**Materials:** Lab packet, pen / pencil, colored pencils, markers or crayons, ruler, calculator;

**Procedure:**

1. The first data table illustrates the composition of the Earth's atmosphere at different times in the planet's history.
  - Write your prediction about the outcome of this investigation in the space provided at the top of the **Investigation Report Sheet**.
  - Create a cumulative line graph using this data.

2. Plot the percentages of carbon dioxide with a colored pencil.

- Place a dot in the correct place for each amount /related time period.

Ex. Carbon dioxide:	4.5 Byr BP	= 80%
	4.0 Byr BP	= 20%
	3.5 Byr BP	= 10%
	3.0 Byr BP	= 8%
	2.5 Byr BP	= 5%
	2.0 Byr BP	= 3%
	1.5 Byr BP	= 1%
	1.0 Byr BP	= 0.07%
	0.5 Byr BP	= 0.04%
	Present	= 0.025%

3. Using a different colored pencil, plot the data for nitrogen in the same way. Proceed with the other gases.
4. After all the points are plotted, connect the points for each gas, producing a curve for each gas.
5. Color in the entire area represented by each gas. The area beneath the line drawn for carbon dioxide represents the proportion of carbon dioxide in the air. Use the same color that you used when plotting the points.
6. The second data table lists some important events in Earth's history. Write the event beneath the graph next to the time that they occurred.
7. When you have complete the graphing part of the activity, complete all of the **Investigation Report Sheet**.

## Investigation Report Sheet

I. Prediction: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### II. Data Analysis:

1. How old is Earth? \_\_\_\_\_
2. What gas has made up the largest portion of the Earth's atmosphere for most of Earth's history?  
\_\_\_\_\_
3. What gas increased dramatically over the history of the Earth? \_\_\_\_\_
4. What gas did not appear in any measurable amount until about 2.0 Byr BP?  
\_\_\_\_\_
5. Which gas has been virtually nonexistent in the atmosphere since about 3.0 Byr BP?  
\_\_\_\_\_
6. Which gas appeared in the atmosphere about the time that limestone deposits became common?  
\_\_\_\_\_
7. Why would the appearance of plants that use photosynthesis to produce their food affect the increase in atmospheric oxygen and the decrease in carbon dioxide?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
8. If the natural trend that you see in the graph continues, how will Earth's atmosphere change in the next 500 years?  
\_\_\_\_\_  
\_\_\_\_\_

9. If human activity continues at its present rate, what will probably happen to the levels of carbon dioxide and the other gases?

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**III. Conclusions:**

1. The atmospheres of Venus and Mars are primarily carbon dioxide, while that of the Earth is mostly nitrogen and oxygen. Why is Earth's atmosphere different?

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2. Hydrogen gas is practically nonexistent in the atmosphere today. Looking at the physical and chemical properties will explain why. What do you think was the cause of the elimination of hydrogen from the Earth's atmosphere by about 2.5 Byr ago?

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3. What event in Earth's history probably had the most effect on the composition of the atmosphere? Why?

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4. How do the changes in the atmosphere's composition throughout Earth's history illustrate the Gaia Hypothesis?

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**Data Table #1: Composition of Earth's atmosphere from Earth's formation until present**

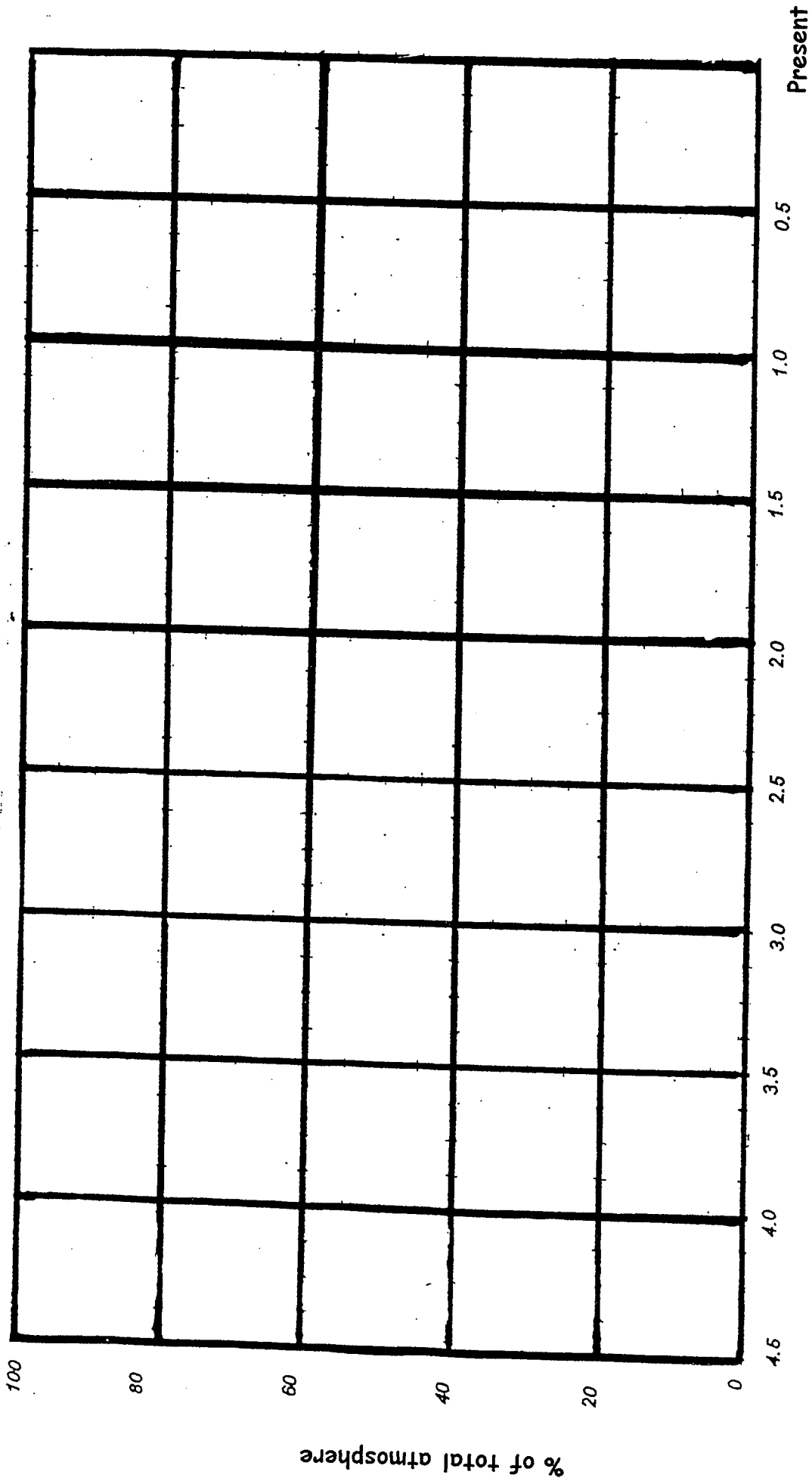
GAS	Billions of Years Before the Present									
	4.5	4	3.5	3	2.5	2	1.5	1	0.5	Present
Carbon dioxide	80	20	10	8	5	3	1	0.07	0.04	0.025
Nitrogen	10	35	55	65	72	75	76	77	78	78
Hydrogen	5	3	1	0.5	0	0	0	0	0	0
Oxygen	0	0	0	0	0	1	5	10	15	21
Other gases	5	42	34	26	23	21	18	13	7	1

**Data Table #2: Major events in Earth History**

Geological Event	Billions of years ago
Origin of Earth	4.5
Formation of oldest known bedrock	3.9
First evidence of organic matter in rocks	3.7
Photosynthesis evolves in plants	3
Limestone deposits become common	1.8
Many fossils of marine invertebrates	0.55
Earliest land plants	0.44
Earliest land animals	0.4
Dinosaurs dominate	0.17



# Evolution of Earth's Atmosphere



Billions of Years Before Present