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ABSTRACT

Designed for integration into existing science curriculum for grades 8-10, this curriculum uses a current environmental issue, climate change, as a vehicle for teaching science education. Instructional goals include: (1) familiarize students with scientific methods; (2) help students understand the role of uncertainty; (3) encourage students to gather meaningful data; (4) engage students in hands-on, experiential learning within the classroom and community; (5) develop student learning artifacts (used in authentic assessment); (6) examine information regarding Earth's climate as it currently exists; (7) analyze information regarding Earth's past climate; (8) develop the concept of a greenhouse; (9) consider factors contributing to Earth's climate; and (10) evaluate controversial issues regarding global climate change. Fifteen activities are contained in five modules five modules that cover climate; the greenhouse effect; the carbon cycle, climate change, and the greenhouse gases; and possible effects of climate change. Teacher and student materials are provided for each activity. Science content includes fundamental components of the climate system, including the hydrosphere, atmosphere, and biosphere; the scientific uncertainties involved in predicting the rate and magnitude of climate change; and the likely impacts of rapid climate change on ecosystems. The publication cites 17 additional curriculum resources. (LZ)

United States Environmental Protection Agency

Office of Research and Development

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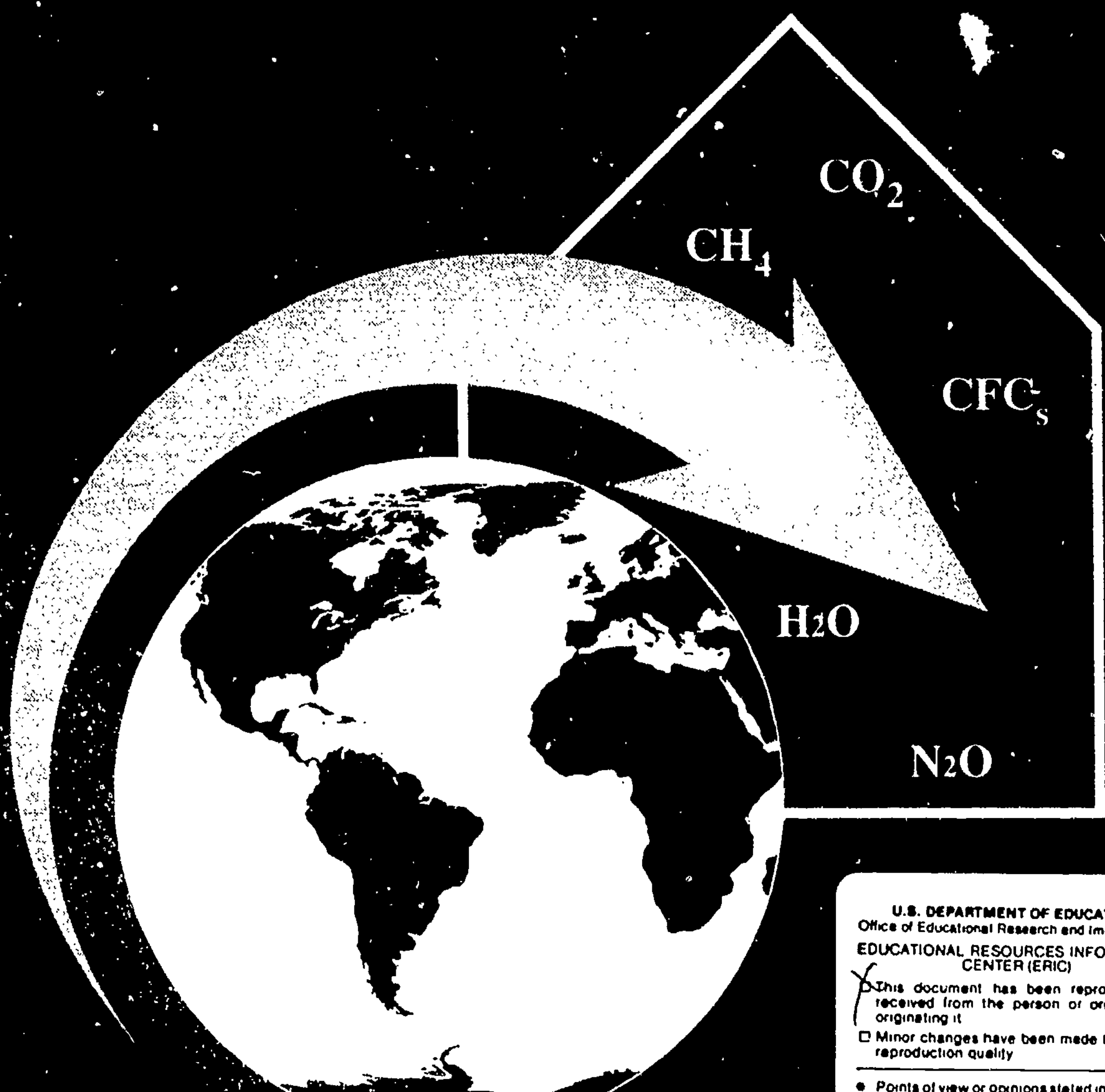
# Global Climates—Past, Present, and Future






## Activities for Integrated Science Education

Edited by: Sandra Henderson, Steven R. Holman, and Lynn L. Mortensen

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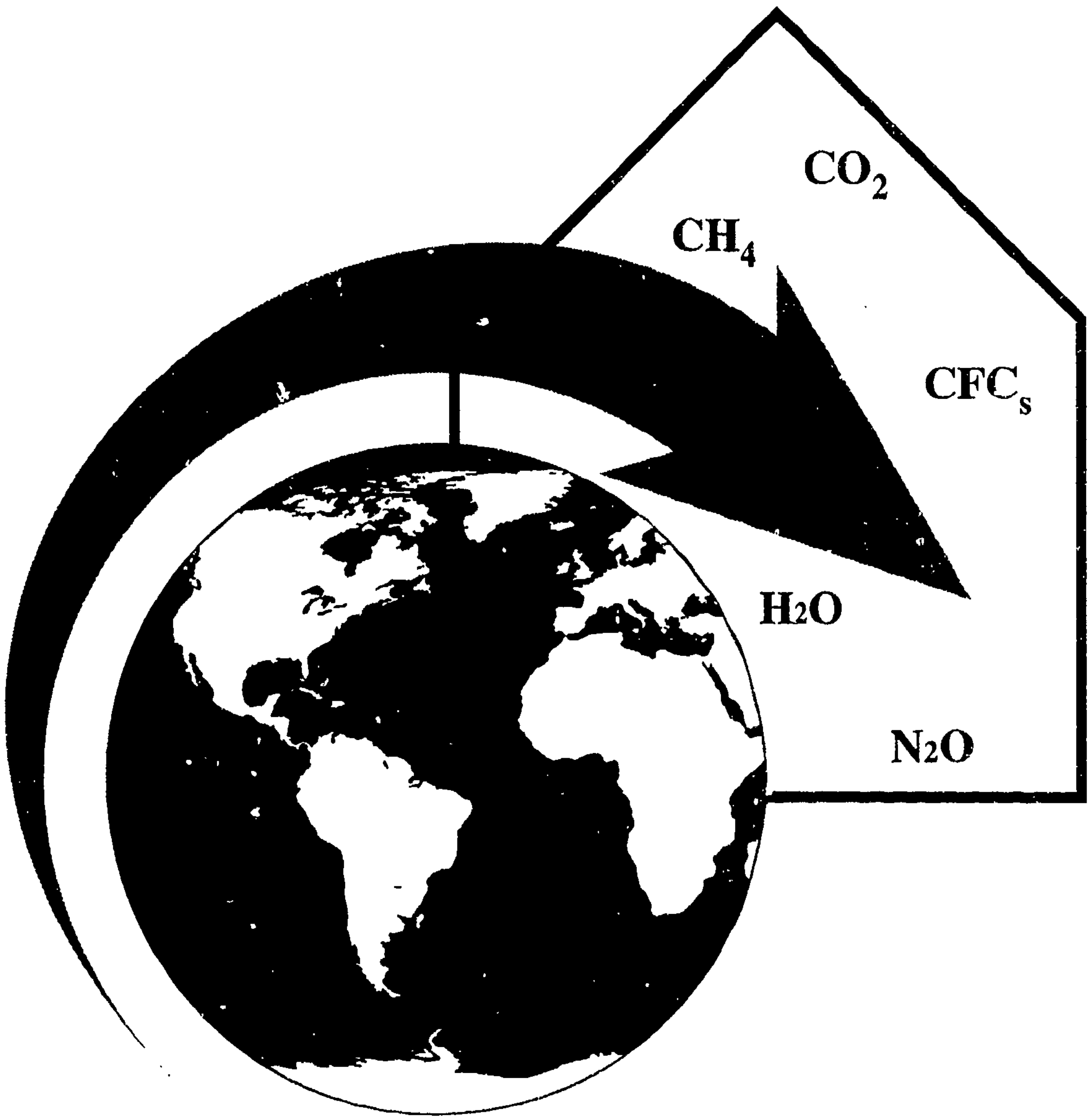


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## DISCLAIMER

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# Global Climates Past, Present, and Future:
## Activities for Integrated Science Education
## (Grades 8 –10)


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# Global Climates Past, Present, and Future:
## Activities for Integrated Science Education

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# Preface

It would be difficult to live in our information-rich society and not be familiar with phrases such as "global warming", "the greenhouse effect", and "global climate change". But, how many people actually understand what these terms mean? Many people do not have an adequate scientific basis to understand global climate change, its causes, or possible effects. The pre-college school system can play an important role in disseminating scientific information on global climate change issues. To do so will require a commitment from those professionals in both the scientific and educational communities. Although government agencies and educational groups have recognized the need for closer communication between research scientists and educators, in practice, the linkage has never been strong or well-defined.

*Global Climates Past, Present, and Future: Integrated Activities for Science Education* is the product of a partnership designed to help bridge the gap between the scientific and educational communities. This curriculum uses a current environmental issue as the vehicle for teaching science education. It is not the intent of the curriculum to convince students that global temperatures are rising at an unprecedented rate, but rather to present the results of research and encourage students to apply critical thinking skills to complex issues such as global climate change.

The project began in January 1991, when five global climate change scientists from the U.S. Environmental Protection Agency's Environmental Research Laboratory in Corvallis, Oregon met with five middle and high school teachers, a university science educator, and a university curriculum development specialist to design the framework for a curriculum addressing global climate change. The scientists brought to the partnership their knowledge and understanding of the complexity of climate change issues as well as their ideas for student activities and experiments. The teachers contributed their expertise in science teaching, understanding student needs, and "what really works in a classroom".

The partnership was further encouraged at an intensive, week long writing workshop in June 1991 where a draft curriculum was developed. Throughout the summer, all involved in the project continued editing and informal testing to ready the curriculum for the actual classroom field test in the fall. During the classroom testing phase, the teachers kept detailed notes indicating the strengths and weaknesses of the various activities and made adjustments where appropriate. The scientists met with the partner teachers and their classes throughout the 1991–92 academic year and were available as resources.

Based on teacher comments and experiences, a final draft of the curriculum was completed during the summer of 1992. The revised copy was sent to global climate change scientists and university science educators for a final review.

The scientific foundation of the curriculum is based on:

1. The fundamental components of the climate system, including the hydrosphere, atmosphere, and biosphere,
2. The scientific uncertainties involved in predicting the rate and magnitude of climate change.
3. The likely impacts of rapid climate change on ecosystems.

The National Science Teachers' Association, in a 1982 position statement, stated that the goal of science education was to "develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision-making." It is the intent of this curriculum project to contribute to this goal.

# Acknowledgements

The planning, testing, and production of this curriculum required the input and support of many individuals. The editors gratefully acknowledge the talents of all persons whose contributions led to the completion of this curriculum. Particular thanks are extended to the following:

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## Curriculum Integration

Global Climates Past, Present, and Future: Activities for Integrated Science Education was designed to be integrated into existing science curriculum for grades 8–10. Each module is written with the developmental needs of these students in mind, recognizing that adaptations will be necessary depending on the unique characteristics of each group of students in each part of the country where this is used.

## Unit Selection

This curriculum is intended to be flexible for the teacher to select some or all of the activities at any time of the year considered appropriate. Units build on the content and learning of previous units yet are not dependent on previous knowledge. Thus, units and activities may be implemented sequentially or the order may be altered to fit existing curriculum organization of content.

## Experiential Learning

Effort was made to incorporate hands-on experiential learning in each activity. Student outcomes include data generation, recording and analysis, as well as problem solving, speculating, and decision-making. Students will be immersed in the process of scientific inquiry while considering actual questions facing the scientific community and general public today.

## Authentic Assessment

Authentic assessment is incorporated through the use of learning logs collected in notebooks or portfolios. In the same way that scientists' notebooks serve as critical records of their thoughts, plans, activities, and conclusions, so should the learning logs serve as records of the students' understanding, reasoning skills, activities, and conclusions. Suggestions for uses of the logbooks are provided below.

## Student Logbooks

Students using this curriculum should keep a detailed logbook of the entire unit. The logbook is analogous to the notebooks scientists keep in virtually every scientific discipline. In these, scientists record not only the technical details of their experiments, they also record their ideas, thoughts, plans, and failures. Students should enter similar information in their logs. Entries should include information and observations on the day's activities, speculations, reflections, and other information the student wishes to express. The students should consider the notebook to be an important scientific accoutrement to the experiments and/or activities. To encourage maximum creativity and freedom of expression, you may wish to minimize the importance of grammar and spelling, and allow students to choose a writing style they are comfortable with. Collect the logbooks periodically and carefully assess the entries. They should accurately reflect the students' understanding of the exercises, the outcomes, and how they relate to the overall lesson goals.

## Each activity is organized into sections:

### Activity Subsections

- Thematic Question
- Lesson Focus
- Student Objectives
- Definition of Terms
- Estimated Time
- Activity Description
- Background Information
- Materials Needed
- Suggested Procedures
- Student Learning Portfolio
- Student Activity Guide
- Extensions

## Partnerships

The scientist/educator partnership used in developing this curriculum proved to be a rewarding and educational experience for all involved. Teachers are encouraged to form partnerships in their own location utilizing expertise available in local universities, cooperative extension services, research facilities, businesses, and appropriate government agencies.

## Additional Information and Resources

A list of additional classroom activities on global science topics is included in the Appendix.

# Instructional Goals

1. Familiarize students with scientific methods allowing them to arrive at their own explanations.
2. Help students understand the role of uncertainty as it exists in the context of global change research.
3. Encourage students to gather meaningful data in the context of actual problems encountered in global change research.
4. Engage students in hands-on, experiential learning within the classroom and community.
5. Develop student learning artifacts (products that demonstrate what students have learned) as assessment tools.
6. Examine information regarding Earth's climate as it currently exists, as it compares to other planets, and as it influences life zones.
7. Analyze information regarding Earth's past climate to gain insight into scientific processes utilized in global climate change research.
8. Develop the concept of a greenhouse and how it affects Earth.
9. Consider factors contributing to Earth's climatic change and otential effects.
10. Evaluate controversial arguments regarding global climate change issues.

# Is the Current Weather "Normal"?

ACTIVITY 1

**Lesson Focus:**
Is the local daily weather different from the "normal" weather?

**Objectives:**
The student will be able to:

1. Distinguish between weather and climate.
2. Describe "normal" weather patterns.
3. Construct and interpret a graph of weather data.

**Time:**
1 or 2 days

**Grade Level:**
8–10

**Key Concepts:**
Current climate, data gathering, data analysis

## Definitions of Terms:

*Weather:* Current atmospheric conditions including temperature, rainfall, wind, and humidity (e.g., what's going on outside now, what's likely to happen tomorrow).

*Climate:* General weather conditions expected in a given area, usually based on the 30-year average weather. May also be applied more generally to large-scale weather patterns in time or space (e.g., an Ice Age climate, or a tropical climate).

## Background:

To separate daily weather from climate, the National Weather Service uses values from the past thirty years to compile "average" weather. This 30-year average is generally considered to represent the climate of the region being measured. In order to investigate the way that the climate may be changing due to human influences, scientists use the 30-year record. They also use weather data from as far back as the historical record will go, as long as the data are accurate. Detailed daily weather data are collected at surface meterological stations (weather stations) located throughout the world. One of the problems scientists face in using historical data to understand climate changes (particularly temperature changes) is that many of weather stations are located in or near urban areas. These areas often experience warmer temperatures than surrounding rural land due to the heat absorbing properties of concrete and asphalt and the lack of shade and evaporative cooling from vegetation. This phenomenon is known as the "heat island effect". Scientists must also consider the fact that the sites of many weather stations have changed over time, often having been moved from rural locations to airports. Long-term weather records for these stations can be difficult to interpret as they contain measurements made at two different locations across different periods of time.

Understanding and interpreting local weather data and understanding the relationship between weather and climate is a very important first step to understanding larger-scale global climate changes.

## Activity:

Have students locate the weather section of a local daily newspaper and graph both daily and average or "normal" long-term data . Newspaper weather sections often include daily high and low temperatures, record high and low temperatures, normal (or average) high and low temperatures and current and cumulative precipitation amounts (see attached examples). By comparing current weather to longer-term climate averages, the students will gain an understanding of the important differences.

## Materials:

- Local weather information from newspaper
- Printed charts for the temperatures
- Colored pencils

## Procedure:

1. Determine how long you want students to collect weather data (a month, 3 months, all year). One month of data collection is usually sufficient to effectively illustrate weather variation, but longer-term data collection can serve to include seasonal changes in the subsequent discussions.
2. Determine what weather data you are interested in having students collect (e.g., daily high and low temperature, normal high and low temperature, record high and low temperature, daily precipitation, normal precipitation, or record precipitation).
3. Have the students prepare graphs to record data (the detail of the graph will depend on the duration of your weather data collection and which data you choose to include). You may wish to have the students post their graphs around the room and add data to them periodically.
4. Have students begin to collect data (don't forget weekends) by clipping weather data from a newspaper. Record this information in a notebook.
5. Either daily or weekly, have students record each day's weather data on the graph. Also be sure to record the average or "normal" values provided in the newspaper. The comparison between the average and daily weather data will form the basis of the discussion of the differences between weather and climate.
6. In a class discussion, ask the students to compare daily weather data to the "normal" or "average" data. What features do they observe? Lead the students to a discussion of the differences between weather and climate that they can observe in their charts. Ask the students to consider the following questions and discuss them with the class:

a. For any of the weather data, which line on the graph is more variable, the daily values or average values? Why?

b. If you were asked to predict the weather for tomorrow from the data shown on the graph, what data would you find the most useful, the daily or average values? Why? How about if you had to predict the weather for next week? Next month?

c. If a scientist reported that last month in Oregon was warmer than the same month a year ago, would you consider this to be evidence for climate change? Why or why not? What kind of data do you think would be the most convincing, changes in short-term (daily, weekly, monthly) weather, or in longer-term climate data?

d. Based on the data the class has collected, does this year appear to be warmer, cooler, or about the same as the average? From this data what, if anything, can you conclude about climate change?

## Student Learning Portfolio:

1. Collected weather data, recorded in a class notebook
2. Graphed weather data
3. Written answers to the questions above

## Extensions:

1. For more detailed information on local weather patterns, a Local Climatalogical Data (LCD) Annual summary with comparative data is available from the National Oceanic and Atmospheric Administration (NOAA) for a nominal cost. Check with your local U.S. Weather Service Office or write to the National Climatic Data Center, Asheville, North Carolina, 28801 to determine the data available for your area. The LCD summary is comprised of temperature, precipitation, and percentage daily sunshine data including normals, means, and extremes for the past 30 years. Using these detailed data may be a more challenging and informative route for students in higher grades than the simple newspaper exercise above. Students should be encouraged to design their own charts for comparisons.
2. In addition to collecting and graphing local data, consider doing this exercise in cooperation with another school(s) in a completely different geographic location. Classes could exchange their data with each other for comparison and discussion. This extension would be enhanced by using telecommunication techniques to establish computer links with other schools to facilitate data exchange and student communication.❑

**Example** —Temperature and precipitation readings from the *Hometown Gazette* newspaper.

## Weather

February 9, 1992

| **Temp.** | **High/Low** |
|---|---|
| Sun. (through 4 p.m.) | **53/44** |
| Normal | **48/35** |
| Last Year | 61/45 |
| Record High | 61 in 1991 |
| Record Low | –3 in 1950 |

| **Precipitation** | |
|---|---|
| Sun. (through 4 p.m.) | Trace |
| To Date This Month | 0.30 |
| Normal to Date | 0.33 |
| To Date This Year | 4.61 |
| Normal to Date | 6.49 |
| Deficit to Date | 1.88 |

## Weather

February 10, 1992

| **Temp.** | **High/Low** |
|---|---|
| Mon. (through 4 p.m.) | **59/35** |
| Normal | **48/35** |
| Last Year | 60/48 |
| Record High | 64 in 1963 |
| Record Low | 4 in 1950 |

| **Precipitation** | |
|---|---|
| Mon. (through 4 p.m.) | Trace |
| To Date This Month | 0.30 |
| Normal to Date | 0.49 |
| To Date This Year | 4.61 |
| Normal to Date | 6.59 |
| Deficit to Date | 1.98 |

## Weather

February 11, 1992

| **Temp.** | **High/Low** |
|---|---|
| Tues. (through 4 p.m.) | **59/42** |
| Normal | **48/35** |
| Last Year | 55/48 |
| Record High | 60 in 1963 |
| Record Low | 14 in 1989 |

| **Precipitation** | |
|---|---|
| Tues. (through 4 p.m.) | 0.00 |
| To Date This Month | 0.30 |
| Normal to Date | 0.65 |
| To Date This Year | 4.61 |
| Normal to Date | 6.81 |
| Deficit to Date | 2.20 |

## Weather

February 12, 1992

| **Temp.** | **High/Low** |
|---|---|
| Wed. (through 4 p.m.) | **54/29** |
| Normal | **49/35** |
| Last Year | 55/39 |
| Record High | 58 in 1961 |
| Record Low | 9 in 1989 |

| **Precipitation** | |
|---|---|
| Wed. (through 4 p.m.) | 0.00 |
| To Date This Month | 0.30 |
| Normal to Date | 0.80 |
| To Date This Year | 4.61 |
| Normal to Date | 6.96 |
| Deficit to Date | 2.35 |

## Weather

February 13, 1992

| **Temp.** | **High/Low** |
|---|---|
| Thurs. (through 4 p.m.) | **53/31** |
| Normal | **49/35** |
| Last Year | 58/33 |
| Record High | 58 in 1991 |
| Record Low | 15 in 1989 |

| **Precipitation** | |
|---|---|
| Thurs. (through 4 p.m.) | 0.00 |
| To Date This Month | 0.30 |
| Normal to Date | 0.95 |
| To Date This Year | 4.61 |
| Normal to Date | 7.11 |
| Deficit to Date | 2.50 |

## Weather

February 14, 1992

| **Temp.** | **High/Low** |
|---|---|
| Fri. (through 4 p.m.) | **53/34** |
| Normal | **49/35** |
| Last Year | 58/37 |
| Record High | 60 in 1945 |
| Record Low | 21 in 1982 |

| **Precipitation** | |
|---|---|
| Fri. (through 4 p.m.) | Trace |
| To Date This Month | 0.30 |
| Normal to Date | 1.10 |
| To Date This Year | 4.61 |
| Normal to Date | 7.26 |
| Deficit to Date | 2.65 |

## Weather

February 15, 1992

| **Temp.** | **High/Low** |
|---|---|
| Sat. (through 4 p.m.) | **52/30** |
| Normal | **49/36** |
| Last Year | 57/35 |
| Record High | 60 in 1970 |
| Record Low | 25 in 1971 |

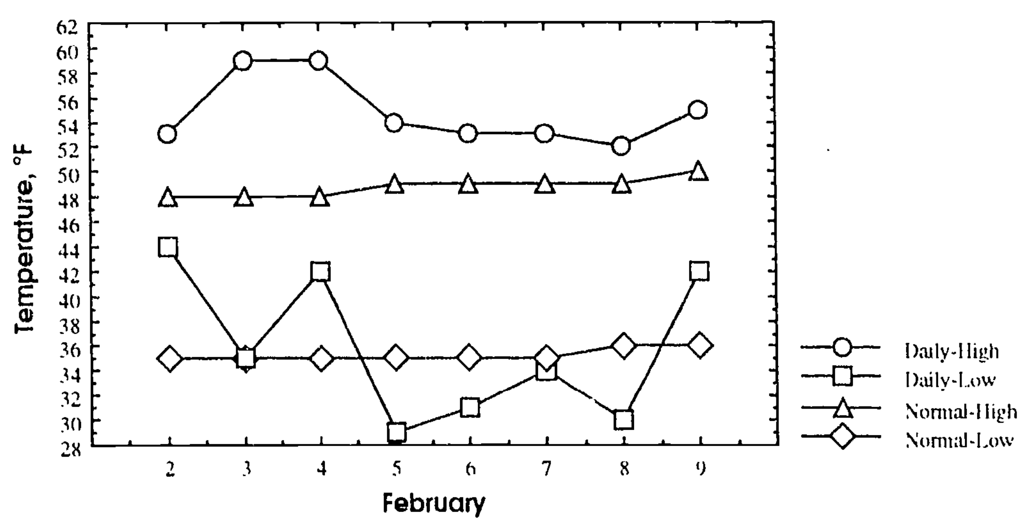
| **Precipitation** | |
|---|---|
| Sat. (through 4 p.m.) | 0.09 |
| To Date This Month | 0.39 |
| Normal to Date | 1.25 |
| To Date This Year | 4.70 |
| Normal to Date | 7.41 |
| Deficit to Date | 2.71 |

## Weather

February 16, 1992

| **Temp.** | **High/Low** |
|---|---|
| Sun. (through 4 p.m.) | **55/42** |
| Normal | **50/36** |
| Last Year | 60/34 |
| Record High | 62 in 1963 |
| Record Low | 25 in 1966 |

| **Precipitation** | |
|---|---|
| Sun. (through 4 p.m.) | 0.15 |
| To Date This Month | 0.54 |
| Normal to Date | 1.40 |
| To Date This Year | 4.85 |
| Normal to Date | 7.56 |
| Deficit to Date | 2.71 |



# Is the Current Weather "Normal"?

STUDENT GUIDE—ACTIVITY 1

**Definitions of Terms:**

*Weather:* Current atmospheric conditions including temperature, rainfall, wind, and humidity (e.g., what's going on outside now, what's likely to happen tomorrow).

*Climate:* General weather conditions expected in a given area, usually based on the 30-year average weather. May also be applied more generally to large-scale weather patterns in time or space (e.g., an Ice Age climate, or a tropical climate).

## Activity:

You will need to locate daily weather data from a local newspaper and record your findings in graph form. Daily weather data often include high and low temperatures, record high and low temperatures, and normal high and low temperatures. Using weather data collected from a local newspaper, graph data and compare daily weather information with longer term climate, trends. To separate daily weather from climate the National Weather Service uses values from the past thirty years to compile "average" weather. In the study of Global Climate Change, scientists use even longer time periods, preferring to go back as far as the historical record will go, as long as it is accurate.

## Materials:

- Local weather information from newspaper
- Printed charts for the temperatures
- Colored pencils

## Procedure:

1. Prepare graphs to record data (the detail of the graph will depend on the duration of your weather data collection and which data you choose to include).
2. Collect data (don't forget weekends) by clipping weather data from a newspaper. Record this information in a notebook.
3. Either daily or weekly, record each day's weather data on the graph.
4. Using your graphs, compare daily weather with normal and record weather and answer the following questions in your notebook and prepare to discuss the answers in class.
   a. For any of the weather data, which line on the graph is more variable, the daily values or average values?
      Why?
   b. If you were asked to predict the weather for tomorrow from the data shown on the graph, what data would you find the most useful, the daily or average values?

Why?

How about if you had to predict the weather for next week?

Next month?

c. If a scientist reported that last month in Oregon was warmer than the same month a year ago, would you consider this to be evidence for climate change?

Why or why not?

What kind of data do you think would be the most convincing, changes in short-term (daily, weekly, monthly) weather, or in longer-term climate data?

d. Based on the data the class has collected, does this year appear to be warmer, cooler, or about the same as the average?

From this data what, if anything, can you conclude about climate change?❑

**Notes:**

# What Factors Influence Climate?

ACTIVITY 2

**Lesson Focus:**
How is climate influenced by both natural and human activities?

**Objectives:**
The student will be able to:

1. Make comparisons between different climates.
2. Identify factors that influence climate.
3. Discover climatic patterns through the use of precipitation, temperature, and biome maps.

**Time:**
3 class periods

**Grade Level:**
8–10

**Key Concepts:**
Current climate, human influence on climate, map reading

## Definitions of Terms:

***Atmosphere:*** The gaseous envelope surrounding Earth.

***Geosphere:*** The solid portion of the Earth comprising the crust, mantle, and core.

***Hydrosphere:*** The portion of Earth where water is present in either a liquid, gaseous, or solid phase.

***Biosphere:*** The portion of earth in which all known life forms exist, consisting of a thin envelope of air, water, and land.

## Background:

Many factors, both natural and anthropogenic (human-made), determine Earth's climate. The *natural* factors can include, but are not limited to the following.

1. *Atmosphere:* sun (energy, orbit, tilt, cycles), reflection (albedo), clouds, precipitation, wind, gases ($H_2O$ vapor, $CO_2$, $CH_4$), feedbacks, and cycles.
2. *Geosphere:* geography (mountains, water sources), volcanoes, surface roughness, earth's core heat, feedbacks.
3. *Hydrosphere:* currents, surface roughness, ice sheets, cycles, feedbacks.
4. *Biosphere:* living organisms, carbon storage and cycling, evapotranspiration, surface roughness, and feedbacks.

The *human* factors are often thought to have influence on local climate, however, they may also have regional and global effects. The *human* factors include, but are not limited to the following.

1. *Land Uses:* slash and field burning, deforestation, agriculture, wetlands, cities ("urban heat island" effect).
2. *Resource Uses:* burning of fossil fuels (oil, wood, coal).

## Activity:

Students will brainstorm and discuss ideas about climate. Then they will create a class mural depicting factors affecting climate

## Materials:

- Maps and atlases (temperature, precipitation, biomes for local, regional, U.S., and world areas)
- Bulletin board or butcher paper
- Magazines
- Glue
- Scissors
- Colored markers
- Pads of sticky paper

## Procedure:

Have the students cover a bulletin board with poster paper or a long strip of butcher paper.

1. *Introductory Discussion*
   (Ask the following questions):
   a. What is the climate like in our area?
   b. What do you think causes our climate to be like this?
   c. What is the climate like in a different area such as the Amazon or the Arctic?
   d. What do you think causes that climate to be different?
2. *Team Brainstorming*
   a. In small teams (3–5 students), have students share their lists with each other and compile a group list of factors associated with climate.
   b. Taking turns, have the teams each read a factor aloud until all the lists are exhausted. The result will be a master class list of factors the students perceive to be associated with climate. Record each factor on separate pieces of sticky paper and stick the papers to the chalk or bulletin board.
3. *Categorize*
   a. Have students organize the sticky paper factors into categories. (Suggested categories: atmosphere, hydrosphere, geosphere, and biosphere [natural categories]; land use and resource use [human categories]). Keep in mind that the factors can overlap the arbitrary categories, in which case, simply make more sticky papers.
   b. Ask students to divide the poster or butcher paper into the above categories (lengthwise) and label them. (See Figure 1 for example.)
   c. Let teams choose one of the aforementioned categories (see 3a.) to find photos (from magazines) to represent the factors in this category (two or more teams per category is acceptable). Students should not be restricted to magazines; original drawings and photographs may be contributed.
4. *Have the students build a mural as an organizing framework.*

**Figure 1.** Suggested Categories.

| | |
|---|---|
| Natural | Atmosphere |
| | Hydrosphere |
| | Geosphere |
| | Biosphere |
| Human Influence | Land Use |
| | Resource Use |

### Student Learning Portfolio:

1. Draw mini-murals in logs
2. Write stories to explain mural's content
3. Generate lists of new questions about climate

### Extensions:

It is improbable that students will think of all the factors listed in the Background section. As these factors are discovered and discussed in the following lessons, photos and drawings can be *added* to the mural, using it as a basis from which to build additional learning.❑

# What Factors Influence Climate?

STUDENTGUIDE—ACTIVITY 2

**Definitions of Terms:**

***Atmosphere:*** The gaseous envelope surrounding Earth.

***Geosphere:*** The solid portion of the Earth comprising the crust, mantle, and core.

***Hydrosphere:*** The portion of Earth where water is present in either a liquid, gaseous, or solid phase.

***Biosphere:*** The portion of earth in which all known life forms exist, consisting of a thin envelope of air, water, and land.

## Activity:

With other students in your class, you will "brainstorm" and discuss ideas about weather and climate. Incorporate these ideas into a class mural depicting factors affecting climate

## Materials:

- Maps and atlases (temperature, precipitation, and biomes for local, regional, U.S., and world areas)
- Bulletin board or butcher paper
- Magazines
- Glue
- Scissors
- Colored markers
- Pads of sticky paper

## Procedure:

1. Cover a bulletin board with poster paper or a long strip of butcher paper.
2. Make a list of factors you associate with climate.
3. Working in small teams, share your list with others in your team. Make a team list of factors you collectively associate with climate.
4. Each team will take turns reading a factor from their lists until all the lists are exhausted. Now you will have a class list of factors you and your classmates associate with climate. Record each factor on separate pieces of sticky paper and stick the papers to the chalk or bulletin board.
5. Organize the sticky papers listing climate factors into categories.
6. Divide the poster or butcher paper into the categories you decided on and label them.
7. Each team will choose a category and find photos or drawings to represent the factors in your category.
8. Using the photos and drawings, build a mural for your classroom.❑

# What Is the Relationship Between Climates and Terrestrial Biomes?

ACTIVITY 3

**Lesson Focus:**

What are biomes and how do they interact with climate?

**Objective:**

The student will be able to:

1. Define the term "biome".
2. Locate and describe the characteristics of the major terrestrial biomes of the world.
3. Compare a variety of biomes throughout the world.
4. Describe the adaptive characteristics needed by plants and animals in different biomes.
5. Summarize the relationship between climates and biomes.

**Time:**

2 days

**Grade Level:**

8–10

**Key Concepts:**

Current climate, geographical regions, environmental adaptation

## Definitions of Terms:

***Biome:*** A geographic area characterized by specific kinds of plants and animals.

***Adaption:*** An inherited trait that increases an organism's chance of survival in a particular environment.

## Background:

Biomes refer to broad geographic regions that are characterized by relatively similar climate, topography, flora, and fauna. These biomes are generally identified by their dominant plant life (e.g., grasslands, forests). Biomes seldom have distinct boundaries. There are many different classifications of the world's biomes in varying degrees of detail. Generally they all include the tundra, desert, forest, grasslands, or some subset of these. Many biology textbooks have maps of the world's biomes. Any of these could be used for this activity.

As with any attempt at regionalization, biomes share key characteristics (they are more similar than dissimilar), however they are not homogeneous. For example, a polar biome is characterized by much lower temperatures than a tropical forest biome. But even within the polar biome, one can expect a range of temperatures (generally –40 °C to –4 °C). If you were high above the ground in a jet you could identify areas that would appear to be deserts, forests, or grasslands. You may find it difficult to determine where one biome begins and another ends as the two merge into areas of transition.

Organisms that live in any given biome have features that have allowed them to adapt to the environment of that biome. Each biome has plants and animals that are uniquely qualified to survive there. Keep in mind there are species that can survive in a number of different biomes.

## Activity:

Using maps and other reference materials, students will demonstrate their understanding of the relationship between biomes and climate. The students will also identify the adaptive characteristics or features of plants and animals representative of the different biomes.

## Materials:

- Biome maps (from textbooks or other sources)
- Biome Characteristic Chart (attached)
- World atlas
- Large sheets of butcher paper
- Felt pens

## Procedure:

1. Based on the number of biomes on the map you choose to use (usually seven or eight), divide the class into small discussion groups and assign each group a different biome to explore. Distribute a Biome Characteristic Chart to each student.
2. Have each biome group gather data from the world atlas (or similar sources) about their biome using the Biome Characteristic Chart as a guide. This task will require estimating and generalizing. For example, the polar biome group will find a range of temperatures in their defined area. They should record the range on the Biome Characteristic Chart. Each group should complete the chart for their biome.
3. Each group should list the key characteristics of their biome on a sheet of paper and hang the papers on the chalk or bulletin board. A spokesperson for each group can share their information with the class.
4. After all the biome characteristics have been covered, students should be encouraged to discuss their findings through open-ended questions. Examples of questions:
   a. What would the seasonal weather be like in the different biomes?
   b. Do different animals live in different biomes depending on the time of year (consider migratory bird species)? How can they survive in such different environments?
   c. Why are humans able to live in all biomes?

d. In what ways are humans changing biomes?

e. Which biome do you currently live in? What do you like/dislike about it?

**Student Learning Portfolio:**

1. List of biomes and their characteristics.
2. Written answers to discussion questions.

**Extensions:**

Have students pick a characteristic plant or animal from any biome and research its life history characteristics. Delineate the plant or animal's range on a large world map. Is it only found in one biome or does its range include more than one biome?

**Notes:**

**Notes:**

# What Is the Relationship Between Climates and Terrestrial Biomes?

STUDENT GUIDE—ACTIVITY 3

**Definitions of Terms:**

***Biome:*** A geographic area characterized by specific kinds of plants and animals.

***Adaption:*** An inherited trait that increases an organism's chance of survival in a particular environment.

**Activity:**

Using maps and other reference materials, you will explore the relationship between biomes and climate. You will identify the adaptive characteristics or features of plants and animals representative of the different biomes.

**Materials:**

- Biome maps (from your textbook)
- Biome Characteristic Chart
- World atlas
- Large sheets of butcher paper
- Felt pens

**Procedure:**

1. Your class will be divided into small discussion groups. Each group will be assigned a biome.
2. With your biome group, gather data from the sources your teacher has provided and fill in the Biome Characteristic Chart for your assigned biome.
3. Your biome group should list the key characteristics of your biome on a sheet of paper. Hang the paper on a chalk or bulletin board. A spokesperson for your biome group can share the key characteristics of your biome with the rest of the class.❑

**Notes:**

**Biome Characteristic Chart:** For each biome, list the following.

1. Average yearly temperature range:

2. Average yearly precipitation:

3. Soil characteristics:

4. Characteristic vegetation:

5. Characteristic animals:

6. Adaptive features of plants to survive in this biome:

7. Adaptive features of animals to survive in this biome:

# How Has Earth and Its Climate Changed Over Time?

ACTIVITY 4

**Lesson Focus:**

How can the Earth's geologic time scale be used to illustrate the evolution of life and climate?

**Objective:**

The student will be able to:

1. Describe the geologic, climatic, and evolutionary changes that have occurred throughout the Earth's history.
2. Locate major geologic, climatic, and evolutionary events on a time line chart.
3. Construct and interpret a chart of the Earth's history.

**Time:**

1–2 days

**Grade Level:**

8–10

**Key Concepts:**

Past climate, major geologic events, major evolutionary events

## Definitions of Terms:

***Geologic Time:*** A term used to describe very long periods of time, typically measured in millions of years. It is termed "geologic" time because this is the time scale over which slow geological events can occur (such as mountain building, changes in the position of continents, the formation or disappearance of rivers).

***Eon:*** A billion years. The Earth is approximately 4.5 eons old.

***Millennium:*** A thousand years.

***Era:*** For our convenience, geologic time is divided into eras of different durations, and eras are divided into periods. For example, we are currently living in the Quaternary Period of the Cenozoic Era. Dinosaurs disappeared at the end of the Cretaceous Period of the Mesozoic Era.

***Plate Tectonics:*** The solid crust of the earth (including the continents and ocean basins) is made up of about a dozen major crustal plates that move across the surface of the Earth due to the influence of currents in the hot, almost molten mantle (the layer below the crust). The movement of these plates is responsible for the slow movement of the continents (continental drift).

## Background:

The oldest rocks known to exist on Earth now are approximately 3.8 billion years old, formed probably less than 1 billion years after the Earth solidified into a planetary body. Rock of such antiquity is extremely rare. Most of the earliest rocks have been eroded away or recycled back into the Earth's core through the process of plate tectonics, providing scientists only sparse clues as to the earliest origins and development of life on Earth. Although these oldest rocks do not contain clear evidence that life was present at the time they were formed, fossil evidence from rocks only slightly younger (3.4 billion years) suggests that forms of bacterial life were present and probably widespread by that time. The processes by which life first developed are still a mystery. Although scientists have successfully simulated certain chemical processes that may have been necessary precursors to the development of life, they are far from actually replicating life's origins in a laboratory. Although the earliest period of Earth's history is not well understood, scientists have gathered sufficient geological, fossil, and radioisotope evidence to construct a generally clear picture of the way that Earth's climate and life have evolved over the more recent history of the planet.

Although scientists may have gathered enough data to reconstruct a general outline of Earth's history, many important questions remain. For example, why and how do organisms disappear from the fossil record? Why did certain groups (such as trilobites and dinosaurs) disappear abruptly, whereas other groups faded slowly from the record, and yet other groups (such as reptiles, sharks, and certain species of bony fishes) have persisted through long stretches of geologic time? We know that Earth's climate has changed drastically through the millennia; what caused these changes? How did the changes affect the Earth's biota?

As humanity becomes increasingly concerned about the possibility that our activities may be changing the climate and biota of Earth in ways we cannot yet understand, it is critical that we understand the interaction of climate and life throughout Earth history. In so doing, we can gain a sense of perspective about our place in the changes that have occurred on the planet through geologic time.

## Activity:

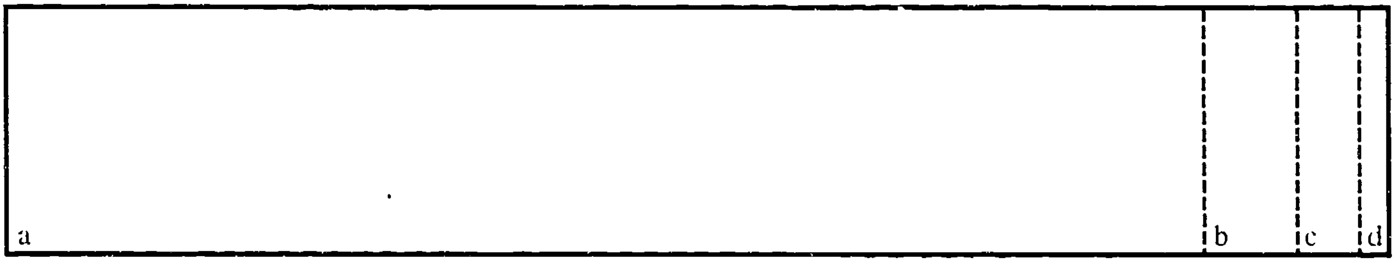
The students will construct a forty-five foot long time line chart of the Earth's history on one continuous sheet of butcher paper. Using resources available in either the library or classroom, the students will be researching geologic and evolutionary events and locating them on the time line chart.

## Materials:

- 45-foot long strip of butcher paper
- Felt pens
- Scissors

## Procedure:

1. Have the students divide the 45-foot long strip of butcher paper into four major divisions as follows. (Starting from left, see illustration on next page)




a. Precambrian (Pre) Era, which will be 39 feet long
b. Paleozoic (Pa) Era, 3 feet long
c. Mesozoic (M) Era, 2 feet long
d. Cenozoic (C) Era, 1 foot long

2. Draw a line separating each era and label them with the appropriate name.
3. Divide the students into 2–3 person teams and ask each team to collect materials to fill in the chart.
4. Using resource materials from the library or classroom, have students research the major geologic and evolutionary events that occurred in each era. (Refer to the Major Events in the Earth's History–see attached–for some possible events you might want to include.)
5. Students should record their findings on the chart. If they copied pictures of dinosaurs etc., they should paste them up in the appropriate areas on the chart.
6. Discuss the chart with the class when done. For example, ask the students to see where dinosaurs are on the chart and how long they existed before they became extinct. Have them identify when humans appeared and where they fit into the time chart.
7. Discuss the Earth's climatic past and how it has changed throughout its history.

## Student Learning Portfolio:

1. Write a short paper on one of the major events found on the time line chart.
2. Identify periods of global climate warming and cooling on the time line chart and record in notebooks.
3. Include a photograph or hand drawn replica of the class time line. The butcher paper time line could be a permanent display in the classroom. Students could earn extra credit throughout the year by adding materials onto the geologic time line.

## References:

*Timescale: An Atlas of the Fourth Dimension*, Nigel Calder, 1983.

*Environmental Evolution*. Edited by Lynn Margulis and Lorraine Olendzenski, 1992.

## Major Events in the Earth's History:

The following question-and-answer list represents a small sample of the significant events that have occurred throughout Earth history. The events are divided into three categories, Geologic, Biological, and Climatic. The eras are indicated as follows: Precambrian (Pre), Paleozoic (Pa), Mesozoic (M), and Cenozoic (Ce). The abbreviations "byr" and "myr" stand for billions and millions of years ago, respectively.❑

**Notes:**

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# How Has Earth and Its Climate Changed Over Time?

STUDENT GUIDE—ACTIVITY 4

**Definitions of Terms:**

*Geologic Time:* A term used to describe very long periods of time, typically measured in millions of years. It is termed "geologic" time because this is the time scale over which slow geological events can occur (such as mountain building, changes in the position of continents, the formation or disappearance of rivers).

*Eon:* A billion years. The Earth is approximately 4.5 eons old.

*Millennium:* A thousand years.

*Era:* For our convenience, geologic time is divided into eras of different durations, and eras are divided into periods. For example, we are currently living in the Quaternary Period of the Cenozoic Era. Dinosaurs disappeared at the end of the Cretaceous Period of the Mesozoic Era.

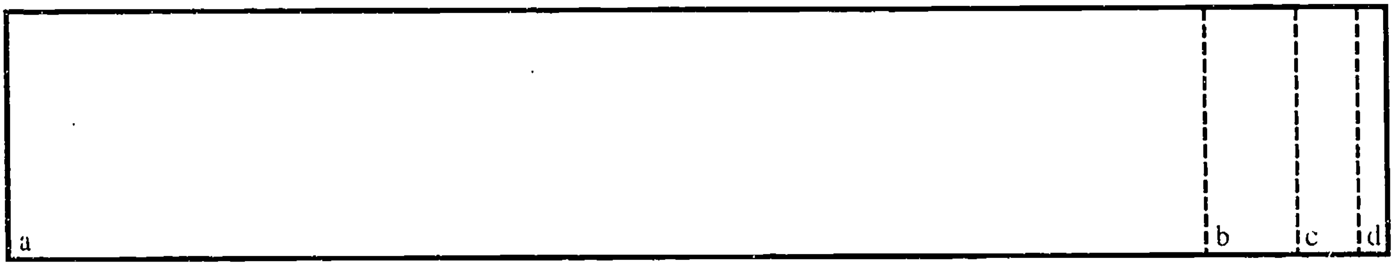
*Plate Tectonics:* The solid crust of the earth (including the continents and ocean basins) is made up of about a dozen major crustal plates that move across the surface of the Earth due to the influence of currents in the hot, almost molten mantle (the layer below the crust). The movement of these plates is responsible for the slow movement of the continents (continental drift).

## Activity:

You will construct a 45-foot long time line chart of the Earth's history on one continuous sheet of butcher paper. Using resources available in either the library or classroom, you will research geologic and evolutionary events and locate them on the time line chart.

## Materials:

- 45-foot long strip of butcher paper
- Felt pens
- Scissors




**Procedure:**

1. Measure and cut a 45-foot long strip of butcher paper and mount on the wall around the room or in the hall. Divide the paper into four major divisions as follows (starting from left to right):
   a. Precambrian Era, which will be 39 feet long
   b. Paleozoic Era, which will be 3 feet long
   c. Mesozoic Era, which will be 2 feet long
   d. Cenozoic Era, which will be 1 foot long
2. Draw a line separating each era and label them with the appropriate name.
3. Working in two- or three-person teams with assignments from your teacher, use library resources to collect facts about the important geological and/or evolutionary events that occurred in the different eras. Take notes on the events you discover and include a short description.
4. As a class, write your findings in the appropriate position along the time line. Discuss with the class the events you discovered and their significance.❑

**Notes:**

1. When was oxygen first evident on Earth?

**Climate Events**

2. What was the Earth's first atmosphere like?

**Climate Events**

3. When did the water vapor in the atmosphere first begin to condense into water and clouds?

**Climate Events**

4. When did the first ice age occur?

**Climate Events**

5. When did ozone first appear in Earth's atmosphere?

**Climate Events**

6. Were there other ice ages during the during the Precambrian Era?

**Climate Events**

7. After the initial warm phase of the early Earth, were there other warm periods?

**Climate Events**

8. Were there any ice ages in the Paleozoic Era?

**Climate Events**

*The Earth's atmosphere was originally composed primarily of water vapor and $CO_2$ about 4.5 byr. (Pre)*

*Oxygen first appeared about 1.8 byr as a by-product of the photosynthesis of primitive blue/green algae. (Pre)*

*2.3 byr. (Pre)*

*The Earth's water and clouds first formed about 4.4 byr. (Pre)*

*There is evidence that ice ages occurred three more times n the Precambrian Era: at 970, 770 and 670 myr . The last one, at 670 myr may have been responsible for a widespread extinction of algal species. (Pre)*

*Ozone first began to develop in the Earth's upper atmosphere about 1.6 byr. (Pre)*

*An ice age occurred around 440 myr (Ordovician period) throughout Africa. Many fish species were destroyed and trilobites suffered. A second ice age occurred near the end of the Paleozoic Era about 360 myr. A third ice age around 290 myr (Carboniferous period) ended a coal-making period in the U.S. and Europe and started one between China and Siberia (see below).*

*In between the ice ages, the Earth had several relatively warm periods. The first of these occurred between 430–60 myr, during the end of the Ordovician through the Devonian periods. A second ice age occurred about 270 myr, during the Permian period. (Pa)*

9. How long was the "greenhouse period" in the Mesozoic era?

Climate Events

10. What happened during this warming trend in the Mesozoic era?

Climate Events

11. What was the climate like at the beginning of the Cenozoic era?

Climate Events

12. What climatic changes occurred during the Cenozoic Era?

Climate Events

13. What caused the Earth's global climate to cool?

Climate Events

14. What were the features of Earth's climate from 25–15 myr.

Climate Events

15. How did the Earth's climate change during the Cenozoic Era?

Climate Events

16. Did ice ages occur in the Cenozoic Era?

Climate Events

*Flowering plants evolved about 123 myr. In addition, several climatic changes occurred throughout this era, causing sea level to rise and fall several times. (M) Flowering plants began to displace conifers, ginkgoes, etc. Insects multiplied, small mammals and birds evolved. (M)*

*The greenhouse period of the Mesozoic era lasted from about 170–117 myr.*

*Up until 50 myr, the climate was mild, then it changed. The oceans cooled by several degrees Centigrade. The global climate then vacilated up and down, but generally cooled. (Ce)*

*The Cenozoic era opened with an ice age, resulting in another period of coal-making in western North America.*

*Between 25–15 myr, the Earth's climate was mild. However, another ice age occurred about 15 myr (Pliocene Epoch). And this time, Antarctica went into a permanent deep freeze. (Ce)*

*The rearrangement of the continents interfered with the ocean currents' distribution of warmth (50–40 myr). (Ce)*

*Beginning about 3.5 myr, ice ages occurred in cycles of about 90,000 years. Initially, they were not severe but became so about 2.4 myr. (Ce)*

*The Earth's global climate switched between cold and mild many times during the Miocene Epoch, 25–14 myr. During this time, the antarctic ice sheets were the largest ever and worldwide volcanic activity occurred. (Ce)*

17. How many ice ages occurred during the Cenozoic Era?

Climate Events

18. When did the last ice age occur?

Climate Events

19. What caused the ice ages?

Climate Events

20. When did the earliest known life-forms develop?

Biological Events

21. What are stromalites and why are they important?

Biological Events

22. When did the nucleus first appear in single-celled organisms?

Biological Events

23. When did chloroplasts first develop?

Biological Events

24. When did multicelled organisms first appear?

Biological Events

*The last ice age ended about 18,000 years ago. Between 18,000 and 450,000 years ago, there were at least five major ice ages, not to mention "false" ice ages. In between these ice ages were periods of global warming. (Ce)*

*Twenty-nine episodes of glaciation occurred between 3.25 myr and 550,000 years ago. The Illinoian Ice Age of 430,000 years ago went as far south as St. Louis, and evidence indicates that icebergs existed within the English channel at this time. (Ce)*

*The earliest life forms, in the form of very primitive bacteria, probably appeared between 3.8 and 3.5 byr. (Pre)*

*Causes of the ice ages include irregular cycles of the Earth's orbit and gravitational tugs of the sun and the moon during these irregular orbits that alter the Earth's tilt on its axis by a few degrees every 40,000 years.*

*The first nucleated (nucleus-containing) cells developed about 1.7 byr. These were similar to today's molds or fungi. (Pre)*

*Stromalites are pigmented, plant-like bacteria that form large colonial structures in shallow tidal waters. Stromatolite colonies formed very early in Earth's history and fossil remains of stromatolites are among the oldest fossils known (3.5 byr). Living stromatolites exist today virtually unchanged in appearance from that of the earliest fossils. (Pre)*

*The first multicelled organism was a type of aquatic plant that occurred about 1.3 byr. (Pre)*

*The first true chloroplasts developed about 1.5 byr. (Pre)*

25. When did the first "brain" develop?

Biological Events

26. What were trilobites and when did they first appear?

Biological Events

27. When did the mollusks first appear?

Biological Events

28. When did the first fish evolve?

Biological Events

29. When did plants first appear on land?

Biological Events

30. When did animal life first occur on land?

Biological Events

31. When did the earliest trees form?

Biological Events

32. When did the first pine trees (conifers) exist?

Biological Events

*They were segmented, shelled organisms with eyes that showed up about 560 myr (Cambrian Period) and survived successfully for millions of years. (Pa)*

*At the very end of the Precambrian Era and the beginning of the Paleozoic Era, worms and arthropods were evolving. These organisms were the first to show brain-like organs (collections of nerve cells)–about 600 myr. (Pre and Pa).*

*"Bony" fish first evolved about 510 myr (end of the Cambrian Period). The first "jawed " fish evolved about 425 myr (Silurian Period). (Pa)*

*Mollusks first show up in the fossil record from about 570 myr (Cambrian Period). (Pa)*

*About 400 myr (Devonian Period), certain predatory fish developed lungs and ventured onto land. (Pa)*

*Plants evolving from the earliest blue-green bacteria and algae first appeared on land about 425 myr (Silurian Period). (Pa)*

*The first coniferous forests occurred about 350 myr (Carboniferous Period). (Pa)*

*Ancient fern-like trees and forests developed in swampy areas 410–370 myr (Devonian Period). (Pa)*

33. When did the first true land animals evolve?

Biological Events

34. When did the first major extinction as recorded by the fossil record occur?

Biological Events

35. When did winged insects appear?

Biological Events

36. When did the first reptiles evolve?

Biological Events

37. When did the largest mass extinction in Earth's history occur?

Biological Events

38. How do scientists explain this mass extinction?

Biological Events

39. What happened after this extinction?

Biological Events

40. When were the dinosaurs the dominant vertebrates?

Biological Events

*The first major extinction occurred about 370 myr (Frasnian stage of the Devonian Period). Some scientists attribute this and other extinctions to a cosmic object colliding with Earth. This catastrophe was followed by the evolution of amphibians. (Pa)*

*Millipedes, mites, spiders, scorpions, and insects such as springtails were the first to adapt to carry out their complete life cycle on land. They did so about 398 myr (Devonian Period). (Pa)*

*The evolution of animals like reptiles onto land occurred about 315 myr (end of Carboniferous Period). (Pa)*

*Dragonflies and other winged insects evolved about 330 myr (Carboniferous Period). (Pa)*

*Two theories have been proposed: 1) The development of supercontinent Pangea and a subsequent drop in the sea level; and 2) A collision between Earth and a large comet. (Pa)*

*About 245 myr (end of the Permian Period and the Paleozoic Era), 96% of all marine species were destroyed. Reefs and seabeds were annihilated.*

*Almost all of the Mesozoic Era, 235–65 myr. (M)*

*Other creatures evolved, including mammal-like reptiles called lystrosaurs, modern corals and squid-like mollusks, and early flowering plants (bennettitales) occurred between 245 and 235 myr (early Triassic Period of the Mesozoic Era).*

41. When did the first bird-like reptile evolve?

**Biological Events**

42. When did monotremes (duckbill platypus) evolve?

**Biological Events**

43. When did the marsupials (kangaroos, opossums) evolve?

**Biological Events**

44. When did the placental mammals evolve?

**Biological Events**

45. What happened about 65 myr?

**Biological Events**

46. What happened during this extinction?

**Biological Events**

47. What animals first appeared in the Cenozoic Era?

**Biological Events**

48. When did the New and Old World monkeys evolve?

**Biological Events**

*The monotremes evolved before 175 myr (Jurassic Period) in Australia. (M)*

*The first bird-like reptile, Archeopteryx, shows up in the fossil record about 123 myr (Cretaceous Period). (M)*

*About 114 myr (Cretaceous period) in Mongolia, according to the fossil record. (M)*

*The marsupials evolved about 125 myr. (Cretaceous Period). (M)*

*Plants in western North America suffered, sea level dropped, and reefs and many species of marine plants and animals died out. Small reptiles, birds, and small mammals survived. (Ce)*

*The fossil record indicates that a mass extinction occurred about 65 myr, possibly as a result of a cosmic object striking Earth. (Ce)*

*New and Old World monkeys evolved about 35 myr, along with rhinos, pigs, and bears. (Ce)*

*The ancestors of lions and bears evolved about 62 myr. (Paleocene Epoch), rodents, bats, whales, horses, elephants, and ancient cats and dogs evolved between 55–35 myr. (Eocene and Oligocene Epochs). (Ce)*

49. When did grasses evolve?

Biological Events

50. When did humans' ancestors first evolve?

Biological Events

51. When did deer and antelope evolve?

Biological Events

52. When did orangutans and baboons evolve?

Biological Events

53. When did early humans evolve?

Biological Events

54. When did humans first use tools and fire?

Biological Events

55. Where did humans originate?

Biological Events

56. When did the modern horse evolve?

Biological Events

*Common ancestors of both humans and the great apes evolved about 20 myr. (Ce)*

*Grasses evolved from bamboo-like plants about 24 myr. It is considered a world-transforming plant as it heralded a global change to a cooler, drier time that allowed for grazing animals to evolve. (Ce)*

*Orangutans and baboons evolved about 10–4 myr. (Ce)*

*Deer and antelope and ancestors of cows evolved between 19–20 myr. (Miocene Epoch). (Ce)*

*Stone tools date back to about 2.4–2 myr, but the use of fire isn't obvious in the paleontological record until about 1 myr. (Ce)*

*Early Australopithecenes evolved about 4 myr, followed by Homo habilis 2 myr, and Homo erectus 1.8 myr. (Quaternary Period, Recent Epoch). (Ce)*

*The modern horse evolved about 3.7 myr, along with primitive cattle. The zebra evolved later (2.5 myr). Lions and leopards evolved about 1.8 myr. (Ce)*

*Humans originated from Africa about 3.7 myr. (Ce)*

57. When did *Homo sapiens* evolve?

**Biological Events**

58. When did wooly mammoths exist?

**Biological Events**

59. When did the Neanderthals exist?

**Biological Events**

60. When did speech and language begin?

**Biological Events**

61. When did art and medicine first appear?

**Biological Events**

62. When did the modern humans first evolve?

**Biological Events**

63. When were calendars developed?

**Biological Events**

64. When were livestock domesticated?

**Biological Events**

*Wooly mammoths existed about 120,000 years ago. (Ce)*

*Homo sapiens evolved between 600,000 and 200,000 years ago. (Ce)*

*Current thinking has complex, modern speech and language beginning about 43,000 years ago and probably Neanderthal people had somewhat more limited speech capacity than modern humans. (Ce)*

*The Neanderthals (Homo sapiens neanderthals) evolved about 120,000 years ago and existed for 80,000 years in Eurasia (longer than the Homo sapiens sapiens, of which we are members, have so far existed). Neanderthals were extinct by about 34,000 years ago. (Ce)*

*Modern humans evolved about 40,000 years ago. (Ce)*

*Both art and medicine show up in the Neanderthal culture around 60,000 years ago, and before. (Ce)*

*Between 12,000–6,500 years ago dogs, sheep, goats, cows, and horses were domesticated. (Ce)*

*Calendars were developed as early as 35,000 years ago. (Ce)*

65. When were crops domesticated?

Biological Events

66. When did human civilizations begin?

Biological Events

67. When was the printing press developed?

Biological Events

68. What was the first important form of energy use?

Biological Events

69. When were the Earth's main population surges?

Biological Events

70. When were the earliest continents formed?

Geologic Events

71. What are the ages of the oldest rocks on Earth?

Geologic Events

72. When did the Earth's moon form?

Geologic Events

*Human civilization began about 10,000 years ago. (Ce)*

*Between 10,600–8,000 years ago, wheat, rice, and other crops were domesticated. (Ce)*

*Steam energy about 1717 A.D., followed by the development of fossil fuels in 1825, and nuclear energy in 1942.*

*The printing press was developed in 1450 A.D.*

*The earliest continents were first formed about 2.8 byr. (Pre)*

*The Earth's population booms were in 1000 A.D., 1700, 1930, and the 1960s.*

*The Earth's moon formed about 4.5 byr. (Pre)*

*The oldest rocks date back to 3.8 byr. (Pre)*

73. Where did the first coal deposits form and how long did it take?

Geologic Events

74. Were other coal deposits formed? If so when?

Geologic Events

75. When did the supercontinent Pangea fully form?

Geologic Events

76. When did the oil deposits form?

Geologic Events

77. When did Pangea begin to break apart?

Geologic Events

78. Were any other oil deposits laid down?

Geologic Events

79. When did Earth's magnetic fields reverse polarity (North Pole became South Pole and vice-versa)?

Geologic Events

80. Have the magnetic reversals stopped?

Geologic Events

*Around 270 myr (Permian Period), other coal deposits were laid down between China and Siberia due to tectonic forces. (Pa)*

*The first coal deposits formed in what is now Poland, Germany, England, Pennsylvania, and Kentucky when Europe and the eastern United States collided. The collision buried ancient fern forests between 320–290 myr (Devonian and Carboniferous Periods). (Pa)*

*The first group of oil deposits formed about 170 myr (Jurassic Period). (M)*

*Pangea fully formed about 230 myr. (M)*

*About 93–85 myr, oil accumulated at the greatest rate ever from organic sediments laid down in the Gulf of Mexico, Venezuela, North Africa, Saudi Arabia, and Iran. (M)*

*Pangea broke apart between 130–40 myr. (M)*

*The magnetic reversals continue and the rate of the reversals has actually increased to about 40 reversals in the most recent 10 myr. (Tertiary and Quaternary Periods). (Ce)*

*Before 65 myr, the Earth's poles had switched only once (between 84–72 myr, end of the Cretaceous Period). In the 10 myr following the presumed cosmic impact at 67 myr, the magnetic reversals occurred 16 times.*

81. What geological events occurred in the Cenozoic Era?

Geologic Events

82. Do scientists think there were any other major cosmic collisions during the Cenozoic Era?

Geologic Events

83. When did Australia, South America, Antarctica split apart?

Geologic Events

84. Were there other episodes of volcanic activity later in the Cenozoic Era?

Geologic Events

85. When did the magnetic poles reach their current locations?

Geologic Events

*Geologic evidence exists to indicate that another cosmic impact occurred about 37 myr. (Ce)*

*The North Atlantic Ocean opened up, Australia and Antarctica split, and India slid into Eurasia between 60–45 myr. (Ce)*

*The last widespread and intense episodes of volcanism occurred about 1 myr. (Ce)*

*These three continents split up between 35–30 myr (Oligocene Epoch). (Ce)*

*About 730,000. (Ce)*

# What Information Do Paleobotanists Use to Study Ancient Climates?

ACTIVITY 5

**Lesson Focus:**

How do paleobotanists use ancient pollen to find out about Earth's climatic past?

**Objective:**

The student will be able to:

1. Distinguish the structural differences that are used for pollen classification.
2. Analyze pollen sample analogs to replicate the way that scientists gather paleo-data.
3. Interpret pollen sample analogs to replicate how scientists determine past climates.

**Time:**

2 class periods

**Grade Level:**

8–10

**Key Concepts:**

Past climates, vegetation changes, scientific investigation

## Definitions of Terms:

*Pollen grain:* The microgametophyte of seed plants; each plant species has pollen grains with a shape unique to that species.

*Paleobotanist:* Scientists who study vegetation of the past.

*Paleoclimatologist:* Scientists who study past climates.

*Palynologists:* Scientists who study pollen.

*Sediment:* Is made up of organic (e.g., dead algae, dead fish, pollen) and mineral (e.g., soil erosion deposited from streams) materials that blanket the bottom of lakes, riverbeds, or oceans.

## Background:

Evidence found in the geologic and plant fossil records indicates that the Earth's climate has been very different from today's in the distant past. There have, however, also been substantial climatic fluctuations within the last several centuries, too recently for the changes to be reflected in the fossil record. These more recent changes are important to understanding potential future climate change, and so scientists have developed methods to study the climate of the recent past. Although accurate human-recorded weather records cover only the last few decades, paleoclimatologists and paleobotantists have found ways of identifying the kinds of plants that grew in a given area in the past, and can infer from the plants what kind of climate must have prevailed at the time. Because plants are generally distributed across the landscape based on temperature and precipitation patterns, as these climatic factors changed, the plant communities also changed. Knowing the conditions the plants preferred, scientists can make general conclusions about the past climate.

One way paleobotanists can map plant distribution over time is by studying the pollen left in lake sediments by wind-pollinated plants that once grew in the lake's vicinity. Sediment in the bottom of lakes is ideal for determining pollen changes over time because sediments tend to be laid down in annual layers (much like trees grow annual rings). Each layer traps the pollen that sank into the lake, or was carried into it by stream flow that year. To look at the "pollen history" of the lake, scientists collect long cores of the lake sediment. Scientists obtain these samples with long tubes that are approximately 5 centimeters (cm) in diameter. A series of casings hold the hole open as the drilling proceeds. The cores can be 10 m long or longer, depending on how old the lake is and how much sediment has been deposited.

The core that is removed is sampled every 10–20 cm and washed in solutions of very strong, corrosive chemicals such as potassium hydroxide, hydrochloric acid, and hydrogen fluoride. This harsh process removes the organic and mineral particles in the sample, except for the pollen, which is composed of some of the most chemically resistent organic compounds in nature. Microscope slides are made of the remaining pollen and are examined to count and identify the pollen grains. Because every plant species has a distinctive pollen morphology (called sculpturing), botanists can identify from which plant the pollen came.

Through pollen analysis, botanists can estimate the species composition of a lake area by comparing the relative amount of pollen each species contributes to the whole pollen sample. Carbon-14 dating of the lake sediment cores gives an approximate age of the sample.

Palynologists can infer the climate of the layer being studied by relating it to the current climatic preferences of the same plants. For example, a sediment layer with large amounts of western red cedar pollen can be inferred to have been deposited during a cool, wet climatic period, because those are the current conditions to which this species is adapted.

There are two reasons that scientists who study climate change are interested in past climates. First, by examining the pattern of plant changes over time, they can determine how long it took for plant species to migrate into or out of a given area due to natural processes of climate change. This information makes it easier to predict the speed with which plant communities might change in response to human-induced climate change. Second, by determining the kinds of plants that existed in an area when the climate was warmer than at present, the scientists can more accurately predict which plants will be most likely to thrive if the climate warms again.

## Activity:

Students will examine pictures of pollen grains representing several different species, showing the structural differences that scientists use for identification. Students will analyze model soil samples with material mixed in to represent pollen grains. They will determine the type and amount of the "pollen" in the samples and, based on information provided to them, will determine the type of vegetation and the age of their samples and will make some conclusions about the likely climate at the time the pollen was shed.

## Materials:

1. Pictures of several types of pollen (attached page 34) (*Note to Teacher:* An excellent example of different pollen types is found in the October 1984 issue of *National Geographic* on p. 492–493.)
2. One large graduated cylinder (1000 mL at least) for the "sediment" column
3. Five different types of "sediment" (any soil, sand, potting mixture, etc. that can be layered to show five distinct layers. You will need enough for the sediment column and the corresponding "samples")
4. Small, resealable plastic bags
5. Pie tins (one for each sediment sample)
6. Eleven different colors of paper "dots" (from a hole punch) to serve as pollen analogs
7. Key to the different "pollen" colors showing which colors represent which plants, and information about the climatic requirements for each plant species
8. Worksheets (provided)

## Procedure:

*Plants have pollen with unique morphology that can be used to identify them.*

Ask the students to carefully examine the pictures of the different pollen types, noting the structural differences in each type. Discuss those differences, and how scientists can use those to identify the plants from which they were shed.

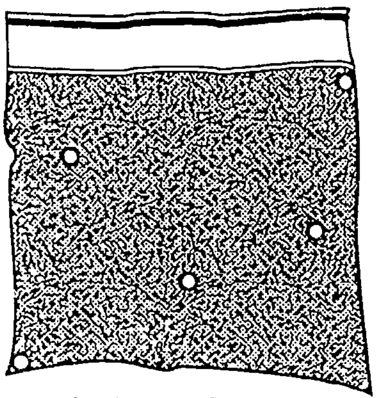
*Analysis of pollen data gives evidence of paleoclimate.*

*Note to Teacher:* The following exercise was developed based on actual pollen data collected from a lake in southwest Washington State. Other regions of the country may have similar pollen records available. The botany departments of local universities may be able to give you information on locally relevant pollen data that you can adapt to this exercise.

1. Layer five different kinds of soil (garden soil, sand, fine gravel, potting mixture, peat moss, vermiculite, perlite, or similar material) into the graduated cylinder so they form five distinct layers. This represents the sediment core with which the students will work. Label the layers with their respective ages as shown in Figure 1.
2. Choose eleven different colors of paper to represent the "pollen" grains. *Note to Teacher:* We have suggested colors (Tables 1 and 2); however, you can make your own

color choices. *To avoid confusion later, make certain you note any color changes on both Tables 1 and 2.*

3. Make the different color pollen grains by using the "dots" from a standard hole punch.
4. "Sediment" samples. Prepare one sample for each pair of students. It is important to make certain that all five layers of your sediment core are represented.
5. Fill the resealable plastic bags with approximately 100 mL of the same material representing a sediment layer in the core. For example, if you have sand representing Layer 1 in the sediment column, place 100 mL of sand in a plastic bag. If you chose a dark soil for Layer 2, place 100 mL of dark soil in a second plastic bag and so on until of 5 layers in the column have corresponding samples. Replicate until you have enough samples to distribute one to each pair of students.



6. Using Table 1 as a guide, place into each sample bag approximately 25 paper dots to represent the pollen found in that layer.
7. Begin by showing the sediment column and discussing the way that sediment is laid down in lakes, how it traps pollen, and how scientists obtain the lake sediment cores.
8. Hand out one sediment sample, a pie tin, and a worksheet to each pair of students. Explain that each sample contains "pollen" from the species prevalent at the time of deposition. Students should empty the contents of their sample into a pie tin. Their task is to sift through the sample to separate out the pollen from the sediment, determine from a key (Table 2) what species of plants are represented and what percentage of the total pollen comes from each species.
9. If more than one pair of students worked on any sediment layer, ask them to get together and come to a consensus on what plants they've found and the relative abundances. The worksheet can be used to keep track of the percentage of plants found in each layer. From the key (Table 2) have them come to a consensus on what the climate must have been like at the time of deposition.
10. Ask each group studying a sediment layer to report their conclusions to the class, then as a class build a consensus on the pattern of climate change represented by this sediment column. Students can complete their worksheets with data provided by students studying different sediment layers.
11. Once a class consensus has been reached, you may wish to share the interpretation of Dr. Cathy Whitlock, the paleoclimatologist that did the research this exercise is based on, with the class. The general conclusions of her paper and a map showing the area studied is provided in the attached summary "The Paleoclimate of Battle Ground Lake, Southern Puget Trough", Washington.

*Note to Teacher:* Ask the students to carefully replace the pollen in the sample bags. These samples can be used again.

## Student Learning Portfolio:

1. Pollen grain drawings in log
2. Log entry on age/type of pollen in soil sample, and how it relates to climate
3. Completed worksheets

## Extensions:

The extensions can be focused on further exploration of the role of pollen analysis in paleoclimate studies, on further student interest in the sculpturing of pollen itself, or on the role of pollen as an allergen. Possibilities are listed below.

1. Discuss some possible difficulties with obtaining sediment cores (tippy boats, bad weather, having the hole you've been drilling fill before you're done, etc.).
2. Discuss some reasons why most lake sediments can only tell you about vegetation hundreds or thousands of years ago (not millions). Possible answers–lakes aren't that long-lived, glaciers, mountain building, etc. will destroy lakes, sediment will eventually fill lakes completely.
3. Provide students with prepared pollen slides, or have students collect and mount their own pollen on slides for examination under a microscope. Ask them to sketch the different pollen types and produce their own identification key to pollen.

**Figure 1. Model Sediment Column**

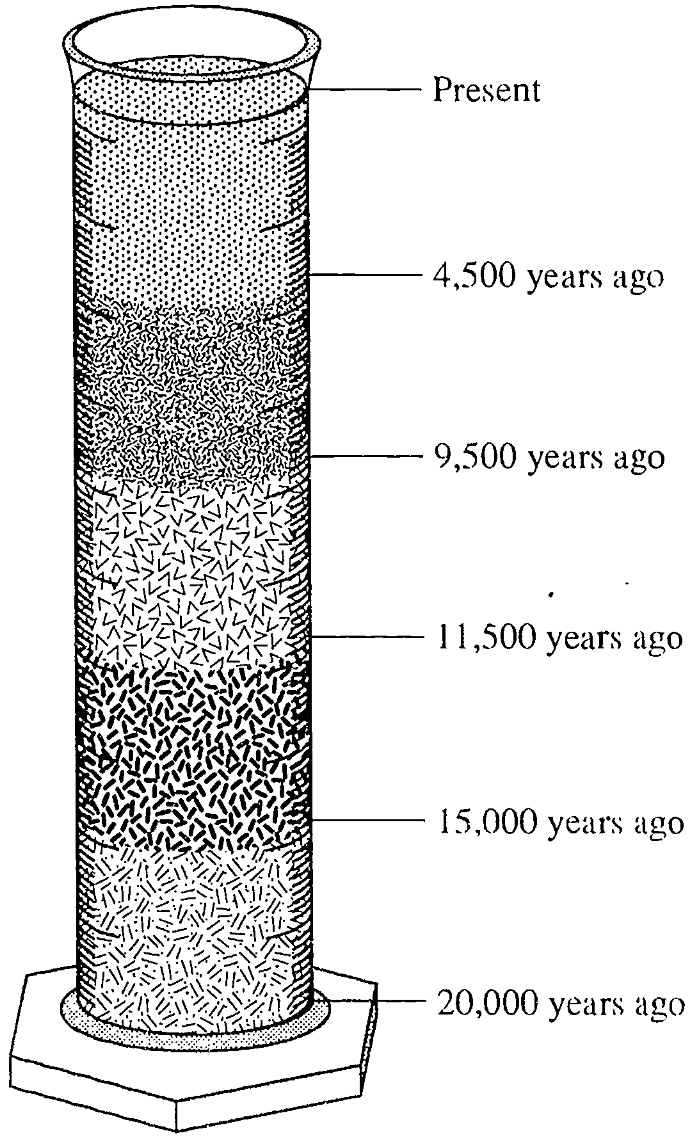


**Table 1.** Paper Dots and Amounts to Be Used to Make Up Each Sediment Sample (In the sediment age designations, ybp = years before present.)

| Sediment Layer | Plant Species | Dot Color | Number of Dots | Percentage of Total |
|---|---|---|---|---|
| 5 (4,500 ypb to present) | Cedar | Dark Blue | 6 | 25% |
| | Hemlock | White | 5 | 20% |
| | Douglas Fir | Brown | 10 | 40% |
| | Alder | Red | 4 | 15% |
| 4 (4,500 ybp to 9,500 ybp) | Douglas Fir | Brown | 3 | 10% |
| | Oak | Bright Yellow | 3 | 10% |
| | Mixed Meadow Species | Light Yellow | 19 | 80% |
| 3 (9,500 ybp to 11,200 ybp) | Douglas Fir | Brown | 7 | 30% |
| | Grand Fir | Pink | 5 | 20% |
| | Alder | Red | 13 | 50% |
| 2 (11,200 ybp to 15,000 ybp) | Lodgepole Pine | Light Blue | 7 | 30% |
| | Englemann Spruce | Light Green | 3 | 15% |
| | Grand Fir | Pink | 3 | 15% |
| | Grasses & Sedges | Dark Green | 9 | 30% |
| | Alpine Sagebrush | Cream | 3 | 10% |
| 1 (15,000 ybp to 20,000 ybp) | Grasses & Sedges | Dark Green | 15 | 60% |
| | Alpine Sagebrush | Cream | 4 | 15% |
| | Lodgepole Pine | Light Blue | 4 | 15% |
| | Englemann Spruce | Light Green | 2 | 10% |

**Table 2.** Pollen Key and Climatic Characteristics of the Vegetation

| Dot Color | Species | Climatic Characteristics |
|---|---|---|
| White | Western Hemlock | Prinicipal dominant tree of many lowland, temperate sites. Requires very moist, temperate conditions for growth. |
| Brown | Douglas Fir | Broadly distributed throughout Pacific Northwest from moderately cool to warm sites. Grows best under temperate, somewhat moist conditions. |
| Dark green | Grasses & Sedges | This pollen from grasses and sedges typically found in very cool alpine/ subalpine meadow sites characterized by very cool summers, harsh winters, and short growing seasons. |
| Red | Alder | Widespread throughout Northwest, often colonizing gravel bars or other poor soils, prefers abundant water and can grow in cool climates. |
| Pink | Grand Fir | Found at mid-elevations in Cascade mountains. Grows in cool climates, but not as cold tolerant as trees found at higher altitudes. |
| Light Green | Englemann Spruce | Found in cold, usually subalpine sites. It is an important timberline species in the Rocky Mountains. |
| Dark Blue | Western Red Cedar | Found only in temperate, very moist climates. |
| Light Blue | Lodgepole Pine | Found in areas of very cool climates typically growing on poor soils, often at high altitudes (above 3,500 feet) under the present climate. |
| Light Yellow | Mixed Meadow Species | This pollen is typical of a mixture of herbaceous plants common to warm-temperate meadowlands, such as may be found in the Willamette Valley in Oregon. Typically, these species grow in areas of warm summer temperatures and summer drought. |
| Dark Yellow | Oak | Found in warm-temperate sites characterized by dry, warm summers, such as can be found today from Oregon's Willamette Valley south into California. |
| Cream | Alpine Sagebrush | Woody, low-growing shrub related to the sagebrush of eastern Washington Oregon. Found only at high-altitude, cold sites. |

### The Paleoclimate of Battle Ground Lake, Southern Puget Trough, Washington State:

The research site is located 30 km north of the Columbia River, in Clark County Washington, near the town of Battle Ground (Figure 2). The lake has been in existence for at least the last 20,000 years, and has continuously accumulated sediments through most of that time. Trapped in the sediments are pollen grains from the plants that grew in the general vicinity of the lake at the time the sediments were deposited. By examining the pollen in different layers of sediment from the bottom layer to the top, we can reconstruct the vegetation changes that have occurred in the area during the lake's existence. Because we know something about the climatic conditions that the plants needed to survive, we can use the vegetation data to reconstruct the past climate in the area for the entire 20,000 year period.

Many layers have been identified by paleoclimatologists. For simplicity sake, we will combine these into five major layers. The age of each layer has been established by radiocarbon dating and by reference to volcanic ash layers of known age from Mt. St. Helens and from the explosion of Mt. Mazama (now Crater Lake in Oregon).

**Figure 2.**


### Layer#1: 20,000 – 15,000 Years Before Present (ybp):

Glacial maximum, with nearly a vertical mile of ice over the site of Seattle, and the continental glaciers extending south of the present site of Olympia. An alpine glacier from Mt. St. Helens extended down the Lewis River Valley to within 30 km of the lake site. The lake area climate was cold, with a short growing season. The landscape resembled an arctic/alpine tundra, with the meadows dominated by alpine grasses/sedges, low woody shrubs, and scattered tree islands of cold-tolerant Engelmann spruce and lodgepole pine.

### Layer #2: 15,000 – 11,200 ybp:

Glaciers have begun to recede as the climate starts a warming trend. Although still cold in comparison to the present climate, the warming has progressed enough to cause the tundra vegetation to begin to be replaced by more extensive forests of lodgepole pine, Engelmann spruce, and grand fir in an open woodland setting. Further north in the northern and central Puget Lowland, many new areas have been opened up to plant colonization by the glacial recession, and lodgepole pine has invaded these new areas.

### Layer #3: 11,200 – 9,500 ybp:

The warming continues and the first occurrence of "modern", temperate coniferous forest is found in this period as Douglas-fir, alder, and grand fir dominate in forests not unlike those that occur today. The climate is similar to today's climate as well.

### Layer #4: 9,500 –4,500 ybp:

The climate continues to warm with mild, moist winters and warm, dry summers predominating. The forests of the previous period (which needed cooler, moister conditions) disappear to be replaced by more drought-adapted mixed oak, Douglas fir, and dry meadowland community. Today such vegetation is typical of areas of the Willamette Valley of Oregon that have escaped cultivation.

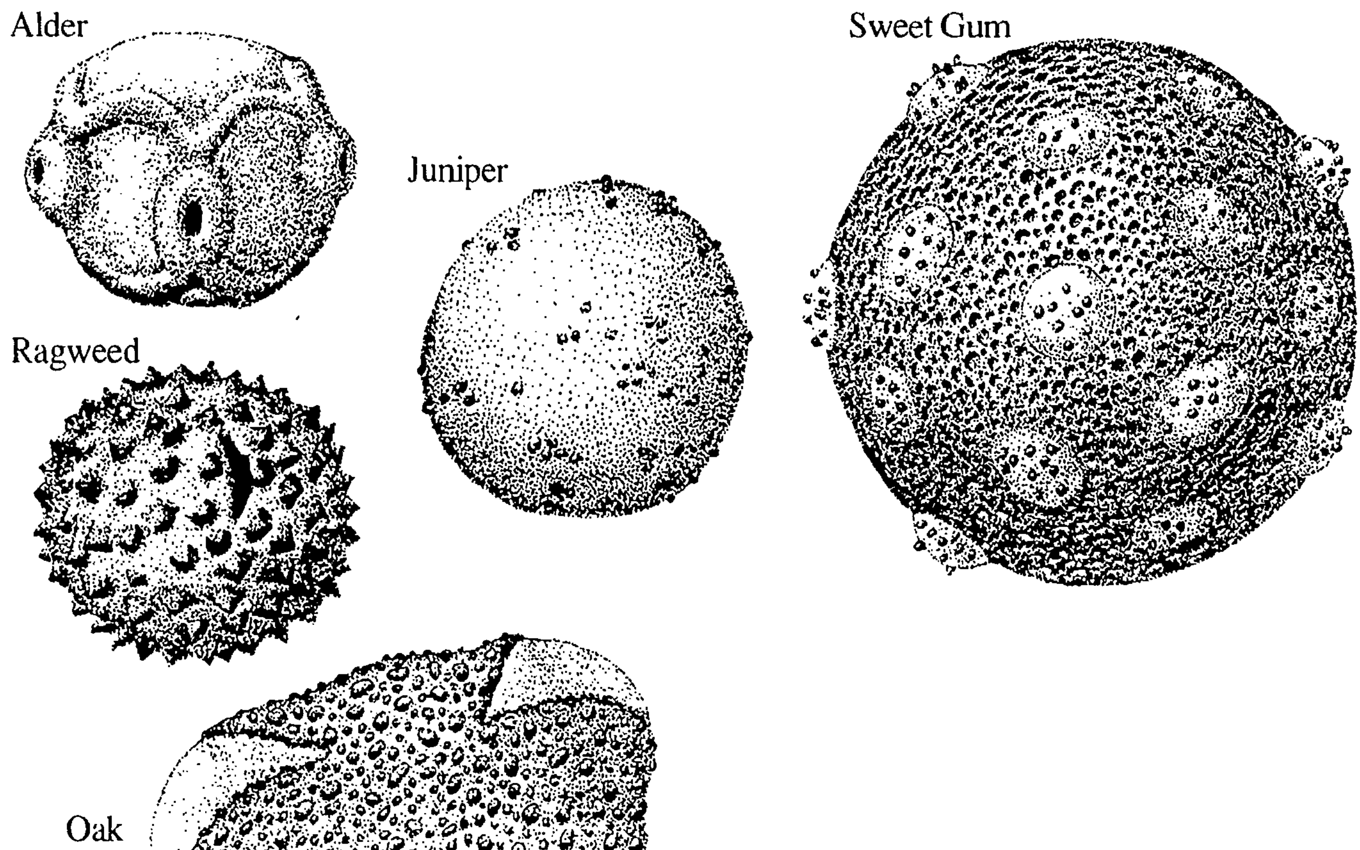
### Layer #5: 4,500 ybp –Present:

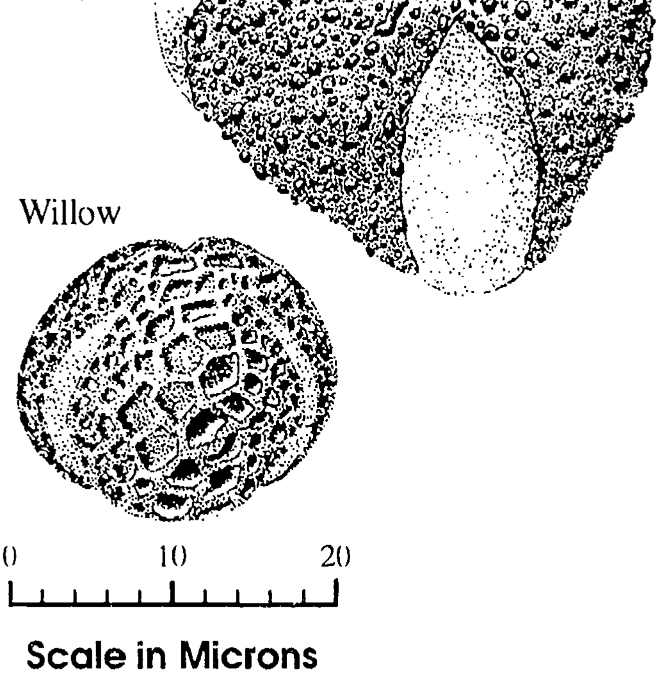
A cooler and moister period than the previous one. The dry-land vegetation is replaced by the extensive closed coniferous forests seen today, with hemlock and western red cedar dominating the areas of forest undisturbed by logging.

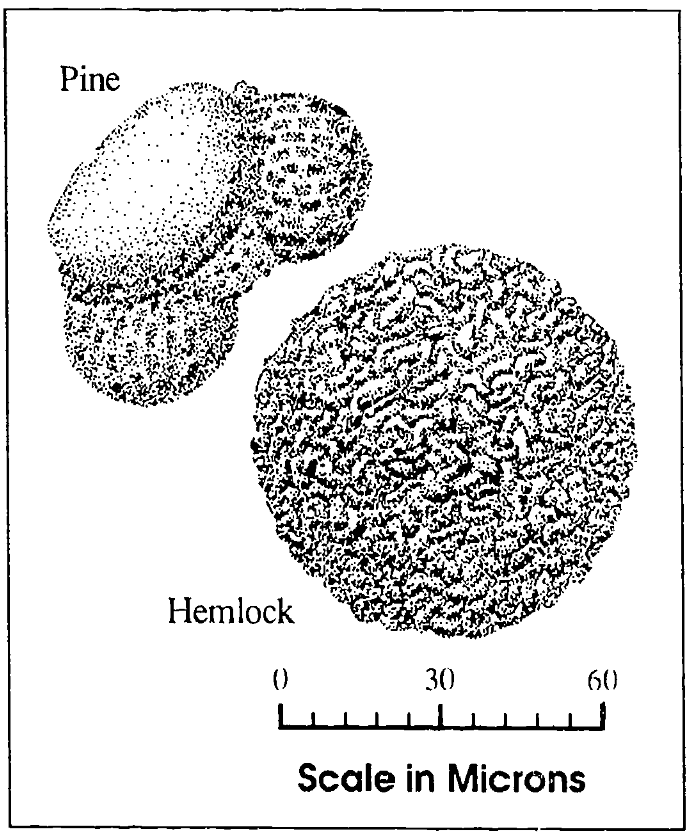
### Reference:

Barnosky, C. W. 1985. Late Quaternary vegetation near Battle Ground Lake, southern Puget Trough, Washington. *Geological Society of America Bull.* 96: 263–271.❑

## Several Types of Pollen




Pollen grain illustration courtesy of Allen M. Solomon, U.S. Environmental Protection Agency, Corvallis, Oregon 97333.

# What Information do Paleobotanists Use to Study Ancient Climates?

STUDENT GUIDE—ACTIVITY 5

**Definitions of Terms:**

***Pollen grain:*** The microgametophyte of seed plants; each plant species has pollen grains with a shape unique to that species.

***Paleobotanist*** : Scientists who study vegetation of the past.

***Paleoclimatologist*** : Scientists who study past climates.

***Palynologists*** : Scientists who study pollen.

***Sediment:*** Is made up of organic (e.g., dead algae, dead fish, pollen) and mineral (e.g., soil erosion deposited from streams) materials that blanket the bottom of lakes.

How do paleobotanists use ancient pollen to find out about Earth's climatic past?

## Activity:

You will analyze sediment samples with other material mixed in to represent pollen grains, determine the type and amount of the "pollen" in the samples. From this information, you will determine the type of vegetation and the age of the samples and will present conclusions about the likely climate at the time the pollen was shed.

## Materials:

1. Samples of sediment containing colored paper dots to represent pollen
2. Pie tin
3. Key to the different "pollen" colors showing which colors represent which plants, and information about the climatic requirements for each (Table 1, page 38)
4. Worksheet (your teacher will hand out)

## Procedure:

The following exercise was developed based on actual pollen data collected from a lake in southwest Washington State.

1. Your teacher will first show you a model sediment core containing five separate layers, each laid down at a different time in the past. Pay attention to the color and texture of each layer to help you identify the samples from each layer you will be working with.
2. Each pair of students will be given a sediment sample, a pie tin, and a worksheet. Each sample contains "pollen" (actually colored paper dots representing pollen, with each color representing pollen from a different species of plant) from

plants that grew in the area at the time the sediment was deposited.

3. Your and your partner will separate out the pollen from the sediment. Empty the sediment into the pie tin. Sift and dig until you have found all of the pollen grains. Keep the pollen grains separated by color.
4. Use the pollen key (Table 1, page 38) to determine what species of plants are represented in your sample and what percentage of the total pollen comes from each species. Fill in the worksheet for the sediment layer you are working on.
5. Use the pollen key also to figure out what the climate was when your layer was deposited (use the climate information given with each species description to do this). Be sure to compare your sediment sample to those in the entire sediment core so that you know what level your sample is from and how old it is.
6. Compare your conclusions with others in your class who were assigned the same sediment layer. Do you all find the same plant types? Do you all agree on the climate that probably existed at the time?
7. With your class, discuss the species of plants found in each layer and the climate that probably existed at the time. Fill in the rest of your worksheet with the information provided by other students who studied different sediment layers. Can you determine what the overall pattern of climate change was during these last 20,000 years? Can you speculate about what might have caused the changes?❑

**Notes:**

## Activity 5 Worksheet – Plant Species

| Sediment Layer | Western Hemlock | Douglas Fir | Grasses and Sedges | Alder | Grand Fir | Engle-mann Spruce | Western Red Cedar | Lodge-pole Pine | Mixed Meadow Species | Oak | Sage-brush |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |

69

69

**Table 1.** Pollen Key and Climatic Characteristics of the Vegetation

| Dot Color | Species | Climatic Characteristics |
|---|---|---|
| White | Western Hemlock | Prinicipal dominant tree of many lowland, temperate sites. Requires very moist, temperate conditions for growth. |
| Brown | Douglas Fir | Broadly distributed throughout Pacific Northwest from moderately cool to warm sites. Grows best under temperate, somewhat moist conditions. |
| Dark green | Grasses & Sedges | This pollen from grasses and sedges typically found in very cool alpine/ subalpine meadow sites characterized by very cool summers, harsh winters, and short growing seasons. |
| Red | Alder | Widespread throughout Northwest, often colonizing gravel bars or other poor soils, prefers abundant water and can grow in cool climates. |
| Pink | Grand Fir | Found at mid-elevations in Cascade mountains. Grows in cool climates, but not as cold tolerant as trees found at higher altitudes. |
| Light Green | Englemann Spruce | Found in cold, usually subalpine sites. It is an important timberline species in the Rocky Mountains. |
| Dark Blue | Western Red Cedar | Found only in temperate, very moist climates. |
| Light Blue | Lodgepole Pine | Found in areas of very cool climates typically growing on poor soils, often at high altitudes (above 3,500 feet) under the present climate. |
| Light Yellow | Mixed Meadow Species | This pollen is typical of a mixture of herbaceous plants common to warm-temperate meadowlands, such as may be found in the Willamette Valley in Oregon. Typically, these species grow in areas of warm summer temperatures and summer drought. |
| Dark Yellow | Oak | Found in warm-temperate sites characterized by dry, warm summers, such as can be found today from Oregon's Willamette Valley south into California. |
| Cream | Alpine Sagebrush | Woody, low-growing shrub related to the sagebrush of eastern Washington Oregon. Found only at high-altitude, cold sites. |

# What Is a Greenhouse and How Does It Trap Heat from the Sun?

ACTIVITY 6

**Lesson Focus:**

What is a greenhouse and how does it trap heat from the sun?

**Objective:**

The student will be able to:

1. Explain that greenhouses are composed of a clear physical barrier that allows visible light energy to enter, but blocks the escape of heat energy.
2. Demonstrate through data collection how visible light trapped in a model greenhouse will cause the temperature to rise.
3. Compare and contrast the processes affecting the heat balance of a green house and the processes affecting the heat balance of the earth.

**Time:**

1 class period

**Grade Level:**

8–10

**Key Concepts:**

Greenhouse effect, prediction, data collection, experimentation

## Definitions of Terms:

***Visible Light:*** Light in the area of the electromagnetic spectrum that can be seen with human eyes, generally extending from violet light (shorter wavelengths) to red light (longer wavelengths).

***Infrared Radiation:*** Although it can not be seen by the human eye, most objects absorb and emit infrared radiation. The infrared portion of the electromagnetic spectrum has longer wavelengths than visible light. It is also known as heat radiation.

***Trace Gases:*** Gases in Earth's atmosphere that make up a very small part of the total atmospheric composition. Important trace gases include water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), and others.

***Greenhouse Effect:*** The atmospheric phenomenon responsible for the Earth being warm enough to sustain life as we know it.

Trace gases in the atmosphere trap heat near the Earth's surface before it has a chance to escape into space. These gases are responsible for keeping the Earth's average temperature above freezing.

## Background:

Greenhouses are used extensively by botanists, commercial plant growers, and dedicated gardeners. Particularly in cool climates, greenhouses are useful for growing and propagating plants because they both allow sunlight to enter and prevent heat from escaping. Because they are covered with a transparent material, visible light from the outside can enter the greenhouse unhindered. Absorbed by the material inside the greenhouse, this visible light serves to warm the interior. The heat is prevented from leaving the greenhouse by the transparent covering, which serves to prevent outside winds from carrying the heat away, and which serves to reflect the heat energy back into the interior.

In some ways like the greenhouse covering, our atmosphere also serves to retain heat at the surface of the Earth. Much of the sun's energy reaches the Earth as visible light. Of the visible light that enters the atmosphere, about 30% is reflected back out into space by clouds, snow and ice-covered land and sea surfaces, and by atmospheric dust. The rest is absorbed by the liquids, solids, and gases that constitute our planet. The energy absorbed will eventually be reemitted, but not as visible light (Only *very hot* objects such as the sun can emit visible light). Instead, the energy will be emitted as longer-wavelength light called infrared radiation. It is also called "heat" radiation, because although we cannot see in infrared, we can feel it's presence as heat. This is what you feel when you put your hand near the surface of a hot skillet. Certain gases in our atmosphere (known as "trace" gases because they make up only a tiny fraction of the atmosphere) can absorb this outgoing infrared radiation, in effect trapping the heat energy. This trapped heat energy makes the Earth warmer than it would be without these trace gases.

The ability of certain trace gases to be relatively transparent to incoming visible light from the sun, yet opaque to the energy radiated from the earth is one of the best-understood processes in atmospheric science. This phenomenon has been called the "Greenhouse Effect" because the trace gases function to trap heat similar to the way that the transparent covering of a greenhouse traps heat. Without our atmospheric greenhouse effect, the surface temperature of the Earth would be far below freezing. On the other hand, an increase in the amounts of these trace gases in the atmosphere could result in more heat being trapped and cause increasing global temperatures.

Even apparently small increases in global temperature can cause major changes in global climate. For example, during the height of the last great ice age (which ended 10,000 to 12,000 years ago), the average global temperatures were only 5 °C (9 °F) lower than they are today. If global average temperatures rise by as little as 2 °C (3.4 °F), the planet would be warmer than any time in human history.

## Activity:

Students will measure, record, and graph the temperature differences between intact and perforated model greenhouses.

**Materials**:

For each team of four students:

- Two soda bottle "experimental chambers" (instructions page 43)
- Knife or scissors
- Tape
- Two thermometers
- One 150-watt floodlight bulb
- Clamp-on, portable reflector lamp
- Stand for lamp setup
- Graph paper

**Procedure:**

1. Introductory class discussion: Who has been inside a greenhouse? What are they like? What are they for?
2. Constructing a model greenhouse. Organize students into teams of four. Each team should use scissors to cut several elongated vents (1 × 4 inches) in the sides of one of the bottles (Figure 1). The vents make the greenhouse "leaky". Heat will escape easily . Leave the second bottle intact.

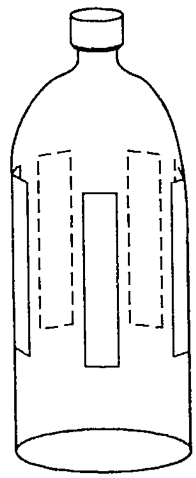


**Figure 1.**

3. The students will tape a thermometer (using cellophane tape or light-colored masking tape, not black electrical tape) to the sides of each bottle (facing out). They should make sure the bulb of the thermometer is just above the top of the opaque base (if the bulb is below the base, the thermometer may record the heat absorbed directly by the dark plastic, and complicate the results). It is important that the two thermometers are reading the same temperature before beginning the experiment. If not, explain how they can "zero" them by recording the difference and adjusting for the difference when the observations are made. The bottles should be capped.
4. Have the students set up a graph of time (in minutes) versus temperature upon which to record their observations. The temperature axis should be approximately 20 °C to 40 °C. Ask them to predict which bottle do they think will get hotter? Why? Record predictions in their logbook.
5. Each student will have a specific responsibility during the experiment. Working in pairs (one for the intact bottle, one for the perforated bottle), have one students keep track of time, and the other student record the temperature every two minutes on the graph.
6. Place both bottles approximately 6" away from the lamp with the thermometers facing away from the light (Figure 2).

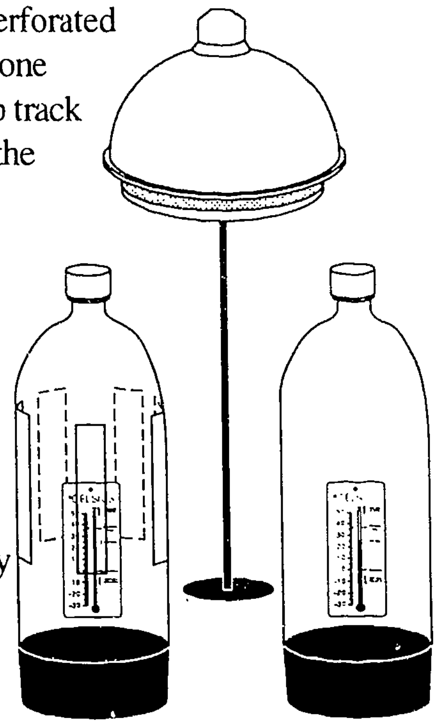


**Figure 2.**

7. Turn on the light and begin collecting your data. Continue the experiment for 20 minutes.

8. Discuss the results, develop some possible explanations (examples—the vents let cool air in). Relate the plastic greenhouse to big glass greenhouses, and then relate it to the Earth as the biggest greenhouse. Figure 3 is a representation of the Greenhouse Effect.

**Caution:** The analogy between the plastic cover and the atmosphere is not a perfect one. Greenhouse covers prevent heat losses from convection (air movement carrying away the heat) as well as by radiation (direct transfer of heat energy). The atmosphere prevents only heat loss by radiation. The greenhouses used in this activity serve as a crude model of the actual atmospheric process and are only of limited use in understanding the nature and scope of the actual Greenhouse Effect.

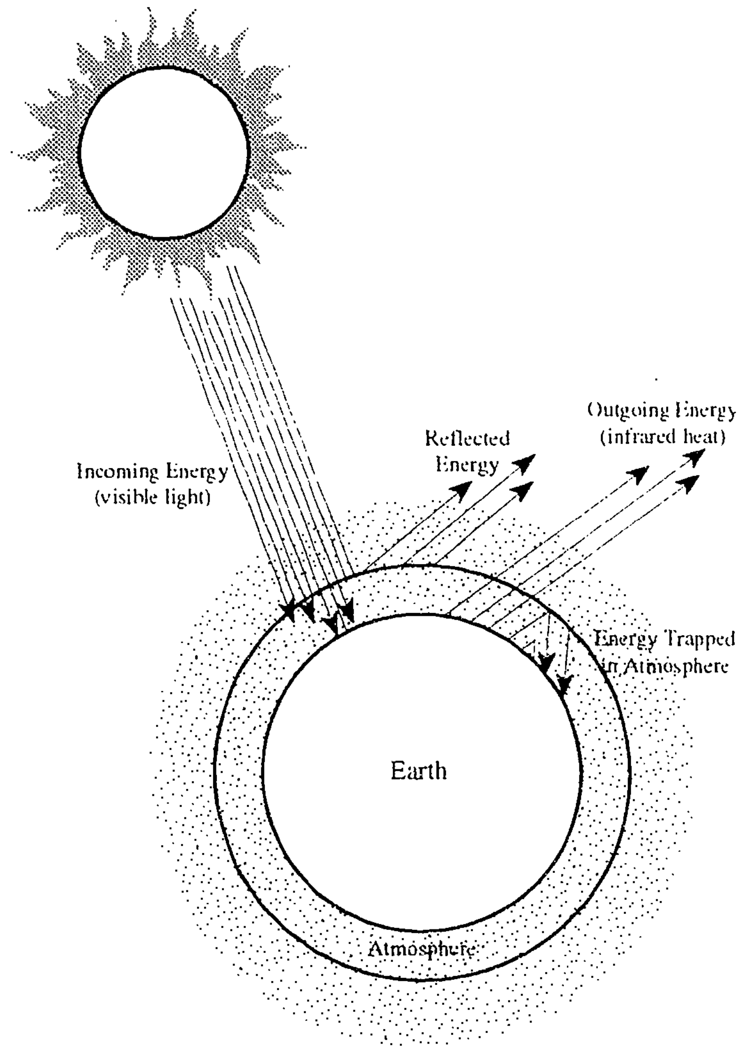



**Figure 3.** The Greenhouse Effect

## Student Learning Portfolio:

1. Construct a graph of temperature changes in the greenhouses. Each student should have a graph for their logbook.
2. Write an explanation of greenhouse warming.
3. Draw a diagram of Earth's greenhouse (possibly a simple picture of Earth, sun, light from the sun, and the atmosphere as a greenhouse cover). Student's develop their own, based on discussion—not just a copy.❑

**Experimental Chamber Construction:**

Clear bottles with removable opaque bases (Figure A) are ideal for these activities, however, their availability is limited in some parts of the country. If these bottles are limited in your area, the one-piece bottles will also work (Figure B). The following information is intended to assist you in preparing the bottles for use.

1. Two-piece bottles. Remove the bottle label by soaking in warm water. Fill the bottle with warm water to soften the glue holding the base. After a few minutes you can easily separate the base from the bottle. Set the base aside for future use. Cut off the end of the bottle approximately 1 inch from the bottom and discard the bottom piece (Figure C). Place the bottle in the plastic base and the experimental chamber is ready for use.
2. One-piece bottle. Remove the bottle label by soaking in warm water. It will be necessary to find a 14–16 oz. plastic container at least 4-1/2 inches in diameter at the top (sour cream, cottage cheese, and salsa containers work well) to serve as the base for the chamber. Cut the end of the bottle off approximately 2 inches from the bottom and discard the bottom piece (Figure C). Place the bottle in the plastic base and the experimental chamber is ready for use.

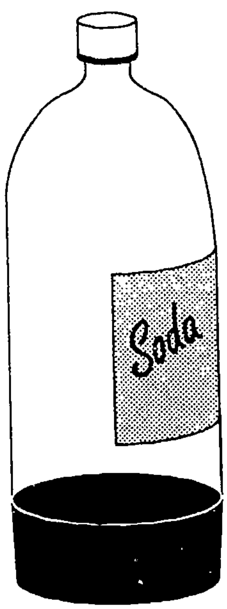



**Figure A.**

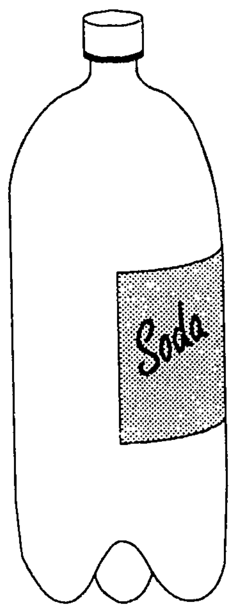



**Figure B.**

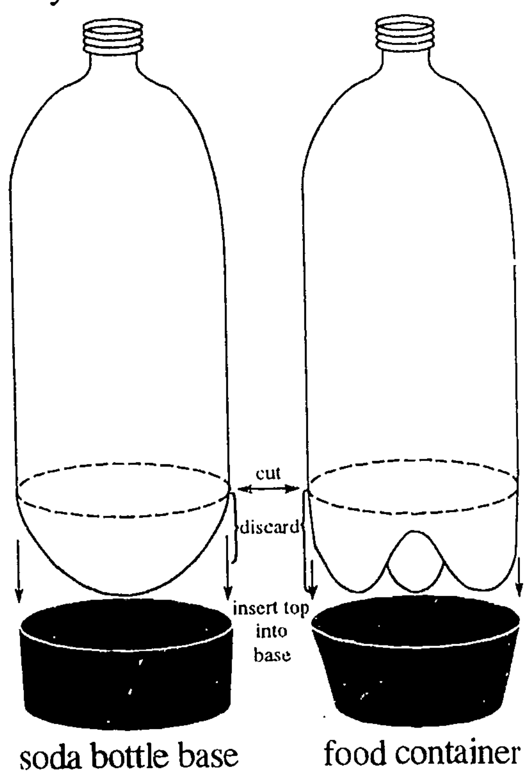



**Figure C.**

**Notes:**

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# What Is a Greenhouse and How Does It Trap Heat from the Sun?

STUDENT GUIDE—ACTIVITY 6

**Definitions of Terms:**

***Visible Light:*** Light in the area of the electromagnetic spectrum that can be seen with human eyes, generally extending from violet light (shorter wavelengths) to red light (longer wavelengths).

***Infrared Light:*** Although it can not be seen by the human eye, most objects absorb and emit infrared radiation. The infrared portion of the electromagnetic spectrum has longer wavelengths than visible light. It is also known as heat radiation.

***Trace Gases:*** Gases in Earth atmosphere that make up a very small part of the total atmospheric composition. Important trace gases include water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), and others.

***Greenhouse Effect:*** The atmospheric phenomenon responsible for the Earth being warm enough to sustain life as we know it. Trace gases in the atmosphere trap heat near the Earth's surface before it has a chance to escape into space. These gases are responsible for keeping the Earth's average temperature above freezing.

## Activity:

You will make model greenhouses. Using the models, you will measure, record, and graph the temperature differences between intact and vented model greenhouses.

## Materials:

For each team of four students:

- Two experimental exposure chambers
- Knife or scissors
- Tape
- Two thermometers
- One 150-watt floodlight
- Clamp-on, portable reflector lamp
- Stand for lamp setup
- Graph paper

## Procedure:

1. With your team, prepare two soda-bottle "experimental exposure chambers". Use scissors to cut several elongated vents (1 × 4 inches) in the sides of one of the bottles (Figure 1). Leave the second bottle intact.

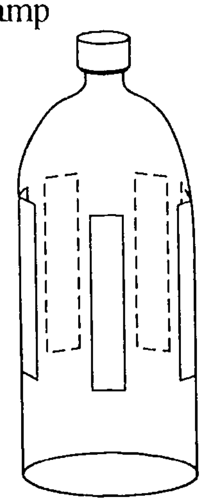


**Figure 1.**

2. Tape a thermometer (using cellophane tape or light-colored masking tape, not black electrical tape) to the sides of each bottle (facing out). Make sure the bulb of the thermometer is just above the top of the opaque base (if the bulb is below the base, the thermometer may record the heat absorbed directly by the dark plastic, and complicate the results). Also make sure that the two thermometers are reading the same temperature. If not, you can take that into account by recording the difference and adjusting for the difference when the observations are made. For example, if thermometer A reads 22 °C and thermometer B reads 23 °C when they both should read the same, you can either add 1 °C to every reading of A or subtract 1 °C from every reading of B to correct for the difference. Cap the bottles.
3. Set up a graph of time (in minutes) versus temperature upon which to record your observations. The temperature axis should be approximately 20 °C to 40 °C. Which bottle do you think will get hotter? Why? Record your prediction in your logbook.
4. Place both bottles approx. 6" away from the lamp with the thermometers facing away from the light (Figure 2).
5. Each of you should have a specific responsibility during the experiment. For each of your bottles, one of you should keep track of the time and the other should record the temperature every two minutes on your graph.

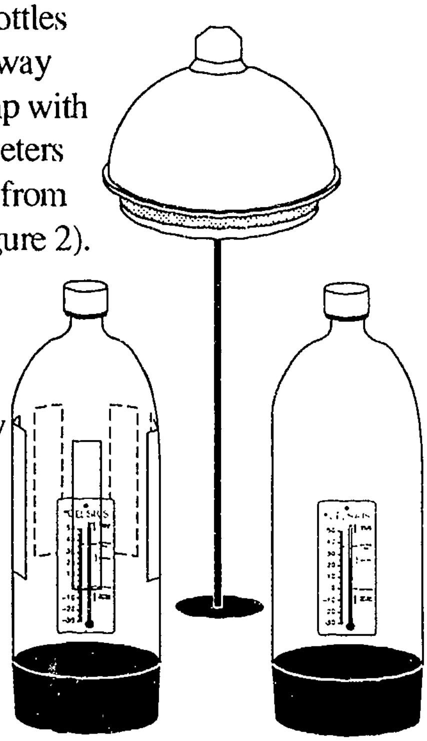


**Figure 2.**

6. Turn on the light and begin collecting your data. Continue the experiment for 20 minutes.
7. Compare the graphed data from the vented bottle and the intact bottle. What happened? How do you explain your observations?❑

**Notes:**

# What Factors Influence a Greenhouse?

ACTIVITY 7

**Lesson Focus:**
What factors affect the heat-trapping ability of a greenhouse?

**Objective:**
The student will be able to:

1. Identify at least three factors affecting the heat-trapping ability of a greenhouse, including transparency of the greenhouse cover, color of the surfaces inside the greenhouse, and the type of surface inside.
2. Record observed temperature data in graph form.
3. Explain the factors important in earth's greenhouse through a diagram.

**Time:**
2 class periods

**Grade Level:**
8–10

**Key Concepts:**
Greenhouse effect, prediction, data collection, experimentation

## Definitions of Terms:

***Albedo:*** The percentage of solar energy reflected back by a surface. In the atmosphere, clouds reflect solar energy into space as visible light. At the Earth's surface, light-colored land (i.e., deserts, snow and ice fields) and sea surfaces also reflect solar energy back into space.

***Feedback:*** A process in which part of the output of a system is fed back to another part of the system. Feedback generally serves as an internal control on what goes on in a system. Positive feedback can encourage more of what is already happening; negative feedback will discourage what is happening. In the case of global climate change, positive feedback would act to increase global warming while negative feedback would act to reduce it.

## Background:

The amount of solar radiation absorbed by the atmosphere and surfaces of the earth, and hence the amount of global warming, is strongly influence by several factors. These factors include:

1. *Clouds:* Depending on their altitude and optical properties, clouds may serve to

either cool or warm the Earth. Many types of clouds (notably large, thick, relatively lower altitude clouds such as cumulus and cumulo-nimbus types) significantly reflect incoming solar radiation, thereby increasing earth's albedo, or reflectivity, and serve to reduce solar warming of the surface. The whitewash on greenhouses has the same effect on a smaller scale. However, high-altitude, thinner clouds such as cirrus types act primarily to absorb long-wave radiation from the earth's surface, causing increased warming. If global temperatures are indeed on the rise, one of the likely consequences is increased surface water evaporation. The scientific community is uncertain whether increased evaporation will result in more cloud formation, and if so, what type of clouds would form. These are clearly critical questions to answer as scientists attempt to predict the future global climate.

2. *Surface Albedo:* Just as some clouds reflect solar energy into space as visible light, so do light-colored land and sea surfaces. This surface albedo strongly influences the absorption of sunlight. Snow and ice-cover is highly reflective, as are light-colored deserts. Large expanses of reflective surfaces can significantly reduce solar warming (white sand in a model greenhouse has the same effect). If global temperatures increase, snow and ice cover may shrink. The exposed darker surfaces underneath may absorb more solar radiation, causing further warming. This is an example of a "positive-feedback" mechanism. Scientists are uncertain as to the importance and magnitude of the feedback and it is currently a matter of serious scientific study and debate.

3. *Oceans:* Water has the capacity to store and transport large amounts of heat energy. (The model greenhouse with standing water demonstrates this in the activity below.) Thus, because of their enormous size and depth, the Earth's oceans are extremely important in determining global heat exchange and, hence, global climate. In addition, oceans are an important sink for atmospheric $CO_2$, and their ability to absorb $CO_2$ is strongly related to ocean temperature. Thus, oceans are important in determining the future rate of increase in atmospheric $CO_2$, as well as influencing the rate of global temperature change. To date, scientists do not have sufficient information to quantify the ocean's effect on the atmosphere and the climate, but significant scientific efforts are under way to do so.

## Activity:

Students will set up a selection of model greenhouses with different properties and will observe, record, and graph the differences in temperature between them. Students will brainstorm possible reasons for the observed differences.

## Materials:

For each team of four students:

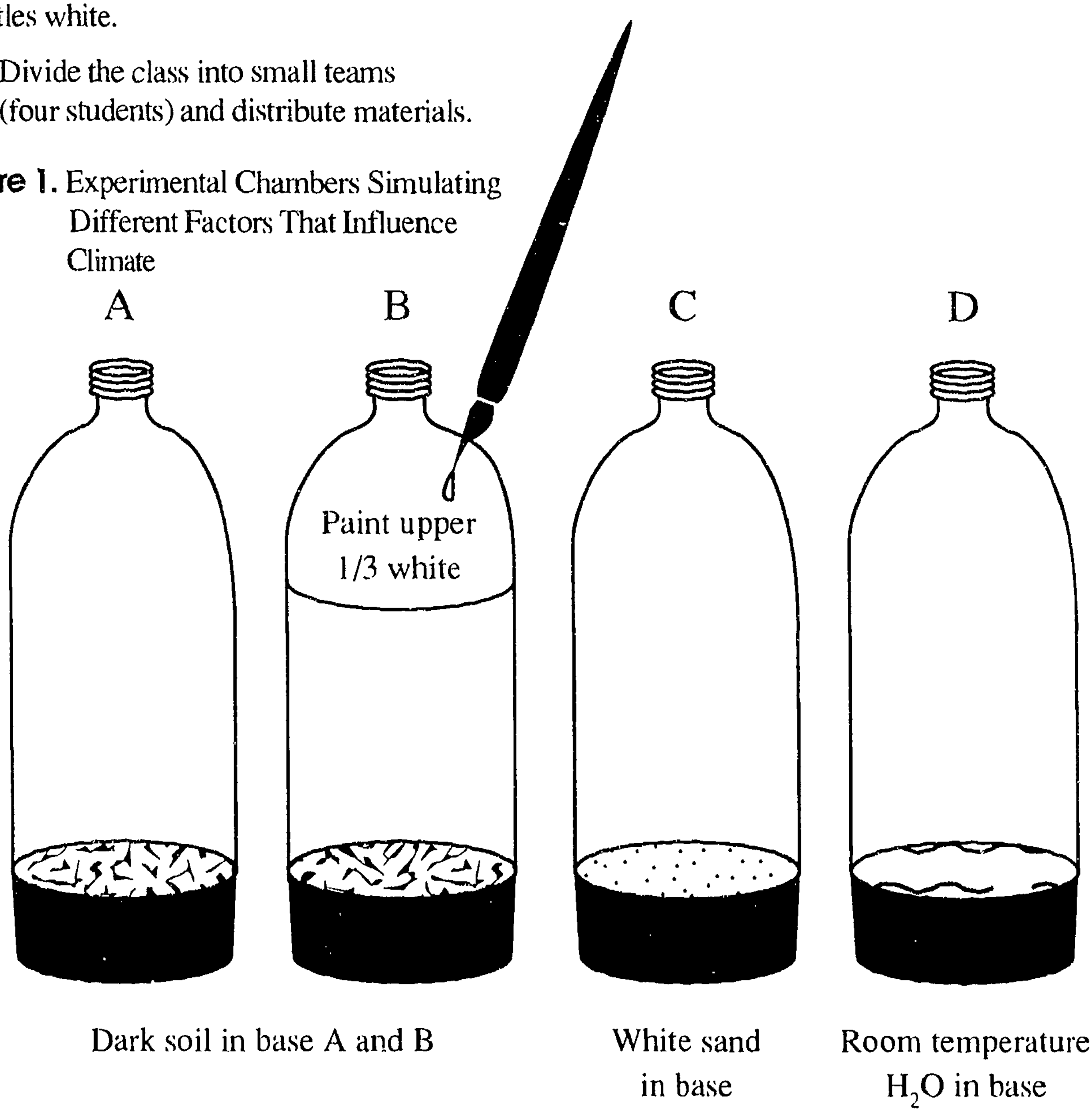
- Four soda bottle "experimental chambers" (see page 43 in Activity 6)
- Four thermometers
- White paint
- 3 Cups of soil (garden soil or potting soil)
- 1.5 Cups of white sand or perlite
- One 150-watt floodlight bulb
- Clamp-on, portable reflector lamp
- Stand to support lamp setup
- Graph paper

## Procedure: Greenhouse Assembly

*Note to Teacher:* To save time, you (or your students) should prepare the model greenhouses prior to class. For each team of four students, you will need to use four experimental chambers. If there are holes in the bases of the experimental chambers, they should be sealed. This can be done using tape or silicon seal. At least one of the bases should be sealed to be able to hold water (silicon seal works well). Paint the upper 1/3 of one of the bottles white.

1. Divide the class into small teams (four students) and distribute materials.
2. Each team should have four experimental chambers (two regular, one that can hold water, and one that is partially painted white). The students should label the bottles A, B, C, and D, with bottle B having the white paint and bottle D having the sealed base to hold water.
3. Have students fill the base of bottles A and B with soil, bottle C with white sand, and bottle D with room-temperature water. The greenhouses are now ready (Figure 1).

**Figure 1.** Experimental Chambers Simulating Different Factors That Influence Climate



4. The students will tape a thermometer (using cellophane tape or light-colored masking tape, not black electrical tape) to the sides of each bottle (facing out). They should make sure the bulb of the thermometer is just above the top of the opaque base (if the bulb is below the base, the thermometer may record the heat absorbed directly by the soil or water, and complicate the results). It is important that the thermometers are all reading the same temperature before beginning the experiment. If not, explain how they can "zero" them by recording the difference and adjusting for the difference when the observations are made. The bottles should be capped.
5. Have each team set up a graph of time (in minutes) versus temperature upon which to record their observations. The temperature axis should be approximately 20 °C to 40 °C. Ask them to predict which bottle they think will get hotter? Why? Record predictions in their logbook.
6. Each student should have a specific responsibility during the experiment (either by keeping track of the time or recording the temperature for the different bottles).
7. Place the bottles approximately 6" away from the lamp with the thermometers facing away from the light.
8. Have students turn on the light and begin recording the temperatures every two minutes. Continue for at least 20 minutes.
9. Discuss the results and propose some possible explanations. Relate the factors affecting the model greenhouse to the factors affecting the "global greenhouse".

**Student Learning Portfolio:**

1. Graph temperature changes in the greenhouses for different surface characteristics and albedos. Each student should have a graph for their logbook.
2. Write an explanation of the effect of albedo and surface type.
3. A diagram of Earth's greenhouse (possibly a simple picture of Earth, sun, light from the sun, and the atmosphere as a greenhouse cover) with clouds, ice/snow/deserts, and oceans included. Students develop their own, based on discussion—not just a copy.

**Extensions:**

The bottles lend themselves to several possibilities and students should be encouraged to design their own experiments.

1. Students may put plants in the bottles and test the effect of plant cover on the greenhouse temperatures.
2. Students may test the effect of wet versus dry soil on greenhouse warming.
3. Students can try different colors or types of lights (lights filtered with colored cellophane, fluorescent vs. incandescent bulbs, etc.) to see which contribute most to warming.❑

# What Factors Influence a Greenhouse?

STUDENT GUIDE—ACTIVITY 7

**Definitions of Terms:**

***Albedo:*** The percentage of solar energy reflected back by a surface. In the atmosphere, clouds reflect solar energy into space as visible light. At the Earth's surface, light-colored land (i.e., deserts, snow and ice fields) and sea surfaces also reflect solar energy back into space.

***Feedback:*** A process in which part of the output of a system is fed back to another part of the system. Feedback generally serves as an internal control on what goes on in a system. Positive feedback can encourage more of what is already happening; negative feedback will discourage what is happening. In the case of global climate change, positive feedback would act to increase global warming while negative feedbacks would act to reduce it.

## Activity:

You will set up a selection of model greenhouses with different properties and will observe, record, and graph the differences in temperature between them. Be prepared to discuss the possible reasons for the observed differences.

## Materials:

For each team of four students:

- Four soda bottle "experimental chambers" (see page 43)
- Four thermometers
- 3 Cups of soil (garden soil or potting soil)
- 1.5 Cups of white sand or perlite
- One 150-watt flood light bulb
- Clamp-on, portable reflector lamp
- Stand to support lamp setup
- Graph paper

## Procedure:

1. Label your bottles A, B, C, and D, with bottle B having the white paint and bottle D having the sealed base to hold water.
2. Fill the base of bottles A and B with soil, bottle C with white sand, and bottle D with room-temperature water. Your greenhouses are now ready (Figure 1).
3. Tape a thermometer (using cellophane tape or light-colored masking tape, not black electrical tape) to the sides of each bottle (facing out). Make sure the bulb of the thermometer is just above the top of the opaque base (if the bulb is below the base, the thermometer may record the heat absorbed directly by the soil or water, and

complicate the results). Cap the bottles.

*Important:* The thermometers should all read the same temperature before beginning the experiment. If not, you can "zero" them by recording the difference and adjusting for the difference when the observations are made. For example, if thermometer A reads 22 °C and thermometer B reads 23 °C when they both should read the same, you can either add 1 °C to every reading of A or subtract 1 °C from every reading of B to correct for the difference.

4. Set up a graph of time (in minutes) versus temperature upon which to record your observations. The temperature axis should be approximately 20 °C to 40 °C. Which bottle do you think will get the hottest? Coolest? Why? Record your prediction in your logbook.
5. Each person in your team should have a specific responsibility during the experiment (either by keeping track of the time or recording the temperature for the different bottles every two minutes).
6. Place the bottles approximately 6" away from the lamp with the thermometers facing away from the light.
7. Turn on the light and begin collecting your data. Continue the experiment for at least 20 minutes.
8. Compare the graphed information from the different bottles. Discuss the results and develop some possible explanations.❑

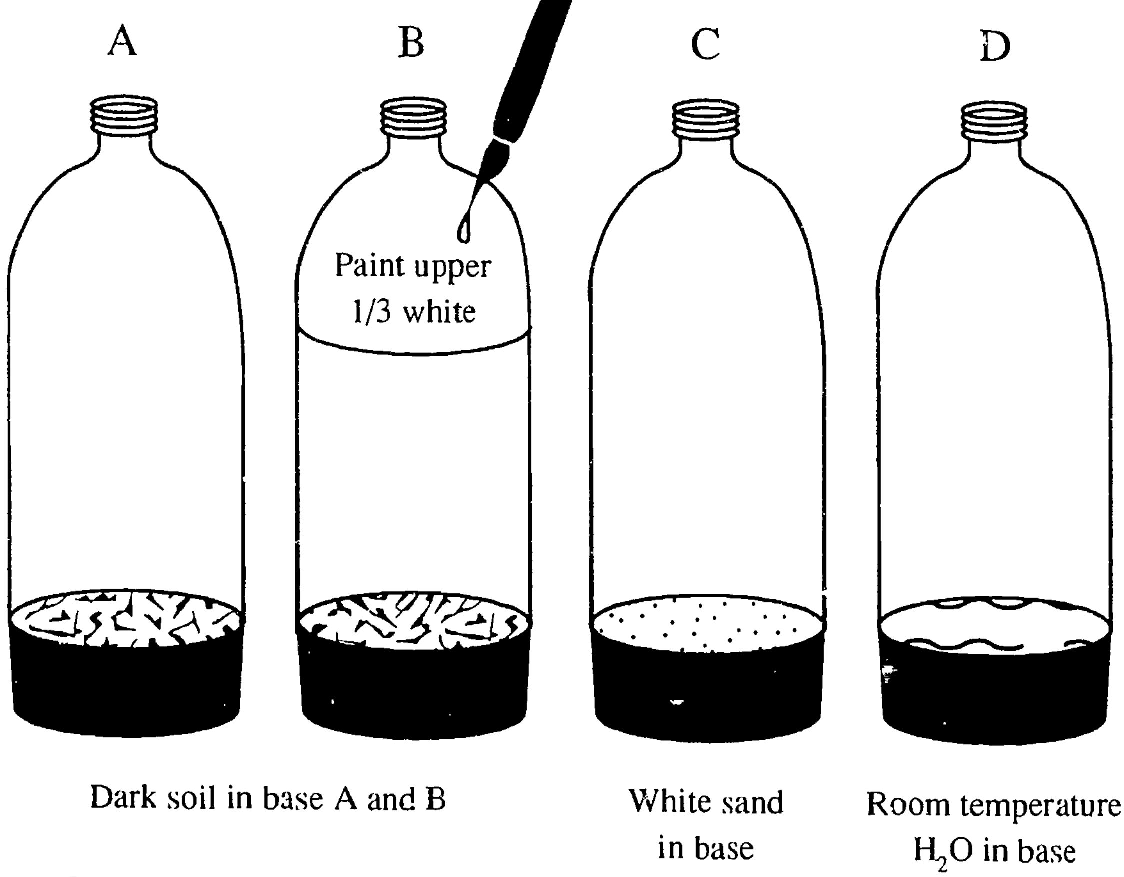



**Figure 1.** Experimental Chambers Simulating Different Factors That Influence Climate

# What Makes the Earth Like a Greenhouse?

ACTIVITY 8

**Lesson Focus:**

What are the atmospheric differences between Earth and other planets in the solar system?

**Objective:**

The student will be able to:

1. Compare the Earth's atmosphere with the atmospheres of other planets.
2. Build a model of the Earth's atmospheric composition.

**Time:**

1 class period

**Grade Level:**

8–10

**Key Concepts:**

Greenhouse gases, atmospheric chemistry, modeling

## Definition of Terms:

***Goldilocks Principle:*** The planets Earth, Mars, and Venus are very different from one another in terms of temperature, atmospheric chemistry, and atmospheric pressure. Planetary climatologists have noted that Venus is too hot, Mars is too cold, but the Earth is just right to support life. This is referred to as the Goldilocks Principle.

***Greenhouse Gases:*** (also called trace gases) Gases in Earth's atmosphere that make up a very small part of the total atmospheric composition. Important greenhouse gases include water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), chlorofluorocarbons (CFCs), and ozone ($O_3$).

***Visible Light:*** Light in the area of the electromagnetic spectrum that can be seen with human eyes, generally extending from violet light (shorter wavelengths) to red light (longer wavelengths).

***Infrared Radiation:*** Although it can not be seen by the human eye, most objects absorb and emit infrared radiation. The infrared portion of the electromagnetic spectrum has longer wavelengths than visible light. It is also known as heat radiation.

## Background:

The greenhouse effect is a well-established theory in the atmospheric sciences. The explanation for the greenhouse effect is that certain trace atmospheric gases appear transparent to incoming visible (short-wave) light but act as a barrier to outgoing infrared (long-wave) radiation. These trace gases are often referred to as "greenhouse gases" because they function much like the glass plates found on a greenhouse used for growing plants. (*Note to Teacher:* if you have done Activity 6 or 7, suggest to your students that although Earth's "greenhouse cover" is not as obvious as that of the plastic bottle, the effect is the same. Earth's atmosphere acts like our "bottle"). The atmosphere is composed of gases (e.g., $H_2O$, $CO_2$) of just the right types, and in just the right amounts, to warm the Earth to temperatures suitable for life. The effect of the atmosphere to trap heat is the true "Greenhouse Effect".

The physical evidence for the effect of greenhouse gases can be evaluated by comparing the Earth with its nearest planetary neighbors, Venus and Mars (Table 1). These planets have either too much greenhouse effect, or too little to be able to sustain life as we know it. The differences between the three planets has been termed the "Goldilocks Principle" (Venus is too hot, Mars is too cold, but Earth is just right).

Mars and Venus have essentially the same types and percentages of gases in their atmospheres (Table 2). However, they have *very* different *atmospheric densities*. Venus has an extremely dense atmosphere, so the concentration of $CO_2$ is responsible for a "runaway" greenhouse effect and very high surface temperatures. Mars has almost no atmosphere; therefore, the amount of $CO_2$ is not sufficient to supply a warming effect and the surface temperatures of Mars are very low as a result (Table 1).

Earth has a vastly different type of atmosphere. The percentage of $CO_2$ in the Earth's atmosphere is much less than that found on Venus or Mars. Earth's atmospheric pressure is between that found on Venus or Mars. Many scientists believe the composition of our atmosphere is due to the presence of life. Life acts to keep Earth's atmosphere in a dynamic balance with a gaseous composition that is chemically unstable. In other words, if life were to completely disappear from Earth, eventually, Earth's atmospheric composition could come to closely resemble either Mars or Venus. Only with life continually producing oxygen (through photosynthesis), and removing and recirculating $CO_2$, does Earth's atmosphere stay fairly stable.

## Activity:

In this activity, students will learn of the differences between the atmospheres of the planets in our solar system. They will also construct models of the Earth's atmosphere and those of other planets in order to understand the relationships among the different atmospheric gases.

## Materials:

- Colored cotton balls, jellybeans, colored paper (or similar materials) to represent gases in the atmosphere
- Resealable plastic bags

**Table 1:**

The atmospheric factors responsible for the planetary differences are provided in the table below. The relative distance from the sun has some influence on planetary temperature, but the greenhouse gases and atmospheric density have more of an impact on temperature.

| | Venus | Earth | Mars |
|---|---|---|---|
| Surface Pressure | 90 | 1 | 0.007 |
| Major Greenhouse Gases (GHG) | $CO_2$ | $H_2O$, $CO_2$ | $CO_2$ |
| Temperature if no GHG (°C) | −46 | −18 | −57 |
| Actual Temperature (°C) | 477 | 15 | −47 |
| Temperature Change due to GHG | +523 | +33 | +10 |

**Table 2:**

The chemical composition of the atmospheres are important as well (at least to the presence of life). The major gases and their percentages are listed below.

| Gas | Venus | Earth | Mars |
|---|---|---|---|
| Carbon Dioxide ($CO_2$) | 96.5% | 0.03% | 95% |
| Nitrogen ($N_2$) | 3.5% | 79% | 2.7% |
| Oxygen ($O_2$) | Trace | 21% | 0.13% |
| Argon (Ar) | 0.007% | 1% | 1.6% |
| Methane ($CH_4$) | 0 | 0.002% | 0 |

## Procedure:

1. Discuss the "Goldilocks Principle". Use the information in Tables 1 and 2 to engage the class in a discussion of the Greenhouse Effect. If available, you may want to share illustrations or slides of Mars, Venus, and Earth.
2. After discussing the atmospheres of Earth and the other planets, ask the students (in teams or pairs) to build models of the atmospheres of Earth and the other planets.
3. Depending on the material available, ask students to represent the atmospheric gases with different colored paper, string, cotton balls or jelly beans (we will use jellybeans for examples in this activity). They might represent nitrogen ($N_2$) with yellow jelly beans, oxygen ($O_2$) with blue, and carbon dioxide ($CO_2$) with black. Representing atmospheric density with jellybeans is impractical - if Earth's atmosphere has 100 jellybeans, Venus will have 9,000, and Mars will have slightly more than 1/2 a jellybean (0.6). Suggest that the students use 10 or 100 as the base number for each planet. Let the students know what the real differences in density are.
4. Challenge the students to produce a model atmosphere for each planet by placing the appropriate number of jellybeans in three, small, resealable plastic bags. The necessary information is provided in Table 2. They will have to translate percentages into numbers of jellybeans, and in many cases, will face the difficulty of cutting the jellybeans into small enough pieces to represent small atmospheric concentrations.
5. Have the students display their work in the classroom and allow time for them to observe and discuss each others work.
6. Discuss the students's models with the class. Ask questions of students regarding why they think Earth's atmosphere is suitable for life while the other planets' atmospheres are not.

## Student Learning Portfolio:

1. Models of planetary atmospheric compositions.
2. A journal entry to explain what they have learned about the Earth's atmosphere as compared to the other planets.❑

# What Makes the Earth Like a Greenhouse?

STUDENT GUIDE—ACTIVITY 8

**Definition of Terms:**

***Goldilocks Principle:*** The planets Earth, Mars, and Venus are very different from one another in terms of temperature, atmospheric chemistry, and atmospheric pressure. Planetary climatologists have noted that Venus is too hot, Mars is too cold, but the Earth is just right to support life. This is referred to as the Goldilocks Principle.

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***Infrared Radiation:*** Although it can not be seen by the human eye, most objects absorb and emit infrared radiation. The infrared portion of the electromagnetic spectrum has longer wavelengths than visible light. It is also known as heat radiation.

## Activity:

You will learn of the differences between the atmospheres of the planets in our solar system. You will construct models of the Earth's atmosphere and those of other planets in order to understand the relationships among the different atmospheric gases.

## Materials:

- Colored cotton balls, colored paper, colored jellybeans (or similar materials to represent gases in the atmosphere.
- Resealable plastic bags

## Procedure:

1. With your partner or team, identify the different gases to be included in a model of the atmospheres of Earth, Mars, and Venus (see Table 1, page 58).
2. Depending on the material available, represent the atmospheric gases with different colored paper, string, cotton balls or jelly beans (we will use jellybeans for examples in this activity). You could represent nitrogen ($N_2$) with yellow jelly

beans, oxygen ($O_2$) with blue, and carbon dioxide ($CO_2$) with black.

3. Determine the practicality of representing atmospheric density with jellybeans. If Earth's atmosphere has 100 jellybeans how many would you need to represent Venus or Mars?

4. For each planet, place the appropriate number of jellybeans in a small, resealable plastic bag. To do this, you will have to translate percentages (from Table 1) into numbers of jellybeans. How do the different "planets" compare?

5. Why do you think Earth's atmosphere is suitable for life while Venus and Mars have no apparent life?❑

**Table 1:**

The chemical composition of the atmospheres are important as well (at least to the presence of life). The major gases and their percentages are listed below.

| Gas | Venus | Earth | Mars |
|---|---|---|---|
| Carbon Dioxide ($CO_2$) | 96.5% | 0.03% | 95% |
| Nitrogen ($N_2$) | 3.5% | 79% | 2.7% |
| Oxygen ($O_2$) | Trace | 21% | 0.13% |
| Argon (Ar) | 0.007% | 1% | 1.6% |
| Methane ($CH_4$) | 0 | 0.002% | 0 |

**Notes:**

90

# What Is the Carbon Cycle?

ACTIVITY 9

**Lesson Focus:**

**Objective:**

The student will be able to:

1. Describe a simple carbon cycle by drawing the key components of the cycle and constructing a collage.
2. Identify carbon sources, sinks, and release agents.
3. Speculate on the connection between the carbon cycle and carbon's role in the Greenhouse Effect.

**Time:**

2–3 Class Periods

**Grade Level:**

8–10

**Key Concepts:**

Carbon cycle, carbon sinks, climate change

**Definition of Terms:**

***Carbon:*** An important element that forms the structure of all life on Earth.

***Carbon Dioxide ($CO_2$):*** The primary form of carbon in Earth's atmosphere.

***Carbon Cycle:*** The cycle of carbon (in solid and gaseous forms) through living organisms (biological) and nonliving forms (geochemical).

***Carbon Sinks (also called reservoirs):*** Locations in the biosphere where excess carbon is stored (e.g., long-lived trees, limestone, fossil fuels).

***Release Agents:*** Events that cause the carbon atom to be released from its sink and reentered into the cycle (e.g., volcanic activity, forest fires).

**Background:**

All living organisms are based on the carbon atom. Unique among the common elements of the Earth's surface, carbon atoms have the ability to form bonds with as many as four other atoms, including other carbon atoms, and to form double bonds to itself. These attributes make possible the existence of all the organic compounds that are essential to life on Earth. Carbon, in the form of carbon dioxide, is also an important part of our atmosphere, and carbon-containing rocks (such as limestones) are an important part of Earth's crust.

Carbon atoms are continually moving through living organisms, the oceans, the atmosphere, and the crust of the planet. This movement is known as the carbon cycle. The paths taken by carbon atoms through this cycle are extremely complex, and may take literally millions of years to come full circle. Consider, for example, the journey of a "typical" carbon atom that existed in the atmosphere as part of a carbon dioxide molecule some 360 million years ago, during the Carboniferous Period. That $CO_2$ molecule drifted into the leaf of a large fern growing in the extensive tropical swamp forests of that time. Through the process of photosynthesis, the carbon atom was removed from the $CO_2$ molecule, the oxygen was released back into the air, and the carbon was used to build a molecule of sugar. The sugar might have been broken down by the plant at a later time, to release the energy stored inside, but this molecule was transformed instead into a long-lived structural part of one of the plant cells. Soon after, the fern died, and the remains sank into the muck at the bottom of the swamp. Over thousands of years more plants grew in the swamp and their remains also sank into the swamp, forming a layer of dead plant material many meters thick. Gradually, the climate changed, becoming drier and less tropical. Sand, dust, and other materials slowly covered the ancient swamp and sealed the decaying vegetation under an ever-thickening layer of sediment. The sediment hardened, turning to sedimentary rock. The carbon atom stayed trapped in the remains of the long-vanished swamp while the pressure of the layers above slowly turned the material into coal. Some 360 millions of years later, the coal bed was mined by humans and burned to fuel industrial civilization. The process of burning released the energy stored in the carbon compounds in the coal, and reunited the carbon atom with oxygen to form $CO_2$ again. The $CO_2$ was released to the atmosphere through the smokestack and the journey continues. Many other paths are possible, some taking only hours or days to trace, some, like the one above, many millions of years.

The aggregation of the possible paths of carbon, where they may be stored for extended periods (the "sinks"), where they are likely to be released back to the atmosphere (the "source"), and what triggers those sources (the "release agents"), together defines the carbon cycle. Carbon sinks may include such things as long-lived trees, limestone (formed from the carbon-containing shells of small sea creatures that settle to the ocean bottoms and build up into thick deposits), plastic (a modern invention, but *very* long-lived), and burial of organic matter (such as formed fossil fuels). Carbon sources include the burning of fossil fuels and other organic matter, the weathering of limestone rocks (which releases $CO_2$), and respiration of living organisms. Release agents include volcanic activity, forest fires, and many human activities.

## Activity:

Students will make carbon cycle drawings and collages.

## Materials:

- Magazines and newspapers
- Tagboard for collages
- Worksheets (provided)

## Procedure:

1. Distribute worksheets to students. Using class discussion, brainstorming, or question and answer methods, discuss the simplified carbon cycle. Students should draw their own carbon cycle.
2. Have students look up carbon and its cycle in a science text, chemistry text, or encyclopedia. Through class discussion, students can share what they have discovered.
3. Discuss a much more complicated carbon cycle with sinks and release agents.
4. Using magazines and newspapers assign the students (working in small groups) the task of developing a collage illustrating the carbon cycle. Display the collages in your classroom.

## Student Learning Portfolio:

1. Student worksheets
2. Written answers in the student notebook to the following questions:
   a. What gas do humans and animals exhale?
   b. Write the formula for this exhaled gas.
   c. List some "sinks" and "release" areas for this fundamental element.
   d. Does the carbon cycle help explain global climate changes?
3. A collage illustrating the carbon cycle.

## Extensions:

Students may be encouraged to write a story about a carbon atom as it moves through its cycle with illustrations of the carbon taking on all its many forms.❑

## Notes:

# What Is the Carbon Cycle?

STUDENTGUIDE—ACTIVITY 9

**Definition of Terms:**

***Carbon:*** An important element that forms the structure of all life on Earth.

***Carbon Dioxide ($CO_2$):*** The primary form of carbon in Earth's atmosphere.

***Carbon Cycle:*** The cycle of carbon (in solid and gaseous forms) through living organisms (biological) and nonliving forms (geochemical).

***Carbon Sinks (also called reservoirs):*** Locations in the biosphere where excess carbon is stored (e.g., long-lived trees, limestone, fossil fuels).

***Release Agents:*** Events that cause the carbon atom to be released from its sink and reentered into the cycle (e.g., volcanic activity, forest fires).

## Activity:

You will make a chart of the carbon cycle and a collage for your classroom.

## Materials:

- Magazines and newspapers
- Tagboard for collages
- Worksheets

## Procedure:

1. With your class, discuss the carbon cycle. Draw a simplified carbon cycle on your worksheet or in your journal.
2. Look up carbon and its cycle in a science text, chemistry text, or encyclopedia. Share your findings with the class.
3. With your class, consider a more complicated carbon cycle including sinks and release agents.
4. Look through magazines or newspapers for illustrations that could be part of the carbon cycle (for example, plants, animals, automobile exhaust, fires, volcanoes). Develop a collage illustrating the carbon cycle and display the collage in your classroom.❑

# The Carbon Cycle and Climate Change

| Some Carbon Facts: | A Simple Carbon Cycle: |
| --- | --- |
| Carbon Sinks: | Carbon Release Agents: |

# Where Does $CO_2$ Come From?*

ACTIVITY 10

**Lesson Focus:**

What are the sources of $CO_2$?

**Objective:**

The student will be able to:

1. Identify sources of $CO_2$.
2. Discuss the use of "control" and "treatment" in experimental studies.
3. Explain the use of a chemical indicator in experimental studies.
4. Formulate conclusions based on observed and recorded data on sources of $CO_2$.

**Time:**

2 Class Periods

**Grade Level:**

8–10

**Key Concepts:**

Carbon sources, scientific inquiry, experimentation

*Adapted with permission from curriculum materials developed by the U.S. Department of Energy, Lawrence Livermore National Laboratory, Livermore, California.

## Definition of Terms:

***Controlled Experiment:*** An experiment that is based on a comparison of a *control* group and a *treatment* group. The control and treatment groups are similar in every way except for the treatment used in the experiment.

***Control Group:*** The group that is not subjected to any experimental changes or manipulations. It is used as a basis for comparison.

***Treatment Group:*** The group that is treated or manipulated according to design of the experiment. The treatment group is also known as the experimental group.

***Indicator:*** A substance used to visually detect the presence of a particular material or compound.

***Carbon Cycle:*** The cycle of carbon (in solid and gaseous forms) through living organisms (biological) and nonliving forms (geochemical).

***Carbon Source:*** Anything that releases $CO_2$ (living, dead, nonliving) into the atmosphere is considered to be a carbon source.

***Carbon Sinks (also called reservoirs):*** Locations in the biosphere where excess carbon is stored (e.g. long-lived trees, limestone, fossil fuels).

## Background:

Carbon dioxide ($CO_2$) is the most important of the "greenhouse" gases – those gases that act to trap solar energy in the form of heat. Although there are other important greenhouse gases, including methane ($CH_4$), nitrous oxide ($N_2O$), and chlorofluorcarbons (CFCs), it was $CO_2$ that scientists first observed increasing in the atmosphere. Many scientists believe that $CO_2$ will be responsible for most of the increases in Earth's temperature. Carbon dioxide concentrations in the atmosphere are presently at approximately 350 parts per million (ppm), and increasing at an average rate of 0.5% per year. If the trend continues, $CO_2$ concentrations will reach 600 ppm or more during the next century.

Anything that releases $CO_2$ (living, dead. nonliving) into the atmosphere is considered to be a *source*. Anything that absorbs and holds $CO_2$ from the air or water is considered a *sink* (because, like a sink in your home, it acts as a "holding reservoir"). The continued build-up of $CO_2$ in the atmosphere is strong evidence that there are currently more sources of $CO_2$ than sinks. What are the sources for the extra $CO_2$? Human activities are thought to be primarily responsible for the observed increases. Of the anthropogenic (humans are the origin) sources of $CO_2$, fossil fuel combustion accounts for 65%, deforestation ($CO_2$ that is released from trees that are cut and burned, or left to decay) accounts for 33%, and the by-products of cement production accounts for the remaining 2%. There are natural sources of $CO_2$ as well. As the students will observe, plants and animals give off $CO_2$. Carbonate rocks contain $CO_2$ that can be released by exposure to acid and/or weathering. Certain naturally carbonated spring waters (e.g., Perrier water) contain $CO_2$ because the water has passed through carbonate rock on its way to the surface. Volcanoes are also a source of $CO_2$. However, these geological sources are insignificant compared to human sources. It is estimated that it would require some 900 volcanic eruptions of the size of El Chicon (Mexico, 1988) every year to equal annual industrial $CO_2$ emissions

Plants (both terrestrial plants and marine plankton) are the most important carbon sinks, taking up vast quantities of $CO_2$ through the process of photosynthesis. To a lesser extent, atmospheric $CO_2$ can also be dissolved directly into ocean waters and thereby be removed from the atmosphere. As this exercise will illustrate, plants also release $CO_2$ through the process of respiration, but on a global, annual basis, the amount of $CO_2$ taken up by plants through photosynthesis, and released through respiration approximately balance out. Thus, the $CO_2$ released from human activities is truly "extra" $CO_2$ and may continue to build up in the atmosphere, unless plants begin to increase their photosynthetic rate to utilize the extra $CO_2$, and/or the amount of $CO_2$ dissolved in the ocean water increases.

Carbon dioxide has the property of forming a weak acid (carbonic acid) when dissolved in water. Chemists have taken advantage of this fact to develop a simple test for the presence of $CO_2$ in gaseous samples. The chemical bromothymol blue (BTB) is a sensitive indicator of the presence of acid. When gas containing $CO_2$ is bubbled through a BTB solution, carbonic acid is formed, and the acid turns the solution from dark blue to green, yellow, or very pale yellow, depending on the $CO_2$ concentration (lighter colors mean higher concentrations). Students will use this reaction to study some sources of $CO_2$, beginning first with a qualitative illustration of the change in BTB color with pure $CO_2$ (from baking soda and vinegar), and proceeding to an exploration of some natural and anthropogenic sources of $CO_2$.

## Activity:

Students will predict, observe, record, and make conclusions about sources of $CO_2$. They will use a color indicator of $CO_2$, bromothymol blue (BTB) to detect the presence and relative amount of $CO_2$ in gaseous samples.

## Materials:

For the class:

- Three to four bottles of BTB working solution (mixing instructions below)
- Vinegar
- Baking soda
- Foil

For each team of students:

- Test tube rack
- Four test tubes
- A hole stopper with tubing attached
- Straw
- Cotton balls
- One sprig of *Elodea* (available in pet stores)
- Balloon
- Hand pump
- Roll of masking tape, or circle of similar diameter as a balloon circumference measuring device.
- Student lab notes (provided)
- Safety glasses

## Safety Precautions:

As with any laboratory activity, safety precautions are critical. All chemicals should be treated as though they are potentially dangerous. Students should be warned not to ingest the BTB. They should take care to avoid prolonged contact with the chemical. In any laboratory activity involving the use of chemicals, safety glasses should be worn. It is important to instill respect for laboratory procedures.

## Procedure:

Preparation of the BTB solution: Measure 0.5 grams of the dry BTB powder into 500 ml of tap water. This will provide a 0.1% *stock solution*. To prepare the working solution, mix 1 part *stock solution* with 20 parts tap water. For classroom use, 1 liter of working solution should serve 10 laboratory teams. To make it faster for the student teams to decant what they need, you may wish to separate the working solution into three or four smaller bottles .

Prior to conducting the following experiments, students should have a working knowledge of the carbon cycle and the importance of $CO_2$ in global climate change. Much of this information is covered in Activity 9 (What is the Carbon Cycle?).

A. *Detecting $CO_2$ Gas*
The students will conduct an experiment designed to detect the presence of $CO_2$. When combined, baking soda and vinegar produce pure $CO_2$. In this experiment, the BTB will dramatically change color (from bright blue to yellow) when introduced to the $CO_2$. This basic experiment will form the basis of the experiments to follow.

*Detailed procedural instructions are included in the student guide.*

*Discussion points*: Discuss the usefulness of an indicator like BTB for scientific experimentation. Discuss the need for the control tube A.

B. *Are animals a source of $CO_2$?*
The students will conduct an experiment designed to determine if animals are a source of $CO_2$. The "animals" used in this experiment are themselves as they determine if $CO_2$ is present in the breath they exhale. In order to be certain that every team uses the same *amount* of breath, they will store their breath in a balloon which will be held at a standard size of 7.5 cm. in diameter. Your students should be aware that human breath is characteristic of animal breath in general. It is important to note that the air we breathe in contains approximately 350 ppm $CO_2$, whereas the air we exhale contains approximately 10,000 ppm $CO_2$. The extra $CO_2$ is a waste product of our respiration (conversion of food to energy).

*Detailed procedural instructions are included in the student guide*

*Discussion points*: Why is it important for everyone to use the same amount of breath? (This is a controlled experiment.) Are there differences in the concentrations of $CO_2$ in human breath and the ambient air? (Human breath is much more concentrated.) How can you tell? (The indicator should be much lighter in color for human breath.)

C. *Are plants a source of $CO_2$?*
Plants, just like animals, respire. When they do respire, they give off $CO_2$ just like animals do. Unlike animals, however, plants can also act as a carbon sink when they take in $CO_2$ through the process of photosynthesis. The balance between $CO_2$ taken in by photosynthesis and that released through respiration determines whether plants act as net sinks or sources of $CO_2$. In this experiment the water plant *Elodea* will be used to examine how plants release $CO_2$.

*Detailed procedural instructions are included in the student guide.*

Discussion points. Why was the light excluded? (Light was excluded to keep the plant from photosynthesizing.) Why was there a second tube without *Elodea*? (The second tube serves as a control.)

D. *Comparing the Results*
Ask students to compare the color differences between the tubes used in the various activities (tube A – control, tube D – animal breath, tube F – plant respiration). Of the three tubes being compared, which is the lightest in color? Why is that? Discuss the design of the experiments with emphasis on the need for control and treatment groups.

**Student Learning Portfolio:**

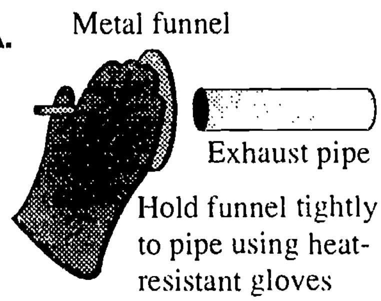
Student data sheets mounted in log books.

**Extensions:**

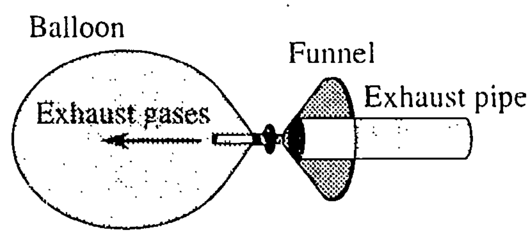
1. Using BTB, students could bring in other possible sources to test (some examples include limestone, chalk, carbonated beverages).
2. What happens to the BTB color if the *Elodea* is placed in the light after incubating in the solution in the dark overnight? How quickly do the changes occur (This activity provides an excellent representation of the balance between photosynthesis and respiration).
3. Teacher Demonstration. *Are fossil fuels a source of $CO_2$?* This experiment will test for the presence of $CO_2$ in automobile exhaust. You will need to fill a balloon full of car exhaust before the demonstration. To do so, have an assistant hold a large metal funnel (10–15 cm diameter) over the end of a car exhaust pipe, with the small end facing out and a balloon over that end (Example A). Handle the funnel with pot holder gloves as it can become hot. Hold the funnel tightly to the exhaust pipe and the balloon should inflate immediately (Example B). Gently pressing on the accelerator may expedite the process. Over-inflate past the 7.5 cm diameter size. Twist the stem of the balloon several times to close it, then roll the stem inward and clamp it with a paper clip or binder clip (Example C).
   a. Use two clean test tubes 1/4 full of BTB (label "treatment" and "control").
   b. *Carefully* let enough exhaust escape from the balloon to reduce it to 7.5 cm (use the template from exercise B).
   c. As in Exercise B, insert the straw into the balloon and *gently* bubble the exhaust through the solution in the treatment tube.
   d. Ask students to record the color differences between the control and treatment tubes in their lab notes. Exhaust is the waste product of the burning of fossil fuel, and is extremely rich in $CO_2$.

***Warning!*** For safety reasons, we recommend that this extension be carried out only as a teacher demonstration. Automobile exhaust contains carbon monoxide, which is an odorless, moderately toxic, poisonous, and flammable gas. Carbon monoxide, may cause headache, dizziness, low blood pressure, damage to blood cells, and asphyxiation.

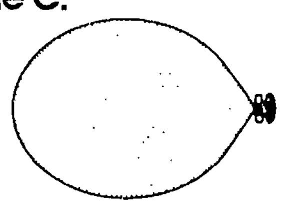
**Example A.**




**Example B.**




**Example C.**



Balloon neck rolled and sealed with a paper clip

Avoid breathing gas. Avoid contact with eyes, skin, and clothing. Wash thoroughly after handling. Use only with adequate ventilation in an exhaust hood. May cause flash fire. Keep away from all ignition sources. Balloons should be labeled as flammable and poisonous gas and stored in an exhaust hood.❑

**Notes:**

101

# Where Does $CO_2$ Come From?*

STUDENT GUIDE—ACTIVITY 10

**Definition of Terms:**

***Controlled Experiment:*** An experiment that is based on a comparison of a *control* group and a *treatment* group. The control and treatment groups are similar in every way except for the treatment used in the experiment.

***Control Group:*** The group that is not subjected to any experimental changes or manipulations. It is used as a basis for comparison.

***Treatment Group:*** The group that is treated or manipulated according to design of the experiment. The treatment group is also known as the experimental group.

***Indicator:*** A substance used to visually detect the presence of a particular material or compound.

***Carbon Cycle:*** The cycle of carbon (in solid and gaseous forms) through living organisms (biological) and nonliving forms (geochemical).

***Carbon Source:*** Anything that releases $CO_2$ (living, dead, nonliving) into the atmosphere is considered to be a carbon source.

***Carbon Sinks (also called reservoirs):*** Locations in the biosphere where excess carbon is stored (e.g., long-lived trees, limestone, fossil fuels).

*Adapted with permission from curriculum materials developed by the U.S. Department of Energy, Lawrence Livermore National Laboratory, Livermore, California.

## Activity:

You will predict, observe, record, and make conclusions about sources of $CO_2$ using a color indicator of $CO_2$, bromothymol blue (BTB) to detect the presence and relative amount of $CO_2$ in gaseous samples.

## Materials:

You and your partners will need the following:

- BTB working solution
- Vinegar
- Baking soda
- Small piece of foil

- Test tube rack
- Four test tubes
- A hole stopper with tubing attached
- Straw
- Cotton balls
- One sprig of *Elodea*
- Balloon
- Hand pump
- Roll of masking tape, or circle of similar diameter as a balloon circumference measuring device

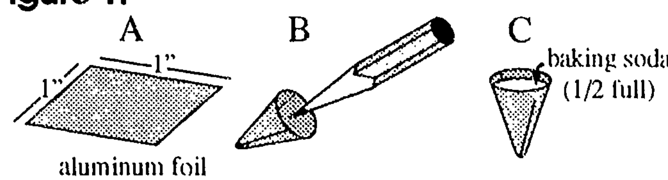
## Procedure:

A. *Detecting $CO_2$ gas*

You are going to conduct an experiment designed to detect the presence of $CO_2$. When combined, baking soda and vinegar produce pure $CO_2$. In this experiment, the BTB will dramatically change color (from bright blue to yellow) when introduced to the $CO_2$. This basic experiment will form the basis of the experiments to follow.

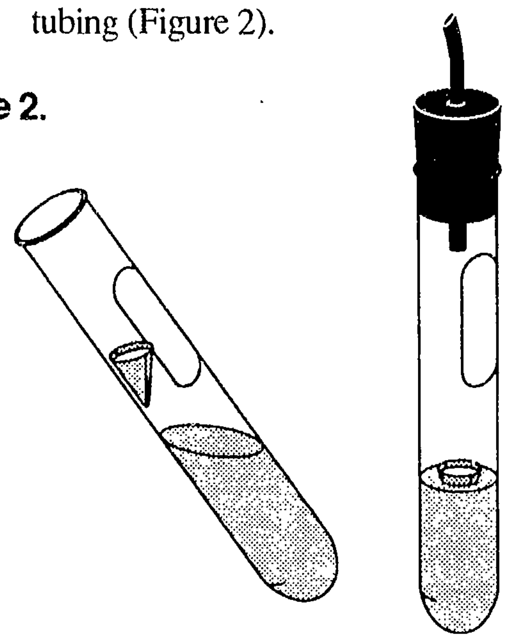
1. For the first experiment, each team will need one test-tube rack, three test tubes, a one-hole stopper with tubing attached, two cotton balls, a 1-inch square of aluminum foil, vinegar, baking soda, and the BTB solution.
2. Two of the test tubes should be labeled "A" and "B"; the other should be left unlabeled. Fill tubes A and B approximately 1/4 full with the BTB solution. The unlabeled tube should be filled approximately 1/4 full of vinegar. Record the color of the BTB in tubes A and B on their lab note sheets. Tube A will be the control; tube B will be the treatment. Place both tubes in the rack. What might happen to the BTB in tube B that is exposed to $CO_2$ from a baking soda/vinegar mix and what will happen to the BTB in Tube A that is left alone? Record your predictions on your lab notes.
3. Make a small "boat" for the baking soda by wrapping the foil square around the tip of a pencil to form a cone (Figure 1). Fill the foil cone 1/2 full of baking soda.

**Figure 1.**



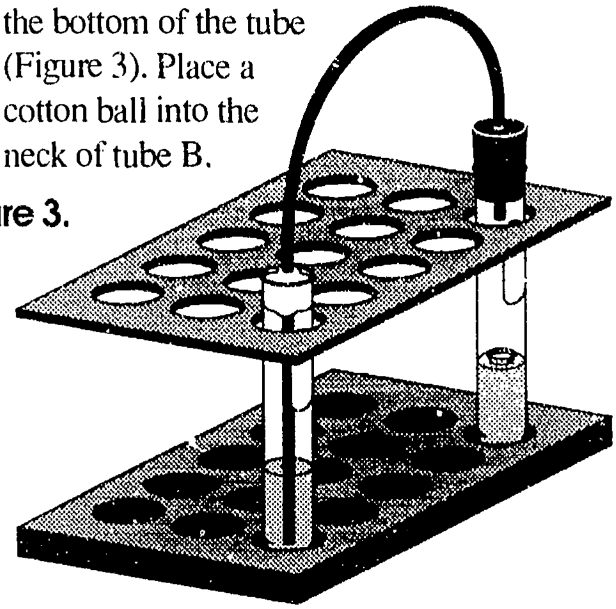

4. Carefully slide the foil container inside the unlabeled vinegar test tube. The foil cone should float upright. It is useful to tilt the tube at an angle to accomplish this. Plug the tube with the stopper and tubing (Figure 2).

**Figure 2.**



5. Place the free end of the tubing in tube B making sure the end of the tubing reaches the bottom of the tube (Figure 3). Place a cotton ball into the neck of tube B.

Figure 3.



6. Mix the vinegar and soda together by *gently* swirling the tube from side-to-side. *Don't shake up and down!* Gas bubbles will begin to bubble rapidly out of the tubing into the BTB solution in tube B.
7. After 1 or 2 minutes, note the color in tubes A and B and record this on your lab note sheets.
8. Why might an indicator like BTB be useful in scientific experimentation? What was the role of tube A in this experiment?

B. *Are animals a source of $CO_2$?*
You will conduct an experiment designed to determine if animals are a source of $CO_2$. Remember, you are an animal and in this experiment, you will determine if $CO_2$ is present in the breath you exhale.

1. For this experiment each team will need a test-tube rack, two test tubes, a straw, a cotton ball, a balloon, BTB solution, and a template approximately 7.5 cm in diameter.
2. Fill two clean test tubes 1/4 full of the BTB solution and label them "C" and "D". Record the color in your lab notes.
3. You are going to test for the presence of $CO_2$ in your breath. You will store your breath in a balloon that will be held at a standard size of 7.5 cm. in diameter. To control the size, blow the balloon up while it is inserted in the 7.5 cm template cutout and stop when the balloon touches the sides of the hole (Figure 4). Twist and pinch the neck of the balloon to prevent air from escaping, but don't tie it.
4. While still preventing the air from escaping, insert a straw into the neck of the balloon up to the twisted portion. Have one team member seal the opening of the balloon around the straw by pulling the neck of the balloon tightly to one side and pinching it off with their fingers. You may need to practice this a few times.
5. Predict what will happen to the color when you bubble your breath through the solution in tube D. Record your prediction in your lab notes.
6. Insert the straw into the BTB solution in tube D. Insert a cotton ball into the top of the test tube to help hold the straw steady. *Gently* release air from the balloon by slowly untwisting the neck. If the air is let out too fast, the solution will bubble up and out of the tube. Allow the air to bubble out at a steady rate until the balloon is empty. Observe

the color of the solution, compare the color with tube C, and record your observations in your lab notes.

7. Tape the tube shut and set aside for later use.

C. *Are plants a source of $CO_2$?*

In this experiment the water plant *Elodea* will be used to examine how plants release $CO_2$.

1. For this experiment, each team will need a test tube rack, two test tubes, enough foil to cover both tubes, a 3-cm sprig of *Elodea*, and BTB solution.
2. Label the two test tubes as "E" and "F". Fill each tube 1/3 full of BTB solution. Record the color of the solution in your lab notes.
3. Place the sprig of *Elodea* into tube F. Use a pencil or pen to push it all the way into the bottom of the tube.
4. Wrap both tubes in foil so that no light can get in. Place them in the rack. They will be left overnight. Predict any color change that you think might occur in the tubes. Record this prediction in your lab notes.
5. Uncover the test tubes and observe the color of the solution. To get a better comparison, remove the *Elodea* and hold both tubes up to a white sheet of paper. Record the color difference on the data sheet. Tape tube F shut and set it aside for later use.❑

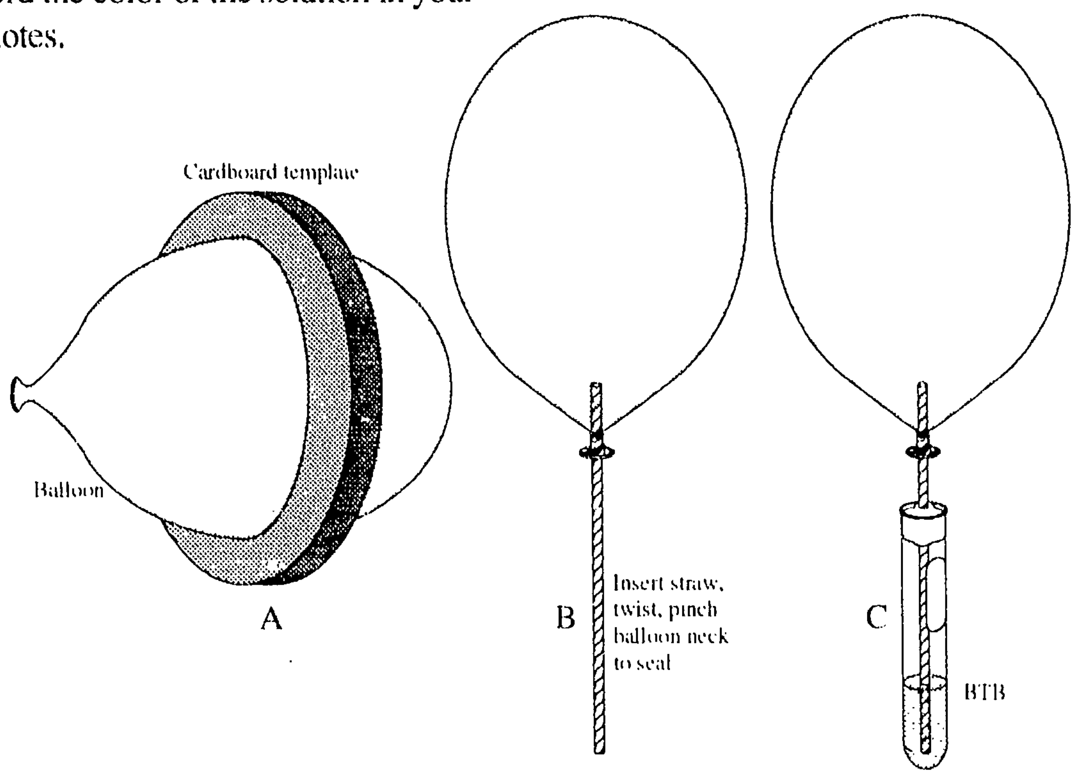



**Figure 4.**

## Lab Notes:

| Activity A | Tube A | Tube B |
|---|---|---|
| What color is the BTB before the experiment? | | |
| Predicted results: | | |
| Observed results: | | |
| What happened and why? | | |

| Activity B | Tube C | Tube D |
|---|---|---|
| What color is the BTB before the experiment? | | |
| Predicted results: | | |
| Observed results: | | |
| What happened and why? | | |

| Activity C | Tube E | Tube F |
|---|---|---|
| What color is the BTB before the experiment? | | |
| Predicted results: | | |
| Observed results: | | |
| What happened and why? | | |

**Notes:**

# How Do Scientists Analyze Greenhouse Gases and Global Temperature Data Over Time?

ACTIVITY 11

**Lesson Focus:**

What do scientists do with research data they collect?

**Objective:**

The student will be able to:

1. Comprehend how scientists gather data.
2. Organize raw data by charting data using charts and graphs.
3. Analyze the charts (graphs) and extend the analysis into the future.
4. Draw valid conclusions based on the research data.

**Time:**

2 Class Periods

**Grade Level:**

8–10

**Key Concepts:**

Scientific inquiry, data analysis, prediction

## Definition of Terms:

***Raw Data:*** Numbers that have not yet been organized or analyzed into meaningful results.

***Graphs:*** Diagrams that represent the numeric differences in a variable in comparison with other variables.

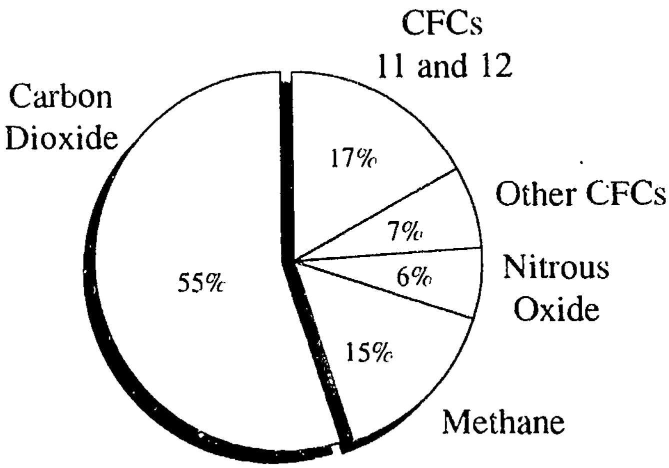
## Background:

The data presented here were collected from basic research on atmospheric gases long before global climate change was a concern. Scientists interested in a particular gas either made or procured the right equipment, found a suitable place to study the gas, then spent several months setting up, calibrating, and checking the data. Eventually, the "raw data" accumulate and require analysis.

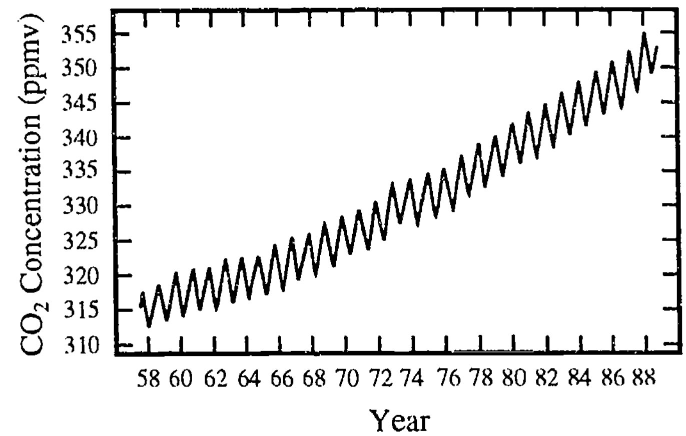
Just how the data are displayed is a question the scientist doing the work must deal with. The form – a chart, a line graph, a pie graph, or a histogram – is often personal preference.

Study the examples provided as possible ways to present the data (Figure 1). More detailed information on how the raw data were gathered is included later in this activity.

**Pie Graph**




**Line Graph**




**Bar Graph**

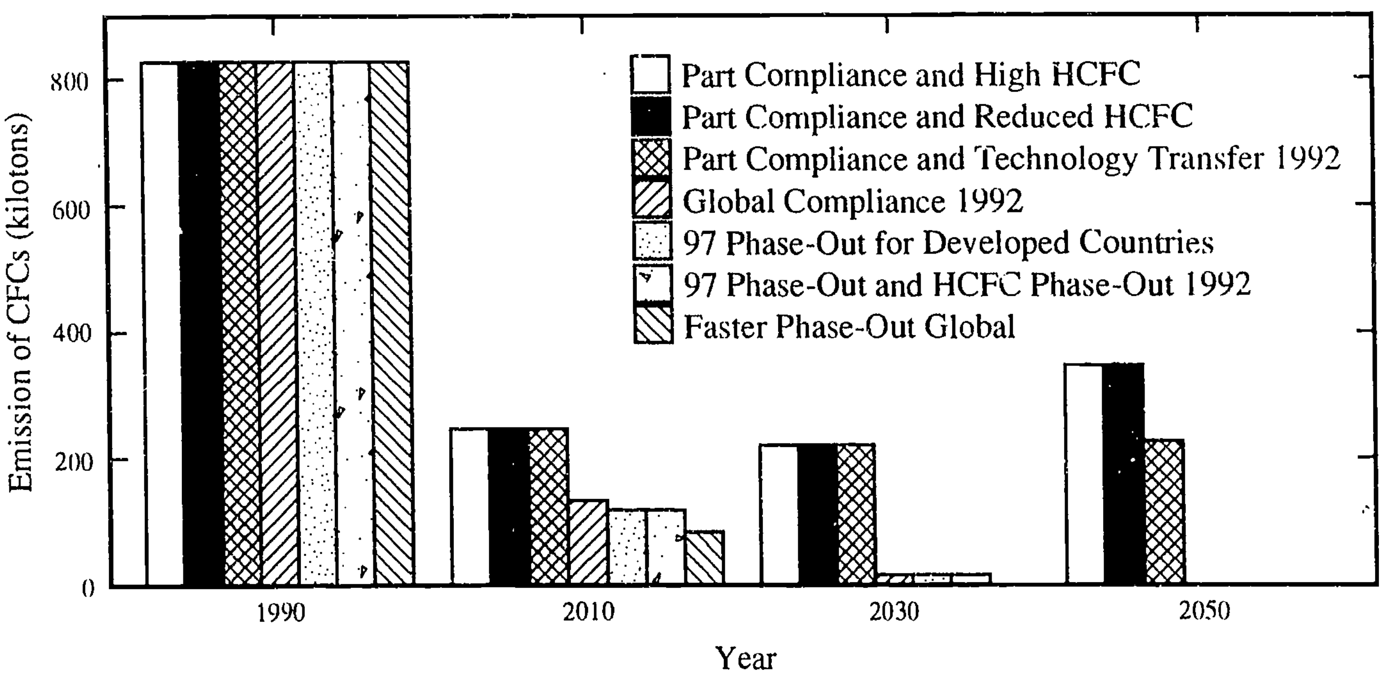



**Figure 1.** Examples of Different Ways to Display Data Graphically. Reproduced with permission from *Climate Change – The IPCC Scientific Assessment* (1990), World Meteorological Organization.

## Activity:

Students will learn about changes that have occurred in some greenhouse gas levels and average annual temperatures within the recent past. The student will make one or more charts (graphs) of actual research data, find the trends, extend the trend into the future, and then draw a valid conclusion(s). The research data will include values for temperature change, carbon dioxide ($CO_2$), methane, nitrous oxide, and chlorofluorcarbons (CFCs) in the atmosphere. The extension to this activity provides information about the people involved in these scientific discoveries.

## Materials:

- Raw data (attached)
- Pencil
- Graph paper
- Ruler

## Procedure:

To familiarize students with scientific discoveries and the people behind them, have them read the Extensions to this exercise (*Monitoring Carbon Dioxide: How Science Is Done* and *The Vostok Ice Core*). Inform the students that they have been assigned a position in a research institution dealing with global issues. A research scientist has just given them some "raw data". Within the week there is a major international conference on this material and they need to analyze it by then. The data need to be presented and organized in a meaningful and useful way. Divide the class into small research teams.

1. Discuss where data come from, types of graphs available, what a trend is, and how to project a trend.
2. Have students simulate the role of a research scientists by telling them they have been assigned to this project.
3. Given the following data, have the students plot the values and make the curve for at least one graph. There are five different graphs, therefore make sure that all five are assigned so that each can be discussed.
4. Upon completion of the graph(s) have the students continue the trend of the curve for another 50 years.
5. Now have each student or student group develop a conclusion for their particular chart. Have students with the same graph get together and compare graphs for accuracy and conclusions.
6. Ask for a spokesperson for each type of graph to report a consensus view and a minority view for the interpretation of the graph.
7. Discuss the role of data analysis in scientific research. How do choices in displaying data affect communication?

## Student Learning Portfolio:

1. A plotted graph of one of the atmospheric gases
2. A conclusion for the "raw data" provided to them

**Raw Data:**

## Carbon Dioxide Concentrations (in ppmv*), Mauna Loa, Hawaii

| Year | ppmv | Year | ppmv |
|---|---|---|---|
| 1958 | 314.8 | 1974 | 330.4 |
| 1959 | 316.1 | 1975 | 331.0 |
| 1960 | 317.0 | 1976 | 332.1 |
| 1961 | 317.7 | 1977 | 333.6 |
| 1962 | 318.6 | 1978 | 335.2 |
| 1963 | 319.1 | 1979 | 336.5 |
| 1964 | 319.4 | 1980 | 338.4 |
| 1965 | 320.4 | 1981 | 339.5 |
| 1966 | 321.1 | 1982 | 340.8 |
| 1967 | 322.0 | 1983 | 342.8 |
| 1968 | 322.8 | 1984 | 344.3 |
| 1969 | 324.2 | 1985 | 345.7 |
| 1970 | 325.5 | 1986 | 346.9 |
| 1971 | 326.5 | 1987 | 348.6 |
| 1972 | 327.6 | 1988 | 351.2 |
| 1973 | 329.8 | | |

*ppmv = Parts per million by volume.

## Methane Gas Concentration

Atmospheric Greenhouse Gas Affected by Human Activities

| Year | ppm* | Year | ppm* |
|---|---|---|---|
| 1850 | 0.90 | 1975 | 1.45 |
| 1879 | 0.93 | 1976 | 1.47 |
| 1880 | 0.90 | 1977 | 1.50 |
| 1892 | 0.88 | 1978 | 1.52 |
| 1908 | 1.00 | 1979 | 1.55 |
| 1917 | 1.00 | 1980 | 1.56 |
| 1918 | 1.02 | 1981 | 1.58 |
| 1927 | 1.03 | 1982 | 1.60 |
| 1929 | 1.13 | 1983 | 1.60 |
| 1940 | 1.12 | 1984 | 1.61 |
| 1949 | 1.18 | 1985 | 1.62 |
| 1950 | 1.20 | 1986 | 1.63 |
| 1955 | 1.26 | 1987 | 1.65 |
| 1956 | 1.30 | 1988 | 1.67 |
| 1957 | 1.34 | 1989 | 1.69 |
| 1958 | 1.35 | 1990 | 1.72 |

*ppm = Parts per million.

Gaps in the record between 1958–1975.

## CFC (chlorofluorocarbon)[1] Production

Atmospheric Greenhouse Gas Affected by Human Activities

| Year | Amount[2] | Year | Amount |
|---|---|---|---|
| 1955 | 100 | 1975 | 350 |
| 1957 | 120 | 1977 | 360 |
| 1959 | 140 | 1979 | 330 |
| 1961 | 150 | 1981 | 325 |
| 1963 | 150 | 1983 | 320 |
| 1965 | 200 | 1985 | 340 |
| 1967 | 225 | 1987 | 300 |
| 1969 | 290 | 1989 | 305 |
| 1971 | 320 | 1991 | 310 |
| 1973 | 375 | | |

[1]CFCs include the manufactured gas combinations of chlorine, fluorine, and carbon. These gases were never present in the Earth's natural atmosphere until the 1930s.

[2]Values are in kilotons per year.

## Nitrous Oxide

Atmospheric Greenhouse Gas Affected by Human Activities

| Year | ppbv* | Year | ppbv* |
|---|---|---|---|
| 1750 | 283.0 | 1880 | 289.5 |
| 1760 | 283.5 | 1890 | 290.0 |
| 1770 | 284.0 | 1900 | 291.0 |
| 1780 | 284.5 | 1910 | 292.0 |
| 1790 | 285.0 | 1920 | 292.5 |
| 1800 | 285.5 | 1930 | 293.0 |
| 1810 | 286.0 | 1940 | 294.0 |
| 1820 | 286.5 | 1950 | 295.0 |
| 1830 | 287.0 | 1960 | 297.0 |
| 1840 | 287.5 | 1970 | 299.0 |
| 1850 | 288.0 | 1980 | 305.0 |
| 1860 | 288.5 | 1990 | 310.0 |
| 1870 | 289.0 | | |

*Values of $N_2O$ concentration are in parts per billion by volume (ppbv).

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## Temperature Deviation Over Time[1]

| Year | Temp. Deviation | Years BP[2] | Temp. Deviation | Years BP[2] | Temp. Deviation |
|---|---|---|---|---|---|
| 1880 | −0.25 | 200 | 0.01 | 80,000 | −0.35 |
| 1885 | −0.27 | 1,000 | 0.01 | 85,000 | −0.30 |
| 1890 | −0.26 | 5,000 | 0.02 | 90,000 | −0.43 |
| 1895 | −0.29 | 10,000 | 0.03 | 95,000 | −0.52 |
| 1900 | −0.20 | 15,000 | −0.83 | 100,000 | −0.36 |
| 1905 | −0.38 | 20,000 | −0.90 | 105,000 | −0.40 |
| 1910 | −0.35 | 25,000 | −0.80 | 110,000 | −0.68 |
| 1915 | −0.33 | 30,000 | −0.82 | 115,000 | −0.64 |
| 1920 | −0.30 | 35,000 | −0.70 | 120,000 | −0.19 |
| 1925 | −0.15 | 40,000 | −0.60 | 125,000 | −0.09 |
| 1930 | 0.00 | 45,000 | −0.75 | 130,000 | 0.03 |
| 1935 | −0.10 | 50,000 | −0.60 | 135,000 | 0.10 |
| 1940 | −0.05 | 55,000 | −0.45 | 140,000 | −0.21 |
| 1945 | 0.05 | 60,000 | −0.80 | 145,000 | −0.75 |
| 1950 | −0.03 | 65,000 | −0.82 | 150,000 | −0.90 |
| 1955 | −0.01 | 70,000 | −0.70 | 155,000 | −0.82 |
| 1960 | 0.05 | 75,000 | −0.70 | 160,000 | −0.70 |
| 1965 | −0.05 | | | | |
| 1970 | 0.00 | | | | |
| 1975 | −0.05 | | | | |
| 1980 | 0.15 | | | | |
| 1985 | 0.18 | | | | |
| 1990 | 0.21 | | | | |

[1]For the purposes of this exercise, the mean average temperature from 1950 to 1980 is used as a baseline for comparative purposes. Note the 5-year average deviation values for the past 100 years, then the change to a 5,000-year spread for average deviation values. The values beyond 100 years were taken from ice core readings made by a USSR team of scientists working for years in the Vostok, Antarctic station.

[2]Years BP = years before present.

**Extension**

## Monitoring Carbon Dioxide: How Science Is Done.[1]

*Dr. Charles David Keeling*

At the age of 26 and a new graduate of Northwestern University, Charles David Keeling went to work as a geochemist at California Institute of Technology in Pasadena. It was there that Keeling was to begin his life's work on little more than a bet.

Harold Brown, the man who had hired Keeling, made a comment that the amount of $CO_2$ dissolved in freshwater is always in balance with the amount of $CO_2$ in the air above the water. Hoping to spend more time out of doors, Keeling challenged Brown's assumption and asked to conduct an experiment to test Brown's ideas.

Keeling spent the following winter and spring developing a manometer to extract and measure $CO_2$ in parts per million. By the end of Keeling's first year at Caltech (1955) his manometer was ready. However, instead of beginning his tests along streams and lakes as the original study required, Keeling began measuring $CO_2$ levels on the grounds of Caltech. His first measurement registered 315 ppm $CO_2$.

Keeling continued taking measurements of $CO_2$ levels at Caltech every 4 hours for a 24-hour period. Keeling was on a roof at Caltech gathering his second set of measurements, when his wife Louise, gave birth to their first son, Drew. After Drew's birth, Keeling and his wife had similar evening schedules – every 4 hours Keeling would awaken to take the $CO_2$ measurements and Louise would awaken to tend to their new baby.

During the summer of 1955, Keeling, Louise and the infant Drew, camped at Big Sur, Yosemite, the Inyo and Cascade mountains, and the Olympic National Park, all the while Keeling filled flasks with air from these very different areas. After returning to the lab Keeling found an interesting pattern in the $CO_2$ levels of the flasks. He found that the $CO_2$ levels rose in the evening and dropped in the morning and afternoon.

Photosynthesis requires plants to take in $CO_2$ all day long to build sugars for growth, repair, reproduction. At the end of the day, however, the plants have all the food they need and must respire in order to use the $CO_2$. In doing so, plants release $CO_2$ back to the atmosphere.

The puzzle of Keeling's measurements was the mid-afternoon reading always measured 315 ppm – no matter where the measurement was taken. It seemed logical that the amount of $CO_2$ might fluctuate a bit due to shifting wind patterns, or changes in location, but that was not the case.

Later that year Keeling ventured back to eastern California and the Inyo mountains with more bottles to take more samples of the winter air. At 12,000 feet, every 4 hours Keeling took $CO_2$ samples for 5 days. The concentration of $CO_2$ in these bottles sat right at 315 ppm.

The reason? At that altitude the atmosphere has undergone significant mixing and is free of local influences of forests, cities, cars, industries. Keeling's findings suggested that the Earth's global average for $CO_2$ in 1955 was

[1]Weiner, J. 1990. *The Next Hundred Years: Shaping the Fate of Our Living Earth.* New York, NY: Bantam Books.

315 ppm. So how was this related to Keeling's afternoon readings of 315 ppm elsewhere?

Although forests are influenced by any number of local conditions, generally, with the warming of the ground in the morning and early afternoon the air rises and is replaced by cooler air from higher in the sky. This is air that has been mixed so well that it represents the atmosphere of the entire planet.

Two weeks after Keeling had returned from the Inyo mountains, he was in Washington, DC, talking with scientists on what would be needed to monitor $CO_2$ levels on a global scale. The International Geophysical Year (IGY) was about to begin which would involve 18 months of global observations of earth air, water, fire, and ice. It was there that Keeling was offered a station at Mauna Loa, HI, to monitor $CO_2$.

Hawaii is the most isolated area in the world. The winds over it would represent a global average, at least for the northern atmosphere. The northern and southern atmospheres do not mix well. According to Keeling's previous measurements, it was expected that the first measurement from Mauna Loa would register 315 ppm. In fact, the first reading was 314 ppm.

In the first few months of the new Mauna Loa station the readings went up and down and then the station had power shortages. Once the station was finally up and running again the $CO_2$ measurements rose throughout the winter and then began to drop in the following spring. The first year's set of data when charted looked like a side view of a roller coaster. Keeling, however, believed he understood its message.

Having observed firsthand the daily cycle of $CO_2$, Keeling now believed he was observing an annual cycle. Here, photosynthesis begins in April, increases to a maximum in June, and continually declines through October. Respiration also peaks in June, however, it continues throughout the rest of the year as decomposition returns $CO_2$ to the atmosphere.

Since that first year of data on Mauna Loa several other stations have been set up in the northern and the southern hemispheres to record and monitor $CO_2$ levels throughout the world. The annual pattern that was observed in the first year continues to occur; however, the amounts of $CO_2$ are increasing.

The first decade of record keeping showed the $CO_2$ levels to be increasing at a rate of 1 ppm each year. After that, the data show that $CO_2$ levels are increasing at a faster pace – about 1.5 ppm per year.

Since Keeling began his measurements in 1955, average $CO_2$ levels have increased from 315 ppm to over 350 ppm. The trend indicates the amount of $CO_2$ in the Earth's atmosphere will likely continue its increase.

When compared to global average temperatures, both $CO_2$ levels and average temperatures are increasing. Is there a connection? Many believe there is, and as a result believe that the amount of $CO_2$ being pumped into the atmosphere from human activities must be reduced or serious social and environmental changes will ensue. For many others the verdict is still out on this issue and research is continuing at a feverish pace.

Keeling is still $CO_2$ dioxide and continues his work at Scripps Oceanographic Institute.

## Extension

### The Vostok Ice Core

Scientists have long sought ways of gathering more direct evidence for conditions on the ancient Earth than can be provided by theoretical ideas and the fossil record. One such method is the analysis of glacial ice cores from Antarctica and the Greenland Ice Cap. Snow that falls on the ice caps of Greenland and Antarctica usually does not melt. Instead, it slowly builds up, layer upon layer, for hundreds and thousands of years. As the snow accumulates and is compressed by the weight of the layers above it into ice, it traps minuscule bubbles of air. The surrounding ice prevents the air from escaping and/or mixing with air from the atmosphere above. As a result, the gas trapped in the ice is truly "fossil air", air from the atmosphere that existed at the time the original snow fell. By digging deep into the thick, persistent glaciers of Antarctica and Greenland, scientists can directly sample air from thousands of years ago.

Since the early 1970s, the Soviets and the French have collaborated on research at Vostok in Antarctica to drill and examine the deepest ice core ever studied. The Vostok core is over 2,000 meters long and samples ice layers deposited as long ago as 160,000 years. The core includes climatic information on the ice age that ended about 8,000 years ago and the ice age before it. The Vostok core is unique. It provides the most accurate $CO_2$ historical information thus far.

Consider the enormous effort involved in obtaining a core from a polar glacier. What were the mechanics involved? What would be some of the obvious hardships in undertaking a project such as this?

The Soviets perfected a thermal technique of drilling where the base of a 8m × 10 cm tube was electrically heated to penetrate the ice without damaging the core itself. In addition, it was not easy to keep the hole vertical. The drill had to descend carefully and excess water had to be quickly recovered to keep from refreezing (the average surface temperatures there were minus 55 °C) and distorting the sample. In the event the drill jammed for any length of time, the relentless movement of the Antarctic ice would deform the hole, destroying the core. The engineers had to be vigilant. It took 5 years (1980–1985) to extract the core. The hole left behind by this sample has been abandoned and another hole is soon to be started with drilling equipment that may probe even deeper than the original core, allowing even more ancient atmospheres to be sampled.

### What the Vostok Core Revealed

Up until examination of this ice core, the connection between $CO_2$ and changes in the Earth's climate as a cause and effect relationship could not be substantially supported. One reason was earlier core samples only went back about 30,000 years and did not contain sufficient information to support $CO_2$ as a cause of climate change.

Studying the Vostok core has shown a positive relationship between increases in $CO_2$ and warm periods of the Earth's past, as well as correlations between ice ages and low amounts of atmospheric $CO_2$. Similar studies have shown that ice cores give reliable information on atmospheric conditions. As a result, the

Vostok $CO_2$ record provides evidence for a connection between the Earth's global climate system and the carbon cycle.

According to the researchers, the Vostok series provides direct support for an interaction between $CO_2$, orbital forcing (a term used to describe climate changes caused, or "forced", by changes in Earth's orbit – e.g., the Milankovitch theory*) and climatic changes. However, they are cautious about this interpretation because the core sample can provide only circumstantial evidence linking these factors. Data from the core cannot prove cause-and-effect relationships.

*The Milankovitch theory suggests that changes in the Earth's climate are related to variation in the Earth's orbital features. The Earth's orbital shape fluctuates at intervals of 90,000 years, the Earth's tilt on its axis changes at intervals of 41,000 years, and the Earth wobbles on its axis at intervals of 19,000 to 23,000 years. The fossil record indicates hat significant changes in the Earth's climate and types of organisms closely follow these cycles.

## 160,000-Year Record

The following information is extrapolated from a series of articles published in *Nature* (1987).

1. The $CO_2$ record seems to exhibit a cyclic change in periods of about 21,000 years. These cycles may be related to the 20,000 intervals described above in the Milankovitch theory. The researchers are very hesitant about this cycle, but it is interesting to note and discuss with your students.
2. The scientists took the ice core samples and crushed them under a vacuum, releasing the trapped gas which was then analyzed by a very sensitive gas sample chemical analyzer called a gas chromatograph. The scientists also measured deuterium (a heavy isotope of hydrogen) and an isotope of oxygen ($^{18}O$). Both of these are good indicators of temperature change; however, deuterium is a better indicator than is $^{18}O$. The amounts of deuterium and $CO_2$ found in the ice core are directly related to the average global temperature at the time the gas was trapped in the ice.
3. The ice core covers the past 160,000 years and includes the Holocene (the last glacial period) the previous interglacial period, and the end of the penultimate (next to last) glaciation.
4. The $CO_2$ record exhibits the following:
   a. Two very large changes – one near the most recent part of the record, about 15,000 years ago, the other about 140,000 years ago.
   b. The high levels are comparable with the "pre-industrial" $CO_2$ levels that prevailed about 200 years ago. The low level ranges among the lowest values known in the geologic record of $CO_2$ over the last 10 million years.
   c. The two large changes in $CO_2$ correspond to the transitions between full glacial conditions (low $CO_2$) of the last and the penultimate glaciations, and the two major warm periods (high $CO_2$) of the record: The Holocene and the previous interglacial period.

**References:**

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Genthon, C., J.M. Barnola, D. Raynaud, C. Lorius, J. Jouzel, N.I. Barkov, Y.S. Korothkevich, and V.M. Kotyakov. 1987. Vostok ice core: Climatic response to $CO_2$ and orbital forcing changes over the last climatic cycle. *Nature* 329:414–418.

Jouzel, J., C. Lousi, J.R. Petit, C. Genthon, N.I. Barkov, V.M. Kotyakov, and V.M. Petrov. 1987. Vostok ice core: A continuous isotope temperature record over the last climatic cycle (160,000 years). *Nature* 329:403–408. ❑

**Notes:**

**Notes:**

# How Do Scientists Analyze Greenhouse Gases and Global Temperature Data Over Time?

STUDENT GUIDE—ACTIVITY 11

**Definition of Terms:**

*Raw Data:* Numbers that have not yet been organized or analyzed into meaningful results.

*Graphs :* Diagrams that represent the numeric differences in a variable in comparison with other variables.

## Activity:

You have been assigned a position in a research institution that addresses global issues. A research scientist has just given you some "raw data". Within the week there is a major international conference on this material and you must analyze it by then. The data need to be presented in a meaningful and useful way. Working with your team, organize, analyze, and present your data.

## Materials:

- Raw data
- Pencil
- Graph paper
- Ruler

## Procedure:

1. Plot the values and make a graph using the data your teacher provides.
2. Upon completion of the graph(s), continue the trend shown in your diagram for another 50 years (i.e., make a prediction on how you would expect the graph to look with 50 more years of data).
3. Develop a conclusion for your chart. If other students in your class are working with the same data, get together and compare graphs for accuracy and conclusions.
4. Share your findings with the class.❑

**Notes:**

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# How Does Human Activity Contribute to Greenhouse Gas Increases?

ACTIVITY 12

**Lesson Focus:**

What are the important sources of anthropogenic (human-caused) emissions of greenhouse gases (GHGs)?

**Objective:**

The student will be able to:

1. Identify anthropogenic sources of GHGs.
2. Describe the increasing magnitude of anthropogenic GHGs.
3. Explain the U.S. contribution to increasing GHGs in the atmosphere.
4. Calculate individual levels of $CO_2$ emissions.
5. Analyze the influence of personal $CO_2$ contributions on larger scales.

**Time:**

1 class period

**Grade Level:**

8–10

**Key Concepts:**

Greenhouse gases, global emissions, personal $CO_2$ contributions, data analysis

## Definitions of Terms:

*Anthropogenic:* Human-caused. Anthropogenic sources of pollution, for example, are human-caused sources (industry, automobiles, etc.).

*Greenhouse Gases:* Gases found in Earth's atmosphere, generally in small (or "trace") amounts that absorb and retain heat. Anthropogenic greenhouse gases include $CO_2$, methane ($CH_4$), chlorofluorocarbons (CFCs), and nitrous oxide ($N_2O$).

## Background:

Many scientists believe that human activity is altering the composition of the atmosphere by increasing the concentration of greenhouse gases. It is important to remember that the greenhouse effect is what keeps Earth warm enough to be habitable. The current concern is directed at an *enhanced* greenhouse effect, one that would put more heat-absorbing gases into the atmosphere and thereby increase global temperatures. The enhanced greenhouse effect has been linked to human activities that result in increased greenhouse gas emissions.

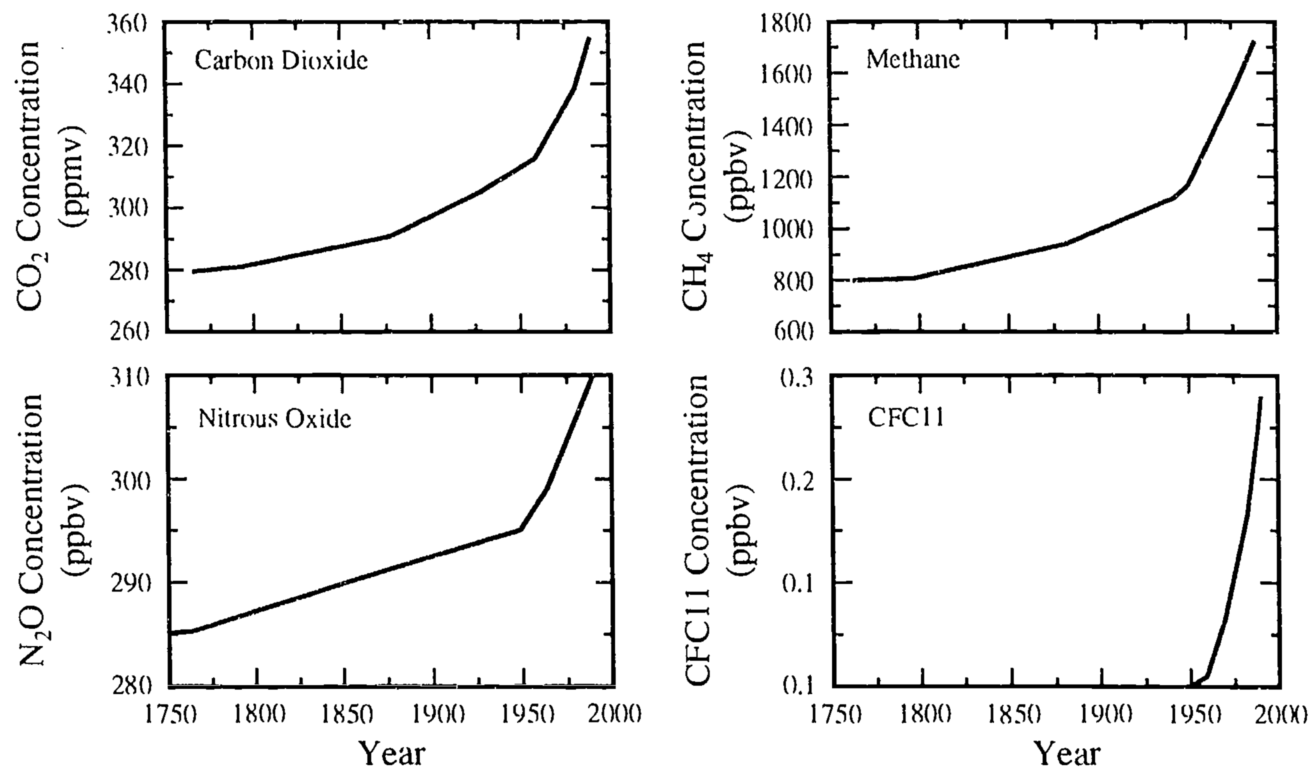
Nitrogen (78%) and oxygen (21%) together constitute 99% of the atmosphere. Most of the remaining 1% (consisting of a number of different gases collectively classified as "trace" gases due to their low concentrations) is composed of greenhouse gases. The recent attention given to the greenhouse effect and global warming is based on the recorded increases in concentrations of some of these trace gases due to human activity.

## Anthropogenic Sources

***Carbon dioxide ($CO_2$)*** is considered to be the most important GHG. It arises primarily from the burning of fossil fuels (motorized vechiles, electric power plants, homes heated with gas or oil) and the burning and clearing of forested land for agricultural purposes.

***Methane ($CH_4$)*** is largely a product of natural biologic processes, but their output can be accelerated by human activities. $CH_4$ is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g., ruminants). The additions from human activities include the expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

***Chlorofluorocarbons (CFCs)*** have no natural source; they are produced entirely by human

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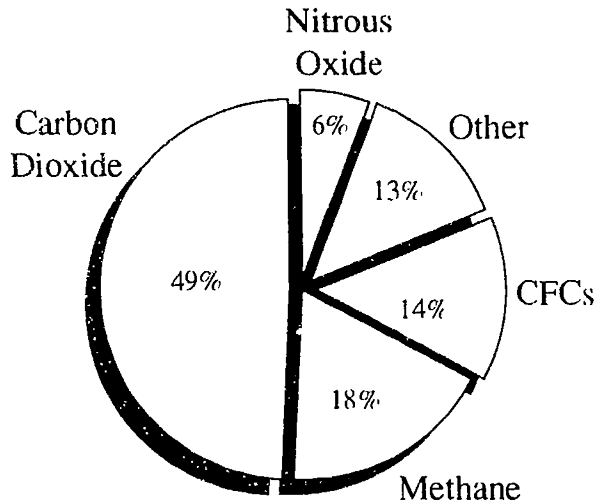
activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

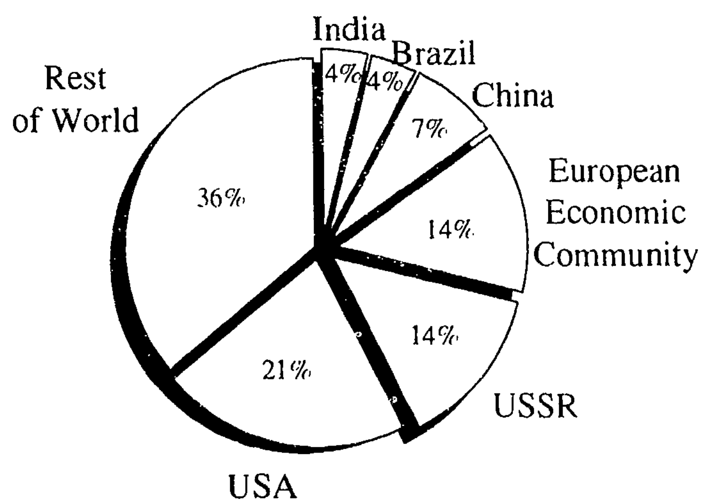
*Nitrous Oxide ($N_2O$)* is emitted from coal-burning power plants and can be released from the breakdown of chemical fertilizers in the soil.

The concentrations of each of these GHGs is increasing. However, the increase in emissions is not uniformly distributed globally. Most of the emissions come from the more developed countries, where power generation, power consumption, and living standards are highest.

### Human Contributions to the Greenhouse Effect




### Regional Contributions to the Greenhouse Effect

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## Activity:

Students will examine graphs of GHG emissions and their increases associated with human activity. The focus will be on $CO_2$, $CH_4$, $N_2O$, and CFCs. Using graphs and tables, the students will examine global sources of GHGs. Students will then calculate some personal contributions to increases in one of the GHGs: $CO_2$.

## Materials:

- Graphs, charts, and tables of GHGs
- City map
- Calculator

## Procedure:

1. Brainstorm possible anthropogenic sources of GHG
2. Read and discuss charts and graphs
3. Encourage the students to compare the GHG graphs with other graphs (e.g., global temperature, human population increases) during the same time span. Students should be encouraged to come up with their own comparisons. What kinds of trends do they predict? Can seemingly upward trends be reversed?
4. Ask students to discuss global emissions of GHGs. For example, the United States has only a small percentage of the world's

population but emits a disproportionate share of the global $CO_2$. China has a population of over a billion people. What would happen if they "developed" to the point where most families owned an automobile that was also emitting $CO_2$?

5. Calculate personal/family/class contribution of $CO_2$ due to vehicle use by using the following steps:
   a. Have each student estimate (with the help of a city map, if necessary) how far it is from their home to school (in miles).
   b. Have each student identify their type of family vehicle based on the types listed in the table below.
   c. Each student will then calculate the amount of gas used weekly *if* they rode to and from school everyday in a private car. To do this, add up the total number of miles for 10 round trips to school (remember, each time they are dropped off at school, the driver has to drive home, so there are 2 round trips a day), divide the total by the miles per gallon to determine the gallons of gas burned, then multiply the result by the $CO_2$ released per gallon. Example: If you live 4 miles from school, your car travels 16 miles per day to drop you off and pick you up, or 80 miles per week. If it is a full-size car, that will burn 5 gallons of gas. Five gallons of gas will produce *100 pounds* of $CO_2$ every week!
   d. Add the class total.
   e. Have those students that ride the bus do the same calculation again, only this time using the figures for the bus, and dividing the total $CO_2$ released by the approximate number of students that ride on the bus.
   f. Determine how many students walk to school. Subtract the $CO_2$ contributions from those students, and correct the $CO_2$ contributions for those that ride buses. Recalculate the class total and compare the results.

### Typical Vehicle $CO_2$ Emission Rates

| Vehicle | mpg | Pounds $CO_2$ per Gallon |
|---|---|---|
| Compact car | 24 | 20 |
| Full-size car | 16 | 20 |
| Truck/van | 13 | 21 |
| Bus | 8 | 22* |

*Buses add more $CO_2$ per gallon, but they carry more passengers, so be sure to consider contribution by passenger, not just vehicle.

### Student Learning Portfolio:

1. Copies of graphs and explanations in logs
2. Class $CO_2$ calculation

### References:

The $CO_2$ You Spew, *Super Science Blue.* Scholastic, February 1991. ❑

# How Does Human Activity Contribute to Greenhouse Gas Increases?

STUDENT GUIDE — ACTIVITY 12

**Definitions of Terms:**

***Anthropogenic:*** Human-caused. Anthropogenic sources of pollution, for example, are human-caused sources (industry, automobiles, etc.).

***Greenhouse Gases (GHGs):*** Gases found in Earth's atmosphere, generally in small (or "trace") amounts that absorb and retain heat. Anthropogenic GHGs include carbon dioxide ($CO_2$), methane ($CH_4$), chlorofluorocarbons (CFCs), and nitrous oxide ($N_2O$).

## Activity:

You will use information (provided in the form of graphs and tables) on GHG emissions and their increases associated with human activity to discuss and analyze global sources of GHGs. You will then calculate some of your own personal contributions to increases in one of the GHGs – $CO_2$ – and analyze the magnitude of your contributions, along with those of your class.

## Materials:

- Graphs, charts, and tables of GHGs
- City map
- Calculator

## Procedure:

1. With your class, discuss possible anthropogenic sources of GHGs. Where do you think these gases come from? Are the sources common all over the world, or are some areas (or societies) larger sources than others?
2. Read and discuss charts and graphs provided by your teacher. How does the information in these support or contradict the conclusions you reached during the brainstorming session?
3. Compare the GHG graphs with other graphs (e.g., global temperature, human population increases) collected by the class or provided by your teacher. Compare the information in these with the GHG graphs. Do you see any common trends? Is there any basis for linking the GHG data with population data or temperature data?
4. Discuss with the class the pattern of global emissions of GHGs. For example, the United States has only a small percentage of the world's population but emits a disproportionate share of the global $CO_2$. China has a population of over a billion people. What would happen if they

"developed" to the point where most families owned an automobile that was also emitting $CO_2$?

5. Calculate your own personal contribution of $CO_2$ due to vehicle use by using the following steps:
   a. Estimate as closely as possible how far you travel between school and home (in miles) on a daily basis (use a city map, if necessary).
   b. Use the table below to identify the type of vehicle (if any) you use to get to and from school.
   c. Calculate the amount of gas used weekly if you rode to and from school everyday in a private car. To do this, add up the total number of miles for 10 round trips to school (remember, each time you are dropped off at school, the driver has to drive home, so there are 2 round trips a day), divide the total by the miles per gallon to determine the gallons of gas burned, then multiply the result by the $CO_2$ released per gallon. Example: If you live 4 miles from school, your car travels 16 miles per day to drop you off and pick you up, or 80 miles per week. If it is a full-size car, that will burn 5 gallons of gas. Five gallons of gas will produce *100 pounds* of $CO_2$ every week!
   d. Add your estimate to the class total being recorded by your teacher.
   e. If you ride the bus, do the same calculation again, only this time use the figures for the bus, and divide the total $CO_2$ released by the approximate number of students that ride on the bus. Your teacher will then subtract the amount of $CO_2$ that you calculated in step "c" from the class total, and substitute the new amount you calculated based on bus use.
   f. If you walk or bike to school, you will contribute no additional $CO_2$ to the atmosphere for your travel. Your teacher will subtract the amount you calculated in step "c" above from the class total.
   g. Contrast the class total calculated as if each student used a private car for transport to and from school with the total that included bus, bike, and walking. How much difference is there? How many students don't use private cars for school transport?

**Typical Vehicle $CO_2$ Emission Rates**

| Vehicle | mpg | Pounds $CO_2$ per Gallon |
|---|---|---|
| Compact car | 24 | 20 |
| Full-size car | 16 | 20 |
| Truck/van | 13 | 21 |
| Bus | 8 | 22* |

*Buses add more $CO_2$ per gallon, but they carry more passengers, so be sure to consider contribution by passenger, not just vehicle.❑

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# How Might Elevated $CO_2$ Affect Plants?

ACTIVITY 13

**Lesson Focus:**

Plants use $CO_2$ as a nutrient, absorbing it through the process of photosynthesis. Do plants respond to increasing $CO_2$? If so, how do they respond?

**Objective:**

The student will be able to:

1. Conduct an experiment on the effect of elevated $CO_2$ on plants.
2. Explain the use of a "control" in scientific experimentation.
3. Analyze observed data and record results.
4. Form reasoned opinions about the relationships between $CO_2$, plants, and climate change.

**Time:**

- 1 class period for setup
- 3–4 weeks of daily care (5 minutes a day)
- 1 class period for observation/discussion

**Grade Level:**

8–10

**Key Concepts:**

Carbon dioxide, plant growth, experimentation, data gathering

## Definitions of Terms:

***Photosynthesis:*** The process used by plants to convert atmospheric carbon dioxide ($CO_2$) into sugars utilizing energy derived from sunlight. The sugars can be further converted into organic compounds needed for plant growth or can be used as an energy source for the plant.

***Carbon Sequestering:*** The act of removing carbon from the atmosphere and storing it for long periods of time. Long-lived forest trees are natural carbon sequesterers in that they use atmospheric $CO_2$ to build woody tissue. That tissue will retain the carbon as long as the tree is alive (for hundreds of years in certain species). In contrast, annual plants (like wheat or corn) will only store carbon for one growing season, then release it as they die and decay at the end of the season.

## Background:

Plants depend on a steady supply of atmospheric $CO_2$ for survival. Through the process of photosynthesis, plants take $CO_2$ out of the air and turn it into sugars, starches, and other organic molecules. Many plants benefit from increasing $CO_2$, increasing growth rates, size, and yield in response, as long as there is sufficient light, water, and other nutrients to support the growth. Different species respond differently, with some species responding far less than others. The projected increases in atmospheric $CO_2$ over the next century may double the average global concentration from approximately 350 ppm (parts per million) (in 1990) to 700 ppm (by the end of the next century). Recent experiments have suggested that many plants will likely respond to such an increase with increased growth, if all other environmental conditions remain the same. This exercise is designed to demonstrate the principle that increased $CO_2$ can act to enhance plant growth. Because the plant response should be rapid and obvious, and cannot depend on elaborate $CO_2$ control or monitoring equipment, we will use human breath (which contains approximately 10,000 ppm $CO_2$) as our source of extra $CO_2$. To enrich the $CO_2$ environment around plants, we will grow them in small enclosed chambers and add human breath to the chambers on a regular basis.

## Activity:

Students will plant, care for, and observe the changes in growing plants under conditions of ambient (normal) $CO_2$ and increased levels of $CO_2$.

## Materials:

For each team of two students:

- Two soda bottle "experimental chambers" (see Activity 6 page 43)
- One plastic saucer for each bottle
- Knife, scissors, tape
- Potting soil sufficient to fill the bottle bottoms
- Seeds of several different species of plants (tomato, wheat, bean, cucumber, clover, etc)
- Water-soluble plant food
- Straws
- Hand pump (often sold as balloon pumps or aspirators)

## Procedure:

1. Fill the plastic bottoms with potting soil and set in the saucers. Water the soil so that it is very moist.
2. Each team should select a plant type to work with from the seeds available. Plant two seeds in each pot, and plant at least two pots, one to add $CO_2$ to and one with normal $CO_2$ to serve as a control. Leave the bottle tops off until the seedlings emerge. Make sure that each plant species is selected by two or more teams to allow conclusions to be checked between teams.
3. After 2–4 days the seedlings should emerge. Thin the seedlings to one per pot and place the bottle tops on each pot. Label one bottle "+$CO_2$", and the other "Normal $CO_2$". Set the bottles in a bright place. Once you place the bottles on the pots, the bottles will serve to trap the moisture inside, so you should be careful not to overwater the plants.
4. $CO_2$ Treatment: Beginning now, and for each school day for the next 3 weeks, enrich the $CO_2$ in the "+" bottle by blowing 10 breaths into the bottle through a straw (Figure 1). Leave the caps off of both bottles, but to reduce the extra $CO_2$ leakage

out of the top of the bottle cover approximately half the opening with a piece of tape. Although some air will exchange through the opening, the extra $CO_2$ will mostly remain in the bottle.

*Control Treatment:* In order to ensure that, except for the extra $CO_2$, both treatment groups are exposed to the same conditions, the Control group will also have air added, at the same time the extra $CO_2$ is put into the other group. To add air without adding additional $CO_2$, use the hand pump to gently pump room air into the bottle (pump approximately 25 times per bottle).

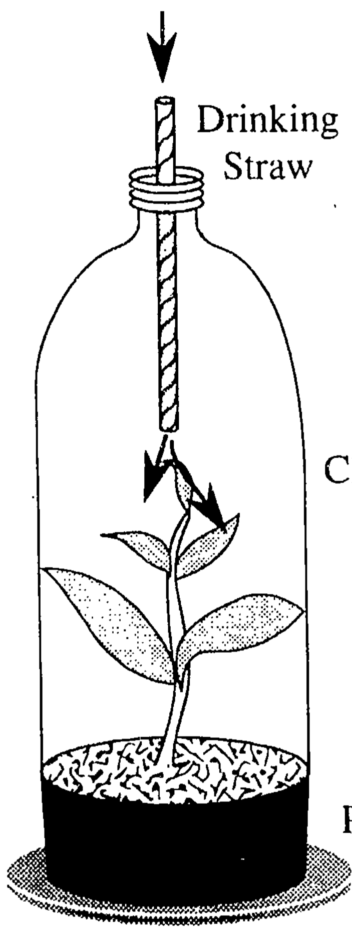


**Figure 1.** Completed Bottle Chamber Assembly

Remind the students not to hold the intake of the hand pump near their faces so that they don't pump their exhaled breath into the control bottles.

5. Have the students describe the experimental setup and $CO_2$ enrichment technique, and record observations of the plant and bottle conditions in a logbook throughout the experiment.
6. Water the plants when necessary by adding water to the saucers. Do not pour water into the top opening or remove the bottle top from the base. Water with a water-soluble plant food each time.
7. At the end of 3 weeks, remove the bottles from the bases, measure the heights, number of leaves, and any other growth parameter of interest. Each student team will record these values in their logs and share their results with the class. Be prepared for some plants responding more than others. If the responses generally seem small, it may be because other factors had limited the plant growth (e.g., There was not enough light, water, or nutrient to support good growth.) Be prepared to discuss these. As with any true experiment, there may be unexpected results.
8. Discuss the results. Consider the following questions:
   A. For the plants that grew better under high $CO_2$, do these results mean that they will benefit from global warming?
   *They might, if all other growth conditions were favorable.*
   B. What about the additional effect of changing weather (heat, drought, etc.)?
   *Unfavorable weather conditions (high*

*temperatures, drought) would reduce the capacity of the plant to benefit from the additional $CO_2$, whereas conditions that might favor growth (such as warmer weather in a cold area, or more rainfall in a dry area) may enhance it.*

C. If plants respond to more $CO_2$ by taking more in, might they take enough in to reduce the $CO_2$ concentration in the atmosphere?

*Yes, they might, if sufficient long-lived plants such as forest trees respond to the $CO_2$, and if enough forests are either re-planted or protected from land-use changes.*

If so, what will happen to the $CO_2$ when the plants die?

*Decay of the plant tissue will release the $CO_2$ back to the atmosphere. Annual plants return their fixed carbon back to the atmosphere within a year, perennials, especially long-lived trees may hold, or sequester the carbon for many decades.)*

D. If you had to select plants that would take $CO_2$ out of the atmosphere and hold it for extended periods, what would you select?

*From the answers above, it is clear that long-lived, fast growing trees or other woody perennials would be the best selections for carbon sequestering. Scientists and policymakers are currently exploring the scientific, social, and economic factors that should be considered in beginning planetary reforestation programs to reduce $CO_2$ buildup.*

### Student Learning Portfolio:

1. Description of the experiment, observations, and final data in the student log.
2. Written summary of class results in log. Which plants responded, how did they respond, etc.
3. Written answers to question for discussion.

### Extensions:

Students may try many different experiments using this bottle-exposure chamber system. They may experiment with plants not examined in class, they may try varying other conditions such as less water, less nutrients, and/or changing light levels.❑

### Notes:

# How Might Elevated $CO_2$ Affect Plants?

STUDENT GUIDE—ACTIVITY 13

**Definitions of Terms:**

***Photosynthesis:*** The process used by plants to convert atmospheric carbon dioxide ($CO_2$) into sugars utilizing energy derived from sunlight. The sugars can be further converted into organic compounds needed for plant growth or can be used as an energy source for the plant.

***Carbon Sequestering:*** The act of removing carbon from the atmosphere and storing it for long periods of time. Long-lived forest trees are natural carbon sequesterers in that they use atmospheric $CO_2$ to build woody tissue. That tissue will retain the carbon as long as the tree is alive (for hundreds of years in certain species). In contrast, annual plants (like wheat or corn) will only store carbon for one growing season, then release it as they die and decay at the end of the season.

## Activity:

You will plant, care for, and observe the changes in growing plants under conditions of ambient (normal) $CO_2$ and elevated $CO_2$.

## Materials:

For each team of two students:

- Two soda bottle "Experimental Chambers"
- One plastic saucer for each bottle
- Knife
- Scissors
- Tape
- Potting soil sufficient to fill the bottle bottoms
- Seeds
- Water soluble plant food
- Straws
- Hand pump

## Procedure:

1. Fill the plastic bottoms with potting soil and set in the saucers. Water the soil so that it is very moist.
2. Each team should select a plant type to work with from the seeds available. Plant two seeds in each pot, and plant at least two pots, one to add $CO_2$ to and one with normal $CO_2$ to serve as a control. Leave the bottle tops off until the seedlings emerge.
3. After 2–4 days, the seedlings should emerge. Thin the seedlings to one per pot and place the bottle tops on each pot. Label one bottle "+$CO_2$", and the other "Normal

$CO_2$". Set the bottles in a bright place. Once you place the bottles on the pots, the bottles will serve to trap the moisture inside, so you should be very careful not to overwater the plants.

4. *$CO_2$ Treatment:* Beginning now, and for each school day for the next 3 weeks, enrich the $CO_2$ in the "+" bottle by blowing 10 breaths into the bottle, through a straw (Figure 1). Leave the caps off of both bottles, but to reduce the extra $CO_2$ leakage out of the top of the bottle cover approximately half the opening with a piece of tape. Although some air will exchange through the opening, the extra $CO_2$ will mostly remain in the bottle.

   *Control Treatment:* In order to ensure that, except for the extra $CO_2$, both treatment groups are exposed to the same conditions, the Control group will also have air added, at the same time the extra $CO_2$ is put into the other group. To add air without adding additional $CO_2$, use the hand pump to gently pump room air into the bottle (pump approximately 25 times per bottle).

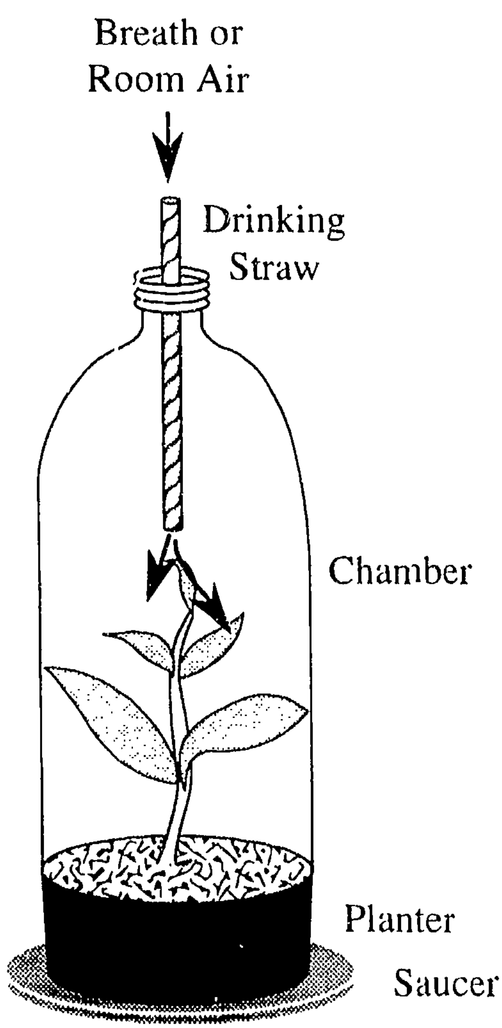


**Figure 1.** Completed Bottle Chamber Assembly

5. Describe the experimental set-up and $CO_2$ enrichment technique, and record observations of the plant and bottle conditions in a logbook throughout the experiment.
6. Water the plants when necessary by adding water to the saucers. Do not pour water into the top opening or remove the bottle top from the base. Water with a water-soluble plant food each time.
7. At the end of three weeks, remove the bottles from the bases, measure the heights, number of leaves, and any other growth parameter of interest. Record the values in your logbook. Be prepared to share your results with the class.❑

# What Impact Might Sea Level Rise Have?

ACTIVITY 14

**Lesson Focus:**
How might thermal expansion of the oceans affect sea level?

**Objective:**
The student will be able to:

1. Describe the change in water level when the water is exposed to heat.
2. Differentiate between thermal expansion and melting snow and ice fields as they relate to sea level rise.
3. Predict the impact of rising sea level on coastal areas.

**Time:**
1 Day

**Grade Level:**
8–10

**Key Concepts:**
Sea level rise, thermal expansion, ice and glacial melting

## Definition of Terms:

***Thermal Expansion:*** When most substances are heated, their volume increases due to increasing vibrations in their component molecules. In the case of oceanic thermal expansion, as the water molecules are warmed, the volume of water increases.

***Sea Level:*** The level of the ocean surface water midway between high and low tide levels.

***Land-Based Ice Fields:*** Ice fields that lie on top of land masses. Examples include mountain glaciers, the Antarctic ice sheet, and the Greenland ice sheet. Melting of these ice fields would add water to the ocean, thus raising sea level.

***Floating Ice Caps:*** Packed ice that covers the sea surface. The Arctic Ocean is generally covered by floating ice caps. Melting of polar ice caps would not have an impact on sea level because this ice is already floating, thus displacing its volume in the water.

## Background:

If global temperature increases, many scientists have indicated that an increase in sea level is one of the most likely secondary effects. Two factors will contribute to this accelerated rise in sea level. First, although the oceans have an enormous heat storage capacity, if global atmospheric temperatures rise, the oceans will absorb heat and expand (thermal expansion) leading to a rise in sea level. Second, warmer temperatures will cause the ice and snowfields to melt, thereby increasing the amount of water in the oceans. It should be noted that only the melting of land-based ice and snow fields (i.e., ice fields of Antarctica, mountain glaciers) will increase sea level. The melting of floating ice (i.e., North Polar ice cap) will not affect sea level. *[This can be demonstrated to your students by partially filling a glass container with water and ice cubes and marking the water level on the glass. When the ice cubes melt, note that the water level has not changed.]*

Throughout the Earth's history there have been periods of glaciation followed by warming trends in which the glaciers retreated toward higher altitudes and higher latitudes. At present, glaciers throughout the world are receding and the masses of ice at both polar regions appear to be shrinking. The present interglacial warming period began approximately 14,000 years ago. At that time, sea levels were 75 to 100 meters below present levels. As the massive snow and ice fields of the world began to melt, sea level rose rapidly at rates of as much as 1 meter per century. Over time, the rate of sea level rise declined to the present rate of 10 to 15 centimeters a century.

An accelerated rise in sea level would inundate coastal wetlands and lowlands, increase the rate of shoreline erosion, exacerbate coastal flooding, raise water tables, threaten coastal structures, and increase the salinity of rivers, bays, and aquifers. Even though sea level rise is considered to be one of the more likely effects of global warming, there's still no scientific certainty as to the rate or amount of sea level rise.

## Activity:

The students will conduct an experiment that demonstrates the effect of thermal expansion on water level. Discussion groups will follow this activity as students explore the potential impact of sea level rise on a global and local scale.

## Materials:

For each team of students:

- Conical flask
- Two-hole cork for flask
- Thin, glass tube
- Long thermometer
- Portable, clamp-on reflector lamp
- 150-Watt floodlight
- Dye

## Procedure:

1. Divide students into small teams.
2. ***Completely*** fill the flask with very cold water (to improve visibility, dye can be added).

3. Place the cork in the stopper. Slide the thermometer and glass tube in the holes in the cork (Figure 1). The water should rise a short way into the tube. Have students record both the temperature of the water and the water level in the glass tube in their log books.

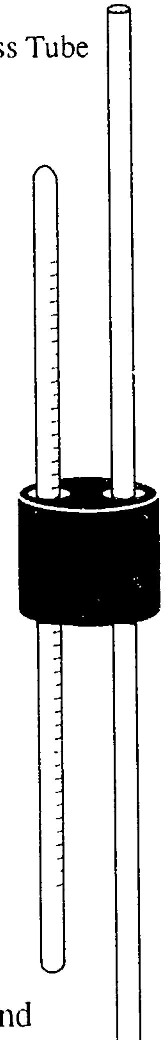


**Figure 1.** Thermometer and Glass Tube Inserted in Cork Holes

4. Ask students to predict what will happen to the water level when exposed to heat. Record prediction in logbook. Place the flask under the lamp (Figure 2). Turn on the lamp and record measurements every 2 minutes.

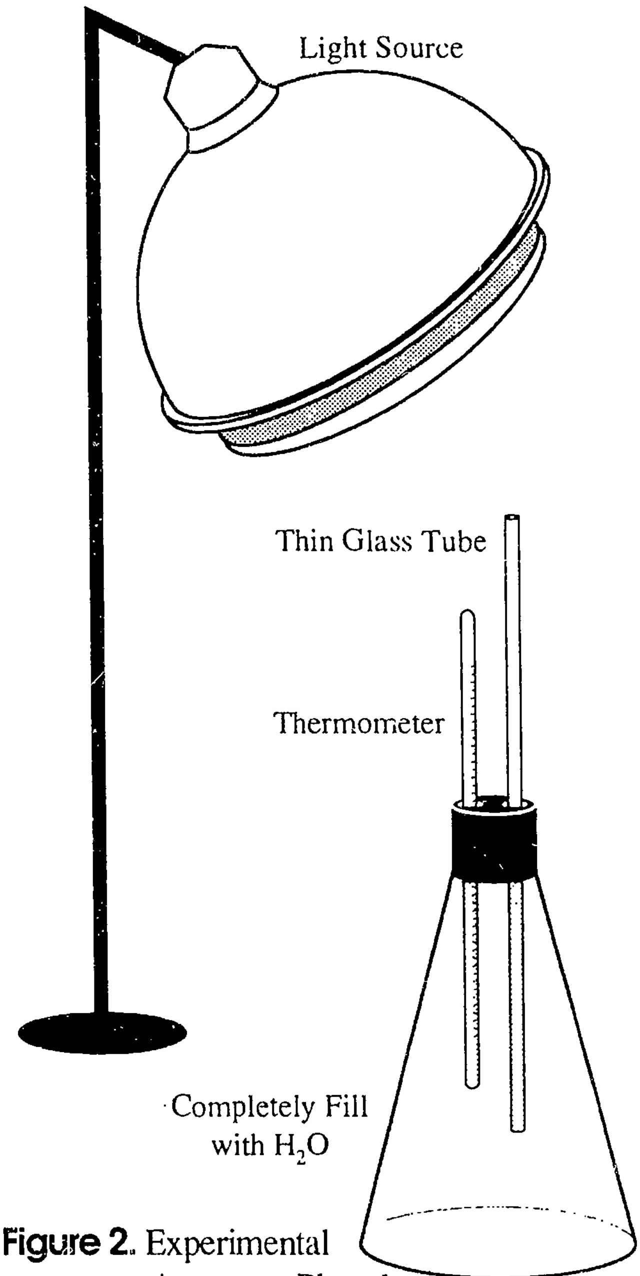


**Figure 2.** Experimental Apparatus Placed Under the Light Source

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**Discussion:**

- Why did the level of water in the flask change?

  *As water warms, it expands.*

- What implications does this experiment suggest might occur if the oceans warm?

  *If the ocean temperatures warm sufficiently to cause expansion, sea level would rise thus inundating coastal wetlands and other coastal low-lying areas.*

  Challenge your students to consider the possible impacts of sea level rise in areas such as South Florida or Bangladesh.

- If global warming is not sufficient to cause significant snow and ice melt, would you expect this thermal expansion to be enough to cause coastal flooding and erosion problems?

  *No, it will likely be enough to measure, but not enough to cause significant coastal problems.*

- Which would you expect to have a greater affect on sea level – the melting of the North Polar or South Polar ice caps?

  *Would it make a difference? Why? North Polar melting would have little effect on sea level. That ice is already floating, thus displacing its volume in water. If the South Polar ice cap melted, the water would run off the Antarctic continent into the ocean, increasing the ocean volume (and sea level) substantially.*

  Challenge your students to design an experiment using ice cubes to test this idea.

**Student Learning Portfolio:**

1. Graph of the thermal expansion experiment
2. A summary of the discussion questions in lab notebook ❑

**Notes:**

# What Impact Might Sea Level Rise Have?

STUDENT GUIDE—ACTIVITY 14

**Definitions of Terms:**

*Thermal Expansion:* When most substances are heated, their volume increases due to increasing vibrations in their component molecules. In the case oceanic of thermal expansion, as the water molecules are warmed, the volume of water increases.

*Sea Level:* The level of the ocean surface water midway between high and low tide levels.

*Land-Based Ice Fields:* Ice fields that lie on top of land masses. Examples include mountain glaciers, the Antarctic ice sheet, and the Greenland ice sheet. Melting of these ice fields would add water to the ocean, thus raising sea level.

*Floating Ice Caps:* Packed ice that covers the sea surface. The Arctic Ocean is generally covered by floating ice caps. Melting of polar ice caps would not have an impact on sea level because this ice is already floating, thus displacing its volume in the water.

## Activity:

You will conduct an experiment that demonstrates the effect of thermal expansion on water level. Discussion groups will follow this activity as you explore the potential impact of sea level rise on a global and local scale.

## Materials:

For each team of students:

- Conical flask
- Two-hole cork for flask
- Thin, glass tube
- Long thermometer
- Portable, clamp-on reflector lamp
- 150-Watt floodlight
- Dye

## Procedure:

1. Working with your team, completely fill the flask with very cold water (for increased visibility, dye can be added to the water).
2. Place the cork in the stopper. Slide the thermometer and glass tube in the holes in the cork (Figure 1). The water should rise a

short way into the tube. Record both the temperature of the water and the water level in the glass tube in your log books.

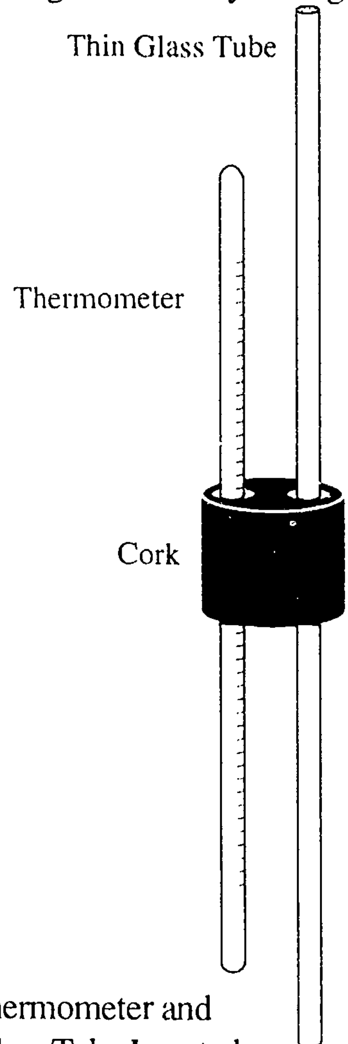


**Figure 1.** Thermometer and Glass Tube Inserted in Cork Holes

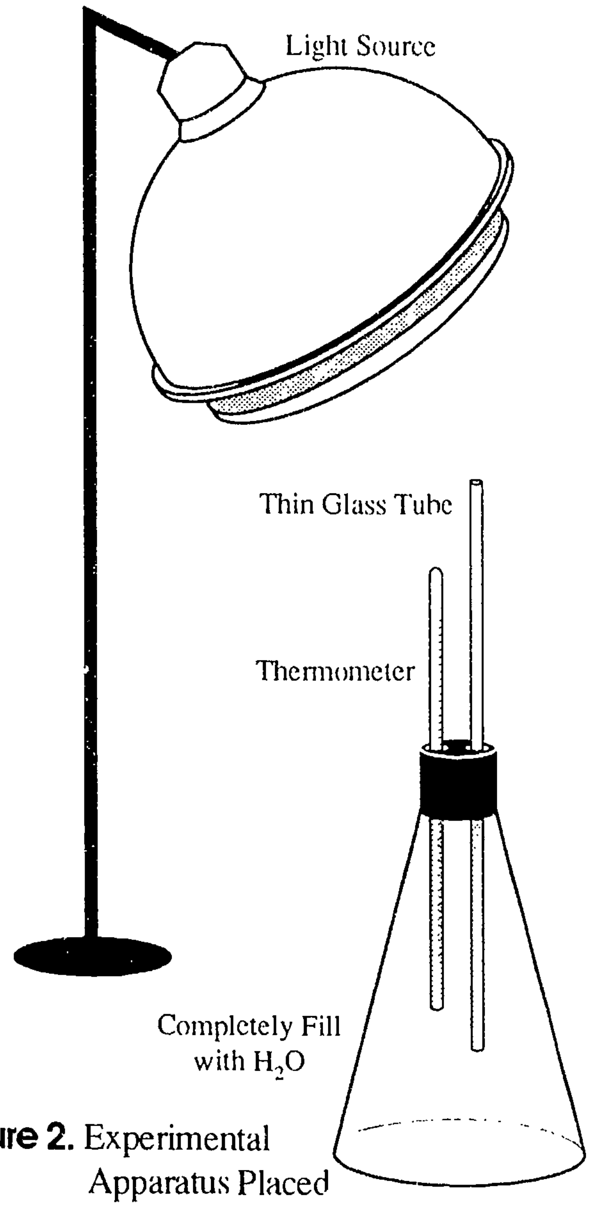


**Figure 2.** Experimental Apparatus Placed Under the Light Source

3. What do you think will happen to the water level when exposed to heat? Record your prediction in your logbook.
4. Place the flask under the lamp (Figure 2). Turn on the lamp and record measurements every 2 minutes.

**Discussion:**

- Why did the level of water in the flask change?
- What implications does this experiment suggest might occur if the oceans warm?
- If global warming is not sufficient to cause significant snow and ice melt, would you expect this thermal expansion to be enough to cause coastal flooding and erosion problems?
- Which would you expect to have a greater affect on sea level — the melting of the North Polar or South Polar ice caps?❑

# How Does Science Contribute to Public Policy?

ACTIVITY 15

**Lesson Focus:**
What can scientists tell citizens and governments about global climate change? Can and should humanity respond?

**Objective:**
The student will be able to:

1. Research, organize, and present information from a perspective of either scientist or policymaker.
2. Make informed decisions supported by evidence.
3. Describe the process and complexity of making policy decisions.

**Time:**
3 class periods

**Grade Level:**
8–10

**Key Concepts:**
Public policy, science-technology-society, subject integration

## Definition of Terms:

***Public Policy:*** The selected standard operating procedure of a governmental body chosen among alternatives to guide and determine present and future decisions.

***Scientific Panel:*** A gathering of scientists (usually considered to be experts in their field) where the results of research are represented and discussed.

***Science-Technology-Society:*** The integration of scientific, technological, and social considerations and concerns that are an integral part of living in our contemporary times.

## Background:

In the field of global climate change, as in many other environmental fields, the goal of much of the scientific research is to determine with some certainty the scope and nature of the environmental threat, and to develop workable, practical ways of responding to it. As such, often the research is very much *applied* in nature (having clear, policy-relevant goals), rather than *basic* (research for the sake of knowledge alone). Applied research, therefore, is of greatest value when it is used to influence environmental policy. Note that the term "policy" is used most commonly to refer to government decisions and regulations, but it can also mean business and/or personal decisions. Scientists and policymakers both have critical roles to play in translating applied research into government policies and actions. Scientists are responsible for communicating their own research to the policymakers. They have to do this in a way that is understandable and clearly relevant. They should work to assist the policymakers to interpret the research, to understand its significance and to appreciate its limitations. Scientists, however, can tell us what we can do, not necessarily what we should do. Policymakers, on the other hand, are responsible for more than just listening to the scientists. Not only do they have to assimilate research results (and sometimes weigh results supporting different conclusions) and work with the scientists to understand the relevance of the research to policy, they also have to balance social and economic issues as well. They then have to make often difficult and perhaps controversial policy decisions. An excellent example of the difficulties faced by scientists and policymakers alike in weighing issues relating to global climate change can be found in Dr. Steven Schneider's book *Global Warming* (1989, Sierra Club Books).

In this activity, the students will role-play participants at a panel on climate change and will represent either scientists or policymakers. They will use the information they've learned in the previous lessons to present to the policymakers. The policymakers will weigh that information, develop their own opinions, and decide what, if anything, should be done about climate change.

## Activity:

The students will role-play participants in a scientific panel. Congress has decided to convene a panel on climate change to determine if the United States should implement a policy on the issue. As part of its information gathering, it has requested presentations from the Nation's top scientists working in the field of climate change. Congress has invited scientists from universities and government agencies to present the latest findings of their research. Students representing scientists will present scientific evidence about climate change to the conference. The policymakers will make fundamental policy decisions based on the evidence. The result of the conference will be a set of policy decisions, based on scientific information, intended to guide the Nation's response to climate change.

## Materials:

- The teacher should make any visual aids (overheads, graphs, charts) used in the previous lessons available to the students for use in their presentations to the policymakers.
- The "scientists" should have blank flip charts, blackboard space, overhead transparencies, and pens.
- The "policymakers" should have notepads for taking notes on the scientific presentations.
- 2–3 Sheets of butcher paper and marking pens

## Procedure:

### Day 1:

1. Divide the class into groups. About eight of the students should be the "policymakers" – Congressional Representatives and their staff – and the remainder of the class will be members of the expert scientific panel. Just as many different areas of scientific expertise are represented in the global climate research community, the "scientist" students should represent different scientific disciplines. Divide the scientists into three or more teams. Each team will be assigned a different area of expertise, and will have to represent the interests and concerns of that area during the conference. Outlines of some of the characteristics of five possible groups are provided below. You may have more teams, and more disciplines represented, or the students may choose their own teams' areas of expertise. If they do, you may wish to have the team research the areas of interest and concern to that scientific group.

   ***Atmospheric Scientists:*** Their expertise is primarily in the composition and nature of the atmosphere (what's in the air and what does it do), and the influence of that composition on the climate itself. Atmospheric scientists could be expected to provide expert testimony on the greenhouse effect itself, what greenhouse gases are, how are they changing in the atmosphere, and how that might affect the climate.

   ***Ecologists:*** Their expertise is in the structure and function of Earth's biosphere, how plants and animals are distributed across the landscape, and how the environment of Earth affects living things and their distribution. Ecologists may wish to provide expert testimony on the way the climate influences important ecosystems, the way that changing climates in the past have affected ecosystems, and how and why future changes might also have an impact.

   ***Agricultural Scientists:*** Primarily concerned with crop production, agricultural scientists deal with issues of crop health, soil fertility and water availability, farming practices, and economic issues affecting farms and food production. They would be expected to testify about the possible impacts of climate change on food production and food distribution.

   ***Oceanographers:*** Their expertise involves the physical makeup of the oceans, how they circulate, and how they interact with climate. They are also concerned with the biota of the oceans. They would be expected to give expert testimony on the interactions of the ocean and the climate, the possibilities of sea-level rise, and the impacts of changing climate on ocean life.

   ***Computer Modelers:*** These scientists are expert in producing complex computer simulations of natural physical and biological processes. These simulations are used to predict the behavior of systems (such as the climate system) that cannot be easily experimented on directly. Computer modelers might be invited to such a conference to provide expert testimony on the way that computer models are used to help the scientific community make predictions about the impacts of possible global climate change, and to discuss the strengths and weaknesses of such models.

2. Discuss with the class the description of each group, what information each group will need, the goals of the panel and how the panel will be conducted. Stress that the presentations, questions and answers, and subsequent discussions are for the purpose of giving the policymakers the *best* available scientific information to help them make their decisions. The personal feelings of the scientists should not be allowed to affect the way the scientists present the data; however, the conclusions the scientists reach based on that data may enter into the discussions. Be sure to stress that the group should develop their own conclusions, based on the data they have at their disposal. They may, for example, decide that there is insufficient scientific evidence to be concerned with climate change, or they may feel that the evidence for climate change is very strong and that significant problems may result. In either case, the scientists should present the evidence that led them to their conclusions, and be prepared to discuss it. The policymakers may ask the scientists for their "best professional opinion". The policymakers have to digest the information, make sure they understand it, and consider their options. They have a particularly tough job because they have to consider not only the scientific evidence, but also the effect their decisions will have on the economic and social welfare of the Nation.

3. Each of the teams within the scientist groups must prepare a 5-minute summary of the most important issues they want the policymakers to know about. They need time here to decide what they want to say, find visual aids to support their position, and select a spokesperson. The policy group must select a spokesperson, and study and discuss among themselves the list of possible policy options they may wish to consider. Examples include the following:

   a. Business as usual – Insufficient evidence that a problem exists.

   b. All-out control strategies – Stringent $CO_2$ controls, accelerated reforestation, careful monitoring of planetary health, international cooperation demanded.

   c. Small concern – Some energy efficiency improvements, wait for more evidence before proceeding.

   *Note to Teacher:* You should spend time helping students consider the economic and social implications of some of the choices.

## Day 2:

1. Arrange the room so that the policymakers are sitting at desks or a table and facing the rest of the room. Set one desk or table facing the policymakers, near the center of the room. This will be used by the scientists making their presentations. Have an overhead projector, flip chart, and/or blackboard available nearby. You may wish to add to the official atmosphere by making a banner with "U.S. Panel on Climate Change" on it, and by giving name tags to each participant.

2. The instructor should give opening remarks and introduce the research teams and policymakers.
3. Each of the research teams will appoint a spokesperson to present a 5-minute summary of their "research" into climate change to the policymakers. The teams should be encouraged to keep their presentations within the time limit, and to be very clear and direct in their summary remarks. In preparing their remarks, the teams should begin by stating the sort of policy they recommend, and then present the scientific evidence for their position. For example, the Atmospheric Science team might decide to begin by urging immediate, drastic efforts be taken to curb $CO_2$ emissions. They may cite the steady, measurable rise in $CO_2$ across the world and the known physical ability of $CO_2$ to absorb heat as their primary reasons to support the control effort. The policymakers may ask questions during or after the presentations, but the total time for each team presentation should not exceed 8–10 minutes. If the policy group needs more information, it can request that the team provide it on the following day. All the teams should be able to complete their presentations during this class period.
4. All the students should take notes on the presentations in their logs.

### Day 3:

1. Room arrangement: same as Day 2.
2. Allow approximately 20 minutes of the class period for the policymakers to confer and make their decisions.
3. The policy spokesperson will announce the decisions, the reasons for the decisions, and the instructor or another student will write them on the butcher paper.
4. For the remainder of the period, the class as a whole should explore the implications of the decisions, and the instructor should provide a final wrap-up. It is important to stress the difficulty of such decisions in the "real world", and how what took 3 hours in class would consume many months or years of expert panels.
5. As homework, each student should select 2 of the policy decisions (assuming there were 2 or more), and, in a short essay, either reject or defend the decision and give the reasons why.

### Student Learning Portfolio:

1. Presentation notes in the logbooks.
2. List of policy decisions and the student's opinion about the correctness of the decision, and reasons for their decisions.

### Extensions:

1. To increase the written component of this exercise, have each research team prepare a 1-page "executive summary" of their presentation to give to the policymakers, and have the policy group prepare a written document detailing its solutions and the reasons they were selected.
2. Research the procedures used at the Rio Earth Summit in 1992.❑

**Notes:**

# How Does Science Contribute to Public Policy?

STUDENT GUIDE—ACTIVITY 15

**Definition of Terms:**

***Public Policy:*** The selected standard operating procedure of a governmental body chosen among alternatives to guide and determine present and future decisions.

***Scientific Panel:*** A gathering of scientists (usually considered to be experts in their field) where the results of research are represented and discussed.

***Science-Technology-Society:*** The integration of scientific, technological, and social considerations and concerns that are an integral part of living in our contemporary times.

## Activity:

The students will role-play participants in a scientific panel. Congress has decided to convene a panel on climate change to determine if the United States should implement a policy on the issue. As part of its information gathering, it has requested presentations from the Nation's top scientists working in the field of climate change. Congress has invited scientists from universities and government agencies to present the latest findings of their research. Students representing scientists will present scientific evidence about climate change to the conference. The policymakers will make fundamental policy decisions based on the evidence. The result of the conference will be a set of policy decisions, based on scientific information, intended to guide the Nation's response to climate change.

## Materials:

- Visual aids to support presentations (overheads, graphs, charts used in the previous lessons, or produced specifically for the presentation)
- Blank flip charts, blackboard space, overhead transparencies, and pens
- Notepads for taking notes on the scientific presentations
- 2–3 Sheets of butcher paper and marking pens

## Procedure:

### Day 1:

1. The teacher will divide the class into groups. One group will be "policymakers" – Congressional Representatives and their staff – and the remainder of the class will be divided up into different "scientist" teams. Just a  many different areas of

scientific expertise are represented in the global climate research community, the "scientist" teams will represent different scientific disciplines. Three or more scientist teams will be needed. Each team will be assigned a different area of expertise, and will have to represent the interests and concerns of that area during the conference. Outlines of some of the characteristics of five possible groups are provided below. Other groups are possible as well.

***Atmospheric Scientists:*** Their expertise is primarily in the composition and nature of the atmosphere (what's in the air and what does it do), and the influence of that composition on the climate itself. Atmospheric scientists could be expected to provide expert testimony on the greenhouse effect itself, what greenhouse gases are, how are they changing in the atmosphere, and how that might affect the climate.

***Ecologists:*** Their expertise is in the structure and function of Earth's biosphere, how plants and animals are distributed across the landscape, and how the environment of Earth affects living things and their distribution. Ecologists may wish to provide expert testimony on the way the climate influences important ecosystems, the way that changing climates in the past have affected ecosystems, and how and why future changes might also have an impact.

***Agricultural Scientists:*** Primarily concerned with crop production, agricultural scientists deal with issues of crop health, soil fertility and water availability, farming practices, and economic issues affecting farms and food production. They would be expected to testify about the possible impacts of climate change on food production and food distribution.

***Oceanographers:*** Their expertise involves the physical makeup of the oceans, how they circulate, and how they interact with climate. They are also concerned with the biota of the oceans. They would be expected to give expert testimony on the interactions of the ocean and the climate, the possibilities of sea-level rise, and the impacts of changing climate on ocean life.

***Computer Modelers:*** These scientists are expert in producing complex computer simulations of natural physical and biological processes. These simulations are used to predict the behavior of systems (such as the climate system) that cannot be easily experimented on directly. Computer modelers might be invited to such a conference to provide expert testimony on the way that computer models are used to help the scientific community make predictions about the impacts of possible global climate change, and to discuss the strengths and weaknesses of such models.

2. Work with your team, and in general class discussion led by your teacher, to understand the area of expertise represented by your group, the information you will need, how your group will contribute to the conference goals, and how the conference will be conducted.

3. If you are assigned to a scientist team, you will work together with your team to

prepare a 5-minute summary of the most important issues you want the policymakers to know about in you area of expertise. You will need to decide what you want to say, find visual aids to support your position, and select a spokesperson. The policy group must also select a spokesperson, and study and discuss among themselves the list of possible policy options they may wish to consider. Examples include the following:

a. Business as usual – Insufficient evidence that a problem exists, so don't do anything about global climate change at this time: Conduct "business as usual".

b. All-out control strategies – The threat from global climate change is real, serious, and demands immediate action. You will require stringent $CO_2$ controls, accelerated reforestation, and careful monitoring of planetary health; and you will demand international cooperation in these areas. These actions may have a negative impact on national and international economics, trade, and development, but the threat is grave enough to justify the actions.

c. Small concern – You think there is some evidence for future global climate changes, but the uncertaintiues are so large that you can't justify large-scale actions at this time. You may support small-scale efforts that will help slow the changes, but until more convincing evidence is presented, you will not support drastic efforts. Some small-scale actions to consider in this case might include increasing energy-efficiency standards for transportation, industries, and homes. This might reduce the rate at which $CO_2$ is increasing; fund additional research into climate change with the goal of reducing the uncertainties in the information currently available; and establish a network of environmental monitoring sites with the goal of detecting climate changes and determining how the changes are affecting biomes in the area.

There are lots of other possible options for the policymakers to consider. As you do so, consider what impacts your decisions might have on economics, politics, etc.

## Day 2:

1. The room will be arranged so that the policymakers are sitting at desks or a table and facing the rest of the room. One desk or table will be facing the policymakers, near the center of the room. This will be used by the scientists making their presentations. An overhead projector, flip chart, and/or blackboard will be available nearby.

2. Your teacher will begin the session with introductions of the research teams and policymakers, and will give instructions on how to conduct the conference.

3. Each of the scientist teams will appoint a spokesperson to present a 5-minute summary of their "research" into climate change to the policymakers. Keep your presentations within the time limit and be very clear and direct in your summary remarks. In preparing your remarks, you

should begin by stating the sort of policy you recommend, and then present the scientific evidence for that position. For example, the Atmospheric Science team might decide to begin by urging immediate, drastic efforts be taken to curb $CO_2$ emissions. They may cite the steady, measurable rise in $CO_2$ across the world and the known physical ability of $CO_2$ to absorb heat as their primary reasons to support the control effort. The policymakers may ask questions during or after the presentations, but the total time for each team presentation should not exceed 8–10 minutes. If the policy group needs more information, it can request that the team provide it on the following day. All the teams should be able to complete their presentations during this class period.

**Day 3:**

1. Room arrangement: same as Day 2.
2. Allow approximately 20 minutes of the class period for the policymakers to confer and make their decisions.
3. The policy spokesperson will announce the decisions and the reasons for the decisions; another student will write the reasons on the butcher paper.
4. For the remainder of the period, the class as a whole should explore the implications of the decisions, and your teacher will provide a final wrap-up.
5. As homework, you will select 2 of the policy decisions (assuming there were 2 or more) and, in a short essay, either reject or defend the decision and give the reasons why.❑

**Notes:**

# Appendix - Additional Resources

**Curriculum Materials** (There may be a charge to order the listed materials)

*Activities for the Changing Earth System*
The Ohio State University
29 W. Woodruff Avenue
Columbus, Ohio 43210

*Earth's Mysterious Atmosphere*
National Aeronautics and Space Administration (NASA)
Education Division
NASA Headquarters, Code FET
400 Maryland Avenue, SW
Washington, DC 20277-2028

*Global Change Educational Diskette Project*
National Geophysical Data Center
NOAA, E/GC1, Dept. 891
325 Broadway
Boulder, CO 80303

*Global Warming and the Greenhouse Effect*
Climate Protection Institute
Lawrence Hall of Science
University of California
Berkeley, CA 94720

*Global Warming: High School Science Activities*
Climate Protection Institute
5833 Balmoral Drive
Oakland, CA 94619

## Books

*Climate Change: The IPCC Scientific Assessment*
Houghton, J.T., Jenkins, G.J., and Ephraums, J.J. 1990. New York: Cambridge University Press.

*The Weather Book- USA Today*
Williams, J. 1992. New York: Vintage Books (Random House).

*The Next One Hundred Years*
Weiner, J. 1990. New York: Bantam Books.

*The Greenhouse Trap*
Lyman, F. (World Resources Institute). 1990. Boston, Mass.: Beacon Press.

*Global Warming*
Schneider, S.H. 1989. San Francisco: Sierra Club Books.

## Journals, Articles, and Reports

*The Climate System - Reports to the Nation on Our Changing Planet.*
University Corporation for Atmospheric Research/ National Oceanic and Atmospheric Administration. 1992. Copies available from: UCAR Office for Interdisciplinary Earth Studies, PO Box 3000, Boulder, CO. 80307-3000.

*Current - The Journal of Marine Education*
Global Change, Volume 10, No. 3, 1991.

"Global Climate Change". *The Science Teacher.*
Hall, D.K. 1989. 56 (6): 66-70.

"Global Climatic Change". *Scientific American* .
Houghton, R.A. and Woodwell, G.M. 1989. 260 (4): 36-44.

*Our Ozone Shield - Reports to the Nation on Our Changing Planet.*
University Corporation for Atmospheric Research/ National Oceanic and Atmospheric Administration. 1992. Copies available from: UCAR Office for Interdisciplinary Earth Studies, PO Box 3000, Boulder, CO. 80307-3000.

"Plants can't do Without CO2". *The Science Teacher* .
Hershey, D.R. 1992. 59(3), 41-43.

*Research and Exploration — Global Warming Debate*
National Geographic Society. Spring 1993, Volume 9, Number 2.