IN A NEW LIGHT

CLIMATE & WEATHER

A Workshop for Teachers, NSTA 2004
University Corporation for Atmospheric Research,
Office of Education and Outreach
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Since the time of the Greek philosophers in the 5th century BC, mankind has speculated about the nature of light. Today, physicists have learned through experimentation that light has a dual nature and behaves as a particle at times and as a wave at other times. We also know that energy from the Sun, some arriving as visible light, is the primary source of all energy on Earth.

Light particles are called photons and are different from particles of matter because they have no mass and always move at a constant speed of nearly 299,792 kilometers per second, or 186,281 miles per second through empty space. This makes light the fastest phenomenon known in the universe. Yet light is also a form of radiant energy, or energy that travels in waves, which only slows down when inside substances such as air, water, glass or diamond.

Light waves come in many sizes, or wavelengths, which are measured from crest to crest (highest point of wave) or trough to trough (lowest point) in meters (m) to nanometers (nm, \(10^{-9}\) meters). Light waves also come in various frequencies, which refers to the number of waves that pass a point per unit of time, usually in one second. These light wave frequencies are measured in Hertz (Hz) with the amount of energy in a light wave proportional to its frequency. This means that high frequency light corresponds to high energy output and low frequency light corresponds to low energy output. The wavelength, however, is inversely related to the frequency and energy. Energy from the Sun with the shortest wavelengths (gamma rays) have the greatest frequency and thus, energy.

When we talk about light, we usually are referring to the range of frequencies that the human eye can see, approximately one-half to three-quarters of a million billion (5 x 10\(^{14}\) to 7.5 x 10\(^{14}\)) Hertz, and with wavelengths ranging from 400 to 700 nanometers. Although this light appears white in color, it is actually composed of various combinations of red, green and blue (RGB). Unlike the primary colors of pigment (red, blue and yellow), RGB refers to the primary colors of light because none of these three colors can be created from the other two, and all other colors can be formed by combining the primary colors in various proportions. Each color found in the visible spectrum of light (red, orange, yellow, green, blue, indigo and violet) corresponds to a particular wavelength, with violet having the shortest wavelength and greatest frequency and red the longest wavelength and lowest frequency.

The Sun produces other energy at higher and lower frequencies and smaller and larger wavelengths that we cannot see. The entire range of energy from the Sun is referred to as the Electromagnetic Spectrum. Gamma rays, x-rays and ultra-violet rays are produced at frequencies and wavelengths with smaller frequencies per unit of time.

To fully understand the nature of light and how it is created, it is necessary to understand matter at its atomic level. It is the motion of electrons within atoms -- the building blocks of matter -- that leads to the emission of light in most sources. Electrons circle atoms in specific patterns called orbitals, each containing a finite amount of energy. The closer the electron’s orbit is to the nucleus of the atom, the less energy it possesses. If an electron in such a low energy level gains some energy, it must jump to a higher level of orbit, and the atom is said to be excited. This jump causes the electron to lose energy and subsequently fall back to a lower level of orbit. The energy the electron releases as a result of this change in orbitals is equal to the difference between the higher and lower energy levels, and can result in the emission of a quantum of energy in the form of a photon.
Standing Wave Demonstration

In this exercise, students will explore wavelengths in several ways. This demonstration is intended to help students better understand the electromagnetic spectrum.

**Background**

To understand how ozone is generated and how it functions in the earth’s atmosphere, it is important to know something about the energy that comes from the sun. When scientists carefully analyze the sun’s energy, they find that only part of the energy comes to us in the form of light we can see. Much of the energy comes in forms that we can't detect directly with our eyes. The full spread of this energy is called the electromagnetic spectrum.

Electromagnetic energy is sometimes described as traveling in waves and sometimes as traveling in packets of energy referred to as photons. Each concept is useful to scientists in explaining the behavior of light energy. This activity is a demonstration of energy as waves. Progressing from short wavelengths to long wavelengths, scientists have identified gamma rays, x-rays, ultraviolet light, visible light (between 400 and 700 nanometers), infrared (heat), microwaves, and radio waves. Short wavelengths have more energy per photon than long wavelengths.

Most of the radiant energy from the sun is concentrated in the visible and near-visible parts of the spectrum. The narrow band of visible light, between 400 and 700 nanometers (nm), represents 43% of the total radiant energy emitted. Wavelengths shorter than the visible account for 7 to 8% of the total, but are extremely important because of their high energy per photon. Ultraviolet wavelengths are divided into three sections: wavelengths between 200 and 280 nm are UV-C, between 280 and 320 nm are UV-B, and between 320 and 400 nm are UV-A.
Ozone absorbs all UV-C, much of the UV-B, and a little of the UV-A. The levels of UV reaching the earth's surface varies with time of day, day of the year, latitude, weather conditions, and the ozone aloft. Even though only a small amount of the sun's total radiation lies in the band of UV wavelengths, these very short wavelengths are damaging because of their high energy. The remaining 49 to 50% of the radiant energy emitted from the sun is spread over the wavelengths longer than those of visible light. These lie in the near-infrared range from 700 to 1000 nm; the thermal infrared, between 5 and 20 microns, and the far infrared regions.

In this demonstration, wavelengths are generated by an electric drill supplying energy to a cord. Energy moves from the drill along the cord to its end, which is held by a student. The cord itself merely moves up and down and does not move forward toward the student. As the wave moves forward along the cord, it carries energy with it. This demonstrates how electromagnetic energy travels from the sun to the earth.

**Learning Goals**

1. Students will be able to explain that energy travels from the sun to the earth by means of electromagnetic waves.

2. Students will understand that the shorter the wavelength, the higher the energy per photon and will be able to explain why shorter wavelengths of electromagnetic energy carry more energy than longer wavelengths.

3. Students will be able to demonstrate how wavelength is measured.

**Alignment to National Standards**

*National Science Education Standards*

- Physical Science, Transfer of Energy, Grades 5 to 8, p. 155, Item #6: "The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation."

- Physical Science, Interactions of Energy and Matter, Grades 9 to 12, pg. 180, Item #1: "Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter."

- Physical Science, Interactions of Matter and Energy, Grades 9 to 12, pg. 180, Item #2: "Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the..."
wavelength."

Benchmarks for Science Literacy, Project 2061, AAAS

- The Physical Setting, Motion, Grades 6 to 8, pg. 90, Item #1: "Light from the sun is made up of a mixture of many different colors of light, even though to the eye the light looks almost white. Other things that give off or reflect light have a different mix of colors."

- The Physical Setting, Motion, Grades 6 to 8, pg. 90, Item #5: "Human eyes respond to only a narrow range of wavelengths of electromagnetic radiation - visible light. Differences of wavelength within that range are perceived as differences in color."

- The Physical Setting, Motion, Grades 9 to 12, pg. 92, Item #6: "Waves can superpose on one another, bend around corners, reflect off surfaces, be absorbed by materials they enter, and change direction when entering a new material. All these effects vary with wavelength. The energy of waves (like any form of energy) can be changed into other forms of energy."

Grade Level/Time

- **Grade level:** 6 to 9

- **Time:**
  - Background discussion: 20 minutes
  - Drill demonstration: 20 minutes
  - Recommended for students to try out the wave generation with hand power: 20 minutes
  - Post-demonstration discussion: 15 minutes

Materials

- 12 to 15 feet of 1/8" nylon cord
- 1 foot of 1/8" nylon cord
- Electric drill and chuck key
- 1 20-penny bent nail
- #2 barrel swivels (found in the fishing section of sporting goods)
- Slinky (optional)
Procedure

1. Before presenting this demonstration, provide some background information on the electromagnetic spectrum.

2. Prior to the demonstration, you will need to bend a 20-penny nail as shown. You will have to use a vise to accomplish this.

3. Attach a swivel to each end of the nylon cord.

4. Tie the 1-foot piece of cord to one of the swivel holders. This is the piece of cord that a student will hold during the demonstration.

5. Slide the bent nail through the eye of the other swivel.

6. The nail end should be put into the drill bit fitting and tightened securely with the chuck key.

7. To ensure the safety of your students, it is imperative that the cord not break during the demonstration. Be sure to test it before you present it to your students.
8. Ask a student to hold one end of the cord.

9. Plug in the drill and the demonstration begins. The less tension you apply, the more waves will appear. You can also vary the speed and reverse the direction of the drill to get different wave effects. Experiment and have fun!

Note: If you do not want the complication of using a drill, you can simply have students use their arms and hands to generate the wave using a length of rope. The more energy they put into the motion, the shorter the wavelength.

Another option is to use a Slinky to demonstrate energy and size of wavelengths.

Observations and Questions

1. The length of the wave is measured as the distance from wave crest to wave crest. What happens to the length of the wave when the drill speeds up, i.e., when more energy is added? (The wavelength shortens.)

2. What occurs to the wavelength when the drill is slowed? (The wavelength increases.)

3. UV radiation is a relatively short wavelength. It is shorter than visible light. What is the energy of UV radiation relative to visible light? (It has higher energy.)

4. Why do you think UV radiation is of such great concern? (Because it has so much energy, ultraviolet light in large doses can be damaging.)

5. We hear so much about ultraviolet radiation these days. What about even shorter wavelengths, such as x-rays and gamma rays, that also come from the sun? Do they cause damage too? (Yes.)

Assessment Ideas

- Have students individually generate waves manually while you observe. Ask them to produce a long-wavelength wave. Then ask them to produce a short-wavelength wave. Ask them to explain the difference in how they produced each wave and what that means in terms of the energy in the wave. Which wave would be most like visible light? Which wave would be more like UV radiation?

Modifications for Alternative Learners

- The visual nature of this demonstration lends itself to diverse learners. Accepting oral rather than written explanations of the lab questions may help some English Language Limited students.
The Behavior of Light

Light’s behavior has been studied for centuries. Terms for some of what we know about light’s behavior are defined below.

**Angle of incidence**: The angle between a wave striking a barrier and the line perpendicular to the surface.

**Angle of Reflection**: The angle between a reflected wave and the barrier from which it is reflected.

**Diffraction**: The bending of light around an edge or through a slit.

**Dispersion**: Dispersion is the change of index of refraction with wavelength. Generally the index decreases as wavelength increases, blue light traveling more slowly in the material than red light. Dispersion is the phenomenon which gives you the separation of colors in a prism.

**Electromagnetic Wave**: A wave that does not have to travel through matter in order to transfer energy.

**Electromagnetic Spectrum**: Transverse radiant energy waves, ranging from low frequency to very high frequency, which can travel at the speed of light.

**Frequency**: The number of waves that pass a point in a given unit of time.

**Index of Refraction**: The amount that light is refracted when it enters a substance; given as the ratio of speed of light in a vacuum to its speed in a given substance.

**Infrared Radiation**: Invisible radiation with a longer wavelength than red light and next to red light in the electromagnetic spectrum; heat.

**Interference**: The addition by crossing wave patterns of a loss of energy in certain areas and reinforcement of energy in other areas.

**Laser (light amplification by stimulated emission of radiation)**: A device that produces a highly concentrated, powerful beam of light, which is all one frequency or color, and travels only in one direction.

**Law of Reflection**: Angle of incidence equals the angle of reflection.

**Polarized Light**: Light in which all waves are vibrating in a single plane.

**Reflection**: The light or image you see when light bounces off a surface; bouncing a wave or ray off a surface.

**Refraction**: Bending of a wave or light ray caused by a change in speed as it passes at an angle from one substance into another.

**Scattering**: The spreading out of light by intersecting objects, whose size is near the wavelength.

**Visible Light Spectrum**: Band of visible colors produced by a prism when white light is passed through it.

**Ultraviolet Radiation**: Radiation that has a shorter wavelength than visible light; next to violet light in the electromagnetic spectrum.

**Wavelength**: The total linear length of one wave crest and trough.
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<tr>
<th>Title:</th>
<th><strong>Blue Skies and Red Sunsets</strong></th>
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<tr>
<td>Summary:</td>
<td>Students will observe how light is scattered with some wavelengths scattered more than others producing blue skies and red sunsets.</td>
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<td>Source:</td>
<td>A classic classroom activity and a favorite of the Education and Outreach staff at NCAR/UCAR!</td>
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<td>Grade level:</td>
<td>Adaptable to grades 3-10</td>
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<td>Time:</td>
<td>5-minute setup, 10 minute experiment or demonstration</td>
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**Student Learning Outcomes:**
- Students will understand that white light is composed of all the colors of the visible spectrum (red, orange, yellow, green, blue, indigo, and violet).
- Students will learn that white light is separated into its color components by particles that scatter light.
- Students will understand that light traveling through the atmosphere scatters when it encounters particles such as dust, gas, and aerosols making the skies appear blue during the day.
- Students will understand that sunsets are red because light travels a longer distance and more wavelengths are scattered.

**Lesson format:** Demonstration or hands-on activity

**National Standards Addressed:**
- **K-4 Content Standard A: Science as Inquiry**
- **K-4 Content Standard B: Light**
- **K-4 Content Standard D: Objects in the sky**
- **K-4 Content Standard D: Changes in the Earth and Sky**
- **5-8 Content Standard A: Science as Inquiry**
- **5-8 Content Standard B: Transfer of Energy**
- **5-8 Content Standard D: Structure of the Earth system**
- **9-12 Content Standard B: Interactions of Energy and Matter**
- **9-12 Content Standard D: Energy in the Earth System**
**MATERIALS:**

For each group of four:

- Tall clear drinking glass or clear soda bottle
- Water
- Milk (whole milk works best)
- Drinking straws
- Coffee stirrers
- Flashlight
- Writing paper and pencil
- Optional: Paint samples of various colors

**DIRECTIONS:**

1. Darken the room by closing shades and turning off the lights. Have student groups shine a flashlight at the top of the tall glass of water.

2. Ask students to describe in their journals the color of the light coming from the flashlight, the color of light as it travels through the glass, and the color of the liquid at the bottom of the glass. (If might be necessary to put a sheet of white paper on the far side to avoid seeing colors through the glass.)

3. Turn on the lights and instruct student groups to fill their straw with about an inch of milk, add it to the glass of water, and use the coffee stirrer to mix. (If you are using a soda bottle, you will need to use more milk, cap the bottle, and shake.)

4. Turn off the lights and again instruct student groups to shine a flashlight at the top of the glass of water.

5. Ask students to describe in their journals the color of the light coming from the flashlight, the color of light as it travels through the glass, and the color of the liquid from the far side of the glass.

6. If your students can’t see any change in color, instruct them to add a couple drops of milk to the mixture and try again.

**BACKGROUND INFORMATION:**
This lesson attempts to answer the age-old question, "why is the sky blue?" through a short inquiry activity.

Sunlight, or visible light, is composed of the rainbow colors: red, orange, yellow, green, blue, and violet. Visible light is a part of the electromagnetic spectrum and carries energy in waves. Colors towards the red end of the spectrum have longer wavelengths and colors near the violet end of the spectrum have shorter wavelengths. Light waves can transfer energy when they interact with matter. Each type of matter is able to gain or lose a particular amount of energy and particular wavelengths.

Earth's atmosphere contains molecules of gas, mostly nitrogen and oxygen, as well as smaller amounts of carbon dioxide, aerosols, dust and ozone. These particles scatter (re-emit) some wavelengths of light more easily than others. The shorter wavelengths, such as violet and blue are the most likely to be scattered. The sky is blue because our eyes are not very sensitive to violet light.

When the sun is low in the sky, during sunrise and sunset, sunlight travels through a much greater thickness of atmosphere than it does when it is overhead. Over this greater distance, light comes in contact with more particles and more wavelengths of light are scattered including longer wavelengths like green, yellow and orange. Only the red light comes through to your eyes; so, the setting sun often looks red.

In this activity, the suspended particles of milk scatter light like molecules and other particles in Earth's atmosphere. Where the light has only traveled through the top layer of water, it appears light blue. Where it has traveled through most of the water, it appears yellow, orange, or red. If you add too much milk to the water, the glass will have a yellowish hue just like the atmosphere on a smoggy day. Sometimes the color variations are rather subtle. Younger children might find it easier to compare the light in the glass to paint samples to identify the color.

**RELATED WEB RESOURCES FROM NCAR and UCAR**

- [Earth's Atmosphere](#) from Windows to the Universe
- [Weather and Climate Basics](#) from NCAR Education and Outreach
Spectroscopy is used by atmospheric scientists, astronomers, physicists and many other scientists to study light from various sources on Earth and throughout the universe. Although light is a mixture of all colors of visible light (red, orange, yellow, green, blue, indigo and violet), not all light that appears white to the eye is made up of the same mix of colors.

So how is light created? When an atom of a given element is heated or excited, the electron(s) in its nucleus begin to collide with one another. The higher the temperature, the greater the number of collisions that will occur. As a consequence of this excitation, electrons can be boosted to higher energy levels. Photons of light are then created when the electrons drop back to the original energy level.

We observe this process every day when we turn on a light and the filament begins to heat or when we light a candle. The difference in the color of the filament or in a flame is an indication of its temperature. At first the filament will give off a reddish light, but as it grows hotter, it will radiate a bluish light of smaller wavelengths. In a candle flame, one can observe areas of red, orange, yellow and blue. A blue flame will be the hottest area of the flame. Similarly, when astronomers look at the spectra of stars, they can tell that those radiating a great deal of blue light are hotter than those radiating red.

It turns out that each chemical element has a unique set of energy levels, and the energies of the corresponding photons it can emit make up its unique "spectral fingerprint" or "signature." Knowing that each chemical element radiates light in specific wavelength combinations, scientists can then identify what stars are made of or the percentage of certain chemicals in our atmosphere. For example, we know the chemical composition of the Sun, its age and life cycle, through an analysis of the Sun's spectra.

Using a spectroscope, we, too, can look at the spectrum produced by various light sources and compare and contrast them. A spectroscope uses a diffraction grating to create the spectrum of light that is visible. Light with shorter wavelengths, such as violet, are diffracted more than light with longer wavelengths, such as red. Our eyes then see each wavelength of light as a separate color and in order of wavelength. While a prism uses the process of refraction to create a rainbow, diffraction gratings disperse white light through interference. The grating is composed of many thousands of microscopic parallel grooves. (The diffraction grating we're using today has 1000 grooves per millimeter.) Light passing between these grooves is dispersed into its component wavelengths and appears as parallel bands of color on the retina of the observer's eyes.

Use a spectroscope to look at the spectrum of various light sources (incandescent, fluorescent, halogen, sodium, mercury or metal halide light bulbs; car lights; neon signs, street lights; light from television and computer screens…). Never use a spectroscope to analyze the Sun. Instead, use a white poster board to reflect the light from the Sun and use the spectroscope to analyze the Sun's light reflecting off of the board.
<table>
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<tr>
<th>Title: Building a Spectroscope to Observe Light Spectra</th>
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<td>Summary: Students will build a simple spectroscope. Next they will observe the spectrum of various light sources such as incandescent, fluorescent, mercury and sodium lights. Finally, they will use the Spectra Reference Chart to identify the gas(es) found in mystery gas tube(s).</td>
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<tr>
<td>Source: Adapted from Stanford Solar Center's Activity Resources</td>
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<td>Grade level: 6-9</td>
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<td>Time: Part 1: 30 minutes; Part 2: 30 minutes; Part 3: 20 minutes</td>
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<td>Student Learning Outcomes:</td>
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<tr>
<td>● Students will observe how white light can be diffracted through interference to form a color spectrum that has a pattern.</td>
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<td>● Students will explore how scientists use special tools, such as spectroscopy, to identify chemical elements on Earth and in the universe.</td>
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<td>● Students will be able to explain/describe how technological design and tools can help scientists better understand the world around us.</td>
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<td>Lesson format: Experiment</td>
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An Activity from the NCAR Educators' Bridge

MATERIALS AND WORKSHEETS:

- Spectroscope (Part I) -- use a model from the internet or order through Stanford Solar Center (48 for $7)
- Scissors and Clear Tape (Part I)
- A variety of light sources (incandescent, florescent..) (Part II)
- Spectra Reference Chart (Part III)
- Gas Tubes (see supply references) (Part III)
- Spectrum Tube Power Supply (Part III)

Worksheets:

- Spectra Recording Sheet
- Mystery Gas Spectra Identification Sheet

DIRECTIONS:

1. Have students carefully put together their spectroscope by following the precise directions given.
2. Students observe and record the spectra of various white light sources.
3. In small groups, have students compare and contrast their observations and discuss what might cause differences among spectra from the various lights.
4. Have students observe and record the spectra from other light sources in their home or around the school. Challenge them to discover a new spectra from those already observed or match one from school to one at home.
5. Have students record the spectra from one or more gas tubes that are excited via a spectrum tube power supply.
6. Using the Spectra Reference Chart, have students identify the mystery gases.
7. In small groups, have students discuss how knowing the spectra of given elements might be used in science or be beneficial in understanding the world around us.
8. Have students research how an atmospheric scientist, astronomer or physicist might might use spectroscopy in their work.

BACKGROUND INFORMATION:
Spectroscopy is the study of the absorption of light. In the gas phase, molecules exhibit absorption lines that are characteristic of the molecule. The precise frequencies of these lines not only help determine the structure of the molecule but also the frequencies and intensities of other lines. Scientists use spectroscopy to detect molecules in the Earth's atmosphere, in the atmosphere of other planets, and in stars.

RELATED WEB RESOURCES FROM NCAR and UCAR

Windows to the Universe's Looking at the World in a Different Light takes students on a tour of the universe as seen from various wavelengths within the electromagnetic spectrum. Students learn about radiant energy and can view familiar sites in a "a different light."
http://www.windows.ucar.edu/tour/link=/cool_stuff/tours_main.html

OTHER RESOURCES:

- Spectroscope posters are available from the Stanford Solar Center to educators (48 posters plus diffraction grating and postage for $7): http://solar-center.stanford.edu/
- Spectroscope patterns are readily available on various internet sites for educators to download Spectra Reference Chart showing the spectra of nine common light sources is on the Journal of Chemical Education site at: http://jchemed.chem.wisc.edu/Journal/Issues/1997/Sep/abs1070.html.
- Project Lite at http://lite.bu.edu/lite1/color/mix/mixmac.html has java applets for color mixing, spectrum explorations and much more!
- Exploratorium's "Seeing" site covers seeing and perception in a fun and informative manner: http://www.exploratorium.com/seeing/index.html
- Molecular Expressions Light and Color site explains the nature and behavior of light and color clearly and concisely: http://www.micro.magnet.fsu.edu/primer/lightandcolor/index.html
- Spectra Tube Power Supply and various spectra gas tubes are available from science supply companies such as Science Kit & Boreal Laboratories at http://sciencekit.com (product # WW6299926 and WW6299905, 06, 07...)
**Science Exploration Guidesheet**

**Spectroscopic Observation #1: Observing Spectra**

**Directions:** Use your spectroscope to observe and record the spectrum for 3 light sources given below. Then choose 2 light sources of your own (for example: streetlight, neon sign light, Television light, computer monitor screen light) and record your spectroscopic observations. Do NOT choose the sun for this activity. When you’re finished compare your results with your classroom scientists.

1. **Light Source: fluorescent lights in the classroom**

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<tr>
<th>Red</th>
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2. **Light Source: soft-white lightbulb**

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Source: Stanford Solar Center “All About the Sun” Curriculum
www.solar-center.stanford.edu
**Spectroscopic Observation #2: Mystery Gas Tubes**

**Directions:** Observe and record using your spectroscope the spectrum for each mystery gas tube. Then use the Spectra Reference Chart to identify what element is in each tube.

1. **Mystery Gas Tube #1:**

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**Source:** Stanford Solar Center “All About the Sun” Curriculum  
www.solar-center.stanford.edu
Ozone (O₃) molecules are composed of three oxygen atoms and comprise a very small part of our atmosphere. In every million molecules of air, fewer than ten are ozone. Nevertheless, the presence of these molecules in the Stratosphere safeguard life on this planet. Without stratospheric ozone’s absorption of harmful ultraviolet sunlight (UV-B at wavelengths between 240 and 320 nm), ultraviolet radiation reaching Earth’s surface would make our planet uninhabitable.

In the stratosphere, ozone is created naturally when sunlight strikes this layer of the atmosphere and splits oxygen molecules (O₂) into two separate oxygen atoms (O). Each individual oxygen atom then quickly combines with an oxygen molecule (O₂) to produce an ozone molecule (O₃). This ozone, often referred to as the “ozone layer”, includes 90% of the ozone total. The so-called “ozone hole” is actually not a hole at all, but an ozone depletion area in the stratosphere found over Antarctica.

The remaining 10% of ozone is in the troposphere, the region closest to Earth’s surface, extending approximately 10 to 16 kilometers (6-10 miles). It is ironic that ozone at this level poses a health hazard and is produced in chemical reactions involving sunlight, naturally occurring gases and gases from pollution sources, namely hydrocarbon and nitrogen oxide gases. Fossil fuel combustion is a primary pollution source for tropospheric ozone production. At this lower level, ozone can reduce one’s lung capacity and crop yields, and is generally harmful to all living systems because it reacts strongly to destroy or alter many other molecules.

Folklore has it that the first measurements taken of stratospheric ozone levels in the mid-1980s were so dramatically low that the scientists thought that their instruments were faulty. It wasn’t until the measurements were repeated with new instruments that both the new and initial readings were accepted as genuine. It also is believed that the Total Ozone Monitoring Satellite (TOMS) initially didn’t show the dramatic loss of ozone because the software processing the raw ozone data from the satellite was programmed to treat very low values of ozone as bad readings. Later analysis of the raw data confirmed that a British Antarctic Survey team in the 1970s was the first to notice a decline in ozone in the stratosphere over Antarctica. Also in the 1970s, scientists Mario Molina and Sherwood Rowland discovered that some human-produced chemicals, most significantly halogens including chlorofluorocarbons (CFCs), could destroy ozone and deplete the ozone layer. This knowledge ushered in a period of research and ozone monitoring that continues to this day. It also resulted in the awarding of the Nobel Prize in Chemistry to Molina and Rowland in 1995.

In 1987 an international agreement known as the Montreal Protocol on Substances that Deplete the Ozone Layer was ratified by over 180 nations that established legally binding controls on the national production and consumption of ozone-depleting gases. As a consequence, all principal halogen-containing gases will be significantly reduced or phased out before the middle of the 21st century. By mid-century, the effective abundance of ozone-depleting gases are expected to fall to values present before the Antarctic “ozone hole” began to form in the early 1980s.

However, the loss of stratospheric ozone over the South Pole in September 2003 was nearly 11 million square miles - almost as large as the largest ever ozone depletion area that occurred in September 2000 that was 28.3 million square kilometers (11 million square miles), three times larger than the entire landmass of the United States.

Source: Twenty Questions and Answers About the Ozone Layer, Scientific Assessment of Ozone Depletion: 2002
Stratospheric Ozone: A Balancing Act

This activity helps students understand the concept of equilibrium as applied to a model system and to stratospheric ozone. Although the materials are easy to come by, this model set-up does require a fair amount of preparation. You may want to do this as a classroom demonstration.

Background

Over the past several years there has been much discussion about the bad effects of ozone. But keep in mind that ozone occurs in two different layers of the atmosphere — the troposphere and the stratosphere. The stratospheric ozone, the so-called good ozone, protects the planet from the harmful effects of the sun's ultraviolet (UV) rays.

About 90% of all ozone is found in the stratosphere, where it plays an important role by absorbing harmful UV radiation. Some of the chemical pollutants that we are releasing into the atmosphere are destroying the ozone in this layer. It is the destruction of this stratospheric ozone, the subsequent formation of the ozone hole, and the general global reduction in stratospheric ozone thickness that should cause grave concern among all people.

The amount of ozone in the stratosphere is the net result of production and loss processes. Ozone is produced by photolysis (breaking apart of molecules by light) of oxygen high in the stratosphere where ultraviolet light is most intense. Ozone is lost by conversion back to molecular oxygen (O₂) through reactions whose net effect is:

\[ \text{O} + \text{O}_3 \rightarrow 2 \text{O}_2 \]

So in the stratosphere, ozone is always being created and destroyed. Normally, this natural cycle is in perfect balance. It keeps just the right amount of ozone in the ozone layer.

With the discovery of the "ozone hole" over Antarctica in 1985, scientists determined that something was destroying ozone faster than nature could replace it. This something, a group of human-produced chemicals called chlorofluorocarbons (CFCs), has shifted the balance in the natural process of ozone production and ozone destruction. CFCs catalyze, or speed the break up of, ozone molecules when UV rays are also present. One CFC molecule can help destroy up to 100,000 ozone molecules over its lifetime of 100 years, and ozone production cannot keep up. In the graphic below, the destructive cycle of a chlorine atom is shown.
1. UV radiation breaks off a chlorine atom from a CFC molecule.

2. The chlorine atom attacks an ozone molecule (O₃), breaking it apart and destroying the ozone.

3. The result is an ordinary oxygen molecule (O₂) and a chlorine monoxide molecule (ClO).

4. The chlorine monoxide molecule (ClO) is attacked by a free oxygen atom releasing the chlorine atom and forming an ordinary oxygen molecule (O₂).

5. The chlorine atom is now free to attack and destroy another ozone molecule (O₃). One chlorine atom can repeat this destructive cycle thousands of times.

The following animation shows the destruction of an ozone molecule by a chlorine atom.

In this activity, students will build a model that represents the natural balance of stratospheric ozone production and destruction. They will then alter their model to represent the changes humans have caused in this ozone balance.

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**Learning Goals**
Students will be able to explain the concept of equilibrium as applied to the model system and to stratospheric ozone.

Alignment to National Standards

National Science Education Standards

- Unifying Concepts and Processes, Evidence, Models, and Explanation, Grades K to 12, pg. 117, paragraph 2: "Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations."

- Unifying Concepts and Processes, Evolution and Equilibrium, Grades K to 12, pg. 119, paragraph 2: "Equilibrium is a physical state in which forces and changes occur in opposite and off-setting directions: for example, opposite forces are of the same magnitude, or off-setting changes occur at equal rates. Steady state, balance, and homeostasis also describe equilibrium states. Interacting units of matter tend toward equilibrium states in which the energy is distributed as randomly and uniformly as possible."

Benchmarks for Science Literacy, Project 2061, AAAS

- Common Themes, Constancy and Change, Grades 9 to 12, pg. 275, Item #1: "A system in equilibrium may return to the same state of equilibrium if the disturbances it experiences are small. But large disturbances may cause it to escape that equilibrium and eventually settle into some other state of equilibrium."

- Common Themes, Constancy and Change, Grades 9 to 12, pg. 275, Item #3: "Things can change in detail but remain the same in general (the players change, but the team remains; the cells are replaced, but the organism remains). Sometimes counterbalancing changes are necessary for a thing to retain its essential constancy in the presence of changing conditions."

- Common Themes, Models, Grades 6 to 8, pg. 269, Item #1: "Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous."

Grade Level/Time

- Grade level: 6 to 9

- Time:
  - Instructions and data collection: 45 minutes
● Questions and discussion: 30 minutes

Materials

- Large, transparent, plastic storage container
- 4 plastic gallon jugs filled with water
- Several 2-liter plastic pop bottles
- 12-inch length of plastic tubing (1/4 inch diameter works well)
- Silicone sealant
- Device to regulate water flow (valve, clamp, holes with stoppers)
- Small soldering iron
- Waterproof tape or modeling clay
- Large needles
- Ring and ring stand (or improvised platform several inches high)
- Marking pens
- Small bucket

Procedure

You will have to first set up an apparatus that will allow water to be poured and collected. If you have access to a sink, you can modify the materials to use the sink as your regulated water source.

1. Cut the bottom off of a 2-liter plastic pop bottle.
2. Bore a hole in the cap of the bottle.
3. Place the plastic tubing through the hole in the cap and seal with silicone sealant.
4. Place the clamp on the tube several inches below the cap.
5. Screw the cap back on the bottle and place in the ring stand over the large storage container. You now have the ability to regulate water flow.
Part 1: A Delicate Balance

1. Using a marking pen, draw a line around the outside of a second bottle—about halfway between the top and bottom.

2. Poke a small hole near the bottom of the second 2-liter plastic pop bottle (the small soldering iron works well for this).

3. Place the 2-liter pop bottle in the middle of the storage container on the overturned small bucket. Insert the plastic tube from the water source bottle.

4. Begin pouring the water from the gallon jugs into the open bottle.

5. Using the clamp on the tube, adjust the flow of water in such a way that the water level in the bottle reaches and stays at the marked line.

6. Now slowly reduce the flow of the water. Make note of changes in the water level.

Part 2: Changing the Balance

1. Using a new 2-liter pop bottle, draw a line around the outside of the bottle — about halfway
between the top and bottom.

2. Poke several holes below the marked line that can then be plugged up with modeling clay or covered with waterproof tape. (Another option is to begin the activity with an intact bottle and 'stab' holes with a large needle as the activity progresses.)

3. Place the bottle in the middle of the storage container on the overturned small bucket. Insert the plastic tube from the water source bottle.

4. Start off with all but one hole covered and adjust the water flow so the water level in the bottle reaches and stays at the marked line.

5. Uncover another hole (or poke with a large needle) and note what happens to the water level. Time the reduction of the water level every 15 seconds for 2 minutes.

6. Uncover another hole and continue to measure the drop in water level every 15 seconds.

7. Cover one hole with tape or modeling clay, but do not readjust the water flow. Continue to measure the water level.

8. Finally, cover all but one hole, and time how long it takes for the water level to reach the marked level.

Questions and Observations

1. Describe what occurs to the water level in Part 1, when the water flow is increased. (The water in the bottle rises.)

2. What occurs when the water flow is decreased? (The water level gradually drops.)

3. Graph the water level in Part 2. The vertical axis represents water level and the horizontal axis represents time. Indicate in your graph when one plug is removed, when two plugs are removed, and then when each of the plugs is replaced.

4. What effect did adding holes have upon the water level? (Water level gradually fell.)

5. This exercise is a model of a dynamic balance. What is meant by a dynamic balance? (Inputs
6. Scientists say that ozone in the stratosphere would naturally be in dynamic balance. What does this mean? (The ozone is created and destroyed at a constant rate; as much is produced as is destroyed.) How is ozone made? (Oxygen molecules are split apart by UV radiation, and one oxygen atom combines with an oxygen molecule to produce ozone.) How is ozone destroyed? (A photochemical reaction with UV light, chlorine, and ozone breaks apart the bond, producing an oxygen molecule and an oxygen atom.)

7. What are we modeling by adding the extra holes in the container in Part 2? (Ozone depletion caused by CFCs.)

8. Relate this activity to ozone in the stratosphere.

Assessment Ideas

- Use question #8 above as your assessment question, though it might be more effective to ask each student to draw two diagrams: 1) a diagram of the water-level model. They should be given the freedom to illustrate it however they want to show the features of the model they think are the most important, and 2) a diagram of stratospheric ozone showing specifically how the water model is related to the atmospheric process.

Modifications for Alternative Learners

- No specific modifications necessary, although relating the model to the atmosphere should be done as visually as possible to assist the English Language Limited students.

When you're finished with the activity, click on Back to Activities List at the top of the page to return to the activity menu.
Whole Body Ozone Chemistry

In this activity, students will play the roles of various atoms and molecules to help them better understand the formation and destruction of ozone in the stratosphere.

Background

Ozone, a molecule containing three oxygen atoms, is made when UV light breaks the bonds of oxygen molecules containing two oxygen atoms in the stratosphere. The single oxygen atom is highly reactive and bonds with another oxygen molecule creating ozone.

By having students play the roles of various atoms and molecules, ideas of basic chemistry in the atmosphere are made more concrete. For example, pairs of students can represent diatomic oxygen while a trio is required for ozone. This illustrates chemical reactions involved in the photochemistry of ozone production and destruction, along with a catalyst that affects the rate of the reaction.

Learning Goals

1. Students will understand how ozone is formed in the earth's stratosphere and will be able to explain the importance of stratospheric ozone.
2. Students will be able to explain how ozone is destroyed in the stratosphere.
3. Students will understand that some chemicals can speed up the breakdown of ozone in the atmosphere.
4. Students will be able to explain why chlorofluorocarbons (CFCs) are destructive to the ozone layer.

Alignment to National Standards

National Science Education Standards
• Physical Science, Properties and Changes of Properties in Matter, Grades 5 to 8, pg. 154, Item #2: "Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties. In chemical reactions, the total mass is conserved. Substances often are placed in categories or groups if they react in similar ways; metals is an example of such a group."

• Physical Science, Chemical Reactions, Grades 9 to 12, pg. 179, Item #2: "Light can initiate many important chemical reactions such as photosynthesis and the evolution of urban smog."

• Physical Science, Chemical Reactions, Grades 9 to 12, pg. 179, Item #3: "Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, the burning and processing of fossil fuels, the formation of polymers, and explosions."

Benchmarks for Science Literacy, Project 2061, AAAS

• The Physical Setting, Structure of Matter, Grades 6 to 8, pg. 78, Item #1: "All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances."

• The Physical Setting, Structure of Matter, Grades 9 to 12, pg. 80, Item #9: "The rate of reactions among atoms and molecules depends on how often they encounter one another, which is affected by the concentration, pressure, and temperature of the reacting materials. Some atoms and molecules are highly effective in encouraging the interaction of others."

Grade Level/Time

• Grade level: 6 to 9 (Note: care must be taken with the younger grades to make the atomic concepts simple and clear. You may wish to eliminate the more complex CFC reactions, for example.)

• Time:
  • Allow a minimum of 30 minutes to run the students through each simulation and discuss the meaning of each.

Materials

• 8 1/2 by 11 sheets of paper or cardboard
Activity 26 Teacher Guide: Whole Body Ozone Chemistry

- Hole punch
- Magic markers
- String
- Flashlight
- Clear red and blue plastic sheets to cover flashlight lens
- String (optional)

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Procedure

Note: As written, this activity requires that students hold hands. Younger students may not have any problems with this, however, the self-consciousness of adolescents may hinder the spontaneous movement and physical contact required for this activity. If you think this will be problematic in your classroom, cut 12-inch lengths of string for the students to hold to make the 'bonds.'

This activity should be done a step at a time, being sure the students understand the analogy. Otherwise the analogy may be confusing or more difficult to understand than the concepts being illustrated. It is essential to stop and discuss after each section.

Part 1: Modeling Oxygen in the Earth's Atmosphere

1. Let 5 or 6 pairs of students represent oxygen molecules. Each student should construct a sign using a piece of paper, writing a large O on it and attaching a string to go around their neck, indicating they are oxygen atoms.

2. Students in each pair should hold hands to simulate the bonding between the atoms of oxygen in each molecule. Have these pairs of students move about in a cleared area in the classroom to simulate molecular motion. It is appropriate for them to bounce off a wall or collide with each other as they move about. After moving about for a minute or so, stop to discuss what has been demonstrated.
Questions and Observations

1. How are the moving pairs of students similar to what occurs in the air in the room? (Oxygen in the air exists as two atoms to each molecule, and, like all air molecules, oxygen is constantly in motion.)

2. How is it different? (Obviously the pair of students is much larger than one oxygen molecule. In addition, air has other gases—nitrogen, carbon dioxide, and other trace gases.)

3. What could be done to make the analogy better? (Some suggestions might include having other students act as nitrogen atoms, carbon dioxide molecules, etc. To make it more realistic, how many nitrogen molecules ($\text{N}_2$) should be used for each oxygen molecule ($\text{O}_2$)? About four, since air contains about 80% nitrogen and 20% oxygen.)

4. What is oxygen called if it has two atoms per molecule? (Diatomic oxygen also known as molecular oxygen. A single O atom is known as atomic oxygen.)

Part 2: Simulating the Formation of Ozone in the Stratosphere

1. Repeat the steps under modeling the earth's oxygen, but this time darken or dim the lights in the room.

2. Add a student who, with a flashlight, simulates solar radiation. Place a clear blue plastic sheet over the lens of the flashlight to represent the ultraviolet short wavelengths that are involved in the breakup of diatomic oxygen.

3. Let pairs of students representing oxygen begin their motion as before. When the student with the flashlight shines the light on a pair of students, the bond between them breaks, and students let go of their partner.

4. As the motion continues, these single atoms of oxygen move around until they bump into a pair of oxygen atoms. Each of the single oxygen atoms combines with the pair they bump into, forming a group of three oxygen atoms. These three students hold hands, representing a molecule of ozone.
Questions and Observations

1. How is this simulation similar to the way ozone is formed in the stratosphere? (UV light breaks the bonds on oxygen molecules, and the free oxygen atom combines with other oxygen molecules to produce ozone.)

2. What is oxygen with three atoms per molecule called? (ozone)

3. How many molecules of ozone can be formed by the breakup of one molecule of diatomic oxygen by ultraviolet light? (2)

4. Why is ozone formed this way in the stratosphere and not in the air near the earth's surface? (Much more ultraviolet light exists in the stratosphere than near the earth's surface.)

Part 3: Demonstrating How Ozone Breaks Down in the Stratosphere

1. Have several groups of three students, each representing ozone, move about the room. Pairs of students representing diatomic oxygen can be added as a touch of realism.

2. This time the lens of the flashlight should be covered with clear red plastic to represent UV light of a longer wavelength.

3. When this light is used to illuminate an ozone molecule, the ozone breaks up to form a diatomic molecule (a pair of students) and an oxygen atom (single student).

4. This process is repeated by shining the light on a second ozone molecule, producing another pair of oxygen atoms and another single oxygen atom.

5. The two single oxygen atoms should then combine to form a pair of atoms, or a molecule of diatomic oxygen.

Questions and Observations

1. How many molecules of diatomic oxygen are formed from the breakup of two molecules of ozone? (3)
2. How is the breakup of ozone in the stratosphere similar to its formation there? (Both the formation and breakup of ozone involve UV light, but different wavelengths.)

Part 4: An Example of a Chemical that Speeds up the Breakdown of Ozone

Of all the chemicals involved in the breakdown of stratospheric ozone, none have received more attention than the chlorofluorocarbons, or CFCs. The two most common are CFC-11 (CFCl₃) and CFC-12 (CCl₂F₂). These compounds can be modeled by letting students represent atoms of carbon (C), chlorine (Cl), and fluorine (F). For example, a molecule of CFC-11 would be composed of one student representing a carbon atom, another representing a fluorine atom, and three students representing three chlorine atoms. The students should hold hands to demonstrate how atoms are bonded in a molecule.

Graphic of the molecular structure of common CFCs

Questions and Observations

1. The CFCs are inert, that is, they do not react with other materials under most conditions. How can this be demonstrated using groups of students to represent atoms of different elements? (The CFCs can move around together, but students should lock elbows, showing that the bonds of these molecules do not break apart easily.)

2. The CFCs that enter the atmosphere at the earth's surface have found their way into the stratosphere. How can this be demonstrated using students to play the role of various gases in the air? (The CFCs can gradually move from the place designated in the classroom as the earth's surface to the place designated as the stratosphere. More ozone molecules should be in the stratosphere. The student with the flashlight representing UV should be in the place designated as the stratosphere.)

Part 5: The Role of Chlorine in the Breakdown of Ozone in the Stratosphere

UV light breaks down CFCs in the stratosphere, releasing chlorine atoms. This can be demonstrated by having a student with a flashlight shine a light on a group of students representing a molecule of CFC-11 or CFC-12. Let one student representing a freed chlorine atom move amidst groups of students representing ozone. The chlorine is involved in the breakdown of ozone as follows:
Activity 26 Teacher Guide: Whole Body Ozone Chemistry

\[ \text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2 \]
\[ \text{ClO} + \text{O} \rightarrow \text{Cl} + \text{O}_2 \]

1. A student representing chlorine pulls an oxygen atom away from an ozone molecule to form chloride oxide (ClO).

2. The two students representing ClO react with an oxygen atom.

3. The two students representing oxygen combine to form an oxygen molecule.

4. The student representing chlorine is then free to attack another molecule of oxygen.

5. Repeat these steps several times to show the chain reaction.

Questions and Observations

1. What is a catalyst? (A chemical that promotes a chemical reaction but is not used up in the reaction.)

2. Does the chlorine act as a catalyst in this reaction? (Yes)

3. Why is the involvement of chlorine in the breakdown of ozone called a chain reaction? (Chlorine can cause the breakdown of many ozone molecules and the chlorine is not altered or destroyed.)

Assessment Ideas

- Because this is a complex, multistep simulation, it would be difficult for the teacher to informally observe or question each student during the activities. We suggest instead that students keep a log of the discussion questions and answers as they go, to be turned in and evaluated by the teacher.

- Draw an unlabeled set of simple "ball and stick" molecular pictures on overheads illustrating each of the activities done by the students. Have students copy the overhead drawings and label each molecule and process.

- Provide gumdrops or clay and toothpicks for students to build the molecular models.

Modifications for Alternative Learners

- The kinesthetic nature of the lesson will be easily followed by English Language Limited students, but the connection to the molecular processes may be difficult. Use overhead illustrations liberally to connect the student activities to the processes, rather than relying only on voice.
heat from the equatorial region of the poles. While winds are the primary driving agents of surface ocean currents, variations in temperature and salinity of the ocean water produce currents that stir up the deeper parts of the oceans creating what is called the ocean’s thermohaline circulation. When altered, these deep ocean currents appear to be very important in switching our global climate from a glacial age to an interglacial age. (See “Thermohaline” animation on CD.)

Others are unfamiliar with a Serbian mathematician, Milutin Milankovitch, who offered a theory in 1924 for what causes the advances and retreats of ice sheets on Earth. Milankovitch hypothesized that the critical factor in determining ice sheet growth is the amount of sunshine reaching high latitudes of the Northern Hemisphere in the summer. Milankovitch predicted that ice sheets would grow when the insolation reaching the high latitude continents was less than normal during summer, since this would allow snow cover to last through the melting season and gradually accumulate over the centuries. He showed that changes of insolation result from subtle variations in Earth’s orbit. Over the last several decades Milankovitch’s theory has received a large boost. Modern techniques enable scientists to estimate past amounts of land ice, based on information contained in layered ocean sediments. For the last several million years, the ice sheets have varied with the same rhythm as Earth’s orbit.

Today the Earth’s axis of rotation is tilted about 23.5 degrees relative to the plane of the Earth’s orbit about the Sun, and this tilt gives us pronounced seasons in middle and high latitudes. This tilt angle varies between 22 and 24.5 degrees within a period of about 41,000 years. The amount by which Earth’s orbit deviates from a perfect circle to elliptical shape also varies over thousands of years. And the day of the year when Earth is closest to the Sun -- currently January 3rd -- varies on a 23,000-year cycle. The effects of all these orbital variations on insolation are largest in middle and high latitudes, where colder temperatures make the development of large ice sheets possible.

It’s possible that the Sun can cause climate to change over periods shorter than glacial cycles as a result of variations in the energy output of the Sun. Observations taken over the last few decades indicate that output is about 0.1% greater when the number of dark spots on the Sun (sunspots) is at its maximum -- roughly every 11 years -- than when it is at a minimum. This change in energy output is too small to cause important climate variations, but the Sun’s output may vary more on a longer time scale. Some evidence suggests that weakened solar energy output may have helped produce the Little Ice Age of 1350-1850 AD.

While changes in solar insolation due to Earth’s orbit around the Sun are believed to have contributed to Earth’s past ice ages, most scientists today believe Earth’s climate is likely to change (or has begun to change already) as a result of human-induced increases in greenhouse gases.
The Sun is the source of all energy on our planet. The Earth may only receive about a billionth of the Sun’s energy, but it is enough to keep our planet a warm, comfortable temperature that is conducive to living things. However, many different factors affect how much of the Sun’s energy is let into the Earth system and how much of it is let out into space. Making sure that just enough is let in and out is a delicate balance. Currently the system is not in balance and more heat is let in than is let out.

Our Sun is an active star. Solar activity causes variations in the amount of energy that is released by the Sun, which affects the amount that reaches Earth. One clue to solar activity is sunspots. A sunspot is a dark area on the Sun where the surface is a little cooler. When the Sun has fewer sunspots, it also gives off less energy. This causes Earth to cool down. In the late 1600s, when the climate was cooler during the “Little Ice Age”, people noticed there were no sunspots for several decades.

Most sunlight that enters the Earth system encounters the surface of the planet where the energy is absorbed or reflected. Forests, lakes, oceans, glaciers, deserts, and cities all absorb, reflect, and radiate heat differently. Light colors tend to reflect light back into space, while dark colors absorb heat, warming the Earth. The percentage of the Sun’s energy that is reflected back by a surface is called Albedo, and it is measured on a scale from zero to one. The type of surface that sunlight first encounters is the most important factor that affects the warming or cooling of the planet. Light colored surfaces like ice have a high albedo (closer to 1), while dark colored surfaces tend to have a lower albedo (closer to 0).

Not all of the energy reflected or radiated by the Earth’s surface is able to easily find its way out of the system. Molecules in our atmosphere called greenhouse gasses absorb some of the energy. Greenhouse gases include water vapor, methane, ozone, nitrous oxide, and carbon dioxide. Most of these gases are not at all abundant in our atmosphere, but a small amount can make a large impact on the amount of energy that is retained in the atmosphere. Each greenhouse gas molecule is made of three or more atoms that are bonded loosely together. When these molecules absorb heat it makes them vibrate. They eventually release the heat energy and it is often absorbed by another greenhouse gas molecule.

Some amount of greenhouse effect is very helpful because it is responsible for temperatures on our planet being mild and suitable for living things. Without its atmosphere and the greenhouse effect, the average temperature at the surface of the Earth would be zero degrees Fahrenheit. However, too many greenhouse gases can cause the temperature to increase out of control.

The current concern about the greenhouse effect stems from evidence that Earth’s greenhouse is warming up very rapidly. The increased rate of warming is caused by our addition of greenhouse gases to our atmosphere. Warming is causing rapid changes to the planet and impacts such as flooding, drought, and an increase in the frequency of severe weather events. These changes are having major impacts on societies worldwide.
**Title:** Looking into Surface Albedo  

**Summary:** This activity will demonstrate how the color of materials that cover the Earth affects the amounts of sunlight it absorbs.  

**Source:** An NCAR Education and Outreach activity  

**Grade level:** 5-9  

**Time:** 20 minutes for activity and short discussion, or 40 minutes to include more thorough data interpretation.  

**Student Learning Outcomes:**  
- Students will explore how the color of materials at the Earth's surface affects warming.  
- Students will collect and interpret data.  
- Students will be able to explain why dark colored materials create hotter temperatures.  

**Lesson format:** Hands-on activity  

**National Standards Addressed:**  
- 5-8: Content Standard B: Properties and Changes of Properties in Matter  
- 5-8 Content Standard B: Transfer of Energy  
- 5-8 Content Standard D: Structure of the Earth System  
- 9-12 Content Standard B: Interactions of energy and matter
MATERIALS AND WORKSHEETS:

For each group of 4 students:

- 2 thermometers (or more)
- One copy of the Bhutan glacier photo (Land and Glacier Picture)
- Tape
- Copy of the worksheet for data collection
- Watch or stopwatch
- Outdoor sunshine or a small desk lamp with a 150 watt bulb
- A copy of the worksheet for each student

WORKSHEETS:

- Data collection and analysis worksheet (pdf format)
- Land and Glacier Picture (pdf format)

DIRECTIONS:

1. Ask students if they have ever noticed that wearing a black shirt on a warm sunny day will make you hotter. Ask them if they have noticed that they are hotter when standing on blacktop pavement/asphalt. Why is that the case? Discuss how light is absorbed and transformed into heat energy.

2. Ask students what they think might happen if the Earth was wearing a white or black tee-shirt. Of course, the Earth can not wear a tee-shirt, but the color of the Earth's surface is not the same everywhere. Show students a picture of the Earth from space. What colors do they see? Which are the lightest colors? Which are the darkest? Where do they expect that most sunlight will be absorbed? Where do they expect that the least sunlight will be absorbed?

3. Have each group of students look at the photo of the Bhutan glaciers. Explain that this picture was taken from a satellite high above the Earth. Ask students what they see in the picture. The dark reddish parts of the picture are land (rocks). The white sections are ice and snow. This ice and snow is in glaciers. Define glacier. Parts of the glaciers are light blue in color. These are made of blue ice, sand and gravel. The very dark patches are lakes that form from from the glacier melt water.

4. Ask students to make a hypothesis about which areas of the photograph they think would absorb the most solar energy and which would absorb the least. Write the hypothesis into the top of the data collection worksheet.

5. Instruct students to fix their thermometers to the back of the picture using tape. One thermometer bulb should be under a section of light colored ice and the other thermometer bulb under a section of dark red land. Remember to place the thermometers so that when you lay the picture down on a table, the thermometers are right side up and can be read.
6. Place the light (not turned on) directly above the picture, about a foot above. Do not turn it on yet!
7. Ask students to decide who in their group is going to record the data, who is going to read the ice thermometer, who is going to read the land thermometer and who is going to be the time keeper.
8. The two students read their thermometers before the light is turned on and give the numbers to the data collector. The thermometer readings should be approximately the same.
9. Once they have the initial readings, groups should turn on their light and the time keeper begins timing. Temperature readings will be taken every two minute (for 6 or 8 minutes total). Advise students to read the thermometers without shading the light if possible.
10. Discuss results (or do a more thorough analysis as described in Assessment section below). Point out how this model is different than the real world (For example, would either ice or the land surface ever get to those temperatures?) This model shows relative differences based on the color of the surface but does not take into account the type of material or its reflective abilities. Explain that ice is melting. How would less ice affect the system?

ASSESSMENT:

- Once each group has collected their data, compile all data on computer, blackboard, or overhead transparency so that all groups can see it. Ask students to make a graph of the data that shows ice shelf and ocean with different colors. Ask students if there a difference in the amount of heat they absorbed.

BACKGROUND INFORMATION:

What Is Albedo?

While the Earth's temperature is dependent upon the greenhouse-like action of the atmosphere, the amount of energy retained by the Earth is strongly dependant on the albedo of Earth surfaces.

Just as some clouds reflect solar energy into space, so do light-colored land surfaces. Scientists use the term albedo to define the percentage of solar energy reflected back by a surface. This surface albedo effect strongly influences the absorption of sunlight. Forests, grasslands, ocean surfaces, ice caps, deserts, and cities all absorb, reflect, and radiate solar energy differently. Sunlight falling on a white glacier surface strongly reflects back into space, resulting in minimal heating of the surface and lower atmosphere. Sunlight falling on a dark soil or rock is strongly absorbed, and contributes to significant heating of the Earth's surface and lower atmosphere.

Understanding local, regional, and global albedo effects is critical to predicting global climate change. Light colored ice and snow are very weakly absorptive, reflecting 80-90% of incoming...
solar energy. Dark-colored land surfaces, are strongly absorptive and contribute to warming, reflecting only 10-20% of the incoming solar energy. If global temperatures increase, snow and ice cover may shrink. The exposed darker surfaces underneath may absorb more solar radiation, causing further warming. The magnitude of the effect is currently a matter of serious scientific study and debate.

How Much Are Glaciers Melting?

Currently glaciers cover about 10% of the Earth's land surface. In most areas of the world, mountain glaciers are melting. Between 1961 and 1998 small glaciers lost an average of 7 meters of ice thickness. Glaciers in mountainous areas near the equator have been particularly hard-hit. According to global climate models, all of the glaciers in Glacier National Park in Montana will be gone by the year 2030.

Snow and ice cover near the north pole is currently decreasing at approximately 0.4% per year. Arctic sea ice has been decreasing at about 2.9% per decade. Since 1974, seven ice shelves, most in Antarctica have retreated by a total of approximately 13,500 square kilometers.

About the Image..

The image used in this activity is of retreating mountain glaciers in Bhutan. It is a satellite image taken by the ASTER instrument aboard NASA's Terra satellite. Visible in the image are several glaciers in the Himalayan mountains of Bhutan. The glaciers have been melting over the past few decades, and lakes have formed on the surfaces and near the termini of many of the glaciers. Some of the glaciers are white as the ice is covered with snow pack. Other parts are rocky and have the same color as the surrounding land.

This image and other satellite pictures can be found at the NASA Earth Observatory web site http://earthobservatory.nasa.gov/.

Other pictures of glaciers and other varieties of snow and ice can be found at the National Snow and Ice Data Center web site http://nsidc.org/.

RELATED WEB RESOURCES FROM NCAR and UCAR

- The Layered Atmosphere from NCAR Education and Outreach
- Earth's Atmosphere from Windows to the Universe
- Glaciers and Snowfields from the NCAR Kids' Crossing web site
- The Sun: It's a Scorcher! from NCAR Education and Outreach

OTHER RESOURCES
The National Snow and Ice Data Center
Take a look at the photograph that says "Land and Glaciers" at the top. Place the bulb of one thermometer under the light colored snow and ice part of the photo. Place the bulb of the other thermometer under the dark colored land part of the photo. (Make sure both thermometers are facing so that you can read them easily.)

What's your hypothesis? (What do you think will happen to the thermometers under the ice colored parts of the photo and the land colored parts of the paper?)

Collect the data! Use the table below to help you collect the temperature data.

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature under ice picture</th>
<th>Temperature under land picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 minutes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What does the data mean? Graph your data by plotting the points and connecting them into two lines:
- One line for the ice photo temperature
- One line for the land photo temperature
(Remember to fill in the temperature axis and the key.)

What do YOU think? How is this different than the real world?

NAME: ____________________________

What do YOU think?

How is this different than the real world?
Land and Glaciers

This picture shows glaciers in the Himalayan mountains of Bhutan. The glaciers have been melting over the past few decades. This makes lakes form nearby.

This picture was taken by an instrument aboard NASA's Terra satellite. You can find more pictures like this at NASA's Earth Observatory and the National Snow and Ice Data Center.
Barely two-billionth of the sun’s energy reaches earth (1370 watts/m²), but it is powerful enough to have an enormous impact. The Sun provides the “fuel” for Earth’s “weather engine” as it unevenly heats the planet and its atmosphere.

Weather is the condition of the air around Earth. The uneven heating of the Earth causes large air masses to form with different temperatures and air pressures. Closely linked with air temperature and air pressure is air movement.

Convection is the primary method of heat transfer in fluids such as our atmosphere and oceans. It is through the process of convection that air first begins to move. On a warm day, certain areas of the Earth’s surface absorb more energy from the Sun, which results in air near the surface being heated somewhat unevenly. The heated air expands and becomes less dense than surrounding cooler air. Consequently, it is buoyed upward, rises, transfers heat energy upward and leaves behind an area of low pressure. Eventually this rising air spreads out, cools and begins to sink, replacing newly rising heated air.

Air masses of opposite temperatures and opposite pressures move toward each other. The point at which the two collide is called a front. The motion of these air masses, their collision with each other, the rotation of the Earth and the amount of water in the sky together create Earth’s weather machine. Without the energy from the Sun, this “engine” would never ignite.

The general circulation of the atmosphere is also a consequence of Earth’s uneven heating and convection. Air around the equator, which receives sunlight rises and moves towards the Poles, leaving behind an area of low pressure. Air moves from areas of high pressure to areas of low pressure, so as this air rises, cooler air moves from the poles toward the equator to replace it. Although this sounds simple, the actual flow of air is extremely complex. The diagram below shows the general wind and surface pressure distribution on our rotating Earth, along with the names of the prominent winds and convection cells.
Atmospheric Processes — Convection

In class, you've learned that the earth's surface absorbs solar radiation, heats up, and transfers some of that heat to the air. The air then circulates, carrying the heat with it, by a process called convection. Convection currents are found in many places and on many scales, such as huge convection currents in the atmosphere, oceans, and even in the earth's interior. Smaller convection currents can be found in a cup of hot cocoa or a fish tank. Meteorologists usually use convection to refer to up and down motions of air. Heat gained by the lowest layer of the atmosphere from radiation or conduction is most often transferred by convection. Convection currents in the atmosphere carry the sun's heat from the warmest places on earth (like the tropics) to colder places (like the polar regions).

In the first part of this activity, you will be working with convection currents in water. It is important to remember that water and air circulate heat by convection in the same way. In fact both water and air can be thought of as fluids, the main difference being that water is a much more dense fluid than air is. In the second part of this activity, you will investigate the fluid nature of air.

---

PART 1: Currents in Water

Materials (per team)

- Clear plastic plant saucer 8 to 10 inches wide
- Pitchers or jugs for hot and cold water
- Food coloring
- Small container for food coloring (a small cup would work fine)
- Medicine dropper or pipette
- Four Styrofoam cups
- Data sheet

Procedure

1. According to your teacher's instructions, form a student team and gather the materials from the list above.
2. Place three Styrofoam cups upside down on a piece of paper.

3. Place the plastic plant saucer on top of the cups as shown. The cups should be near the outer edges of the saucer and evenly spaced.

4. Fill the plastic saucer three-quarters full with cool water. To make certain the water is still, let it sit before the experiment. Be careful not to bump the desk or table at any time during the experiment.

5. Using a dropper, slowly release a small amount of food coloring at the bottom of the saucer of water. Slowly remove the dropper, taking care not to stir the water.

6. Observe and record on the data sheet what the drop does as it sits in the tray. Draw what happens.

Variations

Repeat the experiment with the following variations. Record and draw your observations after each variation. Make certain you start each trial with a clean saucer of water.

For the following three trials, place a cup of hot water under the center of the saucer as shown. Fill the cup almost to the top.

Trial A: Place a drop of food coloring on the bottom of the saucer in the center, over the cup of hot water. Take care not to stir the water.
Trial B: Place a drop of food coloring on the bottom of the saucer about halfway between the center and the side. Take care not to stir the water.

Trial C: Place two drops of food coloring on the bottom of the saucer, one halfway between the center and side of the saucer, the other in the center. Take care not to stir the water.

Observations and Questions for Part 1

In your lab books or on a separate piece of paper, complete the following.

1. For each trial, draw your observations from an overhead view, including a caption for each
drawing that explains what is happening. Now draw the same thing from a side view.

2. What effect does the hot water in the center under the plant saucer have upon the currents?

3. What type of heat transfer is taking place? How do you know?

PART 2: Air is a Fluid

Materials

- Baking soda
- Vinegar
- 500 ml beaker or glass jar of similar size
- Candle
- Matches
- Strip of poster board or cardboard about 12" by 3"

Procedure

1. Fold the poster board or cardboard lengthwise.

2. Place the candle on a plate and light the candle.

3. Put about a tablespoon of baking soda in the glass jar or beaker.

4. Pour about 1/4 cup of vinegar in the jar or beaker.

5. When the fizzing subsides, hold the poster board "funnel" at an angle so that one end is near the candle flame and the other end is slightly higher.
6. "Pour" the gas in the beaker or jar down the funnel. What happens to the flame?

**Observations and Questions for Part 2**

Answer these in your lab book or on a separate piece of paper.

1. What happens when the vinegar and baking soda are mixed?
2. Explain how the flame was extinguished.
3. In this demonstration, how did the gas act as a liquid?

*When you're finished with the activity, click on Back to Teacher Guide at the top of the page.*
A Chilling Possibility

By disturbing a massive ocean current, melting Arctic sea ice might trigger colder weather in Europe and North America.

March 5, 2004: Global warming could plunge North America and Western Europe into a deep freeze, possibly within only a few decades.

That's the paradoxical scenario gaining credibility among many climate scientists. The thawing of sea ice covering the Arctic could disturb or even halt large currents in the Atlantic Ocean. Without the vast heat that these ocean currents deliver—comparable to the power generation of a million nuclear power plants—Europe's average temperature would likely drop 5 to 10°C (9 to 18°F), and parts of eastern North America would be chilled somewhat less. Such a dip in temperature would be similar to global average temperatures toward the end of the last ice age roughly 20,000 years ago.

Right: Retreating Arctic ice, 1979-2003, based on data collected by the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSMI).

Some scientists believe this shift in ocean currents could come surprisingly soon—within as little as 20 years, according to Robert Gagosian, president and director of the Woods Hole Oceanographic Institution. Others doubt it will happen at all. Even so, the Pentagon is taking notice. Andrew Marshall, a veteran Defense Department planner, recently released an unclassified report detailing how a shift in ocean currents in the near future could compromise national security.

"It's difficult to predict what will happen," cautions Donald Cavalieri, a senior scientist at NASA's Goddard Space Flight Center, "because the Arctic and North Atlantic are very complex systems with many interactions between the land, the sea, and the atmosphere. But the facts do suggest that the changes we're seeing in the Arctic could potentially affect currents that warm Western Europe, and that's gotten a lot of people concerned."

Ice is Key

There are several satellites keeping an all-weather watch on ice cover in the Arctic. NASA's Aqua
A Chilling Possibility

A satellite, for instance, carries a Japanese-built sensor called the Advanced Microwave Scanning Radiometer-EOS ("AMSR-E" for short). Using microwaves, rather than visible light, AMSR-E can penetrate clouds and offer uninterrupted surveillance of the ice, even at night, explains Roy Spencer, the instrument's principal investigator at the Global Hydrology and Climate Center in Huntsville, Alabama. Other ice-watching satellites, operated by NASA, NOAA and the Dept. of Defense, use similar technology.

The view from orbit clearly shows a long-term decline in the "perennial" Arctic sea ice (the part that remains frozen during the warm summer months). According to a 2002 paper by Josefino Comiso, a climate scientist at NASA's Goddard Space Flight Center, this year-round ice has been retreating since the beginning of the satellite record in 1978 at an average rate of 9% per decade. Studies looking at more recent data peg the rate at 14% per decade, suggesting that the decline of Arctic sea ice is accelerating.

Above: A global ocean circulation between deep, colder water and warmer, surface water strongly influences regional climates around the world. Image courtesy Argonne National Laboratory. [More]

Some scientists worry that melting Arctic sea ice will dump enough freshwater into the North Atlantic to interfere with sea currents. Some freshwater would come from the ice-melt itself, but the main contributor would be increased rain and snow in the region. Retreating ice cover exposes more of the ocean surface, allowing more moisture to evaporate into the atmosphere and leading to more precipitation.
Because saltwater is denser and heavier than freshwater, this "freshening" of the North Atlantic would make the surface layers more buoyant. That's a problem because the surface water needs to sink to drive a primary ocean circulation pattern known as the "Great Ocean Conveyor." Sunken water flows south along the ocean floor toward the equator, while warm surface waters from tropical latitudes flow north to replace the water that sank, thus keeping the Conveyor slowly chugging along. An increase in freshwater could prevent this sinking of North Atlantic surface waters, slowing or stopping this circulation.

AMSR-E is collecting new data that will help scientists evaluate this possibility. For one thing, it provides greatly improved ground resolution over previous all-weather sensors. AMSR-E images reveal smaller cracks and fissures in the ice as it breaks up in the spring. This detail allows scientists to better understand the dynamics of ice break-up, says Cavalieri, a member of the AMSR-E team.

Right: Sea ice disintegrating off the coast of Greenland on March 15, 2003, as seen by the older Defense Meteorological Satellite Program SSMI sensor (14 km resolution) and the newer AMSR-E (~5 km resolution). Smaller cracks not visible in the left image show up clearly in the right one.

"Other important pieces of the puzzle, like rainfall, sea-surface temperatures, and oceanic winds, are also detected by AMSR-E. Looking at those variables together should help scientists assess the likelihood of a change in the Atlantic currents," adds Spencer.

**Deja Vu?**

Once considered incredible, the notion that climate can change rapidly is becoming respectable. In a 2003 report, Robert Gagosian cites "rapidly advancing evidence [from, e.g., tree rings and ice cores] that Earth's climate has shifted abruptly and dramatically in the past." For example, as the world warmed at the end of the last ice age about 13,000 years ago, melting ice sheets appear to have triggered a sudden halt in the Conveyor, throwing the world back into a 1,300 year period of ice-age-like conditions called the "Younger Dryas."

Will it happen again? Researchers are scrambling to find out.
On Feb. 13, an expedition set sail from Great Britain to place current-monitoring sensors in the Atlantic Ocean that will check the Gulf Stream for signs of slowing. The voyage is the latest step in a joint US / UK research project called Rapid Climate Change, which began in 2001. Another international project, called SEARCH (Study of Environmental Arctic CHange), kicked off in 2001 with the goal of more carefully assessing changes in Arctic sea ice thickness.

Above: The RRS Discovery, on a voyage to measure currents in the Atlantic Ocean. [More]

Much depends on how fast the warming of the Arctic occurs, according to computer simulations by Thomas F. Stocker and Andreas Schmittner of the University of Bern. In their models, a faster warming could shut down the major Atlantic current completely, while a slower warming might only slow the current for a few centuries.

And, inevitably, the discussion turns to people. Does human industry play a major role in warming the Arctic? Could we reverse the trend, if we wanted to? Not all scientists agree. Some argue that the changes occurring in the Arctic are consistent with large, slow natural cycles in ocean behavior that are known to science. Others see a greater human component.

"The sea ice thawing is consistent with the warming we've seen in the last century," notes Spencer, but "we don't know how much of that warming is a natural climate fluctuation and what portion is due to manmade greenhouse gases."

If the Great Conveyor Belt suddenly stops, the cause might not matter. Europeans will have other things on their minds--like how to grow crops in snow. Now is the time to find out, while it's merely a chilling possibility.

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The Science Directorate at NASA’s Marshall Space Flight Center sponsors the Science@NASA web sites. The mission of Science@NASA is to help the public understand how exciting NASA research is and to help NASA scientists fulfill their outreach responsibilities.
### Web Links

**Global Hydrology and Climate Center** -- a joint NASA / University of Alabama at Huntsville center dedicated to studying the Earth's climate system

**AMSR-E** -- NASA home page for the Japanese-built satellite sensor mentioned in this article

**AMSR-E** -- National Space Development Agency of Japan (NASDA) home page for AMSR-E

**Aqua** -- information about the AMSR-E sensor on NASA's Aqua satellite. Aqua is an international project supported by the United States, Japan and Brazil.

**SEARCH** -- home page of the Study of Environmental Arctic Change

**Rapid Climate Change program** -- home page

**More about sudden climate change:**  
- [Abrupt climate change](http://www.whoi.edu/science/stratus/projects/abrupt气候变化/abrupt气候变化.html), from the Woods Hole Oceanographic Institute;  
- [Climate change and Arctic sea ice](http://www.greenpeace.org/international/en/programs/oceans/arctic/), from Greenpeace;  
- [Climate rides on ocean conveyor belt](http://www.sciencenews.org/20010914/wn091401.htm), from Environmental News Network;  
- [The Great Ocean Conveyor](http://www.ysl.com/thesources/1997/1997-08-25/greatocean.htm), from the David Suzuki Foundation;  
- [The Pentagon's weather nightmare](http://www.fortunemail.com/story/fortune/articles/2001/09/05/500012536250377463/1), from Fortune magazine;  
- [The discovery of rapid climate change](http://www.physicstoday.org/articles/01/03/20010303p15.php), from Physics Today

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**More Headlines**

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**THE END**
Our weather is always changing and now scientists are discovering that our climate does not stay the same either. Climate, the average weather over a period of many years, differs in regions of the world that receive different amounts of sunlight and have different geographic factors, such as proximity to oceans and altitude.

Climates will change if the factors that influence them fluctuate. To change climate on a global scale, either the amount of heat that is let into the system changes, or the amount of heat that is let out of the system changes. For instance, warming climates are either due to increased heat let into the Earth or a decrease in the amount of heat that is let out of the atmosphere.

The heat that enters into the Earth system comes from the Sun. Sunlight travels through space and our atmosphere, heating up the land surface and the oceans. The warmed Earth then releases heat back into the atmosphere. However, the amount of sunlight let into the system is not always the same. Changes in Earth’s orbit over thousands of years and changes in the Sun’s intensity affect the amount of solar energy that reaches the Earth.

Heat exits the Earth system as the Earth’s surface, warmed by solar energy, radiates heat away. However, certain gases in our atmosphere, called greenhouse gases, allow the lower atmosphere to absorb the heat radiated from the Earth’s surface, trapping heat within the Earth system. Greenhouse gases, such as water vapor, carbon dioxide, methane and nitrous oxide, are an important part of our atmosphere because they keep Earth from becoming an icy sphere with surface temperatures of about 0°F. However, over the past century or so the amounts of greenhouse gases within our atmosphere have been increasing rapidly, mainly due to the burning of fossil fuels, which releases carbon dioxide into the atmosphere. Consequently, in the past one hundred years global temperatures have been increasing more rapidly than the historic record shows. Scientists believe this accelerated heating of the atmosphere is because increasing amounts of these greenhouse gases trap more and more heat.

Complicating Factors
There are many different factors that complicate this system, including clouds, volcanic eruptions, oceans, and people. Additionally, there are likely factors that affect climate which we have yet to identify. Factors interact, resulting in global cooling, global warming, or even contributing to both. In regard to human contributions, because our activities use huge quantities of fuels that release carbon dioxide, currently far more greenhouse gases are produced than consumed, contributing to global warming. Three greenhouse gases, which humans are adding to the atmosphere include:

* **Carbon dioxide:** Carbon, the building block of life, is released as carbon dioxide gas when fossil fuels, the remains of ancient plant and animal bodies, are burned. Carbon dioxide is taken out of the atmosphere by plants during the process of photosynthesis.
* **Methane:** Methane gas is produced by microbes in natural wetlands and rice paddies and by the digestive tracts of farm animals such as cattle and sheep.
* **Nitrous oxide:** This gas is produced when nitrate and ammonium in human-produced fertilizers breakdown in the soil.

Source: UCAR Website, Education and Outreach, Weather and Climate Basics, http://www.ncar.ucar.edu/eo/basics/cc_1.html
What is a Greenhouse?

This activity is designed to have students become familiar with how a greenhouse retains heat by building simple models. Through discussion, you can explain how the atmospheric 'greenhouse effect' retains heat.

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. The transparent covering of the greenhouse allows visible light to enter unhindered, where it warms the interior as it is absorbed by the material within. The transparent covering also prevents the heat from leaving by reflecting the energy back into the interior and preventing outside winds from carrying it away.

Like the greenhouse covering, our atmosphere also serves to retain heat at the surface of the earth. Much of the sun's energy reaches 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, sea surfaces, and atmospheric dust. The rest is absorbed by the liquids, solids, and gases that constitute our planet. The energy absorbed is eventually reemitted, but not as visible light (only very hot objects such as the sun can emit visible light). Instead, it's emitted as longer-wavelength light called infrared radiation. This is also called "heat" radiation, because although we cannot see in infrared, we can feel its 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 earth is one of the best-understood processes in atmospheric science. This phenomenon has been called the "greenhouse effect" because the trace gases trap heat similar to the way that a greenhouse's transparent covering traps heat. Without our atmospheric greenhouse effect, earth's surface temperature would be far below freezing. On the other hand, an increase in atmospheric trace gases could result in increased trapped heat and rising temperatures.
global temperatures.

Learning Goals

1. Students will understand how greenhouses work to retain heat.

Alignment to National Standards

National Science Education Standards

- Unifying Concepts and Processes, Grades K to 12, pg. 117: "Models are tentative schemes or structures that correspond to real objects, events, or classes of events and that have explanatory power."

- Physical Science, Transfer of Energy, Grades 5 to 8, pg. 155, Item #2: "Heat moves in predictable ways flowing from warmer objects to cooler ones, until both reach the same temperature."

- Earth and Space Science, Grades 9 to 12, pg. 189, Item #3: "Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents."

Benchmarks for Science Literacy, Project 2061, AAAS

- Common Themes, Models, Grades 6 to 8, pg. 269, Item #1: "Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous."

- The Physical Setting, Energy Transformations, Grades 6 to 8, pg. 85, Item #3: "Heat can be transferred through materials by the collisions of atoms or across space by radiation. If the material is fluid, currents will set up in it that aid the transfer of heat."
Grade Level/Time

- **Grade level:** 5 to 9
- **Time:**
  - Introduction by teacher: 15 minutes
  - Student activity (including bottle construction): 50 minutes

Materials

For each team of four students:

- Two two-liter plastic soda bottle "experimental chambers" (instructions to follow)
- Two 14- to 16-oz. plastic containers at least 4 1/2 inches in diameter at the top (sour cream, cottage cheese, or deli containers work well)
- Knife or scissors
- Tape
- Two thermometers
- One 150-watt floodlight bulb
- Portable reflector lamp
- Stand for lamp set-up
- Graph paper

*Experimental chamber construction*

For each chamber, you will need a two-liter plastic soda bottle (with cap) and a 14- to 16-oz. plastic container for the base.

1. Remove the bottle label by soaking it in warm water.
2. Cut off the end of the bottle approximately 2 inches from the bottom and discard the bottom piece.
3. Place the capped bottle in the plastic base and the experimental chamber is ready for use.

**Procedure**

1. Organize students in teams of four.

2. Each team should use scissors to cut several elongated vents (1 x 4 inches) in the sides of one of the bottles.

3. Leave the second bottle intact.

4. Tape a thermometer (using cellophane tape or light-colored masking tape, not black electrical tape) to the inside of each bottle (facing out). Make sure the bulbs of the thermometers are above the top of the chamber base. (See graphic below.)

5. Place caps on both bottles.

6. Place both bottles approximately six inches away from the lamp with the thermometers facing away from the light.
7. Ask students to predict which bottle will get hotter when you turn on the light.

8. Turn on the light and begin collecting data every minute for 20 minutes.

9. Have students graph data.

**Observations and Questions**

1. Compare and contrast the graphed data from the vented bottle and the intact bottle. What happened? How do you explain your observations?

2. Discuss the results with your class and develop some possible explanations (for example, the vents let cool air in).

3. Compare and contrast your plastic greenhouse to the greenhouse effect on earth.

**Cautionary Note:** 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.

**Assessment Ideas**

- Pair two students from different groups. Have each explain what happened in their experiment to the other, and then together draft a written (and hopefully detailed) response to questions two and three.

- Ask students how they could "change" their greenhouse to now have a temperature range in between the two they tested.
Where in the World is Carbon Dioxide?

**Modified with permission from:**


In this multi-part activity, students will set up experiments to help them better understand the atmospheric portion of the carbon cycle.

**Background**

Carbon dioxide (CO₂) provides the bubble in your soda pop and the "rise" in your baked goods. But it is also a very significant greenhouse gas. Carbon dioxide is important in maintaining the earth's average temperature of about 15°C (59°F). The CO₂ traps infrared energy emitted from the earth's surface and warms the atmosphere. Without water vapor, CO₂, and methane (the three most important naturally produced greenhouse gases), the earth's surface would be about -18°C (0°F). At this temperature, it is doubtful that complex life as we know it would ever have evolved.

Where does CO₂ come from? Plants and animals give it off when they extract energy from their food during cellular respiration. Carbon dioxide bubbles out of the earth in soda springs, explodes out of volcanoes, and is released when organic matter burns (such as during forest fires).

- Anything that releases CO₂ into the atmosphere (living, dead, or non-living) is considered a **source**
- Anything that absorbs and holds CO₂ from the air or water is considered a **sink** (because, like a sink in your home, it acts as a "holding reservoir")

Over geologic time, CO₂ sources and sinks generally balance. In today's atmosphere, however, CO₂ levels are climbing in a dramatic and easily measurable fashion, providing evidence that there are now more CO₂ sources than sinks.

**What are the sources for this 'extra' CO₂?** Human activities are thought to be primarily responsible for the observed increases. Of the human sources of CO₂:

[http://www.ucar.edu/learn/1_4_2_17t.htm](http://www.ucar.edu/learn/1_4_2_17t.htm) (1 of 9) [1/14/2004 9:42:13 AM]
- Fossil fuel combustion accounts for 65%
- Deforestation (CO₂ released from trees that are cut and burned or left to decay) accounts for 33%
- The by-products of cement production account for the remaining 2%

There are natural sources of CO₂ as well. Plants and animals give off CO₂ while alive and respiring and when dead and decaying (bacteria that consume the dead bodies respire too, after all). Carbonate rocks contain CO₂ that can be released by exposure to acid and/or weathering. Certain naturally carbonated spring waters (for example, Perrier water) contain CO₂ because the water has passed though carbonate rocks on its way to the surface. Volcanoes are also a source of CO₂. However, these geological sources are insignificant when compared to the human sources.

**Plants** (both terrestrial plants and marine phytoplankton) are the most important carbon sinks, taking up vast quantities of CO₂ through the process of photosynthesis. To a lesser extent, atmospheric CO₂ can also be dissolved directly into ocean waters and thereby be removed from the atmosphere. While plants also release CO₂ through the process of respiration, on a global, annual basis, the amount of CO₂ taken up by plants through photosynthesis and released through respiration approximately balances out. Thus, the CO₂ released from human activities is truly the 'extra' CO₂.

Scientists typically monitor the concentration of CO₂ in atmospheric samples by using sensitive devices called infrared gas analyzers. These devices pass a beam of infrared (IR) light through a sample of gas. The amount of IR that reaches a detector on the other side can be used to determine the amount of CO₂ in the sample. A worldwide network of CO₂ monitoring stations currently tracks the earth's rising CO₂ levels.

Carbon dioxide has another characteristic that enables students to detect CO₂ themselves. When dissolved in water, carbon dioxide forms a weak acid, called carbonic acid. The chemical bromothymol blue (BTB) is a sensitive indicator of the presence of acid. When gas containing CO₂ is bubbled through a BTB solution, carbonic acid forms and the indicator turns from dark blue to green, yellow, or very pale yellow depending on the concentration (lighter colors mean higher concentrations).

This activity has multiple parts:
- In Part 1, students will gain experience in detecting CO₂ through the BTB reaction by using a pure CO₂ gas made from the reaction of baking soda and vinegar
- In Part 2, students will collect and detect relative CO₂ concentrations from a number of natural and human sources
- In Part 3, students will use a simple titration procedure to quantify the amounts of CO₂ that they collected

Note: For the activity to be most effective, students should have a working knowledge of the carbon cycle. Activity 15 provides a good overview of the cycle.
**Learning Goals**

1. Students will be able to explain the concept of 'sources' and 'sinks' as they relate to CO₂.
2. Students will understand the use of an indicator solution (BTB) to reveal the presence of CO₂.
3. Students will understand the qualitative differences between animal and fossil fuel sources of global CO₂.

**Alignment to National Standards**

*National Science Education Standards*

- Earth and Space Science, Structure of the Earth System, Grades 5 to 8, pg. 160, Item #11: "Living organisms have played many roles in the earth system, including affecting the composition of the atmosphere, producing some types of rocks, and contributing to the weathering of rocks."

- Earth and Space Science, Geochemical Cycles, Grades 9 to 12, pg. 189, Item #2: "Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life."

- Science in Personal and Social Perspectives, Environmental Quality, Grades 9 to 12, pg. 198, Item #2: "Material from human societies affects both physical and chemical cycles of the earth."

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- The Physical Setting, Processes That Shape the Earth, Grades 6 to 8, pg. 73, Item #7. "Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms."

**Grade Level/Time**

- Grade level: 6 to 10
- Time:
Activity 17 Teacher Guide: Where in the World is Carbon Dioxide?

- Materials preparation: 20 minutes
- Introduction: 20 minutes
- Part 1 activity: 25 minutes
- Part 2 activity: 30 minutes
- Part 3 activity: 20 minutes
- Discussion & review: 30 minutes

**Materials**

*For each two-student team*

- Test tube rack
- Six test tubes
- One hole stopper with tubing attached
- Baking soda
- Vinegar
- One-inch square of aluminum foil
- Cotton balls
- Bottle of BTB working solution
- Air pump (bicycle pump or sportsball pump will work)
- Squirt bottle of dilute ammonia
- Masking tape
- Duct tape
- Three balloons (different colors)
- Markers
- Balloon-size template (directions below)
- Three straws
- Pipette or eye dropper
- Ten twist ties
- Newspapers
- Student instructions and data charts (in student guide)

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**Procedure**

This activity requires significant preparation. This section addresses teacher preparation only. Detailed procedural instructions for the three parts of the activity are in the student guide. It is strongly suggested that teachers read the student guide prior to implementing this activity.

**PART 1: DETECTING CARBON DIOXIDE GAS**

BTB is available in either concentrated liquid or powdered form. Do the following to prepare the BTB solution.

- If you're using the liquid form
  - Fill a gallon bottle nine-tenths full with tap water and add BTB until the solution is a deep, blue color (this is the working solution).

- If you're using powdered BTB
  - Measure 0.5 grams of dry BTB 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.
One liter of working solution should serve a class of 30 students, in two-person teams.

In Part 1, the students will conduct an experiment designed to detect the presence of CO₂. When combined, baking soda and vinegar produce pure CO₂. In this experiment, the BTB will dramatically change color (from bright blue to yellow) when introduced to the CO₂. This basic experiment will form the basis of the experiments to follow.

**PART 2: COLLECTING SAMPLES OF CARBON DIOXIDE FROM VARIOUS SOURCES (AIR, ANIMALS, AND FOSSIL FUELS)**

The students will analyze the CO₂ from car exhaust (which will represent fossil fuel), their own breath (representing animals), and the outside air by bubbling a known amount of each gas though a standard volume of BTB. They will first simply compare how the different sources change the color of the BTB solution as they did for pure CO₂ in Part 1.

To make a meaningful comparison, it is important that students collect equal volumes of gases. We suggest using rubber balloons blown up to the same diameter from each source as collectors. To do this, make a simple balloon diameter template with a piece of cardboard or half of a manila folder. Draw a circle about 7.5 cm in diameter in the middle. Cut out the circle and discard, saving the frame for use as a template.

You will need one of these templates for each group of students. As they collect samples, the students can use these to make sure that the samples are of approximately equal volumes. The templates can be re-used.

**A. Automobile exhaust collection**

*Important note:* Teachers should provide students with balloons full of car exhaust. It is not recommended that students participate in filling the balloons with car exhaust. An adult assistant (or two) is necessary, however.

*Materials needed for collecting car exhaust:*

- Manila folder
- Roll of duct tape
• Pair of heat resistant oven mitts
• Balloons (8 or 10-inch diameter)

Procedure:

1. Blow up and allow the balloons to deflate. This will stretch the rubber and make them easier to fill with the relatively low-pressure exhaust.

2. Prepare a cone to collect the car exhaust by rolling up a manila folder lengthwise. One end must be larger than the opening for the car's tail pipe and the other end must be small enough for the balloon to fit over it.

   Use plenty of tape to hold the cone in shape and to make the sides of the cone fairly airtight. Note: the paper funnel will work for several fillings without burning. DO NOT use a plastic funnel. As the exhaust pipe heats up, the plastic may melt. You may use a metal funnel, but be VERY careful to avoid any skin contact with the hot metal.

3. Have an assistant turn on the car (make sure brake is on).

4. Put the balloon on the small end of the cone.

5. Using the heat resistant mitts, approach the exhaust pipe from the side. Place the large end of the cone over the tail pipe. Use the gloved hand to help form a seal between the cone and the exhaust pipe. DO NOT BREATHE THE EXHAUST. The balloon should fill quickly; if not, have your assistant step lightly on the accelerator.

6. When the balloon is filled, have an assistant use a twist tie or two to tightly seal the balloon. Do this by twisting the neck several times and doubling it over once, then place the twist tie around the constricted area.

7. You will want to have at least one balloon for each group of students. It is useful to prepare a few extra filled balloons.
B. Animal carbon dioxide collection

Students will fill up balloons with their own exhalations according to the instructions in the student guide. Emphasize to the students that they should hold air in their lungs for a few moments to allow plenty of exchange between \( O_2 \) being absorbed and \( O_2 \) being released in their lungs. Breaths that are too rapid will contain less \( CO_2 \) than normal exhalations.

C. Outside air collection

Students will collect outside air using an air pump (or bicycle or sportsball pump) to blow up a balloon. The sample collection must be done out-of-doors as inside air can be \( CO_2 \) enriched from breath.

At this point, your student teams will each have three balloons, one of car exhaust, one of their own breath, and one of outside air. They will bubble the gases through a BTB solution in test tubes, observing the color changes, according to the student directions. They should clearly observe the rapid and dramatic change with the car exhaust, the less significant change with their own breath, and the minor change with room air. The students will save these test tubes for Part 3.

PART 3: QUANTIFYING CARBON DIOXIDE

As \( CO_2 \) is bubbled through a BTB solution, it reacts with the water to form carbonic acid. The more \( CO_2 \) in the gas, the more acid is formed. As the pH of the solution goes down (becomes more acid), the BTB changes from blue to green to yellow. In order to measure (approximately) how much \( CO_2 \) actually reacted with the solution, we can use a procedure called 'titration.'

To do this titration, we add small volumes of a basic (high pH) solution (such as household ammonia) to the BTB mixture and record how much of this solution it takes to make the BTB return to its original blue color. The more \( CO_2 \) that was bubbled through the BTB solution, the more ammonia will be required to restore the original color.

Students will be provided with dropper bottles of ammonia and will be instructed to slowly and carefully, drop-by-drop, add ammonia to the tubes, until the original color returns. In this way they can compare \( CO_2 \) content of the sources they tested.

Assessment Ideas

In this activity, the students have examined several sources of \( CO_2 \). Ask them the following questions:

- If you wished to reduce the amount of \( CO_2 \) increase in the atmosphere, which source would be most important to control? Explain why.
● Would there be problems with such controls? If so, what might they be?

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**Modifications for Alternative Learners**

● Use appropriate pairing strategies to pair students with difficulty following complex directions with those who have no such difficulty.

● Students with poor fine motor skills may need assistance in handling the balloons.

When you're finished with the activity, click on To Student Guide or Back to Activities List at the top of the page.
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<th><strong>Site Surfers</strong></th>
<th><strong>Climate Change</strong></th>
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<td><strong>The Global Change Instruction Program</strong> (produced at the University Corporation for Atmospheric Research) was designed by college professors to provide needed interdisciplinary materials on global change for undergraduate students. Eleven modules are currently available on the site in PDF format that range from the carbon and biogeochemical cycles to climate variation during Earth’s history. <a href="http://www.dpc.ucar.edu/globalChange/index.html">http://www.dpc.ucar.edu/globalChange/index.html</a></td>
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<td><strong>Global Warming: Focus on the Future</strong> is the official web version of the Environmental Defense Fund’s <em>Global Warming: Understanding the Forecast</em> traveling exhibit. Learn about the changes in our climate over time, the causes and consequences, and what you can do to help. Don’t forget to play some of the games on the site to learn still more on the topic. <a href="http://globalwarming.enviroweb.org/">http://globalwarming.enviroweb.org/</a></td>
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<td><strong>At the Exploratorium’s award-winning Global Climate Change site</strong>, learn how researchers study climate and examine the latest scientific data. With text and supporting images, the site explores our atmosphere, hydrosphere, cryosphere, biosphere, and the predicted global effects of climate change obtained via complex climate models. The site’s <em>Glossary</em>, with definitions of terms used within the site’s pages, provides yet another valuable aid to understanding the data that scientists themselves use to understand and explain Earth’s changing climate. <a href="http://www.exploratorium.edu/climate">http://www.exploratorium.edu/climate</a></td>
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<td><strong>The Environmental Protection Agency</strong> (EPA) has two climate change sites, one designed with Children in mind, and the other for adults. Both are attractive, engaging, and informative. Children can learn about climate, play informative games, and view a Flash animation explaining global warming and earth processes such as the carbon and water cycles. At the site for adults, find the answers to your climate change questions! Kids log in at: <a href="http://www.epa.gov/globalwarming/kids/index.html">http://www.epa.gov/globalwarming/kids/index.html</a> Adults, log in at: <a href="http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html">http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html</a></td>
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<td><strong>Climate Watch</strong> is an audio series about Earth’s atmosphere, climate change, and global warming organized around four areas: origins of climate, climate change, impacts of climate change, and action. Information is provided via the voices of scientists working in the atmospheric sciences. The site is made possible by grants from the Canada Climate Change Action Fund and the Manitoba Climate Change Action Fund. <a href="http://www.climatewatch.net">http://www.climatewatch.net</a></td>
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<td><strong>The US Dept. of Energy’s Atmospheric Radiation Measurement (ARM) Program</strong> offers basic or in-depth information on climate change. Click on the <em>Global Warming</em> icon to check out the 50-minute QuickTime movie, “<em>Climate Change...The Facts!</em>” Be sure to explore the many other excellent offerings on the site: postcards, quizzes, links, lessons, and more. <a href="http://www.arm.gov/docs/education/index.html">http://www.arm.gov/docs/education/index.html</a></td>
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<td><strong>Vital Climate Graphics, from the United Nations Environment Program (UNEP)</strong> and its Intergovernmental Panel on Climate Change (IPCC), catalogs and provides graphic images that focus on the environmental and socio-economic impacts of climate change. Each graphic captures critical information on the climate change, and is paired with a captioned explanation of the image. <a href="http://www.grida.no/climate/vital/index.htm">http://www.grida.no/climate/vital/index.htm</a></td>
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<td><strong>The Union of Concerned Scientists’ site</strong> focuses on sound solutions to major problems of global environmental change. Legislative action is also discussed with avenues for visitors to speak out on issues important to them. Click on the <em>Global Warming</em> icon to get to <em>Special Features, Climate Science</em> (includes FAQs on the topic), and <em>Climate Impacts</em>. <a href="http://www.ucsusa.org/global_environment/">http://www.ucsusa.org/global_environment/</a></td>
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The focus of [NASA’s Earth Observatory](http://earthobservatory.nasa.gov) is to provide information on Earth’s climate and environmental change through satellite imagery and scientific information. Click on the **Features** section to read about the latest research on the subject and explore a wealth of articles relating to our atmosphere, oceans, and land. [http://earthobservatory.nasa.gov](http://earthobservatory.nasa.gov)

[Global Warming: Early Warning Signs](http://www.climatehotmap.org) was produced by seven environmental organizations. The site’s “hot map” illustrates consequences of global warming by location. Visitors simply click on a region to obtain a **Fingerprint** (events due to warmer global temperatures) or a **Harbinger** (events that foreshadow impacts that are likely to become more widespread and frequent with continued warming but can’t be directly attributed to climate change at this time). Curricula materials for the map are available for high school teachers on the site. Copies of the map are also available. [http://www.climatehotmap.org](http://www.climatehotmap.org)

[The National Oceanic and Atmospheric Agency’s (NOAA) Climate Timeline](http://www.ngdc.noaa.gov/paleo/ctl/) site provides an online tool that allows you to examine climate change and variability at different time scales, from daily diurnal cycles to over 100,000 years ago. While the focus is on past climate change, you’ll leave with a better understanding of current and future climate issues. A **Historical Overview** section is provided for each time period listed, as well as sections on **Climate Science**, **Climate History**, and **Resources**. [http://www.ngdc.noaa.gov/paleo/ctl/](http://www.ngdc.noaa.gov/paleo/ctl/)

[The Pew Center on Global Climate Change](http://www.pewclimate.org/) brings together business leaders, policy makers, scientists, and other experts to create a new approach to this complex and often controversial issue. The center produces analyses of key climate issues, works to keep policy makers informed, engages the business community in the search for solutions, and reaches out to educate key audiences like yourself. Find out what’s new at [http://www.pewclimate.org/](http://www.pewclimate.org/)

[The Climate Change Information Kit](http://unfccc.int/resource/iuckit/cckit2001en.pdf), from the World Meteorological Organization and the United Nations’ Intergovernmental Panel on Climate Change (IPCC), is a 63-page downloadable booklet. The kit contains comprehensive information that summarizes the most up-to-date findings of the IPCC in simple language that is easy to understand. [http://unfccc.int/resource/iuckit/cckit2001en.pdf](http://unfccc.int/resource/iuckit/cckit2001en.pdf)

[Teachers’ Guide to High Quality Educational Materials on Climate Change and Global Warming](http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm) is produced by the National Science Teachers Association (NSTA). It offers recommendations for obtaining first-rate background materials, lesson plans, and experiments relating to climate change. The site serves as a one-stop shop for educators wishing to create their own climate change unit. [http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm](http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm)

Dr. Global Change resides at the [US Global Change Research Information Office (GCRIO)](http://www.gcrio.org) site, which provides access to data and information on climate change research and related educational resources on behalf of the various US federal agencies involved in the [US Global Change Research Program (USGCRP)](http://www.usgcrp.gov). Click on the Ask Dr. Global Change icon to read through over 100 questions and answers, or submit a question of your own. Check out the USGCRP site to review the latest government research programs and reports. Last but not least, click on the last link below to obtain the report, *Climate Change Impacts on the United States*. [http://www.gcrio.org](http://www.gcrio.org), [http://www.usgcrp.gov](http://www.usgcrp.gov), [http://www.usgcrp.gov/usgcrp/Library/nationalassessment/](http://www.usgcrp.gov/usgcrp/Library/nationalassessment/)

Opinions, findings, conclusions, or recommendations expressed on these sites do not necessarily reflect the views of UCAR or its sponsors.

*For further information contact: UCAR, Public Visitors Program, 303/497-1152, [pvp@ucar.edu](mailto:pvp@ucar.edu)*
| **Web Weather for Kids**, from the University Corporation for Atmospheric Research (UCAR), presents inquiry-based weather activities and information for children at home and/or in the classroom. This award-winning site offers opportunities to try your hand at forecasting, learn about all types of weather, and enjoy the games, stories, activities, and teacher tips. A Must Visit site for K-8 students. [http://www.ucar.edu/educ_outreach/webweather/](http://www.ucar.edu/educ_outreach/webweather/)

| **Kids’ Crossing**, from UCAR’s National Center for Atmospheric Research (NCAR), is new to the web as of 2003, but it promises to be one of the best sites for those wanting to be weather wise and science savvy! The site lists some of the best weather resources available online, as well as links to fun and informative games and activities on clouds, lightning, and more. Don’t miss the site’s Fun Fact of the Month for some awesome weather-related trivia. Keep logging in and watch the site grow!! [http://www.ncar.ucar.edu/eo/kids/](http://www.ncar.ucar.edu/eo/kids/)

| **LEARN: Atmospheric Science Explorers** was a project funded by the National Science Foundation to help increase middle-school science teachers’ knowledge of, and interest in, the atmospheric sciences. Over 60 scientists from the National Center for Atmospheric Research (NCAR) worked with middle-school teachers over a three-summer period to develop the LEARN modules that include background information, hands-on activities, and authentic assessment tools on various atmospheric science topics. [http://www.ucar.edu/learn/](http://www.ucar.edu/learn/)

| **The GLOBE Program**, under the direction of the University Corporation for Atmospheric Research (UCAR) in partnership with Colorado State University, is a worldwide school-based education and science program that involves students in taking scientifically valid measurements, reporting their data through the Internet, and analyzing data sets. Participants can collaborate with scientists and other GLOBE students from around the world! There are over 20,000 GLOBE-trained teachers and over a million primary and secondary students who have taken part in the program. Join them for a great science experience!! [http://www.globe.gov/](http://www.globe.gov/)

| **WW2010 (Weather World 2010)**, developed by the Department of Atmospheric Sciences at the University of Illinois at Urbana-Champaign, offers superb and extensive online instructional materials on meteorology, remote sensing, and reading and interpreting weather maps. Add to that excellent projects and activities, and a winning site is born! The site presents a wealth of meteorology information with appealing graphics that aid in understanding the material. To learn about meteorology, start here! [http://ww2010.atmos.uiuc.edu/](http://ww2010.atmos.uiuc.edu/)

| **The Weather Classroom** is part of Cable in the Classroom, a philanthropic initiative to provide free access to commercial-free, educational cable content. Check out the new Weather Classroom programs which air Mondays and Thursdays, 2-2:30 am (MST). All shows can be recorded and used in the classroom, and lesson plans are provided to complement each program. Subscribe to the site’s Weather Insights newsletter or peruse the wealth of resources at the site. Add this one to your Favorites or Bookmarks file! [http://www.weather.com/education/](http://www.weather.com/education/)

<p>| <strong>Encyclopedia of the Atmospheric Environment</strong> was developed by the Department for Environment, Food and Rural Affairs (DEFRA) and its Atmosphere, Climate &amp; Environment (ACE) Information Program in the United Kingdom. The encyclopedia covers a range of atmospheric issues including air quality, ozone depletion, weather, and climate change. The site has been a recognized one-stop atmospheric environment resource for all ages since 2000. <a href="http://www.doc.mmu.ac.uk/aric/eae/">http://www.doc.mmu.ac.uk/aric/eae/</a> |</p>
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<td>is the online resource to search when in need of weather facts and figures on high, low, and average temperatures; snowfall; hours of sunshine; and the like for any place in the world. Find out your hometown’s weather trivia here!</td>
<td><a href="http://www.washingtonpost.com/wp-srv/weather/historical/historical.htm">http://www.washingtonpost.com/wp-srv/weather/historical/historical.htm</a></td>
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<td><strong>Plugged In!</strong></td>
<td>is for girls only, or so says the Girl Scouts of the Mid-Continent Council, which produced the site to offer super, sizzling, stimulating, scientific stuff just for girls! Click on The Science Arcade and visit the Weather Wizards section. By doing so, Junior Girl Scouts can obtain their Weather Watch badge.</td>
<td><a href="http://plugged-in.org">http://plugged-in.org</a></td>
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<tr>
<td><strong>One Sky Many Voices</strong></td>
<td>is the University of Michigan’s science curriculum project for grades K-12 that utilizes current data, software, and Weather Net resources during either a four-week or eight-week program. Its Kids as Global Scientists project encourages scientific inquiry and research about basic weather and climate concepts. Check out the link to the University of Michigan’s Weather Underground as well. The site offers current weather data and an extensive list of weather links.</td>
<td><a href="http://groundhog.sprl.umich.edu/index.html">http://groundhog.sprl.umich.edu/index.html</a></td>
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<tr>
<td><strong>Playtime for Kids</strong></td>
<td>was created by the Federal weather agency, the National Oceanic and Atmospheric Administration (NOAA). Winter storms, tornadoes, thunderstorms, floods, safety tips, general weather information, and links to weather-related coloring books and other weather- or science-centered sites are included.</td>
<td><a href="http://www.nws.noaa.gov/om/reachout/kidspage.shtml">http://www.nws.noaa.gov/om/reachout/kidspage.shtml</a></td>
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<tr>
<td><strong>The Franklin Institute Online</strong></td>
<td>examines weather in a light yet informative manner. In addition, it covers careers in meteorology, historical weather data, and tips for making weather stations. The site’s Weather Hotlist is particularly thorough. Explore this site for an excellent adventure in weather forecasting!</td>
<td><a href="http://sln.fi.edu/weather/index.html">http://sln.fi.edu/weather/index.html</a></td>
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<tr>
<td><strong>Science with NOAA Research</strong></td>
<td>provides middle-school science students and teachers with research and investigation experiences using online resources from the National Oceanic and Atmospheric Administration. Find out about El Nino, investigate hurricanes and climate change, interpret maps of winds, waves, and temperature…. There’s no time to get bored here with so much to discover, see, and do!</td>
<td><a href="http://www.oar.noaa.gov/k12/">http://www.oar.noaa.gov/k12/</a></td>
</tr>
<tr>
<td><strong>Weather, Climate, and Seasons!</strong></td>
<td>Learning about climate, weather, and the seasons has never been more fun for K-4 students! Topic overview information and hands-on activities enlighten while the graphics, sound, and text engage! Play the Weather Game and test your smarts! Classroom of the Future (COTF) and its Exploring the Environment (ETE) team have created a Must Visit site.</td>
<td><a href="http://www.cotf.edu/ete/modules/k4/teacher/weather/weather.html">http://www.cotf.edu/ete/modules/k4/teacher/weather/weather.html</a></td>
</tr>
<tr>
<td><strong>The Weather Doctor</strong></td>
<td>was created by meteorologist Keith Heidorn and grew out of his passion for weather, art, and stories. He’s combined these passions here to include all things weather, from art and classic weather stories to weather phenomena, events, people, facts, and history. Pull up a chair, cozy up to your monitor, and enjoy Dr. Heidorn’s site.</td>
<td><a href="http://www.islandnet.com/~see/weather/doctor.htm">http://www.islandnet.com/~see/weather/doctor.htm</a></td>
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