

LESSON 8: OZONE—DOUBLE TROUBLE



OBJECTIVES

Students will do the following:

1. Distinguish between tropospheric and stratospheric ozone
2. Define "smog" and distinguish between "London-type" smog and photochemical smog
3. Discuss air quality and related health and welfare issues involving tropospheric and stratospheric ozone
4. Perform an experiment that demonstrates that ozone can have a detrimental effect on certain materials.

BACKGROUND INFORMATION

The issue of ozone in the earth's atmosphere can be confusing. On the one hand, we know that high above the earth's surface is a layer of ozone that surrounds the planet and helps block out some of the sun's harmful radiation. We hear reports of "holes" developing in this ozone shield and of the harm that the increased ultra-violet radiation can cause on earth. On the other hand, we know that higher-than-normal concentrations of ozone in the ambient air can be harmful to people, animals, plants, and various materials. Indeed, ozone is one of the criteria pollutants, those harmful substances that are most widespread in the ambient air. The ozone gas in both places is the same—it's the chemical O_3 —but in the upper atmosphere it greatly benefits all life, whereas near the earth's surface it can cause problems.

TOPICS:

Stratospheric ozone, tropospheric ozone, and smog

SUBJECTS:

Earth science, chemistry, language arts, art

TIME:

3-6 class periods, plus 15 minutes several times a week for a few months

MATERIALS:

Ozone: Double Trouble videotape - available from A&WMA (412) 232-3444 x3124
Aluminum foil
Two thumb tacks
Seeds for pinto beans, green beans, spinach, and/or pumpkin
8-12 flower pots
Potting soil
Water
Fertilizer
Camera
Film
Outdoor thermometer
Wind gauge
Rain gauge
Potassium iodide

Alternate Activity

Six 1/2-inch (or metric equivalent) threaded hooks.
6 ft. (2 m) of rigid wire
Four cardboard frames (see illustration)
One low relative humidity ozone gas fading control fabric (fabric #109, available from Test Fabrics, P.O. Box 420, Middlesex, NJ 08846)
One combustion sensitive fabric ribbon (ribbon #1, from Test Fabrics)
Scraps of acid-washed jeans
One good quality (15 denier) nylon hose
Rubber band
Contact cement or non-water-base glue
One varnished block of wood 1" x 8" x 4" (2.5 cm x 20 cm x 10 cm)
Four 3 ft. (1 m) long 2" x 2" (5 cm x 5 cm) wooden poles
Two 3' x 3' (1 m x 1 m) exterior-grade plywood boards, 1/2" (or metric equivalent) thick
Overhead transparency master

The Stratospheric Ozone Layer

High in the stratosphere a layer of ozone gas forms an important and effective protective barrier against the harmful ultraviolet radiation from the sun. There has been increasing international concern that chemical pollutants are destroying this ozone layer. The main culprits seem to be in a class of chemical compounds called chlorofluorocarbons, or CFCs. First introduced in the late 1920s, these gases have been used as coolants for air conditioners and refrigerators, propellants for aerosol sprays, and agents for producing plastic foam. Because CFC molecules are extremely stable, they tend not to react with other substances in the troposphere, so they can rise intact into the stratosphere. Here ultraviolet radiation breaks them up into their more-reactive components, including chlorine, which is the culprit in the destruction of ozone. The Montreal Protocol banned the production, by 1995 in developed countries and by 2000 in others, of chemicals that deplete stratospheric ozone. Use of such chemicals will continue, however, until at least 2010.

Increased ultraviolet radiation at the earth's surface can lead to a greater incidence of skin cancer, eye problems, and immune deficiencies in humans and to decreased crop yields and reduced populations of microscopic sea plants and animals that are vital to the food chain. Efforts to protect the ozone layer now involve many different nations and industries. At an international conference in London in 1990, 93 countries agreed to eliminate CFCs entirely by the year 2000. Researchers are busy finding less-harmful, and in many cases more-economical, substitutes for the CFCs.

Ozone Pollution in the Troposphere

High concentrations of ozone in the ambient air that we breathe can present many problems. Because ozone molecules are highly reactive, they have an effect on practically every material they contact, whether it be lung tissue, crops or other vegetation, rubber, plastic, paints, and so on.

What we often refer to as photochemical "smog" is mostly ground-level ozone. Smog (whose name derives from the words *smoke* and *fog*) can be of two types: "London-type" and photochemical. London-type smog is formed when moisture in the air condenses on particulate matter given off by the burning of coal. London-type smog contains a lot of sulfur dioxide, producing a sulfuric acid mist that causes irritation of the airways and breathing problems and damages buildings and plants.

Photochemical smog is the type of smog that is mostly ozone. The recipe for the formation of ozone in the ambient air includes natural atmospheric gases, volatile organic compounds (VOCs), nitrogen oxides, and sunlight. Because sunlight is a key factor, ozone pollution is generally worse during the day and in the summertime. The figure that follows illustrates the daytime buildup of ozone in two cities. Vehicle exhausts provide most of the VOCs and nitrogen oxides that help form ozone, so times of increased vehicle use (such as morning and afternoon rush hours) also increase the possibility of ozone problems. (The problem is usually greatest at mid-day or mid-afternoon because of the effect of the sun.) Ozone can cause eye, nose, and throat irritation, and can damage the lungs.

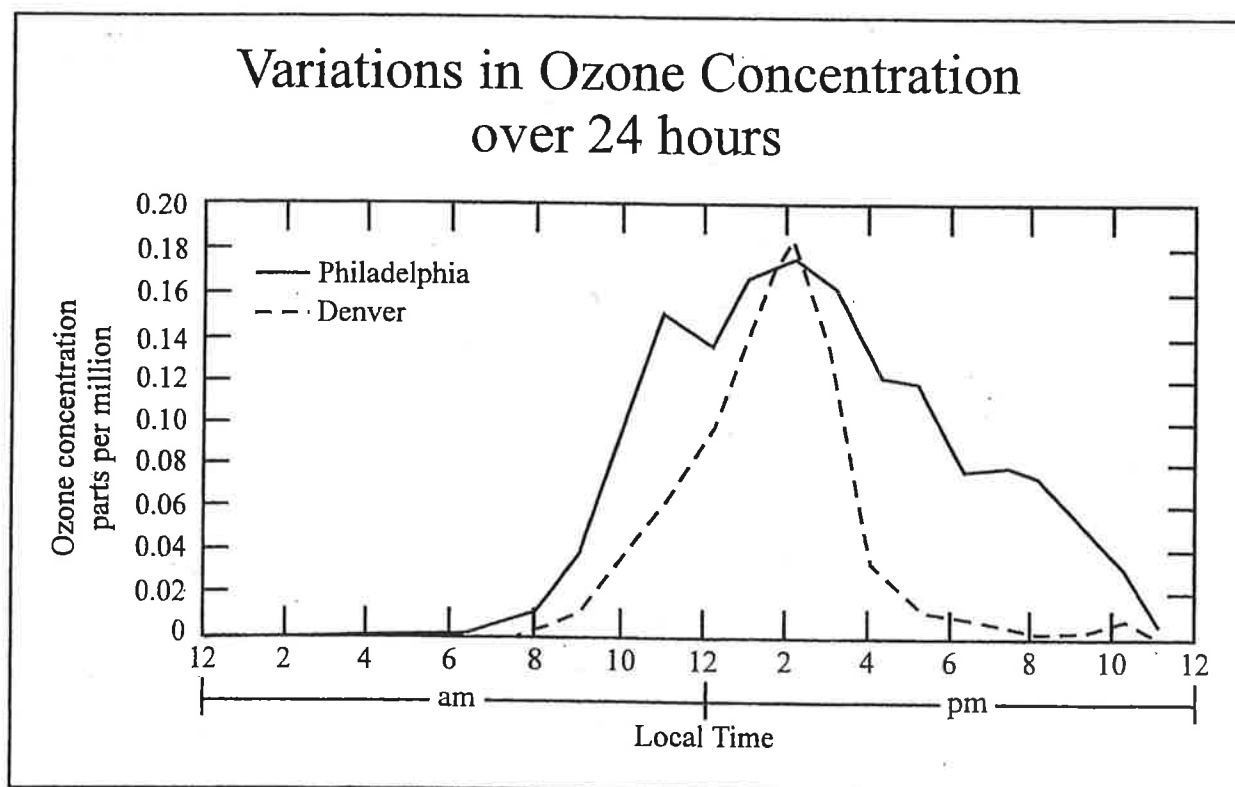
Weather patterns are a factor in photochemical and London-type smog, either helping to disperse the problem or transport it to a different location, or stall it and foster the buildup of

pollutants to extremely hazardous levels. These high levels, which usually occur when there is a temperature inversion, are called air pollution "episodes." In 1948, a heavy build-up of smog in Donora, Pennsylvania, caused 20 deaths and 6,000 illnesses, and in 1952, nearly 4,000 people died from heavy London-type smog in London, England.

What Can Be Done?

Both ozone problems—stratospheric depletion and tropospheric build-up—are created in large part by air pollution. The only practical approach to stopping the destruction of the ozone layer and to minimizing ozone pollution in our ambient air is reducing the human-generated pollutants that contribute to these problems. Finding and using alternatives to CFCs is an essential part of the solution. As individuals we can immediately repair any leaks in refrigerators, have our car air conditioners checked periodically, use alternatives to home air conditioning, use alternatives to foam insulation and containers, purchase halon-free fire extinguishers, and support laws requiring CFC recycling.

Decreasing our use of fossil-fuel-burning vehicles and assuring our vehicle emission control systems are functioning properly is also critical to solving the problem of tropospheric ozone. We can use public transportation for long trips, walk or use bicycles for short trips, carpool to work and other activities, and combine several errands into one outing. Some areas have "ozone action" days, which encourage citizens and industries to follow procedures to reduce their impact on the formation of harmful ozone. On these days, citizens are encouraged to postpone mowing their lawns and refilling their automobile's gas tanks until the evening hours, avoid using lighter fluid for charcoal, and reduce their use of their cars by carpooling or using public transportation.



PROCEDURE

I. Setting the Stage (See Overhead Transparency Masters section)

- A. Show the videotape, *Ozone: Double Trouble*, available from Air & Waste Management Association Publications Department, (412) 232-3444 x3124.
- B. Ask students to research and write a one- to two-page paper on tropospheric and stratospheric ozone.

II. Activity

- A. This activity is from the December 1995 issue of *The Science Teacher*.

You will need the following materials:

- Potassium iodide
- Filter paper
- Corn starch
- Glass stirring rod
- Small paint brush
- 250-ml beaker
- Heat source (preferably hot plate)
- Hot pad for removing the beaker from the heat source
- 8 1/2 X 11-inch (or metric equivalent) paper for drying filter paper or a 9-in. (25-cm) microwave-safe plate
- Wet-dry bulb psychrometer that uses two non-mercury-filled thermometers
- Distilled water
- Heat-safe glass plate
- Full-splash safety goggles
- Aprons
- Schoenbein Color Scale
- Relative Humidity Schoenbein Number Chart (See Overhead Transparency Masters)

<u>Schoenbein Color Scale</u>	
0-3	Little or no change
4-6	Lavender hue
7-10	Blue or purple

B. Prepare Schoenbein paper

1. Place 100 ml of water in a 250-ml beaker, then add 5 g of corn starch.
2. Heat and stir the mixture until it gels. The mixture is gelled when it thickens and becomes somewhat translucent.
3. Remove the beaker from the heat and add 1 g of potassium iodide and stir well. Cool the solution.
4. Lay a piece of filter paper on a glass plate and carefully brush the paste onto the filter paper. Turn the filter paper over and do the same on the other side. Apply the paste as uniformly as possible. The paper can be exposed for immediate testing at this point.

5. Allow the paper to dry. Do not set in direct sunlight. A low-temperature drying oven works best. To save time, place the paper on a microwave-safe plate and microwave for one minute.
6. Cut the filter paper into 1-inch-wide strips. To store the strips, place them in a zipper-lock plastic bag or glass jar out of direct sunlight.

CAUTION: WASH HANDS THOROUGHLY WITH SOAP, AND SCRUB UNDER FINGERNAILS WITH A BRUSH AFTER WORKING WITH THE POTASSIUM IODIDE MIXTURE.

C. Testing Procedure

1. Dip a strip of test paper in distilled water and hang it at a data collection site out of direct sunlight. Make sure that the strip can hang freely.
2. Expose the paper for approximately eight hours. Seal it in an airtight container if the results will not be recorded immediately.
3. To observe and record test results, dip the paper in distilled water. Observe the color and determine the Schoenbein Number using the Schoenbein color scale.
4. Determine the relative humidity of the data collection site by using a bulb psychrometer or local weather data. Round off the relative humidity reading to the nearest 10 percent. (Higher relative humidity makes the paper more sensitive to ozone, and a higher Schoenbein Number is observed. To correct for this, the relative humidity must be determined and figured into the calculation of ozone concentration.) Refer to the Relative Humidity Schoenbein Number Chart. Along the bottom of the chart, find the point that corresponds to the Schoenbein number that you recorded. For that point, draw a line upward until it intersects with the curve that corresponds to your relative humidity reading. To find the ozone concentration in parts per billion, draw a perpendicular line from the Schoenbein number/relative humidity point of intersection to the left side of the chart.

D. Observations and Questions

1. What change in the test paper, if any, did you observe? (The color of the paper may not be uniform. Determine the Schoenbein Number by the color in an area with the most noticeable change.)
2. Compare your test paper to those of other students' test papers. Do all the test papers appear the same? (Individual test papers will vary depending on the amount of oxidants at that site. Be aware that false positive results can occur from nitrous oxides in heavy traffic areas.)
3. Was the relative humidity for your test day high or low? (Individual results will vary depending on the specific relative humidity of the site.)
4. Why do you think the test papers did not all appear the same?

5. Would the parts per billion of ozone be the same for a Schoenbein Number of 4 at a relative humidity of 30 percent and 70 percent? (Hint: Refer to the Relative Humidity Schoenbein Number Chart.)
6. Based on the data you collected, do you think this method is a good way to measure tropospheric ozone? Why or why not?
7. Compare data with those from a local monitoring station. Also, if possible, get information about the wind direction during your study and determine how it affected your measurements.

III. Activity. (Alternative to the above activity.) The Effect of Ozone on Materials. NOTE: The special materials for this activity are relatively expensive.

A. Students will demonstrate that ozone in the atmosphere can have a detrimental effect on certain materials.

You will need the following materials:

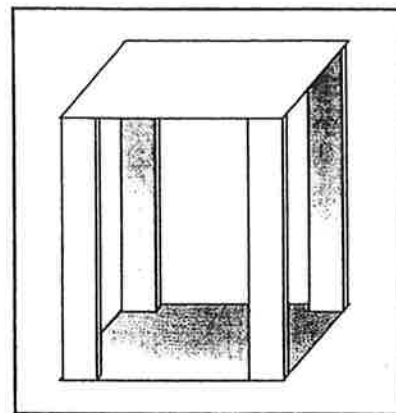
- Six 1/2-inch (or metric equivalent) threaded hooks.
- 6 ft. (2 m) of rigid wire
- Four cardboard frames (see illustration)
- One low relative humidity ozone gas fading control fabric (fabric #109, available from Test Fabrics, P.O. Box 420, Middlesex, NJ 08846)
- One combustion sensitive fabric ribbon (ribbon #1, from Test Fabrics)
- Scraps of acid-washed jeans
- One good quality (15 denier) nylon hose
- One rubber band
- Contact cement or non-water-base glue
- One varnished block of wood 1" x 8" x 4" (2.5 cm x 20 cm x 10 cm)
- Four 3 ft. (1 m) long 2" x 2" (5 cm x 5 cm) wooden poles
- Two 3' x 3' (1 m x 1 m) exterior-grade plywood boards, 1/2" (or metric equivalent) thick
- Aluminum foil
- Two thumb tacks

B. Construct the testing apparatus

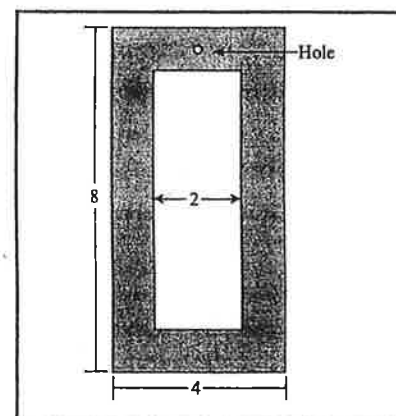
1. To construct the shelter, use the 3-ft. (1-m) poles as legs and nail them to the plywood boards as shown in the diagram. To prevent the shelter from toppling over in high winds, it may be necessary to place several bricks on the plywood base.
2. Construct 4 cardboard frames from cardboard or heavy posterboard.

3. At equal intervals, screw 5 hooks inside the top section of the shelter in a circle 12 inches (30 cm) from the center.
4. Cut sections of each of the control fabric, the ribbon, acid-washed jeans and the hose. The sections should be of sufficient size to cover the opening in the frame. Glue each section to a frame so it covers the opening.
5. In the center of one of the 4-in. (10-cm) sides of each frame, poke a hole for the wire. Use the wire to hang the frames from the hooks in the shelter. They should hang approximately 15 inches (38 cm) from the top of the shelter.

Testing Apparatus

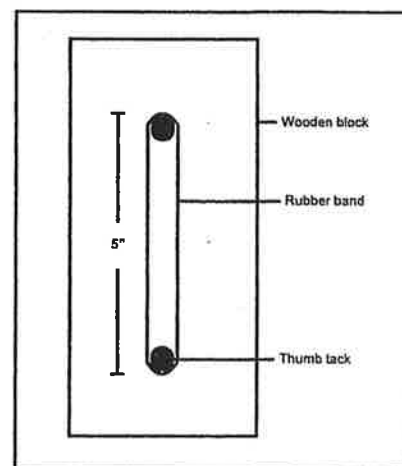


Frame



6. Take the wooden block (see illustration) and screw the remaining hook into the center of the top. Cut a 4-in. (10-cm) length of the rubber band. Stretch the rubber band to 5 in. (13 cm) and fasten it to the block of wood with the thumb tacks. Fasten a length of wire to the hook on the block and hang it approximately 15 in. (38 cm) from the top of the shelter.
7. Allow the test materials to be exposed to the ambient air for 1 month. In some very clean areas, a one-month exposure may not be sufficient to produce any damage. If no damage is observed after one month, expose the same materials for another month. In certain areas, ozone damage may not be observed until the warmer months.
8. Repeat this experiment several times during different months using new fabrics, ribbons, hose, and rubber bands.

Wooden Block



C. Analyze the results

1. Observe the test materials daily and note if any changes have occurred. Also, record daily meteorological conditions and the Pollutant Standards Index (PSI) value for ozone.
2. At the end of each month, examine the test materials, completely wrap them in aluminum foil, and store them for future observations.

3. Before the close of the school year, compare all of the monthly samples.

D. Discuss the following questions:

1. Which test materials showed damage?
2. Compare the dates on which damage occurred with our daily records on meteorological conditions and with the Pollutant Standards Index (PSI) value for ozone.
3. Compare the month-to-month variations in the damage to the test materials. Discuss some possible causes for the variations.
4. List several items that are made out of the materials used for this experiment. How would ozone affect them?
5. If ozone affects materials such as fabric and rubber bands, what do you think it might do to the tissues of the human respiratory tract?

IV. Follow-Up

- A. Observe the effects of ozone on plants. **NOTE:** Before doing this experiment, check with your local air pollution agency to determine the usual ozone levels for your area. It may not be high enough to damage plants. Also, doing this experiment at the beginning of the school year (August and September) might produce more clear effects from ozone because those months are closer to the high-ozone season.

You will need the following materials:

- Seeds for pinto beans, green beans, spinach, pumpkin, and/or melon
- 8-12 flower pots
- Potting soil
- Water
- Fertilizer
- Camera
- Film
- Outdoor thermometer
- Wind gauge
- Rain gauge

(Note: Radio Shack has an inexpensive weather station that could be used.)

B. Set up the experiment.

1. Select one or more of the types of plants listed. Plant more than one species of plant, so that symptoms can be checked on more than one species. Also plant more than one plant of each species.
2. Find out from your local county agricultural extension service the expected date of

the last killing frost in your area. Start the seeds in the pots six to eight weeks before the last expected frost. Keep them on a sunny window sill and water them several times a week, as needed.

3. Several days after the last expected killing frost, set the plants outside in a sunny location. Continue to water them several times a week unless rainfall is abundant. Apply fertilizer if necessary to maintain vigorous growth. Listen to daily weather forecasts, and if a frost is predicted, take the plants that are in pots inside for the night.
 4. Observe the garden regularly and record the presence of foliar injury. Devise a system to distinguish leaves injured on a certain date so that subsequent occurrences of injury can be recognized. (You might use a *small* strip of red cloth or a colored string tied gently around the base of a leaf to indicate injury on a certain date, and another color cloth or string for a later date.) Keep a record of the system that is used to distinguish the dates of foliar injury.
 5. Also, at regular intervals, take close-up photographs of damage to the plants.
 6. Keep a daily record of the weather conditions: record the amount of sun or cloudiness, wind direction and speed, precipitation, and minimum and maximum daily temperatures. If the Pollutant Standards Index (PSI) is available in your area, also record this data.
- C. Compare the information on plant damage, PSI data, and meteorological conditions.
1. What type of damage did you notice? [On pinto beans and green beans, ozone typically causes dark stippling (dots or very small spots) on upper leaf surfaces; on spinach, it causes white, bleached areas on upper leaf surfaces; and on pumpkins and melons, it causes light flecks on upper leaf surfaces.]
 2. What correlation, if any, exists between the damage to the plants and the air quality and meteorological conditions?
 3. What other factors may have damaged the plants? (insects, disease, etc.)

V. Extension

- A. Prepare a display using the information gathered from the plant experiment. Be sure to include the photographs of the plants.
- B. Display the information in a public area.

REFERENCES

Environmental Resource Guide - Air Quality, Grades 3-5. Pittsburgh, PA: Air & Waste Management Association, 1995.

Source Book on Air Pollution Topics for Grade and High School Teachers. Pittsburgh, PA: Air Pollution Control Association (forerunner to A&WMA), 1984.

Stern, Arthur C., editor, *Air Pollution*, Vol. I, 2nd edition. "Effects of Air Pollution on Human Health" by J. R. Goldsmith. New York: Academic Press, 1968.

United States Environmental Protection Agency, Education and Outreach Group, *Ozone, Double Trouble* (videotape). Research Triangle Park, 1992. Available from North Carolina State University Environmental Programs, (919) 515-4265.

United States Environmental Protection Agency, Education and Outreach Group, *Course SI:422, Air Pollution Control Orientation Course*. Research Triangle Park, 1992.

United States Environmental Protection Agency, Education and Outreach Group, *Course 452, Principles and Practice of Air Pollution Control*. Research Triangle Park, 1983.

United States Environmental Protection Agency Office of Air Quality Planning and Standards. *Environmental Science Summer Institute Workbook*. Research Triangle Park, NC. 1995.

United States Environmental Protection Agency, Education and Outreach Group, *Course SI:300, Introduction to Air Pollution Toxicology*. Research Triangle Park, 1993.

World Book Encyclopedia, 1994 edition, s.v. "Air Pollution."