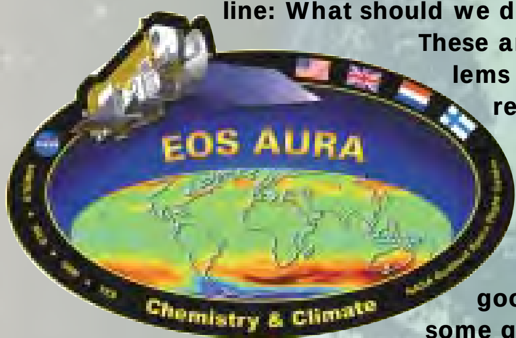
Welcome to This Special Issue of *ChemMatters*

Welcome to the first of four special issues of *ChemMatters*. Whether you are a first-time or long-time reader, we hope you'll share our excitement about a fascinating NASA mission that seeks to learn more about our changing planet.

We all live, and will almost certainly live out our lives, on an immense spaceship called Earth. Prospects for finding a better spaceship are pretty slim, so it's critical that we maintain the quality of this one—both for ourselves and for generations to come.

Environmental concerns are in the news every day. What is happening to the quality of the air we breathe? What is happening to the protective layer of stratospheric ozone that shields us from damaging ultraviolet light? How real is global warming? What causes it? What could result from it? And, the bottom line: What should we do, or not do, in light of these concerns?



These are complex questions. Solutions to environmental problems are never easy. When proposed solutions call for restraint, sacrifice, and lifestyle changes, the debate gets heated. "Who gets to clean up the mess?" and "Who's going to pay for this?" are tough questions in any social situation. Imagine how difficult they become on a global scale!

Making good decisions requires good judgment and good information. Carrying out the decisions will require some great leaders—maybe some future leaders like you!

In 1991, a presidential initiative directed the National Aeronautics and Space Administration (NASA), to develop a comprehensive program called the Earth Observing System (EOS). This ongoing program will launch a series of more than 20 satellites that will gather extensive data on the status of Earth's systems. There are three connected missions, EOS Terra, currently gathering data on landmasses, EOS Aqua, to study oceans, and EOS Aura, to study the atmosphere.

EOS Aura, scheduled for launch in mid-2003, will gather extensive data on the atmosphere, from the ground, up through the troposphere—the layer closest to home—and beyond. Four state-of-the-art instruments are being developed for global remote sensing of the changing chemistry of our air.

***ChemMatters*, the magazine that connects readers with the chemistry of the everyday world, is planning to keep you up to date on NASA and its EOS Aura endeavor. This issue, the first of four special editions, launches our mission. Inside, you'll find information and insight into several complex questions about our atmosphere. You'll learn how EOS Aura chemists are looking for answers.**

Come on board with us to experience the excitement of scientific discovery as NASA and *ChemMatters* take you along to learn about the changing chemistry of the sky!

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ChemMatters *is a quarterly magazine published by the American Chemical Society for high school chemistry students, teachers, and everyone who enjoys articles that "demystify" the chemistry of our everyday world. You can become a regular subscriber by calling 1-800-227-5558. The cost for four school-year editions is still $10. Ask for information about class-set discounts.*

CHEMMATTERS®

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ILLUSTRATION BY RICK STROMOSKI

TEACHERS! FIND YOUR COMPLETE TEACHER'S GUIDE FOR THIS ISSUE AT www.acs.org/education/curriculum/chemmatt.html.

PHOTO FROM PHOTODISC

COVER PHOTO OF DELTA II ROCKET, COURTESY OF NASA

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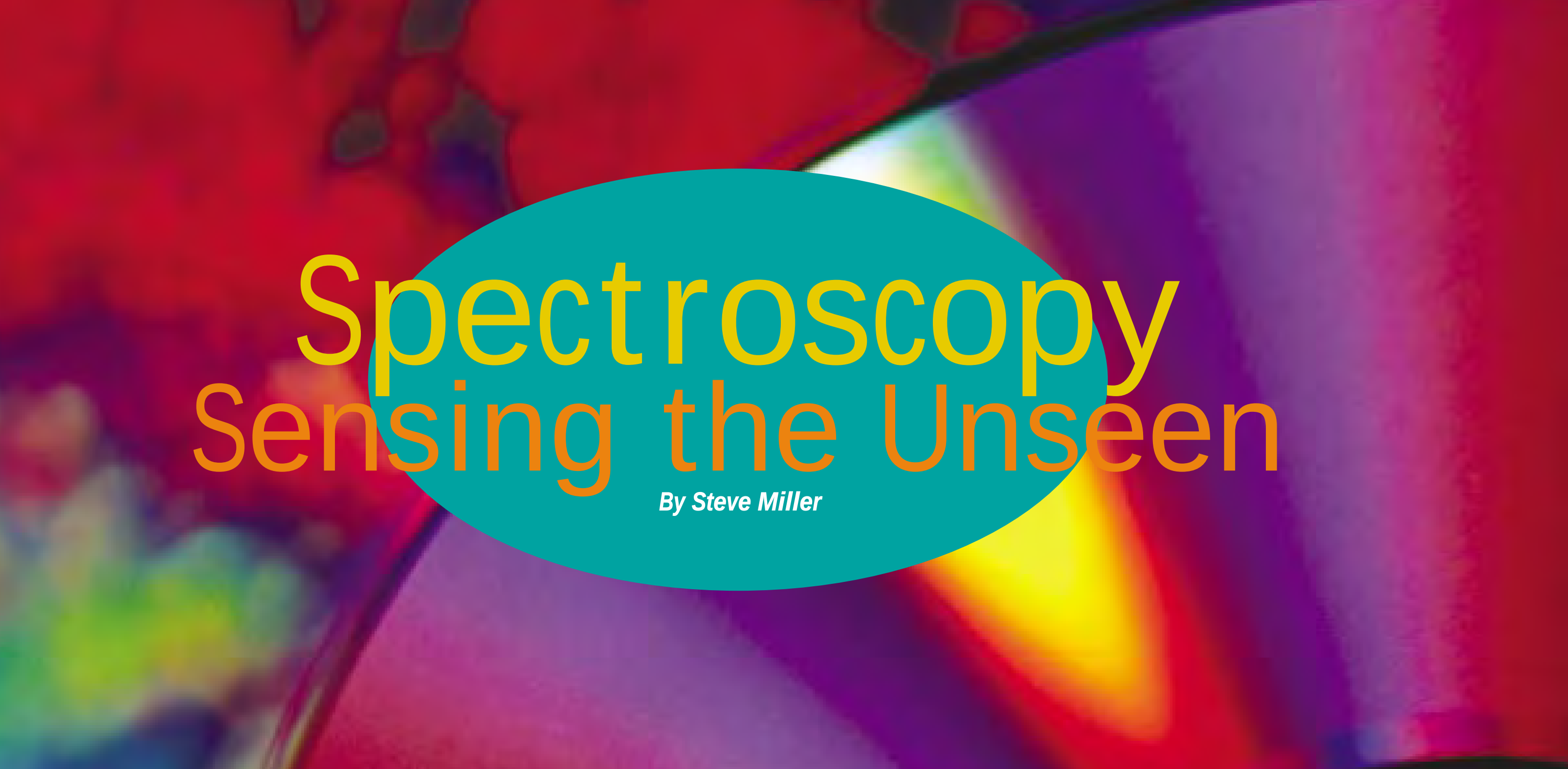
Spectroscopy
Sensing the Unseen

By Steve Miller



The topics of air pollution, ozone depletion, and global climate change are frequently featured in newspapers and abuzz on talk shows. And it's important that they are, since changes in the atmosphere affect us and all of our fellow life forms on earth.

Where is all this new information coming from? Scientists all over the world are conducting or planning studies of how the atmosphere changes and how human activity affects it. Concerned about the health of planet Earth, researchers work to provide information for decision makers. It will be up to us to use their findings for making the right decisions.

Scientists rely on accurate data about the components of the atmosphere, but obtaining that data is not always simple. Some studies can be conducted solely by analyzing samples in the laboratory. For these studies, airplanes and balloons carry sampling containers that collect atmospheric gases for laboratory analysis. However, since the atmosphere extends many hundreds of kilometers above the planet's surface, it's impossible to physically take a sample of everything that is interesting. Besides, some of the compounds that are most important for evaluating the chemistry of the atmosphere are not very stable and may exist only for a very brief time.

EOS Aura will conduct long-distance chemistry

EOS Aura, a NASA mission scheduled to launch in June 2003, will carry instruments designed to gather information about the atmosphere at the required altitude. Instead of bringing air samples back to earthbound chemistry labs, Aura will make its observations from above the atmosphere, allowing chemists to observe changes as they happen. How is it possible for chemists to learn about the colorless gases of the atmosphere so many kilometers away?

Any substance whose temperature is above absolute zero (that's everything) emits "light", and the EOS instruments work by detecting and measuring that light, as well as reflected sunlight in ultraviolet, visible, and near-infrared wavelengths. But "light" doesn't just mean light that you see with your eyes. It includes any type of electromagnetic radiation. Electromagnetic radiation is composed of oscillating electric and magnetic fields with the ability to transfer energy through space in the form of waves. In addition, electromagnetic radiation carries its energy in little "packets" called *photons*. The energy of these photons depends on the wavelength of the light—the shorter the wavelength, the more energetic the photons.

Visible light is just a small portion of the electromagnetic radiation surrounding us. The entire electromagnetic spectrum includes everything from radio waves—the very long wavelength, low-energy waves that carry radio and television signals—to very short wavelength, high-energy waves, such as X-rays and gamma rays with photons so energetic they can pass right through your body. The parts of the spectrum that EOS Aura chemists will use to study the molecules of atmospheric gases are primarily microwave, infrared, visible, and ultraviolet.

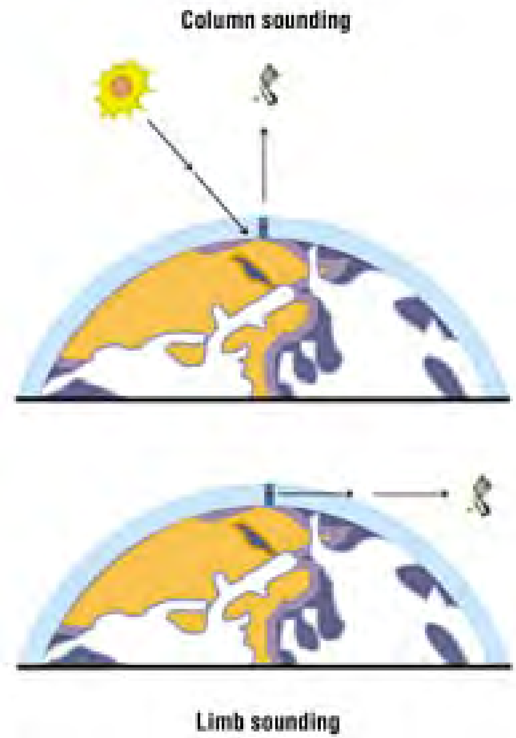
The surface of a compact disk has finely spaced grooves. It acts like a diffraction grating by separating the colors in white light according to wavelengths.

PHOTO FROM PHOTODISC

Light prints

How can you get information about molecules of different chemicals in the atmosphere from light? To understand how observing light can give us information about molecules, consider this: As sunlight travels through a vacuum, the photons travel in straight-line paths. If the light travels through the atmosphere, it encounters atoms and molecules. Each encounter is an opportunity for the photon to either be *absorbed* or *scattered*. The probability that either of these will occur depends on the wavelength of the photon and the type of atom or molecule it encounters. Different atoms and molecules absorb radiation at certain wavelengths in different regions of the electromagnetic spectrum. This means that each chemical has its own molecular “fingerprint” or *spectral signature*, by which it can be identified.

ILLUSTRATION COURTESY OF EOS AURA



An instrument taking *column soundings* samples the atmosphere from top to bottom, by looking straight down to the surface. An instrument taking limb soundings, gathers data from a horizontal slice of the atmosphere by looking out across the atmosphere.

Electromagnetic spectrum

When scientists talk about “light”, they mean more than just the light you see with your eyes. The different parts of the electromagnetic spectrum are distinguished by their wavelengths. Radio waves are very long waves that transmit radio and television signals. Radio wavelengths range from about several centimeters to hundreds of meters. Radar uses radio waves to form images of the ground in complete darkness or through clouds.

Microwave wavelengths range from approximately 1 millimeter to about 30 centimeters. Microwaves, emitted from the Earth and from the atmosphere, can be detected and analyzed to determine the temperature of the object that emitted them. Infrared wavelengths extend from 700 nanometers (billionths of a meter) to about 1 millimeter. Infrared waves include thermal radiation that you feel as heat. Instruments measuring infrared light can observe a heat source, such as a fire or volcano through smoke and dust. The atmosphere itself emits heat.

Visible light is the familiar spectrum of colors, with wavelengths between 400 and 700 nanometers.

Ultraviolet radiation has a range of wavelengths from about 10 to 400 nanometers (nm).

Excessive exposure to the ultraviolet light in sunlight can cause sunburn and skin cancer by damaging cells in your skin. Ultraviolet (UV) wavelengths are very important for measuring ozone in the upper atmosphere. Because ozone absorbs UV radiation (having wavelengths from 210 to 320 nm), scientists can estimate the amount of ozone in the upper atmosphere by measuring the amount of UV that passes through it.

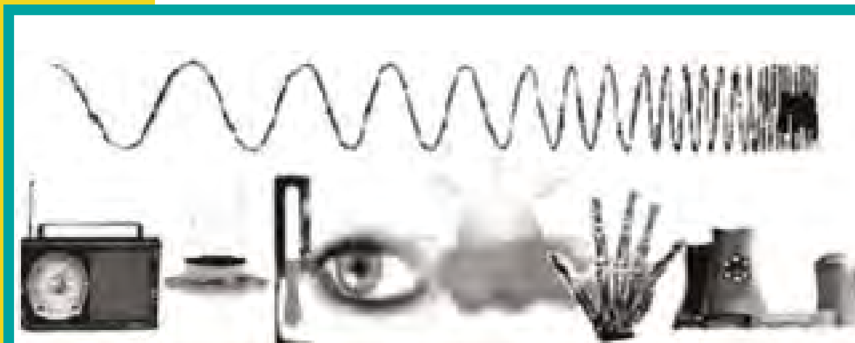
X-rays range from about 10 picometers (trillionths of a meter) to about 10 nm. They are high-energy waves that can pass through your soft tissues, so they are used to make pictures of bones and teeth.

Gamma rays have wavelengths of less than about 10 trillionths of a meter. They are more penetrating than X-rays. Gamma rays are generated by radioactive atoms and in nuclear explosions and are used in many medical applications. None of the EOS Aura instruments measure gamma rays or X-rays.

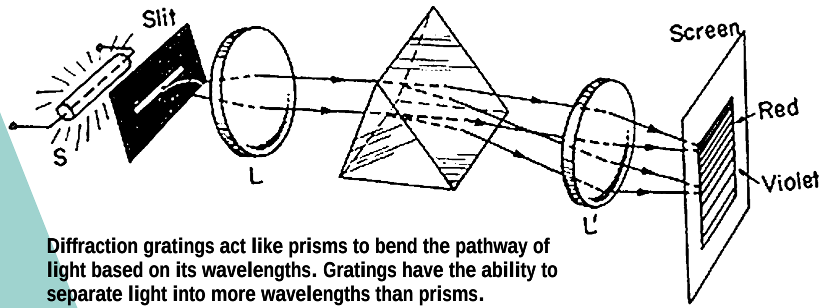
Chemistry on board EOS Aura

EOS Aura instruments will detect the amounts of chemicals and particles in the atmosphere not directly, but indirectly, by detecting changes in radiation from the atmosphere that result from the presence of these chemicals and particles. For example, they won’t detect ozone molecules themselves. Instead, they will measure how ozone molecules alter the radiation traveling through or emitted by the atmospheric regions being observed.

EOS Aura’s instruments will also measure atmospheric radiation in the form of heat (or “thermal” radiation, in wavelengths of the infrared range of the electromagnetic spectrum) that is emitted by the atmosphere. This data will be important for improving scientists’ models that predict changes in climate.



Radio Infrared Ultraviolet Gamma rays
Microwave Visible X-rays



Diffraction gratings act like prisms to bend the pathway of light based on its wavelengths. Gratings have the ability to separate light into more wavelengths than prisms.

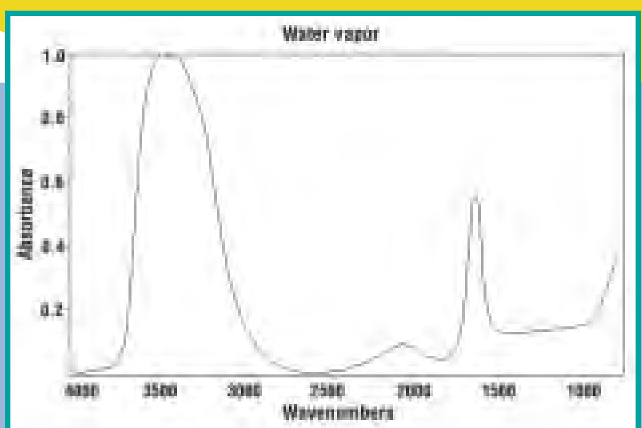
ILLUSTRATION COURTESY OF EOS AURA

Spectrometers read radiation patterns

The instruments aboard EOS Aura will measure and record the amounts of specific chemicals and particles by using a method called *spectroscopy*. The instrument for spectroscopy is called a *spectrometer*. The basic role of a spectrometer is this: It separates incoming light into different wavelengths. Then it uses a detector that registers the presence and the intensity of each of the separated wavelengths of light. You may have held a glass prism in a beam of light, watching as it separated light into its different wavelengths or colors. As light rays pass from air to glass, the direction of the light bends. Different wavelengths of light bend in different amounts, so the direction light is traveling when it leaves a prism depends on its wavelength.

Instead of a prism, most modern spectrometers use a *diffraction grating* to separate incoming light according to wavelengths. Formed from closely spaced transmitting slits on a flat surface or from reflecting grooves on a flat or curved surface, diffraction gratings act like prisms to bend the pathway of light based on its wavelengths.

Try this. Tilt the shiny surface of a compact disk back and forth in a bright light. Do you see colors? The surface, with its finely spaced grooves, is acting like a diffraction grating to separate light by bending it according to its wavelengths.



The figure above shows the infrared spectrum of water vapor. Wavenumbers (the reciprocal of wavelength) are traditionally used for spectral plots. The vertical axis shows how much light of any given type is absorbed. Water vapor absorbs very strongly at a wavenumber just below 3500 and shows other areas of absorption, another strong absorption occurring at a wavenumber a little above 1600.
No other molecule that exists will absorb exactly the same light waves as water, so by comparing the absorption spectrum of a molecule to that of water, you can tell both if water vapor is present and even how much is present. We can "see" that water molecules are present even though they are too small to actually see.

In spectroscopy, the wavelengths of the emitted light are measured and recorded on a spectrograph. The graph made by the emitted wavelengths provides a pattern for comparing to spectrographs of known molecules measured by chemists using earthbound laboratory spectrometers.

EOS Aura will carry four instruments

In total, four EOS Aura instruments will share the tasks of analyzing atmospheric composition and measuring changes. Together, they will gather data about the presence and abundance of different molecules in different parts of the atmosphere.

Some measurements will provide data from the entire atmosphere, from top to bottom. To obtain this information, the instrument will look at a whole column of air, focusing its attention straight down toward the surface of the earth.

Other measurements, called limb soundings, will provide data from a horizontal slice of the atmosphere. Limb soundings measure composition of the atmosphere by looking across it, toward space instead of toward the ground. They are especially important for understanding the chemistry of upper levels of the atmosphere, where ozone protects us from ultraviolet light.

As a group, this set of four remote sensing instruments will give us the most complete picture yet about what is going on in our ocean of air. Future articles in *ChemMatters* will tell you more about the EOS Aura instruments, the people who designed them, and the ways that they work. Meanwhile, for a work-in-progress "sneak preview," go to the EOS Aura Web Site at http://eos-aura.gsfa.nasa.gov and link to "Instruments".

How will EOS Aura find out about changes in the atmosphere?

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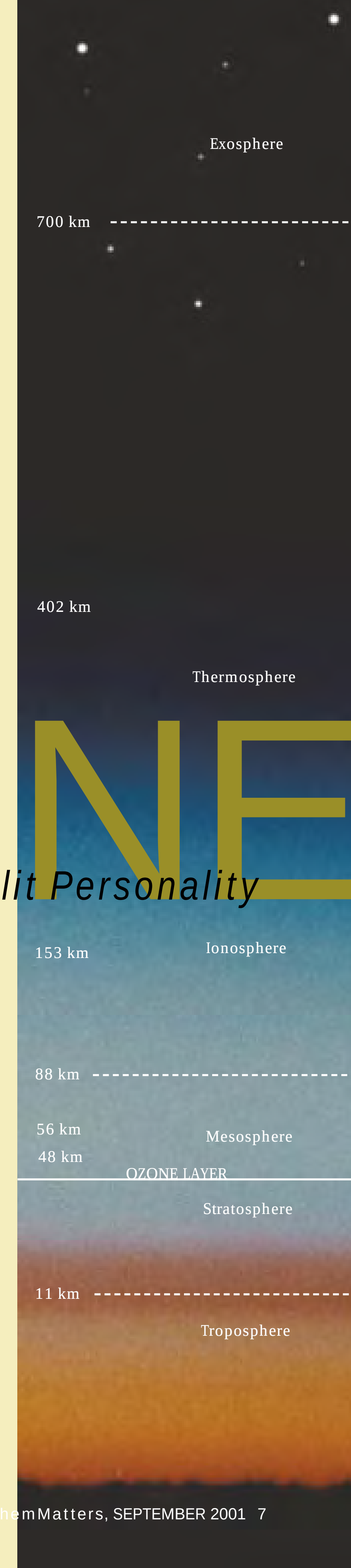
OZONE

Molecule With a Split Personality

By Doris R. Kimbrough



If you keep up with the news, you may have seen headlines like these from *The New York Times*

- **New Survey Shows Growing Loss of Arctic Atmosphere's Ozone** (April 6, 2000)
- **Ozone Loss Tied to Rise In Ultraviolet** (August 4, 1996)

But you were just as likely to read headlines like these, also from *The New York Times*:

- **Pollen, Ozone and Heat Send Dozens to Hospitals** (May 10, 2000)
- **Ozone Increases Asthma Rate Among Poor** (July 6, 1998)

So: Too much ozone gives you asthma and sends you to the hospital. But not enough ozone is blamed for increasing our UV-B exposure—a situation linked to human skin cancer and other biological damage. What is up with that? How can ozone be bad and good at the same time?

In some ways, ozone is a lot like water in a car. In a car radiator, water serves the useful and vital purpose of cooling the car's engine. However, put that water in the gas tank, and now you have a problem. Water in the gas tank causes serious engine problems. In other words, water can be an asset or a problem for the car, depending upon *where* it is.

Ozone in the stratosphere is like water in the radiator—helpful and necessary. The stratosphere is an atmospheric layer extending from about 15 km to about 50 km (10–30 miles) above the earth's surface, and most of Earth's "good" ozone is produced there. At this altitude, high-energy solar radiation splits ordinary oxygen molecules (the kind you breathe) into oxygen atoms.

$$O_2(g) \xrightarrow{\text{solar radiation}} 2\ O(g)$$

This high-energy radiation involves light with wavelengths of 170–195 nanometers (nm). Very high frequency ultraviolet light with wavelengths of between 10 and 200 nm is referred to as "vacuum UV", since these wavelengths are absorbed by air. Loose oxygen atoms are very reactive and combine with other oxygen molecules to make ozone.

$$O(g) + O_2(g) \longrightarrow O_3(g)$$

But that's only half the stratospheric story. Ozone is also naturally destroyed in the stratosphere, and its destruction involves the absorption of even more radiation–lower-energy ultraviolet radiation with longer wavelengths of 210–310 nm.

$$O_3(g) \xrightarrow{\text{210–310 nm}} O_2(g) + O(g)$$

So while we are minding our own businesses down here on the earth's surface, up in the stratosphere, ozone is continually being created and destroyed. The beauty of this system is that most of the high energy and harmful ultraviolet radiation reaching the outer atmosphere from the sun gets tied up in this process. Fortunately for us, thanks to all of this high-altitude ozone chemistry, most harmful radiation never reaches the earth's surface where it would injure our eyes and skin, as well as wreak havoc upon most plants and animals. In short, the "good" ozone layer serves as a huge sponge, absorbing harmful solar radiation before it can harm life on the planet's surface.

PHOTO FROM PHOTODISC

UV exposure is linked to many health problems such as skin cancer, cataracts, and "sunburned eyes". It may even suppress the immune system's ability to fight contagious diseases.

Ozone in the streets

On the other hand, down here in the troposphere where all of us live and breathe, ozone is more like water in a gas tank—an unwelcome problem! On the earth's surface, or rather in the air just above it, ozone is produced in a complicated series of chemical reactions involving the components of automobile exhaust, sunlight, and oxygen.

One of the simpler routes leading to ground-level ozone production looks like this:

$$NO_2(g) + \text{sunlight} \longrightarrow NO(g) + O(g)$$

$$O(g) + O_2(g) \longrightarrow O_3(g)$$

The source of nitrogen dioxide (NO_2) isn't hard to find. Automobiles contribute this pollutant when their engines generate temperatures high enough to cause ordinary oxygen (O_2) and nitrogen (N_2) molecules, components of fresh air, to undergo a reaction.

Does the second reaction for making ground-level ozone look familiar? This stage of ozone production is the same, whether it takes place on a street corner or in the stratosphere. Sunlight, essential for producing ozone in both high and low places, makes this street-level ozone build rapidly in hot summer months.

Sunlight and pollution aren't always to blame for ground-level ozone. Ozone can also form in the troposphere as the result of electrical discharge acting upon O_2. This process is similar to the formation of ozone in the stratosphere, except the energy source in this case is electrical rather than light. The "smell" associated with electrical fires or sparking is due to ozone. It's likely you've noticed this ozone smell during a thunderstorm as lightning supplies the energy for producing O_3.

So back to the problem of water in the car. Why is it that, like gas-tank water, street-level ozone is seen as a problem, while we value every molecule of the higher-altitude stuff? You can see that ozone (O_3) is a fairly simple molecule—not that different from the O_2 molecule that we breathe to stay alive. How can adding one more atom turn ordinary oxygen molecules into health hazards?

Adding that third oxygen atom makes ozone a very pushy and highly obnoxious little molecule. As a very strong oxidizing agent, it reacts aggressively with other molecules, changing their chemical and physical properties in the process. Ozone is especially menacing when it reacts with molecules involved in the functions of living organisms.

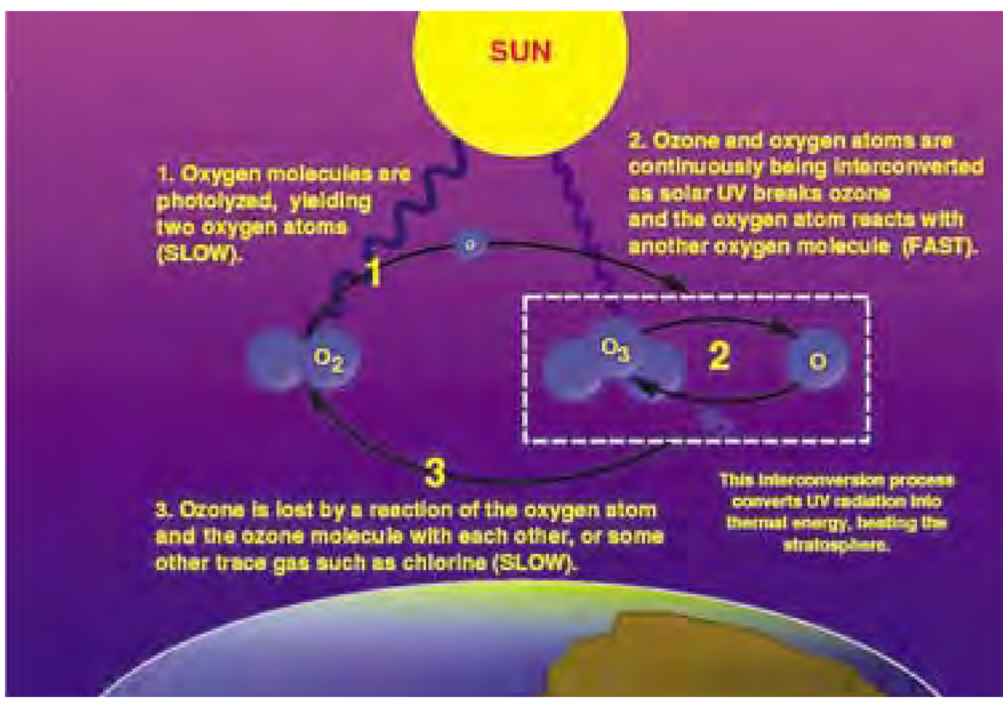
Since ozone is a gas, all of us are exposed to it whenever we breathe. Although there are no ozone-free zones, our total ozone exposure depends on where we live. Not surprisingly, the most direct ozone-related health effect for humans is damage to lung tissue. Research shows that prolonged ozone exposure both diminishes lung function (your lungs don't transfer oxygen and carbon dioxide back and forth as well as they are supposed to), and increases the risk of respiratory symptoms like wheezing, chronic phlegm, and coughing. Small children, whose lungs are still developing, and asthma patients are especially affected by ozone exposure.

Up here, ozone is a good thing

Let's climb back into the stratosphere, where ozone is our hero and protector. The bad news is that, at the same time ground-level ozone is building, other byproducts of our industrial age are attacking the high-altitude "good ozone". Again, the effects take their toll on all living things.

Up here in the stratosphere, it's ozone depletion that is linked to negative health effects. Since stratospheric ozone absorbs ultraviolet radiation, a decrease in the amount of ozone in the stratosphere lets more UV radiation reach the earth's surface. Exposed living tissues, like human skin, are particularly vulnerable. If you have ever had a sunburn, you have felt the effects of ultraviolet radiation!

ILLUSTRATION FROM NASA-GSFC



Ozone in the stratosphere is continually being created and destroyed. The beauty of this system is that most of the high-energy and harmful ultraviolet radiation reaching the outer atmosphere from the sun gets tied up in this process.

But the effects of UV radiation go well beyond a painful sunburn. UV-B (290–320nm) exposure is now firmly established as a cause of far more serious human health problems. Skin cancers receive the most attention, as we are constantly warned by doctors to limit our exposure to the sun. Our eyes are also vulnerable. UV exposure is known to cause *cataracts*, an eye abnormality in which the lens thickens and becomes opaque or cloudy, and *photokeratoconjunctivitis*, an imposing name for a very painful condition that simply translates to "sunburned eyes"—also known as "snow blindness" or "welder's eyes". There is even evidence that UV-B exposure suppresses the immune system, putting us more at risk for contagious disease and less able to fight back when cancers develop.

And the effects of UV go well beyond human effects. Many species of plants are far more dependent upon and sensitive to changes in sunlight than animals. Increased UV-B exposure in some plants inhibits photosynthesis, the process by which plants capture energy from sunlight to make food. In some species, it also affects growth patterns, decreases overall leaf area, and affects flowering times. Although plants have adaptive mechanisms that might allow them to adjust over a long period of time, they may not be capable of adjusting to a relatively rapid increase in their exposure to UV-B radiation. And problems with plants affect more than just the vegetarians among us. Ultimately, all life depends upon the earth being able to sustain healthy plant life.

Depletion of stratospheric ozone affects life in the oceans as well as on land. Too much UV-B exposure damages the ability of phytoplankton, tiny marine plants, to engage in photosynthesis. Abundant phytoplankton organisms are at the base of the ocean's food chain. It's easy to see how any negative effect on their ability to produce food molecules would have a corresponding harmful effect upon any organism depending on them for food.

Sometimes marine animals are directly affected. Solar UV-B also damages the larval development of some fish species and impairs the growth of many invertebrate species. The ultimate effects can be far-reaching.

In fact, the effects of unfiltered UV-B extend to the objects on which we depend. Increased solar UV-B speeds up the breakdown of plastics and other manufacturing materials, causing problems that range from fading colors to loss of mechanical and structural integrity. We may be merely annoyed by breaks and cracks in garden furniture or kiddie swimming pools, but we may be endangered if UV-B were to affect the materials used for airplane parts or gasoline hoses.

In short, our problems with ozone boil down to this: too much nearby and not enough up high. We don't need ozone down here because it is unhealthy and destructive, especially to living organisms. But we depend on ozone in the stratosphere to protect us from harmful solar radiation. In future articles, *ChemMatters* will explore the fascinating chemistry behind our thinning ozone layer. We'll look at the science that explains why in some regions ozone depletion is seasonal, and why the problem is greatest over the North and South Poles. And we'll find out how NASA's EOS Aura mission plans to monitor the presence of ozone—whether close to home or in the sky.

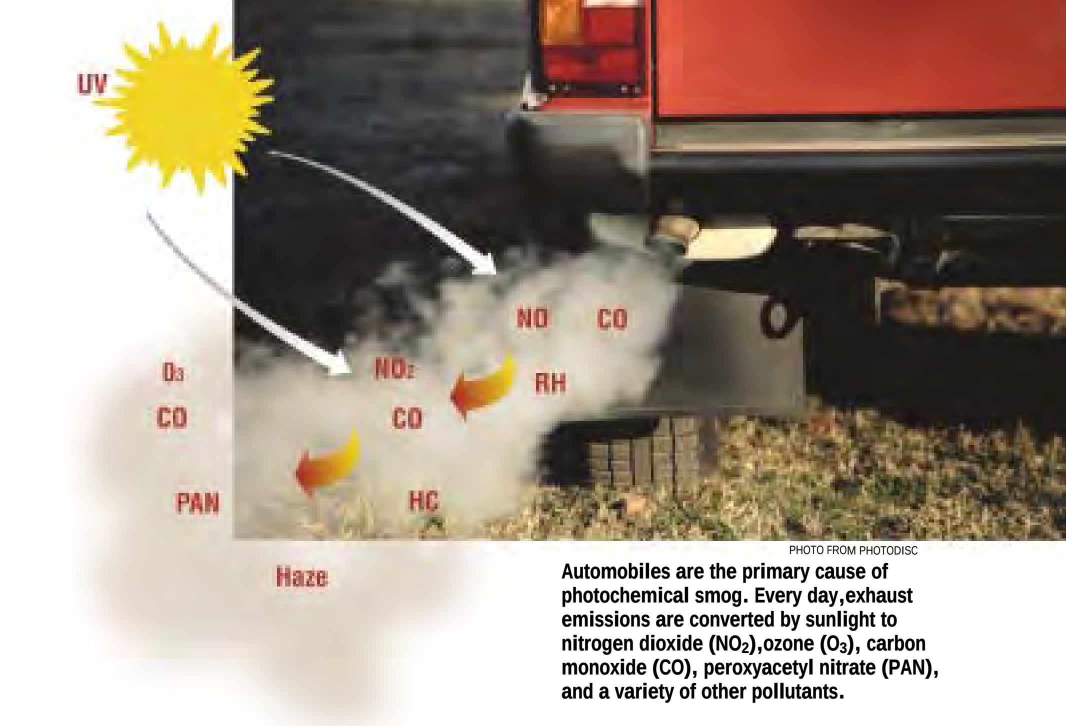


PHOTO FROM PHOTODISC

Automobiles are the primary cause of photochemical smog. Every day, exhaust emissions are converted by sunlight to nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), peroxyacetyl nitrate (PAN), and a variety of other pollutants.

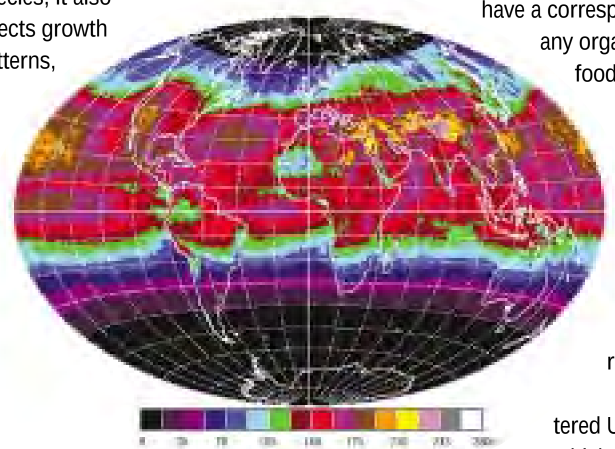
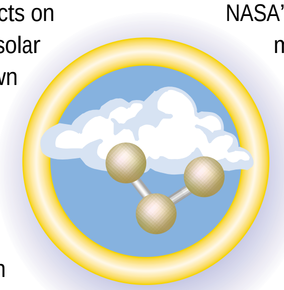


ILLUSTRATION COURTESY OF NASA

Erythemal Spectral Exposure (kJ/m^2) for July 1988 with aerosol. Satellite data like these from NASA's Total Ozone Mapping Spectrometer are used to provide UV "Index" forecasts seen on TV and found in newspapers throughout the world.



Is earth's ozone layer changing as expected?

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A POURABLE Greenhouse Gas

By Bob Becker

Carbon dioxide (CO_2) gas in our atmosphere has the capacity to absorb escaping infrared light and "reradiate" it back down toward the Earth's surface. The role of this atmospheric CO_2 is similar to that of the glass panes in greenhouses that keep indoor temperatures high enough for plants to thrive during winter months. During the long history of life on our planet, CO_2 did its part to keep Earth warm and inhabitable. But if serious measures are not taken soon to curb the increasing amounts of CO_2 that we release into the atmosphere, we could end up with a very different climate than what we have now.

Good ideas about controlling and containing CO_2 start with the knowledge of its chemical and physical properties. Besides trapping radiant energy, carbon dioxide has some other remarkable features. In this investigation, you can find out how carbon dioxide behaves when it is released into the atmosphere.

ILLUSTRATIONS BY CEASR CAMINERO

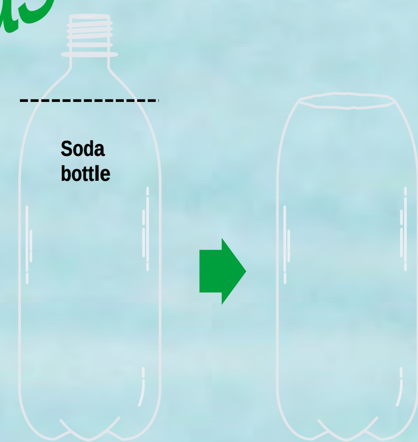


Figure 1

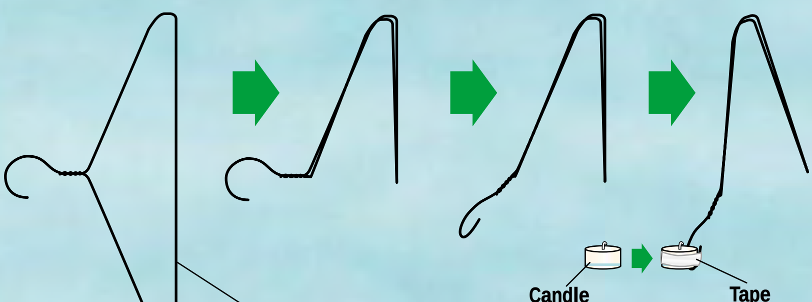


Figure 2

Materials and tools for each group

Safety goggles, apron, and disposable plastic gloves for each student
Two 2-L soda bottles (empty, rinsed out, labels removed)
scissors and utility knife
small, flat candle (sold as "tea light" or "votive")
wire coat hanger
tape
matches
baking soda
vinegar

For extension activities (optional)

0.5-inch-diameter plastic tubing, 60–70 cm long (available at hardware stores)
disposable alcohol pad in sealed package
dry ice (about 1 lb for entire class) in chips (available from ice cream stores and frozen food suppliers)
water

Safety notes: This activity is designed for a supervised safety-equipped chemistry classroom. Students should wear safety goggles, aprons, and disposable gloves throughout the procedure. All combustible materials (papers, books, etc.) should be removed from the area surrounding the open flame. Standard chemistry lab safety rules should be observed.

Preparation

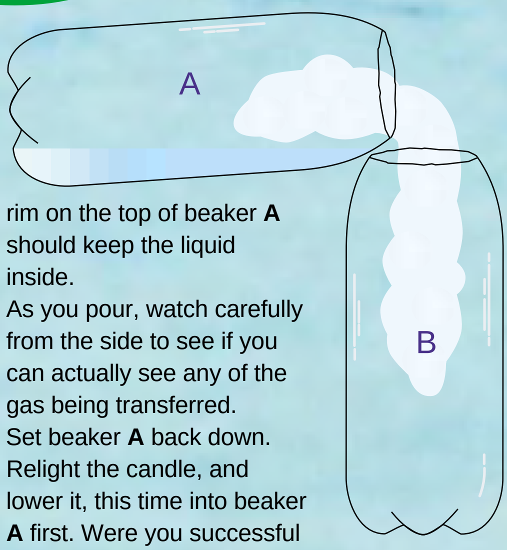
1. Cut the tops off both soda bottles as shown in Figure 1. Use a utility knife to start the cut, then a good sharp pair of scissors to continue it all the way around. When finished, you will have two tall plastic beakers with rims bent slightly inward at the top. Label them "A" and "B".
2. Bend the coat hanger in half, as shown in Figure 2. Bend the hook down and flatten it. Tape the candle to it securely.

Activity

Tip: For best results, this activity should be conducted in a place with very little draft or air movement.

1. Place about 120 mL (1/2 cup) of baking soda into beaker **A**. Pour in about 240 mL (1 cup) of vinegar and observe the reaction. Those are bubbles of CO_2 gas you are seeing!
2. Wait a minute or so to give the CO_2 plenty of time to diffuse out into the room.
3. Light the candle with a match, and slowly lower it into beaker **B**. This serves as a control to show that a beaker filled with regular air does not affect the candle flame.
4. Remove the candle from beaker **B** and, while it is still burning, lower it slowly into beaker **A**.
   What did you observe? What ***chemical property*** of carbon dioxide did this demonstrate? What ***physical property*** did it demonstrate? Why do you think the CO_2 is still in the beaker? How long do you think it would stay in there?
5. Pick up beaker **A** and try to pour the CO_2 slowly over into beaker **B.** Carefully pour only the gas and none of the liquid across. The curved

for you to try!



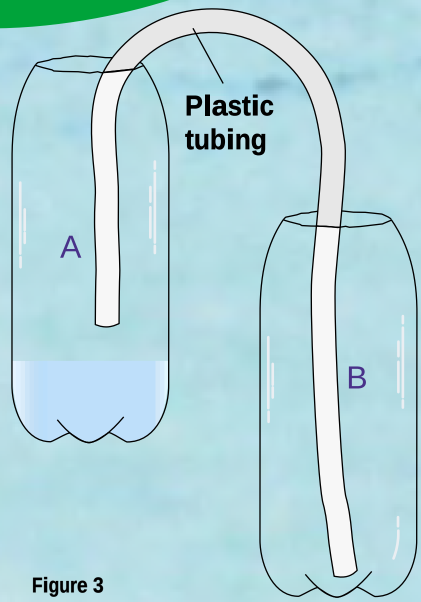


Figure 3

rim on the top of beaker **A** should keep the liquid inside.

As you pour, watch carefully from the side to see if you can actually see any of the gas being transferred.

6. Set beaker **A** back down. Relight the candle, and lower it, this time into beaker **A** first. Were you successful at pouring out all of the CO_2? What evidence supports your answer?
7. Relight the candle if necessary, and then lower it into beaker **B**. Did the CO_2 make it into beaker **B**? What evidence supports your answer? How many times do you think you could pour the CO_2 back and forth? Continue experimenting to test your prediction.

Extension Activities (optional)

Clean and dry beaker **A**, and use it to generate more carbon dioxide following the procedure in step 1. This time, rather than pouring the CO_2 from **A** to **B**, try *siphoning* it across. To do this, clean one end of the plastic tubing with a disposable alcohol pad. Place the other end of the plastic tubing down into beaker **A** so that it extends almost all the way down to the surface of the liquid on the bottom. Then hold the beaker above your head, and "prime the pump" by sucking quickly on the clean protruding end of the tubing, before quickly lowering that end down into beaker **B**. (See Figure 3)

Note: This is somewhat tricky to do, and you may want to practice first by trying to siphon some water from one cup to another. When you prime the siphon, try to avoid inhaling any of the CO_2. If you do, it may cause you to cough, but it will not harm you.

Try generating carbon dioxide gas by a different method. Into a clean and dry beaker **A**, place about 240 mL of warm water. Wearing gloves, place 2–3 thumb-sized pieces of dry ice (solid CO_2) into the water. Caution: **Dry ice is VERY cold. Avoid any direct contact with skin.** The CO_2 that fills the beaker will be "colored" gray—at least for a while—by the misty fog that forms when the cold CO_2 condenses some of the water vapor out of the air. Pour this "visible" carbon dioxide into beaker **B**. Describe and attempt to explain what you see.

Discussion

Baking soda is sodium bicarbonate ($NaHCO_3$). The bicarbonate ion (HCO_3^-) reacts with the hydrogen ion (H^+) ion from the vinegar, a solution of acetic acid ($HC_2H_3O_2$). The two ions produce the compound carbonic acid (H_2CO_3), which readily decomposes into $CO_2(g)$ (appearing as bubbles) and a byproduct you don't see—H_2O.

The two equations for these reactions are shown below.

$$NaHCO_3(s) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + H_2CO_3(aq)$$

$$H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l).$$

In this activity, you noticed an important chemical property of carbon dioxide: It does not allow things to burn the way oxygen does. This property makes CO_2 a good choice for use in fire extinguishers. It's surprising that CO_2 does not allow substances to burn, since carbon dioxide contains a lot of oxygen—about 73% by mass. In contrast, normal air contains only about 21% oxygen, yet it certainly allows many substances to burn. The low reactivity of CO_2 is explained by the fact that the oxygen in it is already bonded—to the carbon. And since the bonds in CO_2 are strong, the oxygen is not readily available to react with other elements.

But, if the oxygen in CO_2 is offered to an element with which it could form an even stronger bond than it makes with carbon, a reaction does take place. Magnesium metal is one such element. It burns quite vigorously in air, as well as in an environment of pure CO_2. This is why a CO_2 fire extinguisher should never be used on a magnesium fire!

Another physical property of CO_2 you observed in this activity is that it tends to diffuse upward very slowly. This is a result of its rather high density—1.96 g/L at standard temperature and pressure. In contrast, ordinary air has a density of only 1.29 g/L. Because CO_2 is so much denser than air, it tended to remain in the beaker, almost as though it were some kind of liquid. And like a liquid, CO_2 is dense enough to be poured, even siphoned, from one container to another. Pourability and siphonability are properties we do not usually associate with gases.

Here's a good question that may have already occurred to you. If CO_2 sinks to the bottom of the container of air, how does it get evenly mixed with other gases in the atmosphere? Think about that one as you learn more about the behavior of gases in your chemistry class.

Carbon dioxide, the greenhouse gas that both enables and threatens life on earth, has many fascinating chemical and physical properties. Any strategies for managing the levels of CO_2 in the atmosphere must result from a thorough understanding of this unique and abundant compound. Future articles in *ChemMatters* will explore more of the problems and some of the solutions challenging chemists who study this pourable greenhouse gas.

Asthma: Attack From the Air

By Helen Herlocker

An estimated 17 million Americans suffer from asthma, and 5 million of these are under 18.

What are the worst things about being a teenager with asthma? A panel of high school sufferers responded to this question in an interview conducted by *Advance,* a quarterly newsletter published by the Asthma and Allergy Foundation of America (AAFA). Their responses varied, but most of them related to social concerns: "Will I have to take my nebulizer to college?" "I hate being the only one in my group with an inhaler." "I worry about having an embarrassing asthma attack when I'm in class." "I don't like having to stay indoors when it's one of those 'bad air' days."

Embarrassment and frustration are bad enough, but health officials convey concerns that go even further. Statistics show that asthma is increasing across all ages and ethnicities. An estimated 17 million Americans suffer from asthma, and 5 million of these are under 18. According to a fact sheet posted by AAFA, asthma has become the leading cause of school absences due to a chronic disease. And it gets worse. Asthma shares the distinction with AIDS and tuberculosis of being the only chronic diseases with increasing death rates. Although successfully managed by most sufferers, asthma is the cause of death for an average of 14 Americans each day.

What is it like to have an asthma attack?

Most sufferers describe asthma as a fight for air. Doctors explain that most episodes are triggered by something from the environment, like dust, pollen, mold spores, smoke, or vapors, entering the lungs and breathing passages. Once inside, the irritant sets the immune system of a sensitive individual into full combat mode. As antibodies and white blood cells respond to the invasion site, local tissues swell with fluid, muscles in the walls of the airways tighten, and access to air shuts down.

You can get the picture by doing this. For just a moment, hold your nose and try drawing several breaths through a narrow drinking straw. Not easy!

The underlying causes of asthma and the identity of environmental triggers are subjects of ongoing medical research. In many people, asthma is a symptom of an allergic condition. Allergies, as any sufferer will tell you, are managed in two ways. You can take a medication to keep your immune system from mounting an attack, or you can stay away from the particular trigger, the *allergen.* If your allergen is something in the air you breathe, you've got a problem. Neither wearing a breathing mask nor living in a bubble are appealing options.

Explaining the increase

The alarming increase in asthma cases in the last decade has prompted scientists to look for an explanation. Could widespread changes in air quality account for the change in the incident rate? If a sufferer's allergic asthma symptoms are triggered by airborne particles like molds, pollen, wood burning products, secondhand cigarette smoke, or by chemical fumes from cosmetics and paint, the indoor environment may be to blame. In fact, many reports show that the effort to make homes, schools, and workplaces more draft-free and energy-efficient presents the disadvantage of shutting us in with our allergens.

Not all cases of asthma appear to be linked to allergies. Medical literature identifies individuals who are sensitive to a broad range of irritants. Members of this bronchial-hyper-responsive (BHR) group get asthma attacks as symptoms of ordinary colds or in response to physical exertion, air-polluting chemicals, or even to cold, dry weather. For still others, once an asthma attack is under way, other irritants only make it worse.

Pollution is everybody's problem

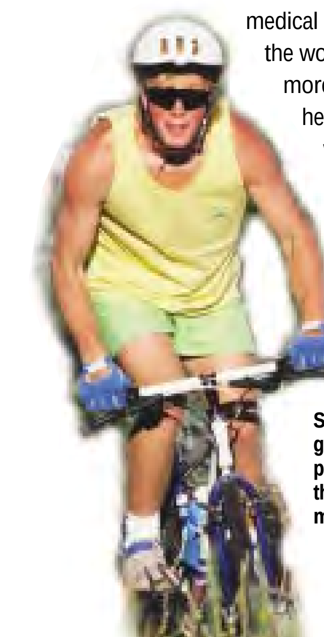
Pollution makes it worse

Asthma, like many childhood diseases, particularly affects those living in the world's least healthy environments—areas likely to be occupied by the poorest families. An October 2000 release by the National Institutes of Health described a 10-year study of children living in the smog-ridden neighborhoods of Southern California. By monitoring air pollution throughout the study, the researchers established a link between air quality and long-term respiratory health.

According to John Peters, a University of Southern California professor of preventive medicine and one of the study authors, "Long-term exposure to air pollution has long-term effects on children's lungs, and the effects are more pronounced in areas of higher air pollution."

Peters explained that normally, a person's lung function grows steadily, reaching full potential in late teens or early twenties. The study showed that as children grow up, those who breathe smoggier air tend to lag in lung function behind those who grow up breathing cleaner air. And the researchers predict that the children with decreased lung function and capacity are more likely to be susceptible to respiratory disease—like asthma.

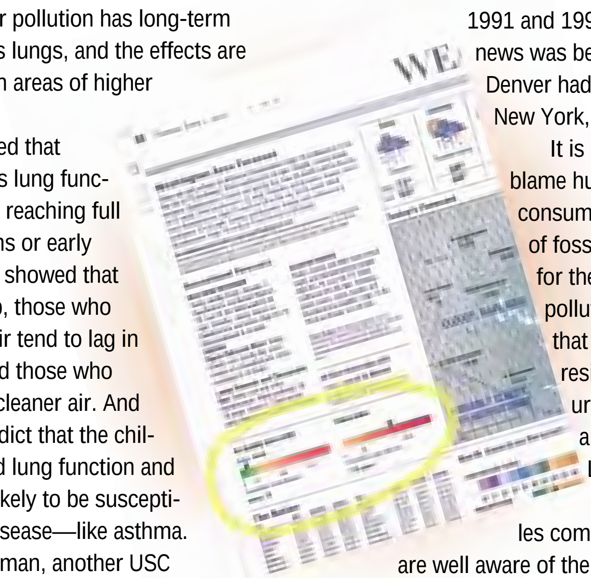
James Guaderman, another USC researcher, stated that the negative effects of air pollution on lung development were greatest for kids who spent the most time outdoors. He reported that the effects of nitrogen dioxide (NO_2), acid vapors, and airborne particulate matter, all products of the burning of fossil fuels, were the chief offenders.



Some asthma sufferers get attacks as a result of physical exertion. For them, air pollution only makes it worse.

At the same time that medical authorities around the world are sounding more alarms about the health risks associated with air pollution, some of the news is getting better. Between 1985 and 1994, during which an amended Clean Air Act went into effect in the United States, sulfur dioxide (SO_2) concentrations decreased by 25%, nitrogen oxides (NO_x) by 9%, carbon monoxide (CO) by 28%, ground-level ozone (O_3) by 12%, and particulates by 20%.

"Poor Air Days" reported in local news media as days for reducing automobile use and limiting outdoor physical activities dropped during the same period in several major cities. Between 1984 and 1986, Denver had 147 of them and New York had 210. Between 1991 and 1993, the news was better: Denver had 17; New York, 34.



It is easy to blame human consumption of fossil fuels for the air pollution that resides in urban areas. Los Angeles commuters are well aware of the daily rise of smog following morning rush hour. But it is equally apparent that the environment itself has a controlling hand in the way that pollution is distributed. For Los Angeles, sea breezes and mountains play a role in spreading the products of fuel burning to the surrounding areas.

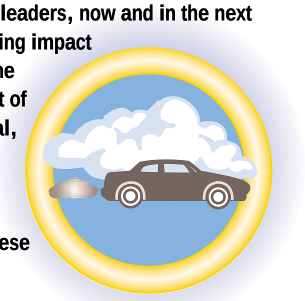
There was a time in history when air pollution was viewed as a local problem. If you suffered from asthma, hay fever, or any other respiratory sensitivity, you could usually move to a place with cleaner air, leaving your worst problems behind. Today, the sources of pollution in one area affect the quality of life in wide regions.

Instruments on orbiting NASA satellites are detecting the spread of pollutants far from their sources. These data confirm that pollution is a global problem. But solving that problem won't be easy. Global politics are sensitive. What are the responsibilities for restraint and cleanup? Should emission restrictions apply to all countries equally?

Global policies can only be effective if decision makers have good data. The planned NASA satellite research mission, EOS Aura, will build on other NASA data collecting missions to determine how the troposphere, the lower atmosphere in which we live and breathe, is changing. Previous NASA missions and many ground-based measurements have indicated that ozone—the ground-level "bad" ozone—continues to accumulate as a result of agricultural burning, deforestation, urban activity, and industry. At the same time, aerosols, the airborne particulate matter in the form of smoke and dust, appear to be rising as well.

Aura will make the first space-based, comprehensive, and near global measurements that will serve to map the sources and transport of aerosols and pollutants on regional and super-regional scales. Aura scientists anticipate that many of these sources will be linked to human activity, but others will include natural sources such as volcanoes and lightning-generated forest fires.

Decisions made by world leaders, now and in the next decade, will have a long-reaching impact on human respiratory health, the quality of food crops, the extent of global warming, and, in general, the quality of our life on earth. Officials planning NASA's EOS Aura mission make the importance of the mission clear. "These measurements are critical in assessing the future habitability of the planet."



Is the air quality of the lower atmosphere changing?

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hot topic ge

G L O B A L W A R M I N G

Some people would have us believe
Disaster is what we'll receive,
From spewing vast masses
Of heat-trapping gases
A web of upheaval we weave.

But others will argue, "Not true!"
The Earth won't turn into a stew
We're not going to burn,
There's no need for concern,
And if we're not concerned, why are you?

By Frank Cardulla

Global warming is a complex topic, and one filled with emotional and political ramifications. All said, it's the environmental *hot* topic of the '00s! On one side is a virtual army of scientists and citizens concerned about the environment, arguing that human activities over the past couple of centuries are pushing our environment toward a somewhat unpredictable and potentially devastating series of consequences. Opposing this view is a smaller, equally vocal group of scientists who may doubt that global warming is real, may question the extent to which it is caused by human activities, or may disagree with the dire predictions made by environmentalists.

The vast ecosystem

It's difficult to envision the dimensions of the ecosystem called Earth, the magnitude of its oceans, the seemingly endless area of its land. Can the activities of man really affect something so vast?

Evidence is mounting that the answer is "Yes".

Literally hundreds of distinct observations provide evidence that global warming is real. Many plants and animals are shifting their ranges toward the earth's poles and to higher altitudes, where average temperatures are cooler. Glaciers are melting and oceans are rising. And in the northern polar region, Arctic permafrost is melting, gradually increasing the depth at which the soil stays frozen year-round.

Over the past century, climate records confirm an average global surface temperature increase of about 1 ˚C, with more than half of that increase occurring within the past 25 years. Ocean temperatures also appear to be rising, as the seawater acts to absorb much of the heat that might otherwise be trapped in the atmosphere.

A milestone report issued by the United Nations-sponsored Intergovernmental Panel on Climate Change (IPCC) concluded that the trend toward a warmer world is under way and has been for some time, a view largely supported by a National Research Council report of June 2001. A change of one degree doesn't sound impressive. Skeptics even argue that this small change may just represent a normal fluctuation in earth's average temperature. A few scientists even argue that the temperature change is simply due to changes in the sun's output. Perhaps changes in the sun's magnetic field have altered the amount of cosmic radiation reaching the earth, which in turn affects cloud formation, which in turn affects the average temperature on earth.

Despite the continuing debate, the emerging consensus is that global warming is real and that human activities are the primary cause.

It's almost impossible to sense global warming on a personal or local level. Global warming, by definition, is *global*. The fact that you may have sweltered this past summer or froze this past winter doesn't mean much on a global scale.

If there is mounting evidence that the world is getting warmer, what might be causing it? *Greenhouse gases*. That's the mainstream scientific answer.

How did we get the name *greenhouse*? One way a greenhouse keeps the temperature inside warm is by allowing sunlight to enter, and then "trapping" some of the heat.

Greenhouse gases work in a similar manner. Certain atmospheric gases such as carbon dioxide, water vapor, methane, tropospheric ozone, chlorofluorocarbons, as well as soot (carbon) particles are known to be particularly good at trapping heat energy. Sunlight passes through the atmosphere and warms the earth. Greenhouse gases absorb, then re-emit some

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etting hotter

of this energy, but at longer wavelengths, in the infrared region of the electromagnetic spectrum. Without greenhouse gases in the atmosphere, this radiation would simply escape back into space. But re-emitting some of it back to earth produces a warming effect.

The greenhouse effect isn't "bad." Just the opposite is true. Without it, earth would have an average temperature of about –18 °C. Life as we know it would simply not exist. A delicate balance exists between the amount of energy reaching the earth from the sun and the amount escaping back into space. A look at our neighboring planets confirms our good luck. Venus has too much of a greenhouse effect; Mars, almost none.

Now this balance is endangered. Since the start of the Industrial Revolution, roughly 200 years ago, human activities, especially the burning of fossil fuels (coal, oil, and natural gas) have released enormous amounts of carbon dioxide into the atmosphere. For every burned gallon of gas, the atmosphere gained 21 pounds of CO_2! It's estimated that today's atmospheric concentration of CO_2 is 30% greater than preindustrial levels. In addition to fuel burning, other human activities, like planting rice and raising herds of cattle, have contributed methane, another greenhouse gas.

The majority of scientists accept the ample evidence that the average temperature on earth is rising. With evidence that the concentration of greenhouse gases has also increased in the atmosphere over the past two centuries, the connection seems obvious. Most scientists agree that the greenhouse effect explains the warming temperatures.

Wouldn't a warmer earth be a good thing?

A reasonable question is "So what?" What's so bad about a slightly warmer earth? If you live in Northern Minnesota, and you happen to be reading this in January, global warming probably sounds pretty appealing. Let's look at some of the global consequences. This is where we enter the realm of speculation. Guessing is easy. Scientific prediction? That's a bit more complex.

Scientists turn to a variety of computer models to predict the probable effects of various increases in earth's temperature. Computer models are certainly not infallible. They must be constantly revised, and they are only as good as the data on which they are based.

Because of the technical challenges involved in constructing good models, some argue that they should play no role in making important decisions. But should a degree of uncertainty be our excuse for doing nothing? The question is complex, and the actions that we take or do not take are likely to have significant effects on our future lives and the lives of our children.

IPCC scientists fed a number of different estimates of population growth, technological changes, and economic growth into computer programs. First they estimated the annual amount of excess carbon dioxide that might be spewed into the atmosphere over the next century. Their estimates ranged from 6 billion to 35 billion tons. Using these estimates, they ran seven different computer models to predict the resulting temperature increase by the year 2100. Their estimates, posted on their Web site in April 2001, ranged from an average global temperature increase of 1.4 to 5.8 °C. New data and refinements in climate models have resulted in these estimates being about 50% greater than those posted only five years ago.

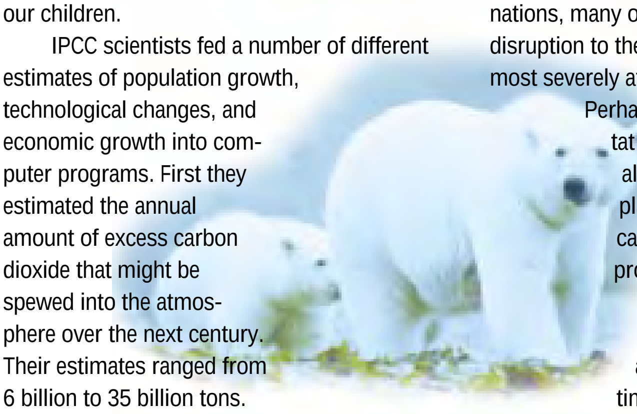


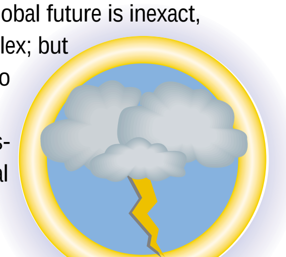
PHOTO FROM PHOTODISC

The behavior of ordinary clouds is particularly difficult to factor into climate change computer models. Cloud origins as a result of evaporation patterns and cloud impacts on surface temperatures are among the research goals of scientists planning NASA's EOS Aura mission. EOS, an acronym for Earth Observing System, includes a series of satellite missions for providing data on the functioning of Earth as a system—and, particularly, how humans affect that system. EOS Aura will study the atmosphere, including greenhouse gases such as methane, tropospheric ozone, and aerosols.

The specific effects of global temperature increases are difficult to predict. Some areas of the world might benefit from a moderate amount of warming. Growing seasons in parts of the United States and Canada could lengthen. But crop yields in regions closer to the equator could be drastically reduced. If temperature increases are at the higher ends of the prediction scale, widespread catastrophic droughts might occur. Developing nations, many of which can least afford any disruption to their food supply, may be the most severely affected.

Perhaps 35% of earth's natural habitat could be fundamentally altered. Although populations of plants and animals are genetically adaptable, natural processes of adaptation and selection take generations. Many species might not adjust to climate changes in time. Already, in the Arctic regions, thinner, later-forming Hudson Bay ice is affecting polar bears dependent on ice slabs for hunting seals. The migration routes of the caribou have changed, and grizzly bears, insects, and birds are now found in areas north of their traditional ranges.

Predicting our global future is inexact, frustrating, and complex; but too much is at stake to abandon the effort. NASA's EOS Aura mission will collect critical data to increase our understanding of the phenomenon of global warming. With this understanding, it will be the responsibility of all of us to decide on a course of action to ensure that earthly life not only survives, but prospers.



How is earth's climate changing?

GLOBE—View From the Ground Up

Students all over the world are doing more than just worrying about the problems facing our changing environment. They are getting into the act of collecting important research data for NASA. As participants in a program called GLOBE (Global Learning and Observations to Benefit the Environment), students, in cooperation with their teachers and the scientific research community, are learning to collect data in four areas: atmosphere, hydrology, soil, and land cover/ biology. Students worldwide submit these data to the GLOBE Student Data Server, thereby providing scientists and students a better understanding of Earth's integrated systems.

GLOBE students are getting ready to play an important role on the EOS Aura mission. The new protocol, "Surface Measurement of Ozone", is designed to support and expand the Atmosphere Protocol in the GLOBE Program. And the data that they collect will help NASA scientists understand how ozone data collected by remote sensors are related to simultaneous measurements made at ground level.

PHOTOGRAPH COURTESY OF LANGLEY REAEARCH CENTER, HAMPTON, VA

Students in the Czech Republic receive training for making surface ozone measurements using the new GLOBE protocol.

Jack Fishman, an EOS Aura team member and a research scientist at NASA Langley Research Center in Hampton, VA, leads the Surface Ozone Project for GLOBE. Fishman has conducted research on the composition of the lower atmosphere since 1976. Over the past three years, he and Irene Ladd, the education director for the Surface Ozone Project, have developed a new and effective method for measuring surface ozone that is to be used by teachers and students of all countries and all school levels.

Tests of the new surface ozone protocols at a GLOBE site in Nashua, NH, showed that the technology performed reasonably well most of the time. Since then, teachers have been trained to use the methods at sites in Michigan, Alabama, South Carolina, New Hampshire, Massachusetts, Greece, and the Czech Republic.

The research goals of this GLOBE project are impressive. GLOBE will strive to involve students from all over the world in making accurate measurements of surface ozone. By doing this, the students will be contributing vital information about this critically important atmospheric trace gas. Their measurements of ozone presence and distribution at the earth's surface will increase our understanding of the relationship of ozone to both human activity and natural processes. Read more about GLOBE at www.globe.gov.

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