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.

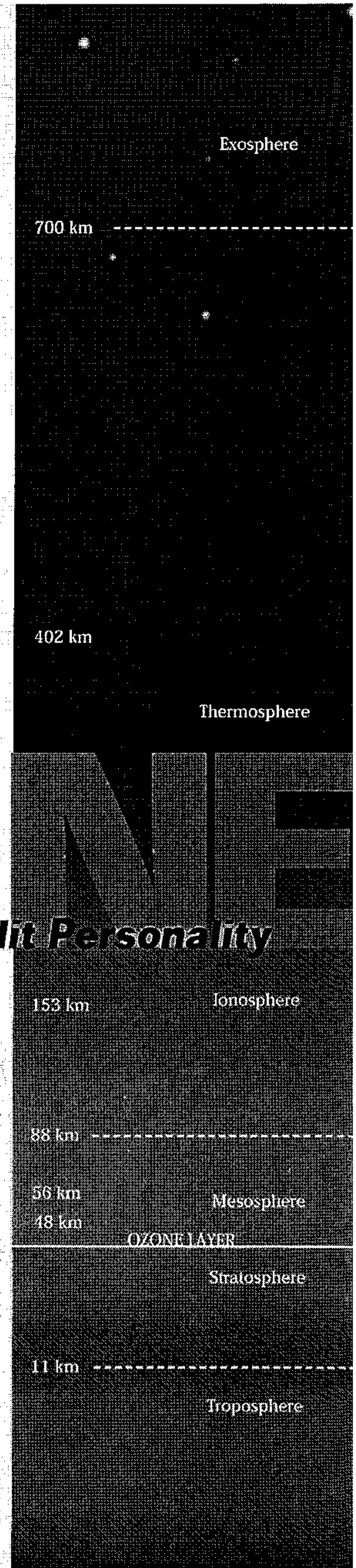


PHOTO FROM PHOTODISC

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.

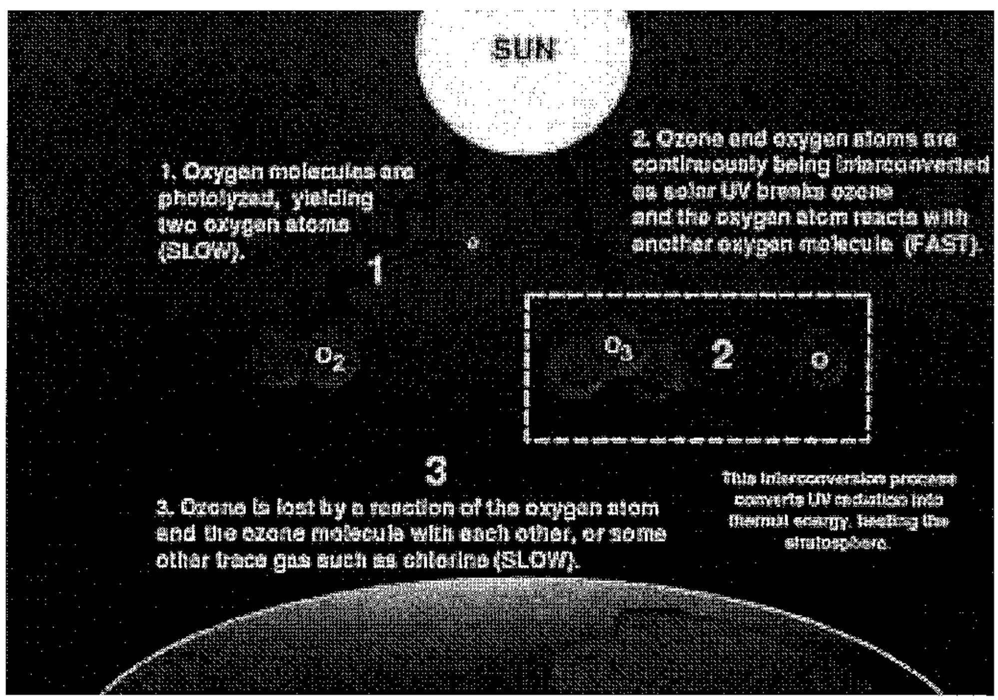
Since ozone is a gas, all of us are exposed to it whenever we breathe. Although there are no ozone-free zones, our total ozone exposure depends on where we live. Not surprisingly, the most direct ozone-related health effect for humans is damage to lung tissue. Research shows that prolonged ozone exposure 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



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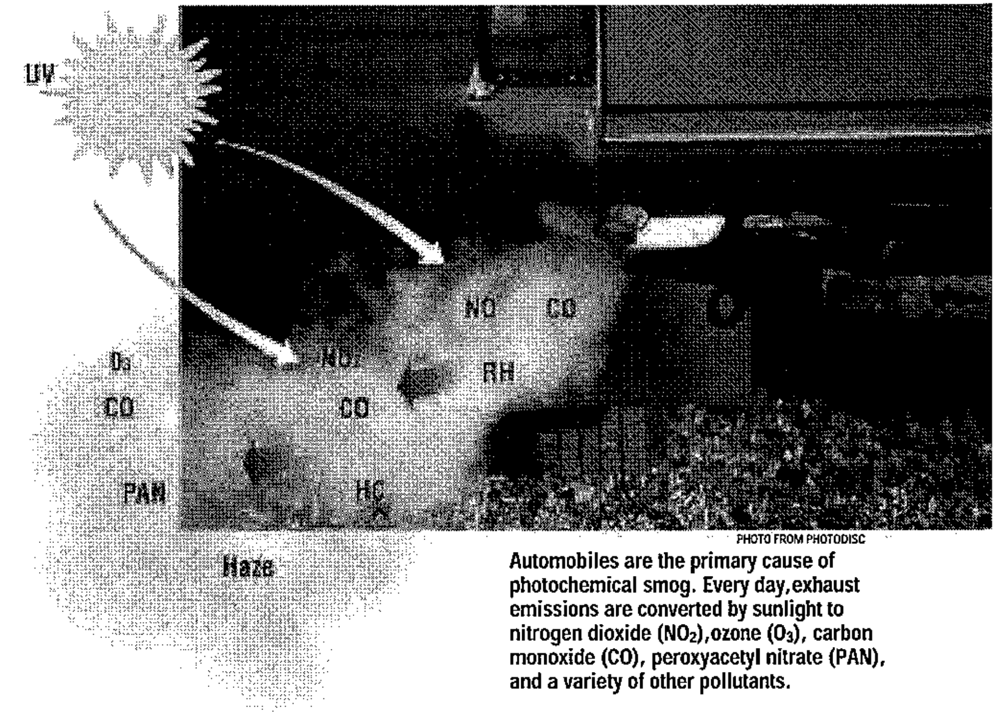


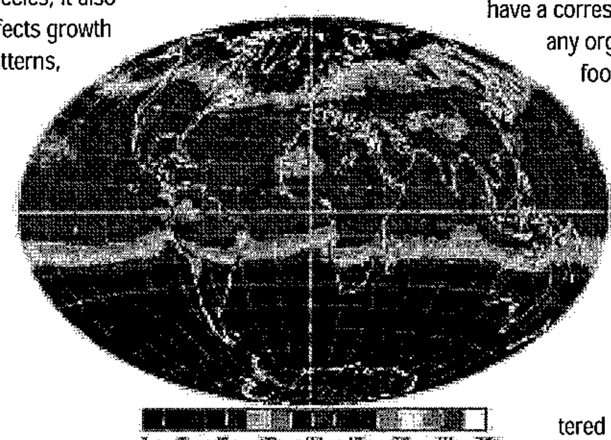
PHOTO FROM PHOTODISC

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.

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,

ILLUSTRATION COURTESY OF NASA



Erythemal Spectral Exposure (kJ/m²) 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.

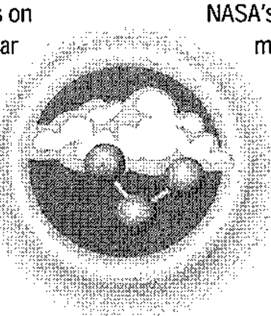
decreases overall leaf area, and affects flowering times. Although plants have adaptive mechanisms that might allow them to adjust over a long period of time, they may not be capable of adjusting to a relatively rapid increase in their exposure to UV-B radiation. And problems with plants affect more 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. ▲



Is earth's ozone layer changing as expected?

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United Nations: *Environmental Effects of Ozone Depletion: 1994 Assessment, Pursuant to Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer Under the Auspices of the United Nations Environment Programme (UNEP),* Nov. 1994

1. How is ozone like water in a car?
2. Where is the ozone layer?
3. Write the steps for the formation of ozone.
4. What part of the electromagnetic spectrum is involved in the formation of ozone? ________________
5. How is the ozone like a sponge? What is it absorbing?
6. What is the mechanism for the formation of ground-level ozone?
7. What is the overall reaction for the formation of ground-level ozone?
8. Which species in the mechanism is an intermediate?
9. What are the health effects of ozone?
10. What is UV-B radiation?
11. In the IB Book read about the depletion of ozone. Write the mechanism for ozone depletion from CFC's below. (pg 449-450)
12. What does CFC stand for?
13. What are CFCs used for?
14. If CFCs are used in commercial products because they are stable, why are they such a problem?
15. List 4 alternatives to CFCs