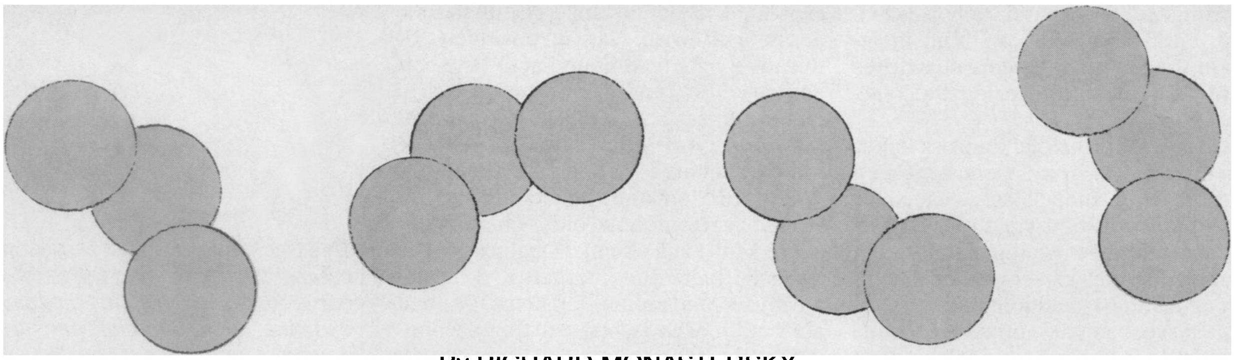
The Two Faces of Ozone



By RICHARD MONASTERSKY

Summer in the city: a time for baseball games, barbecues and smog so noxious it sears the lungs.

From Los Angeles to São Paulo, the problem is ozone, a key element of urban smog. When ozone levels increase in the bottommost atmospheric layer, or troposphere, breathing can become a dangerous pastime, especially for asthma sufferers, exercisers and the elderly.

Ozone shows its kinder, gentler side more than 10 kilometers above Earth's surface. In this region, called the stratosphere, ozone molecules shield the planet by absorbing ultraviolet radiation that can harm plants, animals and humans, in which it can cause skin cancers and cataracts. Yet pollutants threaten this lifesaving ozone layer, and many countries are now taking action to prevent further destruction (SN: 9/26/87, p.196).

Too much ozone where it's unwanted, not enough where it's needed. The predicament seems to prove that Murphy's law – "If something can go wrong, it will" – applies to planets as well as to supermarket lines.

Many people remain confused by the seeming paradox of ozone's hero/villain personality and by scientists' insistence that limiting pollutants is the only practical way to save the protective shield. Why, some wonder, can't the excess in the troposphere be shifted to the ozone-starved stratosphere? A few have gone so far as to suggest using the space shuttle to salve the world's ozone worries.

Thousands of media reports have focused on the ozone problem while leaving underlying questions unanswered. The more fundamental of these include:

Q: *Why is some ozone good and some bad?*

A: Ozone is ozone. At the ground or miles up, it's all the same molecule, made of three oxygen atoms. What differs is the setting.

In the troposphere, ozone threatens the health of plants, animals and people. It develops when sunlight cooks an atmospheric stew of nitrogen oxides and hydrocarbons emitted from motor vehicles, power plants and a myriad of other sources. An extremely active molecule, ozone will react with most anything in sight, including lung and eye tissue (SN: 7/22/89, p.53).

Stratospheric ozone is just as harmful, but nobody is up there to breathe it. In this region, ozone molecules created by solar radiation wrap a protective veil around the globe. Humans are thinning this safety blanket by releasing ozone-destroying chlorine and bromine compounds into the atmosphere.

In 1974, F. Sherwood Rowland and Mario J. Molina from the University of California, Irvine, first proposed that chlorine from human-made chlorofluorocarbons (CFCs) threatens the ozone layer. They predicted that as chlorine levels increased, global ozone concentrations in the upper stratosphere would gradually drop.

This vision of slow change crumbled a decade later, when events over the Antarctic revealed the ozone layer faces more danger than scientists had imagined. Each September since the late 1970s, sunlight and chlorine have combined to eat away portions of ozone over the far southern latitudes, creating the so-called ozone hole. In 1987, more than half disappeared from Antarctic skies during the austral spring (SN: 10/10/87, p.230). Scientists are now finding evidence that the Arctic suffers a similar but far less pronounced ozone loss during late winter (SN: 7/22/89, p.54).

While few people live in the Antarctic or Arctic, ozone destruction near the poles may affect more populated areas. Some scientists think loss near the poles can dilute the global ozone layer. Supporting this concept, researchers reported in the July 27 NATURE that ozone levels dropped sharply over New Zealand and Australia in late 1987 after the Antarctic ozone hole broke up and ozone-poor air moved northward.

As they learn how ozone succumbs to chemical pollutants, atmospheric scientists are discovering other potential threats. Evidence indicates large volcanic eruptions may substantially lower stratospheric ozone levels over the heavily populated midlatitudes. Extrapolating from this, some researchers even suggest ancient eruptions could have destroyed enough ozone to kill off the dinosaurs.

Q: *Might the excess ozone at ground level rise to replace ozone lost in the stratosphere? And if not, couldn't scientists construct huge pipes to send up smoggy air?*

A: Pollutants such as CFCs can enter the stratosphere because they survive for such a long time in the troposphere. But most air from the troposphere tends not to rise into the stratosphere, where temperatures are warmer. Think of it this way: A hot-air balloon filled with nothing but cold air would never get off the ground. Warm air rises, but cold air sinks.

Some ozone does shuttle between the troposphere and stratosphere, but it goes down instead of up. In fact, scientists believe the stratosphere supplies an important fraction of the "natural" ozone in the troposphere, says Rowland.

The troposphere is actually ozone-poor compared with the stratosphere. During the worst days in Los Angeles, ozone can reach levels of 0.3 parts per million for a few hours. That's less than one-thirtieth of the *normal* concentration in the midstratosphere. So even if humans could pump city smog into the stratosphere, this would only dilute the protective ozone layer rather than repair it, says Gary Whitten, who studies smog ozone at Systems Applications Inc., in San Rafael, Calif.

Q: *Why not produce pure ozone at the ground and carry it to the stratosphere in airplanes or the space shuttle?*

A: Several factors, including ozone's explosive nature, keep this idea in the clouds. The paramount problem lies with the energy needed to add ozone to the stratosphere. Total up all the energy humans use today, and it still would not equal the amount needed to reverse the ozone thinning, Rowland says.

As ultraviolet radiation from the sun continually creates vast amounts of stratospheric ozone, other atmospheric processes continually destroy the molecule. The ozone concentrations in the stratosphere therefore represent a balance between these two processes – a situation resembling water flowing into a hole-riddled bucket, says Mark R. Schoeberl, an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Md.

Theoretically, humans could continually pump up artificially produced ozone molecules in hopes of raising stratospheric levels. Using the water analogy, this would correspond to pouring another stream into bucket. But the artificial stream would not necessarily raise the water level because the laws of physics require that the amount leaking out the bottom must increase as the flow into the bucket grows.

To raise the net water level, humans would have to create an artificial stream nearly as big as the natural stream – in other words, to add almost as much ozone as the sun's energy creates. Such a task would require an energy source that rivals the sun – something clearly out of the human league, Rowland says.

Q: *How can humans reverse the loss of stratospheric ozone caused by chlorofluorocarbons?*

A: The only realistic way to raise ozone levels is to plug up some of the holes in the bucket. "That's what we're trying to do by banning [chloro]fluorocarbons," Schoeberl says.

Chlorine levels in the atmosphere have grown significantly since CFCs first reached the market in the 1930s. Today, natural sources such as sea salt contribute only about a third of the chlorine in the stratosphere. The rest comes from CFCs and other industrial chemicals.

Chlorine's destructive power lies in its ability to act as a catalyst. Relatively few chlorine atoms float around in the stratosphere, but a little goes a long way. A single chlorine atom can split 100,000 ozone molecules over the course of a year. Scientists say ozone's only hope lies in lower chlorine levels.

To that end, an international treaty went into effect this year limiting production and consumption of CFCs and related chemicals called halons, which contain destructive bromine. By the end of the century, participating nations must reduce CFC use to half the 1986 levels. But even this will not stabilize the growing chlorine levels in the stratosphere, and many countries now lean toward a full ban on CFCs as early as possible. Other industrial chemicals, such as methyl chloroform and carbon tetrachloride, also release chlorine into the stratosphere, and the Environmental Protection Agency wants to limit these as well (SN: 6/10/89, p.367).

In a sense, humans *can* set the ozone level of the stratosphere, by deciding how much chlorine and bromine to leak into the air. But the protective layer will be a difficult patient to revive. Even if all emissions of these pollutants were to cease today, it would take hundreds of years for chlorine and bromine levels in the stratosphere to return to preindustrial amounts. □

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may prove useful as sensors and diagnostics," he says. He also suggests attaching highly charged metal atoms to the antibodies to enhance some reactions. In another application, Schultz says researchers might hook drug molecules into the handles of antibodies designed to deliver the drug specifically to menacing viruses or cells.

Lerner has made antibodies that have one binding site for a target and another site for hosting a catalytic cofactor. In an example often cited by researchers in this field, Lerner and Scripps co-worker Brent L. Iverson created antibodies that selectively cleave the amide bond between glycine and phenylalanine, two of the 20 amino acids that make up most mammalian proteins. By using a cobalt-containing chemical analog of the glycine-phenylalanine compound as an antigen, the researchers obtained antibodies that bound the amino acid pair along with the metallic (cobalt) cofactor.

Last spring, Janda, Benkovic and Lerner published research results that they say bring catalytic antibodies closer to the toolbox of organic chemists. They reported in the April 28 SCIENCE making a pair of catalytic antibodies, each operating nearly exclusively on one of two mirror-image forms – called enantiomers – of some ester-containing compounds. Quite often, chemists would prefer to work with just one enantiomer. In practice, however, they find it difficult or impossible to separate these otherwise identical chemicals, which often form in equal amounts during chemical reactions. Enantiomer-specific antibodies might enable chemists to routinely focus on just one enantiomer. Other researchers have shown that some catalytic antibodies work even in nonwater, organic solvents, opening the door to their use in a still wider variety of reactions.

Because researchers can make antibodies that bind to virtually any chemical structure, the technology's ultimate applications should reach beyond the horizon of envisioned possibilities, they say. "This technology puts at our fingertips the means to create entirely new enzymes for use as research tools and also in medicine and industry," says Hilvert.

Developing antibodies that catalyze any particular reaction takes a lot of time, money and technical expertise. At least initially, and perhaps for a long time to come, the new chemical tools will find their primary use in the creation of specialized, high-value compounds such as flavor and aroma chemicals, Benkovic and others suggest. In the longer term, Lerner foresees a battery of catalytic antibodies capable of cutting amino acid chains at specific locations that would closely resemble the restriction enzymes that genetic engineers use to specifically snip DNA chains.

Benkovic looks toward pharmaceutical applications. Many drugs come from the manufacturer as an even mix of two enantiomers. Most often, only one enantiomer is medically active, and sometimes the other causes unwanted side effects. Benkovic envisions using custom-designed catalytic antibodies to edit out the unwanted enantiomer, leaving behind a purer drug with fewer side effects.

"Every time we get new antibodies, I kind of look at them like lottery tickets," says Janda of the Scripps Clinic. "When we test them, it's like scratching and seeing if we get rich." Some biotechnology companies already have started catalytic antibody projects in collaboration with university researchers. Schultz says he expects these companies to assemble their own interdisciplinary research teams soon, developing catalytic antibodies independently.

So look out, Raquel Welch. If Hollywood ever decides to remake "Fantastic Voyage," you could end up as a human pretzel. □