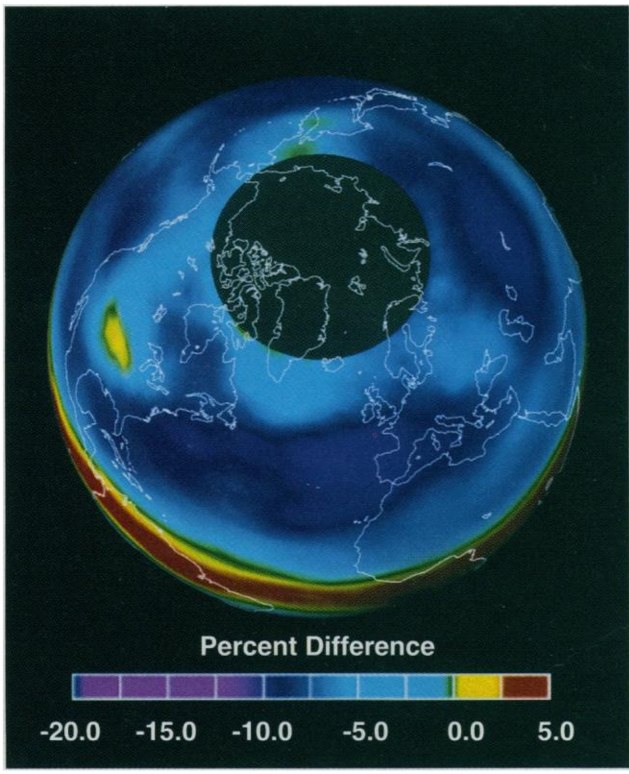
GLOBAL CHANGE

Ozone Takes a Nose Dive After The Eruption of Mt. Pinatubo

Lately, the stratospheric ozone layer has been taking a beating—from both human society and nature. In the late 1970s, natural ice particles in the frigid clouds over Antarctica began acting as a chemical accomplice to chlorine from manmade chlorofluorocarbons, opening the infamous ozone hole. Next it seemed that the stratosphere's natural haze might be doing the same thing year-round at mid-latitudes, causing the slow year-to-year decline in ozone discovered there. As if those blows weren't enough, along came Mt. Pinatubo. The debris that spread through the stratosphere after its June 1991 eruption in the Philippines seemed to promise even more ozone losses, perhaps catastrophic ones, as the particles changed the chemistry of the stratosphere.

A catastrophe seems to have been averted, but on page 523 of this issue of *Science* a group of researchers reports that outside the polar regions, global ozone has plummeted to a record low: 4% below levels typical of the past dozen years and 3% below even the very lowest level seen in those years. The low, measured in late 1992 and early 1993 by the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus-7 satellite, is dramatic enough that researchers are still holding Pinatubo to blame—perhaps with some help from unusual meteorology over the Arctic. But the failure of the direst predictions has left them wondering whether the chemical effects of the debris were simply more modest than expected, or whether the debris worked some or all of its mischief by a quite different mechanism: changing the wind patterns in the stratosphere. Either way, the ozone layer should show clear signs of recovery next year after the debris has settled out and sun-driven production of ozone re-stocks the atmosphere.

For now, some parts of the global ozone layer are suffering more than others. TOMS measured below-normal levels of ozone everywhere outside the poles (between 65°N and 65°S) except near the Equator. Between 10°S and 20°S and north of 10°N, the levels were lower than anything the satellite had ever seen. Late in 1992, the mid-latitudes in the Northern Hemisphere (between 30° and 60°N, where most Americans, Canadians, and Europeans live) were 9% below normal, according to Paul Newman of the National Aeronautics and Space Administration's Goddard Space Flight Center in Greenbelt, Maryland, which operates TOMS. And at 60°N—the latitude of Anchorage and southern Scandinavia—ozone was down 14%.



A blue November. Although ozone remained near or above normal *(yellow and red)* near the Equator last November, the rest of the hemisphere experienced an ozone shortage *(blues)*, mapped here by the satellite-borne TOMS instrument.

That's bad, but not as bad as some theorists had forecast after Pinatubo erupted. Based on computer models of ozone-destroying chemistry, they predicted that ozone in temperate latitudes might fall as much as 10% to 20% shortly after the eruption—a point when the actual losses had reached only 2% to 4%, according to Sushil Chandra of Goddard. The idea was that the volcanic debris, like the ice particles in the polar clouds, would catalyze the destruction of nitrogen oxides that normally lock up chlorine and thus protect ozone.

The disparity between predictions and measurements has led some researchers to doubt that volcanic debris made much difference in stratospheric chemistry. Instead, these researchers think the Pinatubo debris may have worked much of its effect another way: by interfering with the transport of ozone around the stratosphere. By absorbing solar radiation and warming parts of the stratosphere, they say, the cloud may have changed the high-altitude winds that sweep ozone out of the tropical stratosphere, where much of it forms, and around the rest of the globe.

Atmospheric chemist Richard Stolarski of Goddard is in this camp."It looks a lot like a circulation effect," he says. One sign that the cloud was affecting atmospheric circulation came soon after the eruption, when ozone concentrations in the lower tropical stratosphere declined. It seemed that as sunlight warmed the newly formed cloud, it in turn warmed the surrounding air, which rose and drew up ozone-poor air from below. And as evidence that circulation effects may still be important, Stolarski points out that ozone loss is showing up in both hemispheres simultaneously. Chemical effects, he says, would be expected to alternate between hemispheres depending on the season, some chemical effects being highly sensitive to temperature.

But atmospheric chemist David Hofmann of the National Oceanic and Atmospheric Administration in Boulder argues for a middle ground. "I think it's both [types of volcano effects]," he says. Evidence that the cloud could play a chemical role, he says, comes from last fall's Antarctic ozone hole, where he and his colleagues were able to detect ozone destruction in a thin layer just where the Pinatubo debris was hovering. And the latest computer simulations of chemical effects, by Jose Rodriguez and his colleagues at Atmospheric and Environmental Research Inc. in Cambridge, Massachusetts, match the observations much better than earlier chemical models did. Rather than predicting 10% to 20% losses at mid-latitudes, the group's best estimate is that chemical effects could account for early declines of 2% to 4%, about what was measured. Notes atmospheric physicist Mark Schoeberl of Goddard: "We had everything working together this year. The situation is extremely complicated, and it's going to take us a while to sort it out."

Complicating the picture still further is the fact that the volcano isn't the only thing amiss in the stratosphere. The north pole's equivalent of the swirling vortex that holds the Antarctic ozone hole was unusually strong and long-lived last winter, says Stolarski. The extreme stratospheric cold that allows ozone destruction persisted unusually far into the Arctic spring, when another essential ingredient—sunlight—became available. That unleashed an abundance of chlorine in its destructive form, driving Arctic ozone into a sharp decline that continued into March, according to Joe W. Waters of the Jet Propulsion Laboratory, where the stratosphere is monitored through the Upper Atmosphere Research Satellite. (Waters and his colleagues reported their Arctic observations in the 15 April issue of *Nature*.)

Even with all that help, the Arctic depletions still didn't rival the Antarctic ones. Because ozone concentrations are normally relatively high over the Arctic, notes Stolarski, even extensive ozone destruction is unlikely to create a "hole" there. It's like taking the top off a mountain, he says; you've lost something, but you're a long way from digging a hole. But the resulting pool of ozone-depleted air, Stolarski thinks, flooded south over populated areas in late winter and early spring during the annual vortex breakup, augmenting the effects of the volcano.

After that one-two punch, the ozone layer is likely to be down for the count. Researchers say the 9% decline in ozone at mid-latitudes will be with us into summer, along with the resulting 12% or so increase in harmful ultraviolet. If you haven't already heeded doctors' warnings about overexposure to the sun, all the more reason to put on that hat and slather on the sunscreen.

–Richard A. Kerr

CHEMISTRY

How to Drive Nucleic Acids Up a Tree

When chemist Masad J. Damha and his colleagues set out to study the curious branched RNA molecules found in the cell nucleus, they never imagined they'd find themselves in a hotbed of polymer science. But not only is that exactly where their artificially structured RNA has landed them; their work shows signs of heating up the field even more. And in the final twist, this foray into unfamiliar territory may end up leading the McGill University researcher and his colleagues back to the answers they had sought in the first place.

As the group reports in the 24 March issue of the *Journal of the American Chemical Society*, they've succeeded in training RNA to form an intricate branching molecule known as a dendrimer. Until now, dendrimers—which have already energized a new subdiscipline of polymer science (*Science*, 29 March 1991, p. 1562)—have been made of non-biological ingredients, notes Donald Tomalia, a leading dendrimer researcher at the Michigan Molecular Institute in Midland. Damha's work, he says, is "the first time that biological polymers have been synthesized in this architectural form." And while ordinary dendrimers have already begun catching the eyes of industrial chemists for everything from catalysis to drug delivery, these biodendrimers may turn out to be just the thing for fishing for DNA or RNA fragments—a common challenge in biomedicine.

Damha had set out in the late 1980s to uncover the role of the branched RNA structures that form in the nucleus during the production of messenger RNA (mRNA), the linear molecules that carry genetic information to the cell's protein-making factories. Although scientists have known about these "forked" and "lariat" shaped RNA intermediates for about a decade, they have yet to determine how these structures take part in the molecular cutting and pasting process that produces mRNA.

Damha and his colleagues realized that probing the branched RNA (bRNA) molecules systematically would be a whole lot easier if there were a ready and abundant source of them. The minuscule amounts and fleeting life of naturally produced bRNA makes cells a poor source. So Damha (then at the University of Toronto) and his Toronto colleagues decided to synthesize their own bRNA molecules chemically.

The Canadian chemists' first task was to develop a chemical procedure in which automated synthesizers, which normally produce linear RNA or DNA molecules, could create branched versions instead. They directed a commercial synthesizer to build up pairs of identical nucleotide chains from nearby anchor points on a solid surface. Once the chains reached a preset length, the machine introduced another nucleotide. This one, an adenosine, was chemically modified so that it would link to and join the ends of the pairs of nucleotide chains. The results: V-shaped RNA molecules, or, if the chemists directed the synthesizer to continue adding building blocks to the vertex of the V's, Y-shaped RNA molecules. That much they reported last December in *Nucleic Acids Research*.

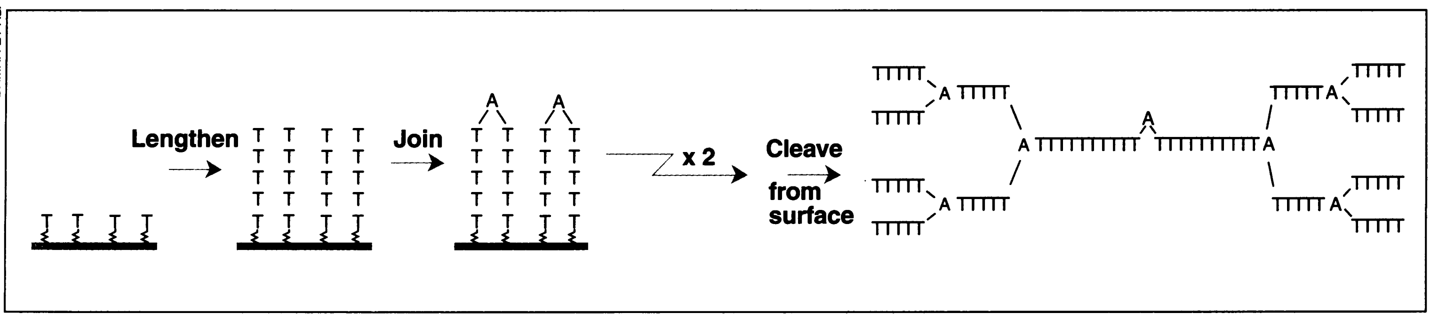
Even before they had had a chance to study their synthetic forks and lariats, Damha and University of Toronto graduate student Robert Hudson decided to push the synthesis process several steps further. They now start with many more chains—so far, as many as eight of them—and iterate the process of chain-extension and chain-joining until the chains converge into one. The resulting, much more intricate, structures fall squarely into the dendrimer category. The researchers are now developing a divergent approach, in which the molecules grow by branching outward from a core.

Because of the unique, biological character of the branching RNAs, Damha and other dendrimer growers speculate that they will be more than a structural curiosity. For one, the dendrimers' multiple arms, each with an identical genetic message, may prove especially effective at capturing and binding matching nucleotide sequences. That could open the way to using them as "antisense" agents, which can turn off genes by intercepting and deactivating mRNA or DNA, says Damha. Or, says Tomalia, dendrimers based on RNA or other nucleic acids could be designed as diagnostic tools, if they were built with sequences complementary to those of say, pathogenic agents such as viruses.

As for the original mystery about the RNA forks and lariats in normal cells, Damha thinks that the dendrimers may help out there as well. They might serve as selective fishing hooks capable of snagging those RNA curiosities from a cellular digest. "In a sense, we are still quite unaware of the potential of these [structures]," says Hudson.

–Ivan Amato

DAMHA *ET AL.*



All together now. In a scheme for creating branched RNAs, chains are extended, joined with modified adenosine nucleotides, and extended again.