both the number of quanta caught from a reflecting object of particular dimensions and the number of photosensitive molecules exposed to these quanta increase as the square of eye size; in contrast, thermal noise increases only linearly because it is proportional to the square root of the number of photosensitive molecules. Hence large eyes are more sensitive, which explains why nocturnal animals have large eyes and why small animals need eyes that are relatively large for their body size.

It is only the ultimate sensitivity, measured in the absence of all light except that from the target, that has been shown to be limited by thermal noise. But it is obviously a very great advantage to be able to catch and eat your prey in the dawn and dusk when your competitors, and the prey itself, are still blind; perhaps we can now discern the unalterable physical factors that limit the evolution of better visual performance under these conditions. □

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Ozone depletion

Reactions on ice crystals

John Pyle

RESULTS from several Antarctic observations, including the US Airborne Antarctic Ozone expedition last August to September were discussed at a recent meeting.* They show that the springtime ozone level in the polar stratosphere fell to 40 per cent of the values measured in the 1970s, the strongest depletion yet recorded. Other data confirm the leading role played by heterogeneous chemistry on ice particles in the stratospheric clouds in producing the ozone hole. Measurements from the Arctic stratosphere show ozone depletion could happen there, although no strong effect has yet been observed.

The rapid loss of ozone above the South Pole, first reported in 1985, occurs during about 6 weeks after the return of sunlight in the Antarctic spring but is reversed by December. The depletion has been getting steadily worse each year. The Antarctic has a unique meteorological environment: strong zonal winds produce a cold air mass in the lower stratosphere, chemically isolated from lower latitudes by poor north–south mixing. Ozone depletion is caused in this vortex by a catalytic cycle based on chlorine atoms (see the News and Views article by Brian Thrush in *Nature* **332,** 784; 1988) originating from man-made chlorofluorocarbons. Ice crystals in the stratospheric clouds that can form in the cold vortex are thought to be sites of crucial heterogeneous reactions that free active chlorine.

The principal catalytic cycle, involving the chlorine monoxide dimer, that destroys ozone is:

$$\begin{aligned} ClO + ClO + M &\rightarrow Cl_2O_2 + M \\ Cl_2O_2 + h\nu &\rightarrow ClO_2 + Cl \\ ClO_2 + M &\rightarrow Cl + O_2 + M \\ 2 \times (Cl + O_3 &\rightarrow ClO + O_2) \end{aligned}$$

where M is any third molecule and $h\nu$ is a photon of light. Measurements of ClO were made last year by an *in situ* resonance fluorescence technique from an ER-2 aeroplane, flying at about 18 km in the lower stratosphere (J. Anderson, Harvard University). Typical flights were from Punta Arenas (58° S) to about 72° S. The most striking feature seen in all the flights was the very high level of ClO concentration, up to 1 p.p.b.v. (part per billion by volume), observed at southernmost latitudes. At the most northern latitudes, the ClO level was approximately constant at 0.1 p.p.b.v.. These values are higher than predicted by numerical models. The sharp gradient in ClO separating the two regimes was found across about 1 degree of latitude. Many other measurements showed similar sharp gradients in constituent concentrations, confirming that there is an isolated, distinct air mass (the 'chemically-perturbed region') over Antarctica.

In August the ozone levels measured by the ER-2 were relatively constant. By mid-September the ozone levels in the region of high ClO were reduced dramatically. Anticorrelations with ClO were seen on both large and small scales. Furthermore, Anderson could infer the Cl_2O_2 mixing ratio in his experiment; all the recorded levels agree well with theoretical predictions.

The role of polar stratospheric clouds (PSCs) in ozone depletion was mere hypothesis in 1986 (Solomon, S. *et al. Nature* **321**, 755–758; 1986). Now many of their physicochemical properties are known. For example, the reaction probabilities of several important surface reactions have been measured in the laboratory. Both the ER-2 and DC-8 aircraft were used to identify two populations of particles in the PSCs (D. Fahey, National Oceanic and Atmospheric Administration (NOAA); L Poole, NASA). Below about 195 K, micrometre-sized particles (type-I PSCs) containing nitric acid and water were found. These could be frozen droplets of nitric acid trihydrate which, as pointed out by several authors, freezes at higher temperatures than water, providing sites for heterogeneous chemistry. It is supposed that reactions on the surface of these small crystals such as

$$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$$

liberate molecular chlorine which is rapidly photolysed to produce chlorine atoms, the nitric acid being absorbed into the droplet.

At temperatures below about 187 K larger water–ice crystals (type-II PSCs) were found. These larger crystals, which also can absorb HNO_3, could settle out from the lower stratosphere, leaving it denitrified and dehydrated. The denitrification is essential for the ozone depletion, otherwise excess $ClONO_2$ would act as a reservoir tying up active chlorine.

Measurements have also been made this year in the Arctic stratosphere. Relatively high column densities of OClO, an indicator of unusual chlorine chemistry, were found above Thule (G. Mount, NOAA). Balloon measurements from northern Sweden (U. Schmidt, Julich Nuclear Research Centre) indicate that the levels of CH_4 and N_2O are very low in the Arctic lower stratosphere and similar to levels above Antarctica. There is no good evidence in the north of strong ozone depletion such as that seen in Antarctica but some of the conditions are evidently favourable for depletion to occur.

Measurements from the ER-2 in the north taken outside the vortex confirm that the Arctic may be perturbed. W. Brune (Harvard University) reported that the concentrations of ClO are much higher than predicted by models. These measurements could also have important implications globally: there is more active chlorine in the lower polar stratosphere than models currently predict. How much of this chlorine is then transported towards the Equator in the lower stratosphere and, therefore, how inadequate are present models for global prediction? It seems likely that models are particularly poor in this most important region. Measurements which could support this suggestion were presented by A. Tuck (NOAA), who showed evidence of dehydration of the lower stratosphere at latitudes north of Punta Arenas. If this air had previously been within the vortex, other constituent concentrations too should be quite untypical for mid-latitudes. □

* Polar ozone workshop, Aspen, Colorado, 9–13 May 1988.

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