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T
he manufacture and emission of chlorofluorocarbons (CFCs), our inadvertent global experiment in modifying the Earth’s stratosphere, has dam-
aged the ozone layer for decades to come. The
Montreal Protocol, which was agreed in 1987
and revised several times in the 1990s, and has
the aim of reducing global emissions of
ozone-depleting chemicals, has gone a signif-
ificant way to solving the ‘ozone problem’ 1. However, as described by Montzka and col-
leagues on page 690 of this issue 2, the road to
ozone recovery remains uncertain.

The authors report the good news that, by 1997, the lower-atmospheric burden of
ozone-depleting halogen compounds (chloro- and bromocarbons) had declined by 3% from its 1993–94 peak; and they pro-
vide a reminder that this decline is almost entirely due to the rapid atmospheric
removal of the solvent methyl chlorofluoromethane (CHMC), global emissions of which are now virtually zero. But concentrations of
other halocarbons — carbon tetrachloride
(CCL) and CFC-11 (CCLF), for instance — are falling more slowly, and those of others
such as CFC-12 (CCLF) are still rising. If the
decline in emissions of these other halocarbon species does not gather pace, the overall fall in halogen concentrations in the atmos-
phere will stall sometime during the next decade.

What are the barriers to ozone recovery?
Montzka et al. have identified several, namely,
emissions of refrigerant CFCs, of HCFCs (hydrochlorofluorocarbons) as interim
CFC replacements, and of halons (bromocarbons) as fire-fighting chemicals. In the
developed world, a large ‘bank’ of CFC-12 in
old refrigeration and vehicle air-conditioning
systems continues to leak slowly into the
atmosphere. Although new CFC production
depended by a factor of 4–5 from 1986 to 1995
in accord with the Montreal Protocol, the
developing world (China, India, Mexico) has
increased production by 2–3 fold (largely of
CFC-12), so that in 1995 it accounted for
45% of global CFC production. This figure
is presumably even larger now. The com-
bined effect of these emissions is continuing
growth of CFC-12 in the atmosphere (Fig. 1a, overleaf), and this is the biggest single
long-term threat to ozone recovery.

Fortunately, HCFC emissions to date have been only 50% of those permitted
under the Protocol; in large part this is because HCFCs are due to be phased out by
2030, and some parts of the refrigeration and air-conditioning industry have hesitat-
ed to invest in short-term HCFC technolo-
gies. Likewise, HCFCs have not replaced
CFCs in aerosols or foam plastics, where
hydrocarbons or ‘not-in-kind’ substitutes have filled these niches. Yet HCFC use —
and therefore emissions and atmospheric
concentrations — are predicted to increase
substantially, and legally, under the Protocol
over the next decade 3 as HCFCs continue to
be used as CFC substitutes in refrigeration
(Fig. 1b).

Another emerging player is halon-1211
(CBrClF2), a fire-fighting chemical used increasingly in developing countries such as
China and Korea, which now account for
over 95% of global production of halons. 4

Under the Protocol, emissions of halon-1211
were thought to have peaked in the late 1980s
(ref. 4), but atmospheric observations indi-
cate near constant 5–6 possibly growing 7
emissions (Fig. 1c and d). Using inventories
based on atmospheric observations, emis-
sions in the late 1990s are 50–60% higher
than those predicted from global production
data. Presumably global production has
been underestimated, or emissions from the
bank are larger than assumed (or both). Studies by Montzka et al. 8 and a group
involving one of us 9 conclude that, in the
near term (as opposed to CFC-12 in the long
term), halon-1211 emissions pose the largest
threat to ozone recovery.

Prompt and continuing progress towards
ozone recovery requires that emissions of
halocarbons must be reduced faster than is
apparent from current observations of the
atmosphere. The United Nations Environ-
mental Programme is facilitating such an
accelerated phasing out of halon use in
China, with production of halon-1211
scheduled to end by 2006, four years ahead of
the Protocol. In addition, the technology
exists to recycle or destroy the bank of CFC
refrigerants that would otherwise vent to the
atmosphere when refrigeration systems are
scraped. The uses of HCFCs could be
restricted to refrigeration, where their identi-
fication and recycling is again possible, and
emphasis could be placed on use of very
short-lived gases such as HCFC-123
(CHClCF3) that pose a minor risk to the
ozone layer. All in all, it is possible that ozone
depletion can be halted in the next decade.

But it will require a level of global stewardship
that still poses a substantial challenge to all
parties to the Montreal Protocol.

Atmospheric chemistry
Uncertain road to ozone recovery

Paul J. Fraser and Michael J. Prather

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100 YEARS AGO
The Groundwork of Science; a Study of Epistemology. By St. George Mivart. The chief definite conclusions which are drawn are that it (the universe) cannot consist of one kind of energy only, that it is impossible that intellect can have been evolved from mere physical force, and that animals show no signs of latent intellectuality. It is further insisted “that the portion of truth which we are able to attain to in our investigations of the cosmos, is but an unimaginably small portion of the whole”; a statement which will, we imagine, not be seriously challenged by workers in science. To the latter, viz. the science workers, Dr. Mivart devotes some attention in the concluding pages of his book. The narrowing effect of extreme specialization upon the mind is an undoubted evil … But there is the opposite evil of becoming diffuse to the extent of a practically useless attenuation of the mental faculties.

From Nature 20 April 1899.

50 YEARS AGO
Mr. H. E. Hadley, well known as the author of many elementary text-books of physics, died on March 6, at the age of eighty-two. Mr. Hadley had lived rather a retired life. He was appointed headmaster of a small science school in Kidderminster, where he combined with physics a lectureship in chemistry. In those days, physics was considered of less importance than chemistry; but Mr. Hadley was always at heart a physicist.

… Mr. Hadley was a contemporary of Sir Richard Gregory and H. G. Wells at [The Royal College of Science, London], and from his training there and association with C. V. Boys he acquired a special genius for making his physical apparatus. His teaching equipment at Kidderminster was largely of his own making, and it would seem that this gave physics an added attraction to his students.

We regret to announce the following death: Mr. Will Hay, well known as an actor and also a distinguished amateur astronomer, on April 18, aged sixty.

From Nature 23 April 1949.

Many more extracts like these can be found in A Bedside Nature: Genius and Eccentricity in Science, 1869–1953, a 266-page book edited by Walter Gratzer. Contact Lisa O’Rourke. e-mail: Lorourke@nature.com

Figure 1 Ozone-destroying trace gases now and in the future — observed1,15,16, and predicted1 atmospheric chlorine loading, in parts per billion of Cl, from various halocarbons. a, CFC-12; b, HCFCs; c, halon-1211 (effective Cl); d, Halon-1211 emissions calculated from atmospheric measurements and from a production-based emissions model16.

Ozone depletion is the dark side of the CFC experiment. But, for science, there is a bright side — the great progress in atmospheric chemistry, made over the past 25 years, which stems in part from the scientific and political drive to understand CFCs and ozone depletion, and in part from the study of the rapid yet transient rise of the synthetic halocarbons. For example, the earliest measurements of CFC-11 envisaged its use as a tracer of air motions1, and it has become a standard test of global models of atmospheric chemistry10 (and also a diagnostic indicator of ocean circulation); the first meaningful measure of the mean tropospheric concentration of hydroxyl radicals (OH), which destroy CH3CCl3 and HCFCs, is derived from observations of CH3CCl3 (refs 11, 12); CFC pollution events in Ireland are used to calibrate European emissions of other greenhouse gases13; and study of CH3Br (a crop and soil fumigant) has shown us the importance of the ocean in determining the atmospheric residence time of a solvable trace gas, and has resulted in revision of the concept of ozone-depletion potential for short-lived gases14.

What new opportunities will the second phase of the CFC experiment provide? Through its latitudinal gradient, the decay of CH3CCl3 will give us a measure of the north–south hemispheric difference in OH concentrations, plus a long-term record of possible OH trends. And, after sources of CFC-11 have diminished sufficiently, its atmospheric decay will provide the first accurate lifetime for a CFC, and the north–south differences at the surface will measure hemispheric asymmetry in stratosphere–troposphere exchange. It is serendipitous indeed that CFCs and related halocarbons have provided, and will continue to provide, some of the benchmarks of progress in atmospheric chemistry.

Paul J. Frayer is at CSIRO Atmospheric Research/CRC Southern Hemisphere Meteorology, PMB 1, Aspendale, Victoria 3195, Australia. e-mail: paul.frayer@darp.csiro.au

Michael J. Prather is in the Earth System Science Department, University of California, Irvine, California 92697-3100, USA. e-mail: mpfrather@uci.edu


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