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# Ozone and interdisciplinary science teaching

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**Abstract:** Many of the most significant contemporary issues have a strong physics component. Examples include global warming, energy resources, nuclear power, nuclear weapons, technological risk, and pseudoscience. There is plenty of good physics, and good pedagogy, in such topics. It is not difficult to insert one or more societal topics into existing introductory courses. This paper provides instructions for teaching one such topic: stratospheric ozone depletion. Includes the history of ozone depletion 1930-1992, the physics and chemistry of ozone depletion, also tables, graphs, and diagrams suitable for reproduction as overhead transparencies.

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When talking with general audiences, I often begin with a challenge: "Call out twenty significant contemporary issues." Within about two minutes, we will have a list that typically includes: overpopulation, AIDS, deforestation, nuclear weapons, global warming, poverty, famine, solid waste, acid rain, drugs, inner cities, racism, crime, ozone depletion, air pollution in cities, the economy, resource depletion, traffic, oil depletion, war, species extinction.

We discuss the list. It holds several lessons. By listing these items, aren't we saying that they are what our era is about? So shouldn't anybody who wants their life to make a difference get involved with some of these issues?

This list is reason for everybody to study science. How many of these issues relate to science? All of them, apparently. So perhaps anybody who wants their life to make a difference should consider studying enough science to understand these issues.

We connect all this with the audience's science education. How many have studied any of these topics in a science course? The question can be broken down: How about high school science courses? How about college science courses? Physics courses? How many have had any science course that includes a serious discussion of perhaps the next century's dominant issue, global warming? How about ozone depletion? Nuclear weapons? Without exception, positive responses are sparse. Although most people have had several high school and college science courses, few courses dealt with any of these topics. Discussion often brings out complaints about previous science courses, and resolutions to urge teachers to deal with the science-related realities of our times.

## The ozone story

Here, I would like to focus on just one issue, an issue that points up the importance of filling the gaps between the disciplinary boundaries in college science teaching. My example is the ozone story. It makes an excellent case study for the entire range of science-related social issues, because the history of ozone depletion is in a sense finished. We have nearly finished damaging the ozone layer, and we have taken about all the action we can possibly take to fix it. The verdict is now back in nature's hands.

Chlorofluorocarbons (CFCs), first synthesized in 1930, formed the foundation for the coolant and foam industries, facilitating America's air-conditioned shopping cathedrals and fast foods. They created large profits and no known problems for over four decades, until 1973-74 when academic chemists Mario Molina and Sherwood Rowland discovered that free chlorine has a fatal attraction for laboratory ozone, and wondered if CFCs might be drifting from foams and air conditioners up to the stratosphere's life-preserving trace of ozone. Their theory sparked the ozone war of 1974-78, a stand-off between environmentalists and business that ended by banning the smaller and easier part of the problem, CFC-powered sprays, while leaving coolants and foams undisturbed. We all forgot CFCs for a decade.

Fortunately for humankind, a few scientists happened to be permanently stationed in the Antarctic since 1950, and they were looking upward during 1977-85. They discovered a hole in the ozone that opened for a few months every spring, broadening and deepening every year. It was an entirely unexpected development, and so surprising that the observing team withheld publication for years while they re-confirmed their results. This information, finally published in 1985, stimulated others to mount Antarctic ozone expeditions that confirmed the ozone hole and sorted out the subtle low-temperature solar-assisted stratospheric surface chemistry that produced it.

Meanwhile, and nearly independently of Antarctic developments, negotiations began in 1982 that led in 1987 to an international treaty phasing out and eventually banishing CFCs. It was a victory for the United States, which generally played a leading role in the negotiations, for the United Nations Environmental Program, and for the human race: Inspired mainly by a scientific theory, a popular and profitable but dangerous technology was phased out. The recently-discovered and still-controversial ozone hole was not a big factor in the 1987 agreement. For once in our history, we had taken large-scale action to avert damage before the damage had become obvious. In other words, for a change we actually *thought* about what we were doing.

Paradoxically, despite this victory for scientific rationality acting in the realm of human affairs, the ozone that makes life and therefore science and shopping and clam-shell containers possible is entering severe shock. We have slipped a lot of chlorine into the stratosphere, and it won't go away anytime soon. Chlorine levels will rise for a few years, and won't return to "safe" (1975) levels until 2075 at the earliest. Our grandchildren will be proud.

Although we can make plausible predictions about future chlorine levels, we have little notion of what the future holds so far as ozone concentrations themselves are concerned. Ozone erosion is now above 4% per decade and accelerating, year-round and world-wide. We expect an extra 12 million skin cancer cases in the US, including 200,000 deaths, over the next 50 years. The ozone hole continues setting new records. In Australia, people are advised to stay covered during bad ultraviolet days. Rowland declares that "What's happening is close to our worst fears." How far will ozone concentrations fall after chlorine has remained at high levels for several more decades? Time will tell.

It is a parable for our times, and we had better pay attention now as we enter the greenhouse century. Educationally, it is the tale of an interdisciplinary problem lost among narrow disciplinary corridors. Who can teach such a subject? Who wants to teach it? Ozone depletion is an intellectually fascinating subject that resonates with fundamental topics in biology, chemistry, geology, and physics, yet how often during say 1974-1987, when the dangers were well known, did ozone find its way into our classrooms? In my own field, it is a topic that even today cannot find a place in the encylopedia of topics that we feel must be "covered" in introductory physics.

Such problems really come back to old moral issues of power, knowledge, and responsibility. When we create technologies, such as CFCs during 1930-1974, without making every effort to understand their full range of effects, we are using power without knowledge. When we consume such technologies even after possible harmful effects are known but without demanding an education about the matter, as we did with CFCs after 1974, we are using power and knowledge irresponsibly. Not surprisingly, this gets us into trouble.

## Putting science into the context of our times

Ozone is only one of many such science-related issues that educated people must consider if we are to make sense of the powerful technologies around us. How can such issues be brought to students? How can teachers deal with these interdisciplinary topics, topics on which few can claim expert knowledge? Do we dare step outside of our disciplines, should we bring in panels of experts to team-teach our classes, or will we continue just sticking to our comfortable specialties?

In my experience, it is possible, and it is stimulating for the teacher and the students, to deal seriously with these science-related interdisciplinary issues in existing introductory science courses. This can be done by a single instructor, without the complications of team teaching, if the instructor is willing to spend a little time understanding some of the issues. In my field, physics, it is difficult to blend many such topics into the technical courses for scientists, because the calender is already so full of technical topics. It is much easier to include societal and cultural topics in introductory courses for non-scientists, because these courses are not set in the stone of professionalism. These topics need not be introduced wholesale, but can be introduced gradually, adding one or two new topics each term.

Everybody's list of preferred topics will be different, but my list of physics-related topics includes:

- Scientific methodology, "how do we know?"
- Pseudo-science, including odd ideas about UFOs, astrology, and ESP, but also more culturally significant problems such as creationism and literal belief in (in other words belief in the scientific and historical accuracy of) the Bible and miracles
- Exponential growth, with examples including energy use and world population growth (which has been much faster than exponential)
- Ozone depletion

- Global warming
- Energy resources, energy supply, and the energy future
- Radioactive dating, age of Earth and the human race
- Biological effects of radiation
- Nuclear weapons
- Nuclear power
- Technological risk, quantitative risk analysis, comparison of risks

I blend these topics into my introductory liberal-arts physics course. Some topics, such as global warming, the energy future, and exponentiality, are related, and occur several times. Scientific methodology is central to the entire course and recurs throughout. Because interdisciplinary topics are easiest to include in liberal-arts science courses, it has always seemed to me to be a good idea to give all science majors a broad one-semester qualitative liberal-arts introduction to their discipline before going into technical details in the traditional introductory disciplinary course. In any case, it is a shame to fail to deal with at least some of these topics in non-majors' courses, where instructors do have flexibility in choosing topics.

As a concrete example of how one such topic might be treated, I conclude with a lecture outline on ozone depletion, suitable for a liberal-arts physics course. The outline is flexible; parts can be dropped (e.g. the thermodynamics of refrigerators), and other topics can be added or expanded (e.g. further chemical details). I have included tables and figures suitable for transparencies. Instructors who wish to include ozone in their courses and who want further information might consult some of the references in the ozone bibliography below.

Don't feel that you must be an expert on ozone to discuss it in your classes! There are no experts on these interdisciplinary problems. Some specialists might have expertise about particular facets: chemical, meteorological, physical, geological, political, historical, social, economic, psychological. But a topic like this is far too broad for any single expert. So, if anybody is going to present this topic to students, it will have to be nonexperts. Such as you.

## A lecture outline on ozone depletion

- The solar spectrum (Figure 1).
- Define "CFCs."
- CFCs are used as the working fluid for cooling systems. Use previous knowledge of heat engines to indicate, schematically, how refrigerators work (Figures 2 and 3).
- Ozone ($O_3$), its location, concentration, and function in the atmosphere.
- Composition of the atmosphere, the major and trace gases and their concentrations (Table 1).
- The two linked chemical reactions that break down ozone: $Cl + O_3 ==> ClO + O_2$, followed by $2ClO + \text{sunlight} ==> 2Cl + O_2$. Chlorine is a "helper" that participates in the reaction and is freed at the end. A single Cl can break down $10^5$ $O_3$ molecules.
- Brief history of the discovery of the CFC problem and the ozone hole (Figure 4).
- The evidence that CFCs are destroying atmospheric ozone: The correlation of atmospheric chlorine with ozone destruction over Antarctica (Figure 5). This is a good example of scientific methodology.
- The ozone-destroying chemicals in the atmosphere, their technological uses, lifetimes, and share of the problem (Table 2).
- Some of the effects of ozone depletion: 12 million additional US skin cancer cases including 200,000 additional deaths during the next 50 years (EPA estimate), eye cataracts, supression of immune system responses, decreased crop production of UV-sensitive plants, depletion of micro-organisms living near ocean's surface, threat to the Antarctic food chain.
- Brief description of the Ozone Treaty.
- Past and expected future atmospheric concentrations of chlorine, with and without the Ozone Treaty (Figure 6).
- For discussion: Are we doing enough to educate people about problems such as ozone depletion? Have students studied this or similar topics in other classes? What lessons can we learn from the ozone story; what might we have done differently? To what other problems might these lessons be applied? How should we deal with scientific uncertainty concerning the possible effects of technology?

**Table 1. Composition of the atmosphere**

| Molecule | Concentration |
|---|---|
| **Major constituents:** | |
| $N_2$ | 78.084 % |
| $O_2$ | 20.946 % |
| A | 00.934 % |
| total | 99.964 % |
| **Trace gases (in ppm*):** | |
| $CO_2$ | 330 ppm |
| $H_2O$ | 20-20,000 |
| Ne | 12 |
| He | 5 |
| $NO_2$ | 2 |
| $CH_4$ | 2 |
| $NO_2$ | 2 |
| Xe | 2 |
| $NO_2$ | 2 |
| $O_3$ | 1-2 |
| Kr | 1 |
| $H_2$ | < 1 |
| NO | < 1 |
| CO | < 1 |
| $N_2O$ | < 1 |
| $SO_2$ | < 1 |
| $NH_3$ | < 1 |

* Parts per million.
1 ppm = 0.0001% = 0.000001

**Table 2. Ozone-destroying chemicals in the atmosphere**

| Chemical | Uses | Lifetime in atm | Share of problem | US share of use |
|---|---|---|---|---|
| CFC-11 | coolant, aerosol, foam | 60 yr | 28% | 22% |
| CFC-12 | coolant, aerosol, foam | 130 yr | 47% | 30% |
| CFC-113 | solvent | 90 yr | 5% | 45% |
| Carbon tetrachloride | solvent | 50 yr | 15% | 27% |
| Methyl chloroform | solvent | 7 yr | 2% | 50% |
| Halon 1211 | coolant, foam | 25 yr | 1% | 25% |
| Halon 1301 | fire extinguisher | 110 yr | 2% | 50% |

Source: United States Office of Technology Assessment

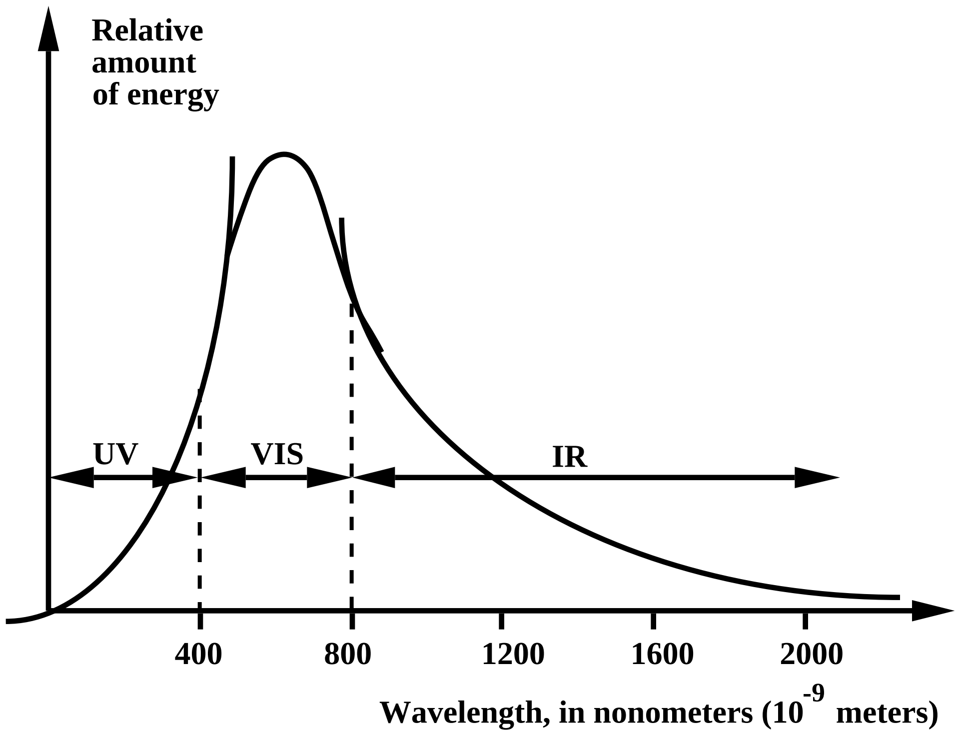


*Figure 1. The relative amounts of energy at different wavelengths in the solar spectrum. The human eye has evolved to take maximum advantage of the peak in the solar spectrum, and is in fact most sensitive at the yellow-green wavelengths at the peak of the solar spectrum. Infrared rays, created by thermal motions in the sun's surface, are the rays that warm you. Ultraviolet rays, created by higher-energy electron transitions within atoms in the sun's surface, are the rays that sunburn you.*

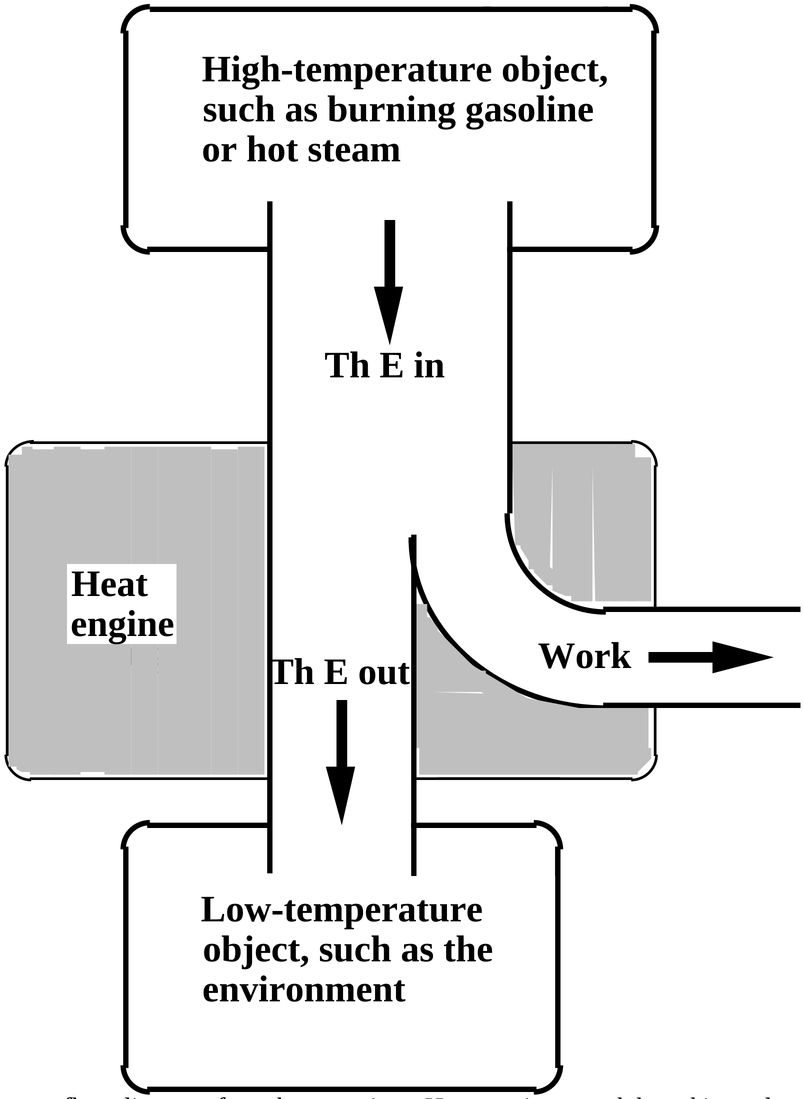


*Figure 2. Energy-flow diagram for a heat engine. Heat engines work by taking advantage of the natural tendancy of thermal energy to flow from higher temperatures to lower temperatures. According to the second law of thermodynamics, a certain fraction of this energy can be "shunted aside" to do useful (i.e. macroscopic) work. Compare with Figure 3.*

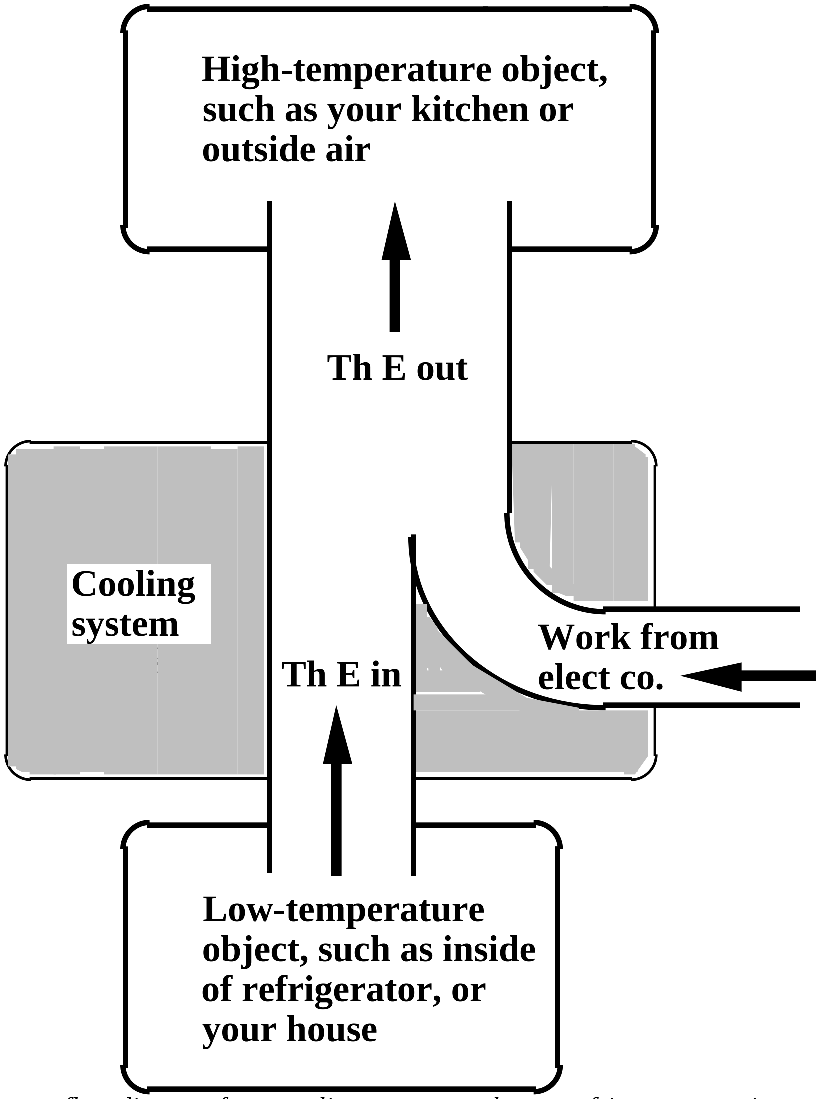


*Figure 3. Energy-flow diagram for a cooling system, such as a refrigerator or air conditioner. Cooling systems act like heat engines in reverse. An outside energy source does work to push thermal energy "uphill," removing it from the refrigerator and delivering it to the kitchen. For air conditioners, the low-temperature region is your house. "Heat pumps" to warm your house also work this way; the low-temperature region is the cold outside air and the high-temperature region is the inside of your house.*

**Figure not available in web version**

*Figure 4. Atmospheric chemist Susan Solomon, a key player in the ozone story. She organized the first National Ozone Expedition in 1986, which found evidence that the hole in the ozone over Antarctica was growing larger and that ozone-destroying agents were present. A second, and larger, National Ozone Expedition was organized in 1987 by NASA, the National Oceanic and Atmospheric Administration, and several other national and international organizations. The suggestion, based on evidence from the first expedition, that the ozone hole is caused by chlorine chemistry, was confirmed by the second expedition. From* National Science Foundation Mosaic, *Fall/Winter 1988.*

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*Figure 5. Evidence of chlorine chemistry at work in the Antarctic stratosphere. Panel **a** shows ozone (light graph) and chlorine monoxide (dark graph) concentrations measured by the second National Ozone Expedition on 23 August 1987. These measurements, taken at the end of the Antarctic winter, show ClO levels increasing sharply south of 65$^o$ S, while ozone levels are flat and uncorrelated with ClO. Panel **b** shows concentrations of the two species on 16 September, after the sun has risen at the end of the Antractic winter. Ozone concentrations are now severely depleted south of 67$^o$ S, and concentrations of the two species are inversely correlated. Source:* Physics Today, *August 1988, p. 21.*

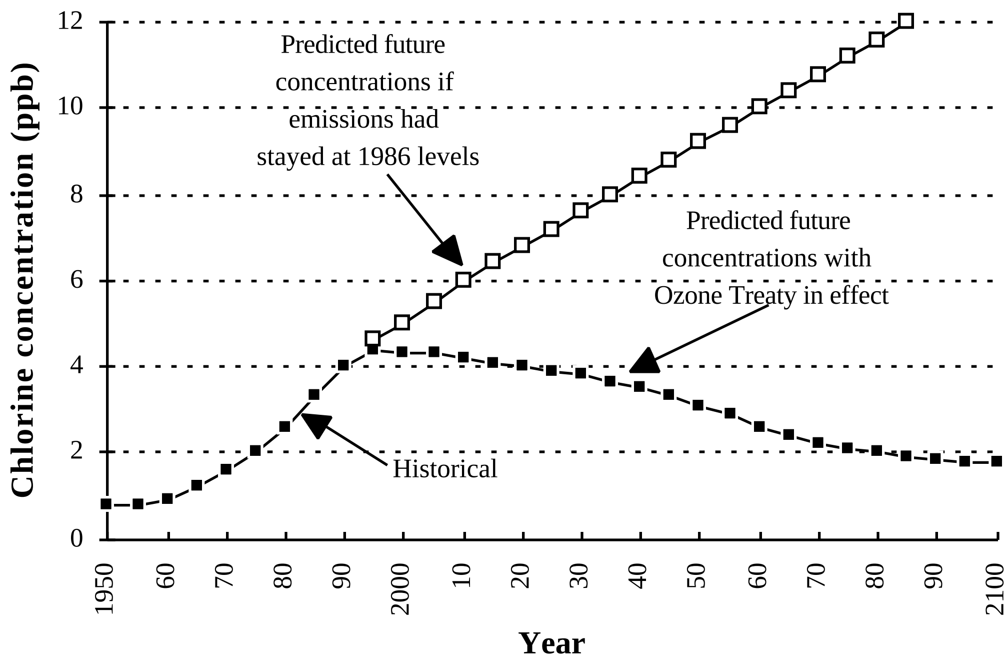


*Figure 6. The effect of the Ozone Treaty on atmospheric chlorine concentrations. Concentrations are in parts per billion. Even though CFCs and other ozone-destroying chemicals will be nearly phased out by 2000 AD, chlorine concentrations will remain above 2 parts per billion until 2075. Because the first observed effects, in the Antactic, occurred when the global chlorine concentration reached about 2 ppb, this is sometimes assumed to be the "safe" level. Source: US Office of Technology Assessment.*

**An annotated bibliography on ozone depletion, for science teachers**


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**Figure captions, Hobson.**

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