Chapter 27

Greenhouses of Salt

In This Chapter

- Solar energy warms Earth beneficently
- The atmosphere balances energy coming in with energy flowing out
- The greenhouse effect is increasing because of human contributions
- The ozone hole over Antarctica admits solar ultraviolet at certain times of year
- Controlling the release of Freons and certain other gases should heal the ozone hole

We may get an occasional cold wave in many parts of the United States, with temperatures of 0°F (–18°C), but on the whole, the temperature is within a comfortable range. Earth is warmed by energy from the Sun. But a steady contribution from trapped radiation—the "greenhouse effect"—also makes life on Earth possible for us. Many people are now worried that too much of a good thing may be upon us. Also, an entirely separate effect, the ozone hole, opens over Antarctica each Antarctic springtime and sometimes extends farther north.

Energy In and Out

Most things in the universe are in a state of balance. Without this condition of equilibrium, everything would be changing all around us. For example, the Sun itself is in balance, with gravity pulling inward on its gas at the same strength as pressure from its internal energy pushes out.

In the Earth's atmosphere, we have a balance. Energy from the Sun comes in, and energy from the Earth goes out. If the energy balance is not exact, then the Earth's atmosphere would heat up or would cool down. We know we are more or less in balance each year since we don't see a major trend in temperature. But serious investigation seems to be showing that there is, in fact, a slight trend in temperature. We may not notice it year to year, given the natural variation in temperature and climate, but over decades or a century, it looks as though it will amount to quite a significant effect.

Planetary scientists can calculate what the temperature of the Earth should be, given the value of the solar constant and the Earth's distance from the Sun. They merely compare the energy coming in with the energy going out. The energy coming in is the solar constant times the area of the Earth's disk. The energy going out follows the same black-body law of temperature that the Sun itself follows. The hotter an object is, the more total energy it gives out.

We can consider the energy balance of Earth. Let us first imagine that the Earth had no atmosphere. Then Earth's surface would merely heat up until it radiated the same amount of energy coming in. It is easy for physicists to calculate that temperature. The planet would be very cold—too cold for us to be comfortable on Earth.

But we can measure the Earth's average temperature, and it comes out about 60°F (33°C) warmer than the temperature we would have without an atmosphere. We are warmed by the presence of the atmosphere to the livable Earth climate that we have.

The Terrestrial Greenhouse

How does the atmosphere do this warming? It does so by trapping the solar radiation. But we know that the atmosphere is transparent to incoming sunlight. The trick is that Earth itself transforms the sunlight from the incoming wavelengths to wavelengths that don't pass through the atmosphere.

Let us return to our toaster, which we used as an example in Chapter 8. When you turn it on, it glows faintly and then eventually glows red hot. Objects that are being heated from cold temperatures start radiating most of their energy in the infrared. As they are heated, more of the energy is given off at shorter infrared wavelengths. Some even appears in the longer part of the visible spectrum, the red. Eventually, if we heated an object to the 11,000°F (6,000°C) or so temperature of the Sun, most of the energy would appear in the visible, centered in the yellow and green part of the spectrum.

Greenhouse Gases

But for terrestrial temperatures, most of the energy is in the infrared. The sunlight comes through Earth's atmosphere, which is transparent at the yellow and green wavelengths where the Sun gives off most of its energy. Then the Earth's surface heats up and radiates mostly in the infrared. Something in the Earth's atmosphere keeps that infrared radiation from getting through. Eventually, the atmosphere heats up sufficiently that just enough infrared energy gets out to balance the incoming visible radiation. And that is where our atmosphere sits.

What traps so much of the infrared radiation? It has to be some gas or gases in our atmosphere. The gas that captures most of the outgoing radiation is water vapor. And infrared radiation is also strongly absorbed by the gas carbon dioxide. The carbon dioxide absorption fills the gaps in the spectrum of water vapor through which infrared would otherwise get out. Between the two gases, little infrared escapes. Increasing the "greenhouse gases," especially carbon dioxide, warms the atmosphere enough so it holds more water vapor.

The spectrum of carbon dioxide shows some strong spectral lines in the visible. In fact, for molecules, the absorption is spread over a range of wavelengths rather than being at narrower bands of wavelengths, as for ordinary atoms. We thus speak of molecular bands, the wide ranges of wavelengths that molecules absorb. Because the molecular bands are broad, infrared energy from the warm Earth doesn't get out.

Fun Sun Facts

The Earth's atmosphere is about 75 percent nitrogen molecules and about 20 percent oxygen molecules. It is the oxygen that we breathe. The rest includes carbon dioxide and various other gases, to lesser percentages.

Not Your Ordinary Greenhouse

How do we describe the trapping effect of the Earth's atmosphere for infrared radiation emitted by the Earth's surface? People make an inaccurate analogy to a greenhouse on Earth, where the air inside the greenhouse is warmer than the air outside. It is easy to think that a terrestrial greenhouse is warm because its glass absorbs infrared. If that were so, we could say that solar energy passes through the glass—which is transparent

> **Fun Sun Facts**
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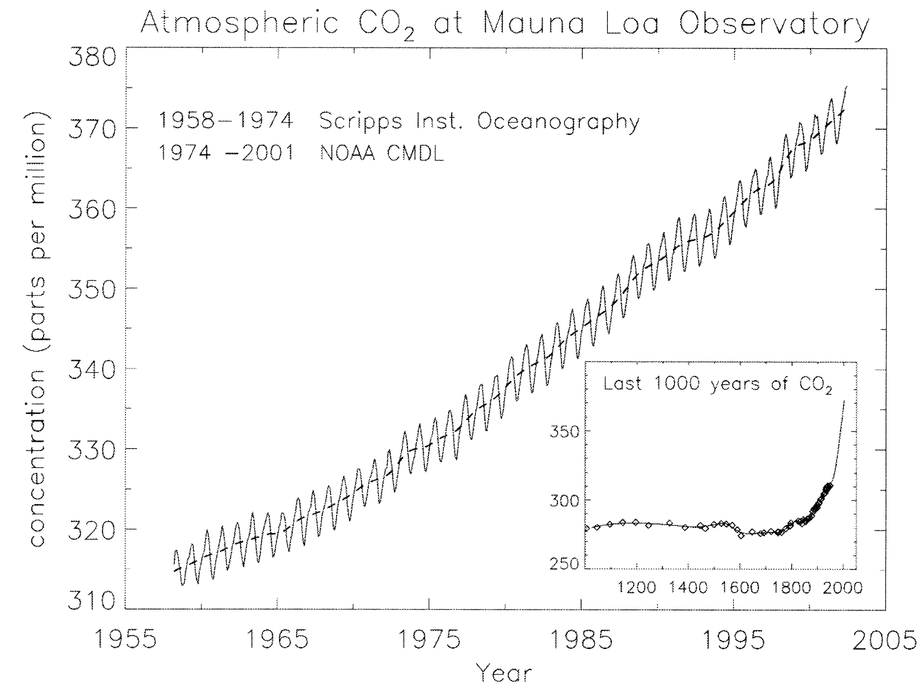
> If you were to make a greenhouse out of salt, which is transparent in the infrared, it would still heat up. This test proves that infrared blocking isn't heating the air inside a greenhouse on Earth. Thus terrestrial greenhouses aren't warmed by the "greenhouse effect."

in the visible—that it heats up the ground, tables, plants, and whatever else is inside until they radiate in the infrared, and that then the infrared is trapped. (Even so, eventually, the energy getting out must balance the energy coming in, and the temperature stabilizes at a new, higher, level.) Unfortunately for this easy analogy, that isn't the major effect for a terrestrial greenhouse. Greenhouses on Earth get warmer inside primarily because the surface keeps outside air, which we can think of as wind, from mixing the warm air that is formed inside with cooler outside air.



The percentage of carbon dioxide in our Earth's atmosphere has doubled in the last hundred years or so and continues to rise year by year. (The graph shows a yearly cycle, but the trend is clearly strongly upward.) These observations continue to be made at the Mauna Loa Observatory in Hawaii.

(Pieter Tans, NOAA)

> **The Solar Scoop**
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> A team of scientists with which I work has found signs of global warming on both Neptune's moon Triton and Pluto. We watched Triton and Pluto pass in front of stars and carefully measured the rate at which their atmospheres dimmed the starlight.

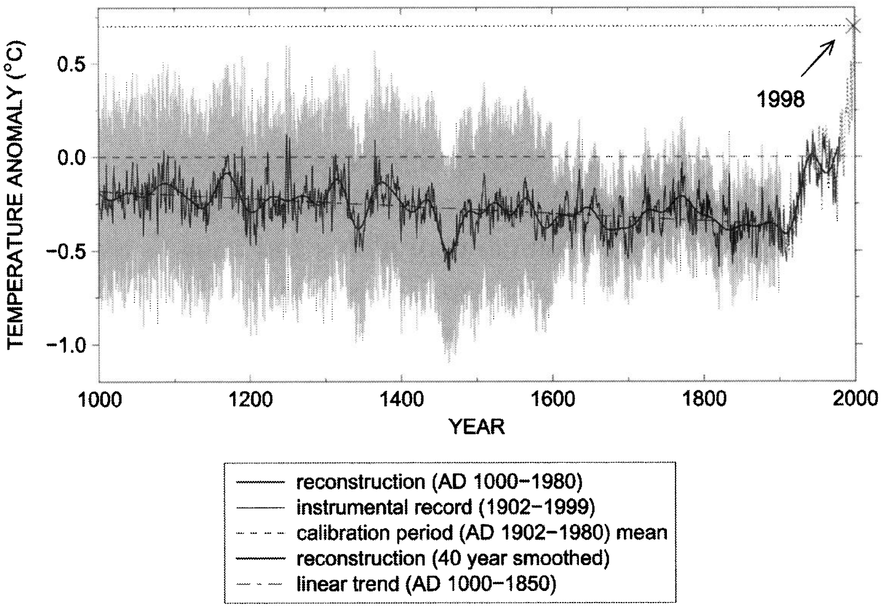
Whether or not the effect is the same in the Earth's atmosphere as it is for an actual greenhouse, the trapping effect is known as the *greenhouse effect.* The greenhouse effect works on other planets as well as on the Earth.

The importance of the greenhouse effect was realized in part by studying the atmospheres of the planets Venus and Mars. Studying them helped show that our models for how planetary atmospheres were affected by various changes were correct. For example, substances suspended in the air—sulfates for Venus and dust for Mars—have effects on global warming.

Sun Words

The **greenhouse effect** occurs when incoming sunlight passes through a transparent atmosphere and is transformed to infrared radiation that is partly blocked from escaping by the atmosphere. Global warming is the upward trend in temperature. Most scientists have concluded that most of it comes from the greenhouse effect caused by human contributions of carbon dioxide and other gases to the Earth's atmosphere.

A runaway greenhouse effect, like that on Venus, occurs when the blocking in the infrared is so severe that the atmosphere heats up drastically.



Earth's average temperature over the last millennium. The rise in the last century appears to be too much to come from natural causes. The scientific consensus is that much of it is from the greenhouse effect caused by carbon dioxide introduced into our atmosphere by us humans.

(Michael E. Mann, DES, U. Virginia)

Venus's atmosphere is 96 percent carbon dioxide, and its greenhouse effect is therefore much more significant than Earth's. The temperature on Venus reaches about 900°F (about 500°C), hot enough to melt lead. It is a hellish atmosphere now, perhaps with rain of sulfuric-acid droplets to make it even worse than it would be with merely the high temperature. Nobody has suggested that our Earth's greenhouse effect would run away the way Venus's did. That's a good thing, because though Venus and Earth are near twins in terms of size, we don't want to

Solar Scribblings

Billions of years ago, Venus's atmosphere was probably very nice. Perhaps life even evolved there. Though most efforts have been placed on searching for life on Mars, or even on Jupiter's moon Europa, a few people wonder whether life arose long ago on Venus and is surviving deep underground or in clouds.

become like Venus. Studying the atmospheres of Venus and Mars helps us understand our own atmosphere. Though nothing so totally hellish as Venus is likely, global warming could make extra greenhouse gases slowly evaporate from frozen arctic soil and seabed muck, bringing yet more warming and vast harm.

We Are Changing Our Atmosphere

Since the beginning of the Industrial Revolution on Earth about 200 years ago, we humans have been sending greenhouse gases into our atmosphere. The largest contribution is the gas carbon dioxide, the byproduct of many burning processes and engines. A secondary greenhouse gas is methane. The absorption bands in its spectrum tend to plug up some of the gaps in the absorption bands in the spectrum of carbon dioxide. The windows of transparency in the infrared between absorption bands of carbon dioxide are closed by the absorption by methane.

Solar Scribblings

Many sources of greenhouse gases are natural. Carbon dioxide and methane are given off by decaying plants, for example. Cows give off methane in their flatulence, after digesting their food. So we can't cut off all sources of greenhouse gases, but we can limit the amount that humans contribute.

The Solar Scoop

The Earth may have gotten most of its water from comets. Billions of years ago, the rate of comets hitting the Earth was a lot higher than it is now, and they carried tons of water.

A major source of greenhouse gases now comes from fossil fuels. These fuels—chiefly oil, gas, and coal—are today's remnants of plants and animals that died millions of years ago. The remains were transformed into oil, gas, and coal, which we can now mine. But using these fossil fuels releases carbon dioxide into the atmosphere. The amount of carbon dioxide in the atmosphere has increased greatly over the past couple of centuries.

Finding two things that both increase and decrease at the same time doesn't necessarily mean that one causes the other. But there are persuasive links between the amount of carbon dioxide in the atmosphere and the Earth's overall temperature. Still, there are other possible contributions. Changes in the solar constant over time are something to consider. The measurements of the solar constant find a variation of about 0.1 percent over the sunspot cycle, but perhaps there has also been a variation of some tenths of a percent over centuries.

Can the increase that has been measured in the Earth's average temperature be attributed to changes in the solar constant rather than the greenhouse effect? Though a handful of scientists disagree, the overwhelming consensus is that the link between the greenhouse effect and the Earth's average temperature is definite. Careful consideration indicates that much of the gain in the Earth's average temperature measured in the past half century comes from carbon dioxide and other gases that humans have injected into the Earth's atmosphere, largely through burning fossil fuels.

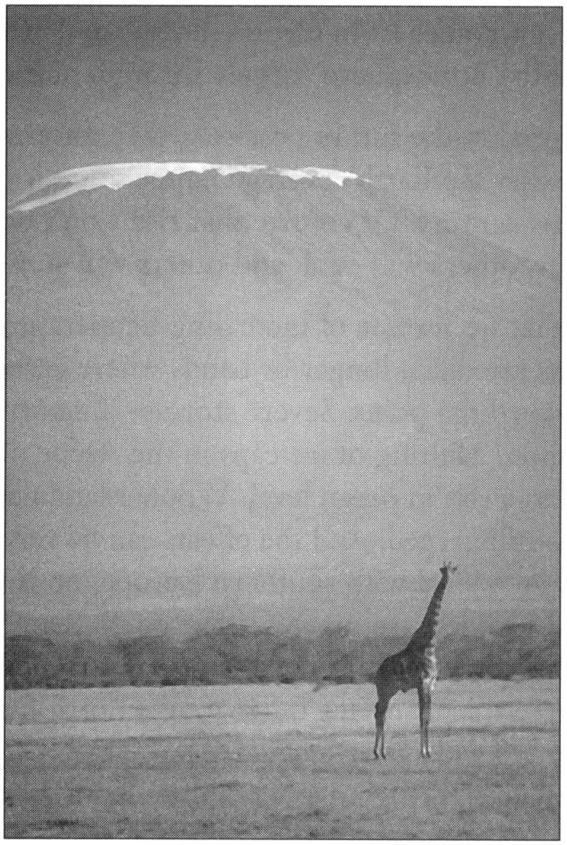
While it is hard to predict the future precisely, the consensus, based mainly on supercomputer studies, is that the Earth's average temperature is likely to rise several degrees by the the end of this century. Of course, that rise won't be uniform; some places will become a lot warmer, others will cool, and others will stay the same.

The consequences that we foresee of increasing temperature can be severe. It isn't just that growing seasons are made longer or bands where certain crops or other plants grow are pushed toward the poles. Severe storms—hurricanes and tornadoes—may become more common. Melting of ice caps in the Arctic or Antarctic and warming of the oceans will lead to a rise in ocean level. Whole island nations and coastal regions of other nations will be submerged. And the effects can be very widespread. Little realized is that New York is on a level with southern Europe, on the same latitude as Madrid. Cities like Paris and London are much farther north than New York, yet they have similar climates. The northern European cities are warmed by winds crossing the Atlantic Ocean, where warm surface water moves north from the tropics (the Gulf Stream), then cools and sinks near Iceland. Many scientists think that global warming could halt this circulation, bringing a big chill to lands all around the North Atlantic.

Sometimes a few particular examples drive home a point better than even strong general warnings. A photograph of open water at the North Pole did so. It turned out that pack ice drifts about, and it has long been common to find open water at that cardinal point; however, it is true that the thickness of the northern polar ice cap has diminished by a factor of 2 in a decade. Glaciers in Alaska and the Alps and elsewhere are retreating and may soon disappear. Even Mt. Kilimanjaro, the tall mountain standing on the equator in Africa, famous for its ice cap in Hemingway's *The Snows of Kilimanjaro*, may soon be bare.

What Can We Do?

How can we limit our human contribution to greenhouse warming? International meetings are devoted to the topic. There is widespread consensus that our use of fossil fuels must be limited. But the economic consequences of such limiting can be debated, and political questions arise over just how much we should do now. And can we compensate for greenhouse gases by planting trees, since trees take in carbon dioxide and give out oxygen? The emissions and absorptions by trees are undergoing increased scrutiny. Cutting down forests, for example, can leave a lot of material on the ground to decay, releasing its carbon dioxide into the atmosphere.



Africa's Mount Kilimanjaro. Its perennial ice cap may melt in a decade or so, as a result of global warming.

(Jay M. Pasachoff)

The Solar Scoop

A 1997 treaty was negotiated in Kyoto, Japan, specifying how nations should cut emissions of carbon dioxide and other greenhouse gases. Several international meetings have been held since on how to carry out this Kyoto Protocol. But the matter has become very politicized. The United States, in particular, has refused to ratify the Protocol. One issue raised especially by the United States is whether developed countries should be held to the same standards as the developing world.

Energy sources that do not contribute greenhouse gases should be adopted. Energy directly from the Sun causes the wind to blow and the tides to come in and out. Wind farms and tidal stations are being developed all over the world. But these currently are on a much smaller scale than the many fossil fuel power plants.

Direct usage of solar energy is increasing. Solar cells exist that take in solar energy and put out electricity. But they currently are so expensive to make that, even though they cost nothing to use, the total cost of energy using solar cells is prohibitive except for isolated locations where it is expensive to install power lines.

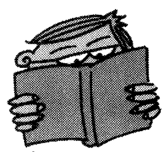
Nuclear energy, which provides over 15 percent of Earth's energy needs, is the sole major method of providing a lot of energy without giving off greenhouse gases. Many scientists think that nuclear energy usage should be increased for this reason and that the objections to the storage of nuclear waste products are overblown. But these objections are widespread, and there is a significant "nuclear fear," to use a psychological term popularized and explained by historian of science Spencer Weart. Nuclear proliferation issues, with worries that nuclear reactors could provide material for nuclear bombs, are also important. And there are fears of exploding reactors, with the Chernobyl runaway historically being the major nuclear debacle.

The holy grail for many people is nuclear fusion, the process that fuels the Sun and the stars. In fusion, hydrogen itself is the fuel, and the oceans are full of it as part of each molecule of water: H_2O. Some major international research projects are underway to develop fusion reactors. But what the Sun does easily 93 million miles from us is hard to reproduce on Earth. There are those who say, "Fusion is 50 years in the future, and always will be." Let us hope that this cynical comment is wrong.

Hole in the Sky

The people of Puenta Arenas, Chile, bundle up when they go out. But they bundle up whenever they are in the Sun, especially in their springtime. They slather themselves with highly absorbent suntan lotions. (Spring, at their southern-hemisphere location, is in September and October.) They are concerned less with the cold than with the ultraviolet radiation that is coming from the Sun. For they are in one of the prime cities troubled with what has come to be called the *ozone hole.*

Ozone is a simple gas, a form of oxygen. Whereas the oxygen that we breathe is the O_2 oxygen molecule, ozone is O_3. This ozone molecule has both favorable and unfavorable consequences for us on Earth. At ground level, the ozone is a pollutant that we find, for example, in automobile exhaust. It isn't good to breathe. But high in the atmosphere, at an altitude of about 25 miles, a layer of ozone protects us from the Sun. This ozone layer absorbs the ultraviolet light that would otherwise come through to hit us, increasing skin cancer and other problems.



Sun Words

The **ozone hole** is a thinning of the ozone seen in the Antarctic region each southern-hemisphere spring. It results from the breakdown of ozone molecules by chlorofluorocarbons, or CFCs.

Scientists Sherwood Rowland, Mario Molina, and Paul Crutzen received the 1995 Nobel Prize in Chemistry for their work on the ozone hole. Crutzen did the basic chemistry about how ozone is formed and decomposes in the atmosphere. Rowland and Molena noted the threat to the ozone layer based on Freons in the atmosphere. They published an article about it in 1974, and some limitations on Freons resulted. A major shock then came in 1985, when Joseph Farman and colleagues in England realized that measurements over Earth's South Pole started showing a drop in ozone content around 1980. The ozone level dropped year by year in an increasingly wide area. The region of low ozone came to be called the ozone hole, though it is a hole in only a figurative sense—similar to our astronomical use of the term *window of transparency*, referring to a wavelength band.

Fun Sun Facts

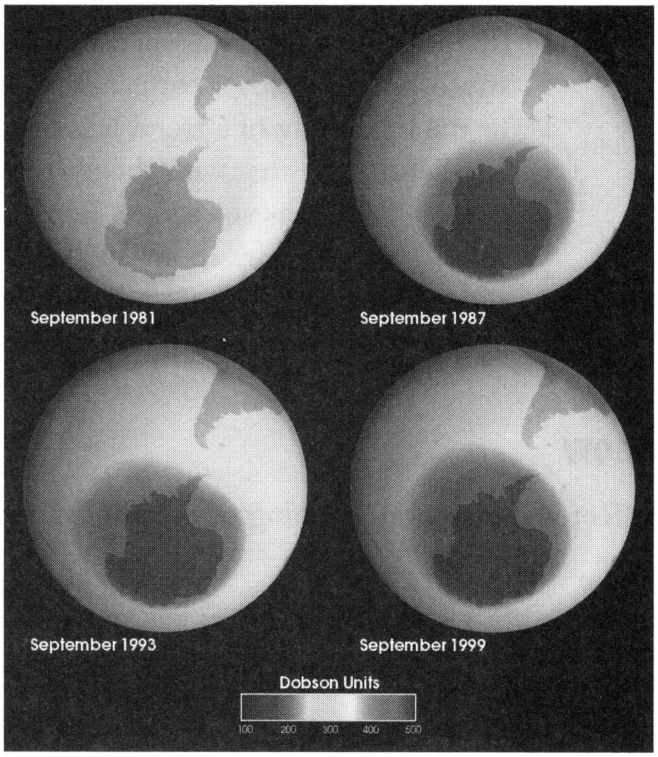
Ultraviolet is the name given to wavelengths shorter than about 4,000 Å, just short of the blue, and extending down to x-rays at about 100 Å. The ultraviolet between about 3,000 Å and 4,000 Å comes through our atmosphere, although we can't see it with our eyes, except for a glimpse of the extreme long-wavelength end. That radiation gives us our suntans. UV-A is from 4,000 Å down to 3,200 Å. UV-B is from about 3,200 Å down to 2,900 Å. When you buy sunglasses, look for pairs that are certified to block 99 percent of both UV-A and UV-B, to impede the passage of ultraviolet that can eventually lead to cataracts. The ozone completely blocks over 90 percent of the UV-B as well as even shorter wavelengths of ultraviolet, those shorter than 2,900 Å, known as UV-C.

NASA has an ambitious program of monitoring ozone. Several satellites take measurements of ozone on a daily basis, and the results are available for all to see on the web. Analysis of the process has shown that certain molecules rise into the stratosphere and that they attack ozone molecules, breaking them apart. The chief set of culprits are molecules known as chlorofluorocarbons. These are molecules that contain chlorine ("chloro-"), fluorine, and carbon atoms. (Freon is a common trade name for them.) The molecules were discovered in the 1930s and were thought to be inert—that is, unchanging. Therefore, they were considered harmless when they were used for many purposes, especially refrigeration and air conditioning. The discovery in the 1970s that they broke apart stratospheric ozone came as a shock.

Other gases also affect the ozone layer when they get up there. Halons are a serious problem as well. Some fire-fighting systems—such as those in libraries, where flooding with water would be disastrous—use these halons, which are compounds based on bromine rather than on fluorine.

We now know that the CFCs and halons aren't entirely inert. They break down when they get into the stratosphere. Then the chlorine and bromine atoms interact with the ozone molecules, breaking them down into oxygen, chlorine-oxygen molecules, and so on. These new molecules do not have ultraviolet-absorbing power.

The ozone hole is the result of what happens during the long, cold Antarctic winter. Ice crystals form in the air, and the molecules that arose from breaking down CFCs and halons attach themselves to the ice crystals. When sunlight hits these cold crystals each Antarctic spring, as the months-long nighttime ends, it starts chemical processes that break down the ozone very efficiently. Atoms such as chlorine, which break down the ozone, are left over after each reaction to break down still more ozone. Both sunlight (and its variation over the seasons) and the interacting molecules and atoms are needed to make this effect. The more CFCs and halons there are in the atmosphere, the deeper the ozone hole can become and the farther north of Antarctica it can extend.



The growth of the spring Antarctic ozone hole.

(NASA's GSFC)

The ozone hole has been restricted to southern regions—at least, so far. Though some drop in atmospheric ozone has been detected over northern polar regions in northern hemisphere spring, the effect has never been as deep as it has been in the southern hemisphere. Most scientists, therefore, have not given the name "ozone hole" to the northern effect.

Many steps have been taken to control the release of CFCs. For example, they were often used in propellants in cans of things like shaving cream. They have been replaced by compressed air or by other gases for that purpose. Newer air conditioners substitute other molecules for CFCs. These substitute molecules are apparently not as efficient as refrigerants, but they are safer for the environment. The use of CFCs in making computer chips is being better controlled as well.

Steps also are being taken to keep CFCs already in use from making their way into the upper atmosphere. For example, recycling is required for the CFCs in car air conditioners. Use of CFCs in household air conditioners and refrigerators is restricted, though use of recycled CFCs as opposed to newly made ones can continue until 2020.

Fun Sun Facts

Ozone in the atmosphere is measured in Dobson units. G. M. B. Dobson was a British atmospheric physicist. Each Dobson unit gives the amount of ozone in a column that is 1 cm^2 in size and that extends upward through the entire atmosphere.

The ozone hole got bigger year by year through 2001. Strangely, the 2002 hole did not continue that sequence. It split in two parts and never got as deep as preceding years. But whether that is an aberration (theories for why it was special, based on an unusual stratospheric weather pattern, have been advanced) or the beginning of a trend remains to be seen. Predictions are that with the current steps taken to control the release of ozone, Earth's ozone layer should be healed by about 2050. That would be a success story for the reclamation of part of our damaged environment as the result of scientific vigilance.

The Least You Need to Know

- The greenhouse effect is the natural warming of the atmosphere by trapping sunlight.
- The greenhouse effect is life-giving on Earth but has run away on Venus.
- Human-caused contributions of carbon dioxide have increased the greenhouse effect.
- The ozone hole is caused by sunlight hitting chlorofluorocarbon molecules in the cold Antarctic air each spring.
- Steps taken to limit ozone-depleting gases, such as Freons, should heal the ozone hole.