Atmospheric Reactions and Pollution

12.4

Section Preview/ Specific Expectations

In this section, you will

- **explain** Canadian initiatives to improve air quality
- **communicate** your understanding of the following terms: *chlorofluorocarbons (CFCs), Montréal Protocol*

It is a warm summer weekend, so you decide to visit a national park. It is nice to be away from all that pollution. But are you bringing the pollution with you? Take a look at Figure 12.18. How did these campers get to the park? Cars and buses release gaseous pollution into the air. On the other hand, what would it be like to live without vehicles? Can we compromise in a way that protects the environment while maintaining a reasonable standard of living?

Figure 12.18 **These campers are enjoying the environment, but they are harming it at the same time. How?**

Fortunately many people are now aware of issues such as pollution from car exhaust and ozone depletion. At the same time, Canadian chemical and related industries employ about 250 000 people and generate tens of billions of dollars annually. These industries make the products that entertain, feed, clothe, and keep Canadians comfortable. When discussing atmospheric chemistry and pollution, we must consider two important influences: the economy and the environment.

In this section, you will look at the chemistry that takes place among the gases in the atmosphere. You will examine an important gas called ozone and the pollutants that affect this gas.

Gas Chemistry in the Atmosphere

Many important chemical reactions take place in the atmosphere. All these reactions involve gases. There are two main types of gas chemistry in the atmosphere:

- interactions between gases already present in the atmosphere
- interactions between atmospheric gases and gases produced by processes on Earth

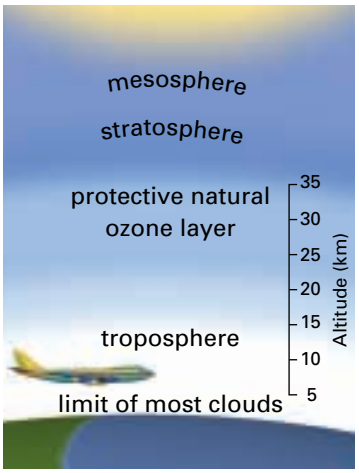

Figure 12.20 Most ozone is located about 25 km above Earth's surface. This is a very thin level, however. If all the ozone in the atmosphere were compressed, it would be only a few millimetres thick.

The Ozone Cycle

High in the atmosphere, a gas called ozone, O_3, absorbs ultraviolet (UV) radiation from the Sun. The radiation separates the ozone into oxygen gas, O_2, and an oxygen atom. After passing through a few more steps, ozone is re-formed when molecules of oxygen gas combine with oxygen atoms. By absorbing energy from the Sun in this way, ozone prevents harmful UV radiation from reaching Earth's surface. Figure 12.19 illustrates the cycle that occurs as ozone is formed, absorbs UV radiation, and breaks up. Figure 12.20 shows where ozone is located in the atmosphere.

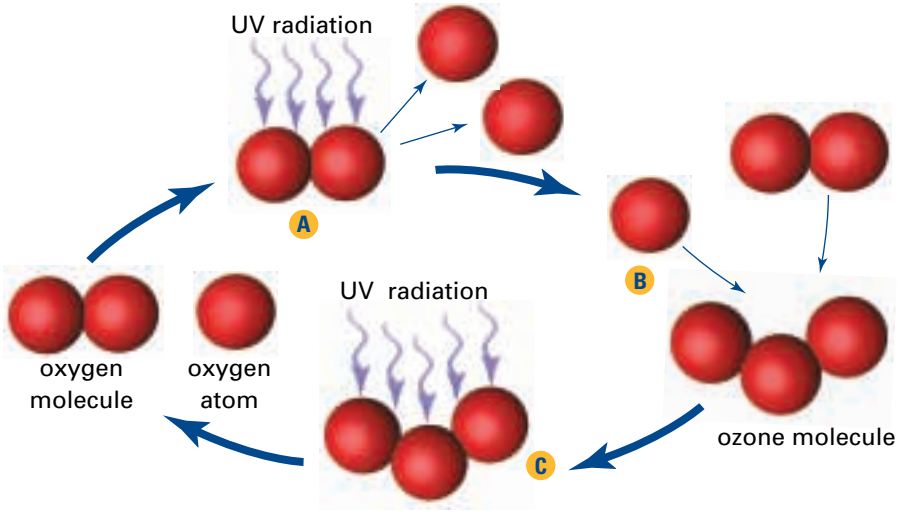

Figure 12.19 The ozone cycle: (A) Oxygen gas in the atmosphere absorbs energy from the Sun. Each oxygen molecule breaks up into two oxygen atoms. (B) An oxygen atom combines with a molecule of oxygen gas to form ozone. Another molecule is needed to absorb extra energy. (C) Ozone absorbs ultraviolet radiation and breaks up again into oxygen gas and an oxygen atom.

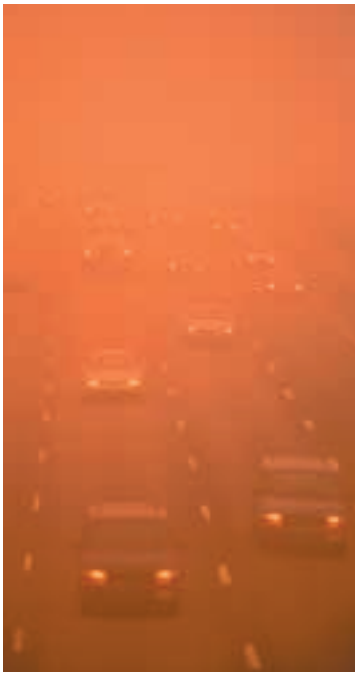

Figure 12.21 Smog was originally defined as a mixture of smoke and fog. Today it can also be photochemical, caused by sunlight breaking down air pollutants.

Pollutants in the Atmosphere

Gases from living and non-living processes on Earth's surface interact with the gases in the atmosphere. For example, oxygen and carbon dioxide in the air are involved in animal and plant respiration. A forest fire burns plants to produce carbon dioxide gas. On a more damaging level, human technology and industrial processes produce many polluting gases. As you will learn in Chapter 14, burning fossil fuels is a major source of gas pollution in the atmosphere.

Chlorofluorocarbons (CFCs) are an important class of polluting gases that are not usually caused by burning fossil fuels. CFCs are stable and harmless near the ground. When they make their way up into the atmosphere, however, they interact and interfere with atmospheric processes. In particular, these gases interfere with the production and reactions of ozone, O_3. You will learn more about CFCs later in this section.

Ozone Near the Ground

Ozone does not only exist high up in the stratosphere. It is also present much closer to us, in the *troposphere*: the layer of the atmosphere that lies directly over Earth. Ozone near the ground is largely produced when nitrogen oxide gas from car and truck exhaust fumes reacts with oxygen gas in sunlight. Ozone is a major component of smog in cities. (See Figure 12.21.)

At this level, ozone is a pollutant with a harsh odour. In humans and animals, it causes respiratory problems, including coughing, wheezing, and eye irritation. It retards plant growth, reduces the productivity of crops, and damages forests. Concentrations of ozone as low as 0.1 ppm (parts per million) can decrease photosynthesis by 50%. In addition, it damages plastics, breaks down rubber, and corrodes metals.

Careers in Chemistry

Environmental Technician

Gases in the atmosphere (such as carbon dioxide and methane) allow heat from the Sun to enter the atmosphere and prevent it from leaving again. This is called the *greenhouse effect*. Thanks to the greenhouse effect, Earth remains fairly warm, with an average temperature of about 15.5°C. Without this effect, Earth's temperature would be about –18°C.

Human activities over the last hundred years have caused the level of carbon dioxide and other gases in the atmosphere to increase. As a result, more heat is trapped in Earth's atmosphere. According to Environment Canada, Canada's average temperature has risen by about 1°C over the last century. This is causing more frequent and more intense winter storms.

Change from the Ground Up

How can we decrease the production of greenhouse gases? One way is to focus on the sources of these gases. As global warming increases, chemists who study atmospheric processes will be more in demand.

Change begins with accurate measurements. Environmental technicians assess and monitor pollution levels in air, water, and soil. To become an environmental technician, you need a high school diploma, with advanced-level credits in mathematics, English, and science (preferably chemistry or physics). You also need a two- or three-year community college program in environmental technology.

Environmental technicians gather gas samples from smokestacks and PCBs from transformers. They also set up equipment in the field to create baseline studies and monitor changes in the environment.

Make Career Connections

Human Resource Development Canada has offices in every province. It also has a web site where you can access descriptions and requirements for many careers, including that of environmental technician. What other environmental career opportunities can you locate? Prepare a brief report of your findings, and present it to the class.

CFCs and Ozone Depletion

As you learned earlier, **chlorofluorocarbons (CFCs)** are chemicals that interfere with the ozone cycle high up in the atmosphere. CFCs are non-toxic, nonflammable compounds that contain atoms of chlorine, carbon, and fluorine. These gases are human-made compounds that were released into the atmosphere primarily from refrigeration and aerosol devices.

In 1928, Thomas Midgley invented the first CFC compound. Because they were useful but safe, they were referred to as "miracle compounds." In particular, dichlorodifluoromethane, CCl_2F_2, also known as Freon, was discovered to be an efficient refrigerant.

Figure 12.22 **CFCs have been used as refrigerants, coolants in home and automobile air conditioners, and propellants in aerosol containers such as hair sprays.**

Because of Freon, household refrigeration became common. In fact, much of our modern-day life style first became possible because of CFCs. By 1974, millions of tonnes of CFCs had been produced (see Figure 12.22). At the University of California, chemists F. Sherwood Rowland and Mario Molina began to wonder where all of these CFCs ended up. They realized that CFCs are chemically very stable. However, they began to calculate what happens when CFCs are exposed to high levels of radiation far up in the atmosphere. As it turned out, their fears were well-founded. In 1985, British scientists in the Antarctic noticed a large decrease in the ozone layer above the Antarctic. A "hole" in the ozone layer was beginning to form. In 1995, Rowland and Molina, along with a third ozone scientist, won the Nobel Prize for their work with CFCs.

How CFCs Attack Ozone

Today we know that CFCs high in the atmosphere break apart under ultraviolet radiation to produce chlorine atoms. These chlorine atoms destroy ozone molecules.

$$Cl + O_3 \rightarrow ClO + O_2$$

The product, ClO, reacts with an oxygen atom and releases the chlorine atom. The chlorine atom attacks another ozone molecule. Over time, one chlorine atom can destroy thousands of ozone molecules. Figure 12.23 illustrates this process for the CFC trichlorofluoromethane, CCl_3F. Eventually the chlorine atom reacts with a different compound in the atmosphere to form a stable, less harmful product.

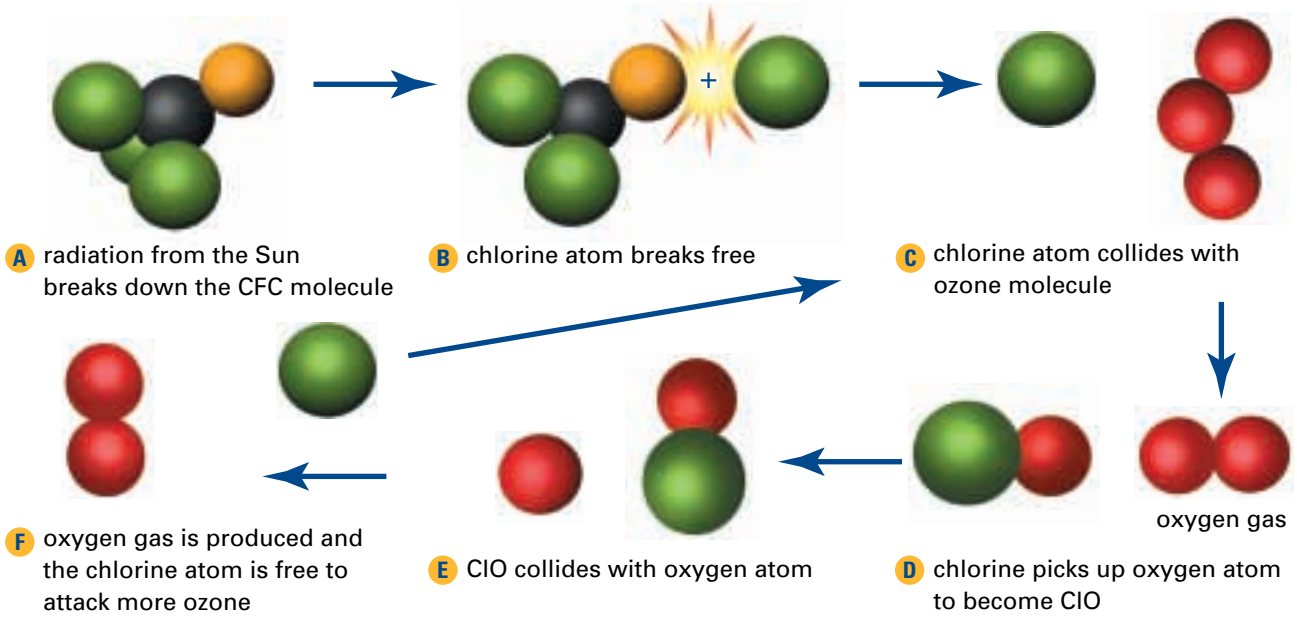

Figure 12.23 **The breakdown of a CFC by ultraviolet radiation produces single chlorine atoms that attack and destroy ozone. Because the chlorine atoms are released, they attack ozone again and again in a chain reaction.**

Although they are the most abundant ozone-depleting substance, CFCs are not the only culprits. Other chemicals that damage the ozone layer include methyl bromide, CH_3Br, carbon tetrachloride, CCl_4, and halons such as carbon trifluorobromide, CF_3Br.

The Effects of Ozone Depletion

How do we know that CFCs and other ozone-destroying molecules are having an effect on the atmosphere? As Figure 12.24 illustrates, ozone levels over Canada and other parts of the world have decreased significantly since the late 1970s.

With reduced ozone levels, more ultraviolet radiation from the Sun reaches Earth. Among humans, UV-induced skin cancer and eye damage are becoming a serious threat. The increased levels of radiation also damage phytoplankton in fresh and marine ecosystems. Since phytoplankton are the base of the aquatic food chain, this damage affects all other water species. As you learned earlier, the *presence* of ozone close to Earth damages crops and forests. A *lack* of ozone in the atmosphere, however, also reduces the yield of crops, such as barley and canola, and harms forests.

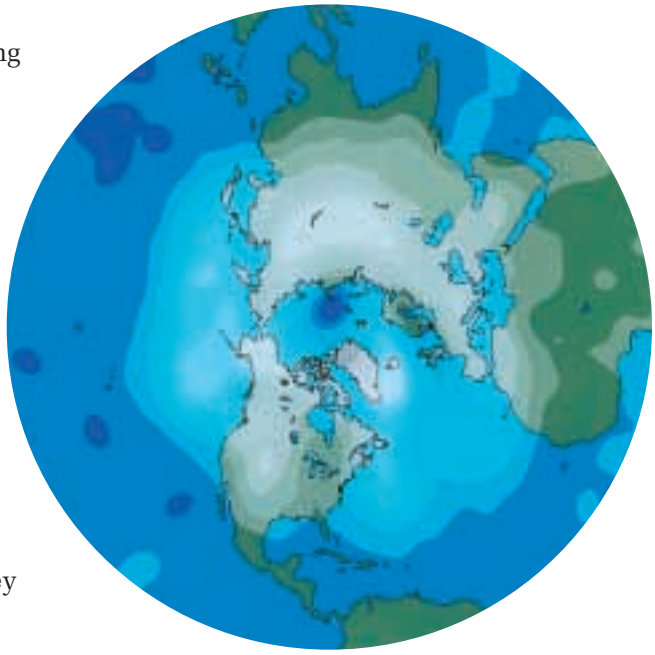

Figure 12.24 **Ozone thinning is still occurring over the northern hemisphere, as shown here. The dark blue in the centre indicates the presence of an ozone "hole."**

Improving Air Quality

What has happened since the discovery that CFCs and other chemicals were harming the ozone layer? The chemical industry has invented and produced environmentally friendly refrigerants. All new cars produced in North America have air conditioners that contain ozone-friendly refrigerants. Used CFCs from older refrigeration units are being recycled so that they do not escape into the atmosphere. A lot has already been accomplished, but more remains to be done.

Much of the positive activity comes from an international agreement called the **Montréal Protocol**. This agreement was signed in Montréal, Canada, on September 16, 1987. It has been successful in drastically reducing the use of CFCs worldwide. The Montréal Protocol is particularly significant because, for the first time, individual countries put a common planetary goal ahead of their own economic interests.

The Montréal Protocol stated that the production and consumption of all substances that deplete the ozone layer would be phased out by the year 2000 in developed countries. (Methyl chloroform would be phased out by 2005.) The chemicals that are named in the agreement include CFCs, halons, carbon tetrachloride, methyl chloroform, and methyl bromide. Once CFC production and consumption are stopped, scientists hope that the ozone layer will recover within 50 or 60 years. The success of the Montréal Protocol depends however, on the co-operation of both developed and developing countries.

Section Wrap-up

In this section, you learned how ozone high in the atmosphere interacts with UV light from the Sun. In addition, you learned where CFCs come from, and how they damage the ozone layer. Finally, you saw that the Montréal Protocol is striving to prevent further ozone damage.

CHEM FACT

In 1993, a scientific link was established between ozone depletion and increases in ultraviolet radiation. It was found that increased exposure to UV-B radiation causes skin cancer, the formation of cataracts, and the suppression of the human immune system. Research has shown skin cancer to be as common as all other types of cancer combined. Sunscreens can protect humans from the risk of some skin cancers. Unfortunately they do not appear to provide protection against damage to the immune system.

Canadians in Chemistry

Parisa Ariya was born in Tehran, the capital of Iran. She chose atmospheric chemistry for a career. Scientists in this field study the transformation of molecules in the atmosphere (the layer of gases surrounding Earth). They also study the atmosphere's interactions with oceans, land, and living things. After studying in several countries, Dr. Ariya became a professor at McGill University in Montréal.

Dr. Parisa Ariya

One of Dr. Ariya's particular areas of interest is halogen chemistry. Halogens such as chlorine, Cl, and bromine, Br, occur naturally in ocean waters. As well, they enter ocean waters as run-off from human activities. The oceans emit these halogens into the atmosphere. There they react with, and destroy, ozone, O_3.

Ariya and her students are trying to determine what kinds of halogens exist in Earth's atmosphere, how quickly they are produced and degraded, and what their major sources are. As they find answers to these questions, they may be able to recommend ways to reduce halogens in the oceans and atmosphere. They may also develop ways to modify halogens' reactions with ozone and other gases so that the halogens do less harm.

Another of Ariya's research interests is sulfur, S. She and her students are studying its atmospheric reactions with ozone and hydrogen peroxide, H_2O_2. Through field studies, laboratory experiments, and modelling, they are trying to determine the impacts of such reactions.

"You can enjoy nature through sports," says Dr. Ariya, who is an avid soccer player and swimmer. "But as a scientist you also enjoy nature intellectually, methodically. Science keeps the mind alive because you're constantly learning. Science is fun!"

Unit Issue Prep

Research the Ontario Drive-Clean program. How is pollution from car exhausts being regulated by the government? Search for information in preparation for the Unit Issue.

Section Review

1. C Describe the cycle that ozone goes through as it absorbs ultraviolet radiation. Use a diagram.
2. C Compare the effects of ozone near the ground with its effects high in the atmosphere.
3. K/U What are chlorofluorocarbons? How do they affect the ozone layer?
4. K/U Describe the Montréal Protocol. Why is it so significant?
5. MC Canadian scientists developed the Brewer Ozone Spectrophotometer, a state-of-the-art ozone-measuring device. It is the most accurate ozone-measuring device in the world. Use the Internet or reference books to find out how the Brewer Ozone Spectrophotometer works. Report your findings to the class.