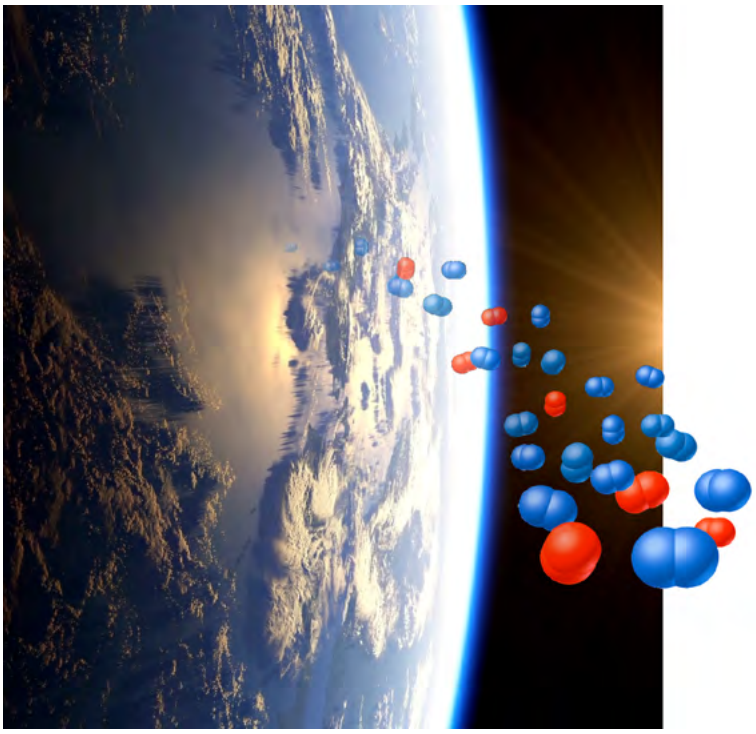


Chapter 16

Water and Air Resources

THE MAIN IDEA

The Earth is huge, but so is our ability to transform the environment.

16.1 Water on the Move
16.2 The Water We Consume
16.3 How We Pollute Water
16.4 Wastewater Treatment
16.5 The Earth's Atmosphere
16.6 How We Pollute Air
16.7 Global Warming

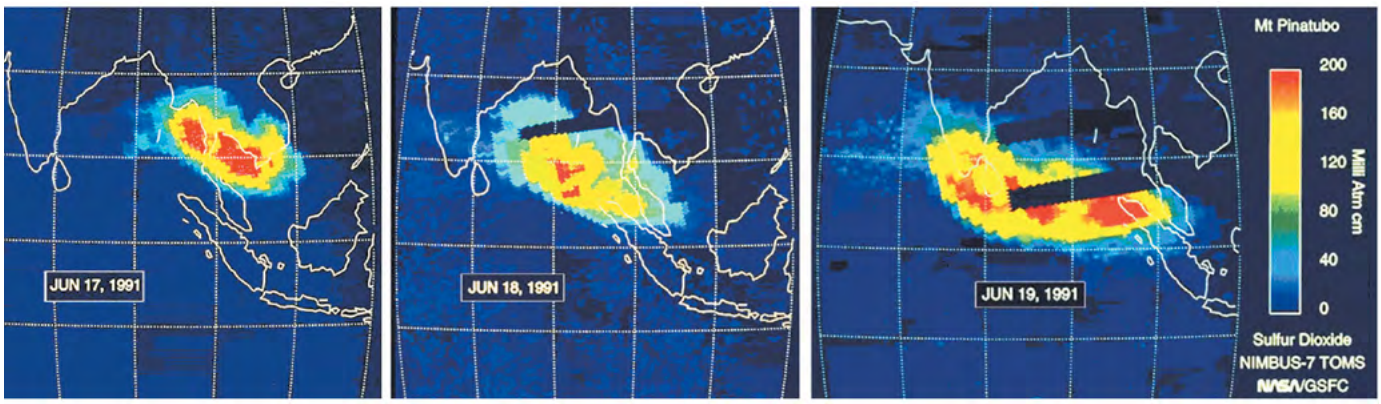
16.6 How We Pollute Air

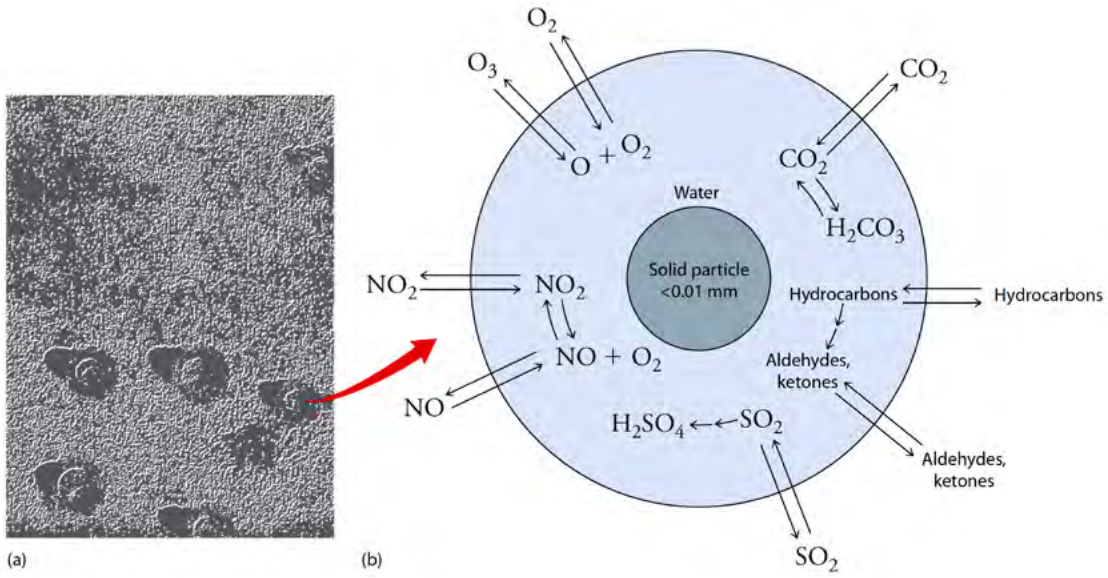
Any material in the atmosphere that is harmful to health is defined as an *air pollutant*. One major source of air pollutants is volcanoes. The largest volcanic blast of the 20th century, for example, was the 1991 eruption of Mount Pinatubo in the Philippines, an eruption that released 20 million tons of the noxious gas sulfur dioxide, SO_2. As **Figure 16.16** shows, this sulfur dioxide managed to travel all the way to India in only 4 days.

In a number of ways, however, humans have surpassed volcanoes as sources of pollution. In the United States alone, for example, industrial and other human activities have been depositing about 20 million tons of sulfur dioxide in the air *every year* since around 1950. By one estimate, human activities account for about 70 percent of all sulfur that enters the global atmosphere. To stem the human production of air pollutants, the U.S. government passed the Clean Air Act in 1970. This act regulated the gaseous emissions of various industries but was not comprehensive. An amendment in 1977 greatly restricted car emissions, and the most recent amendment, enacted in 1990, overhauled the act by regulating the emissions of nearly all air pollutants, including *aerosols*, *particulates*, and the components of *smog*.

V Figure 16.16

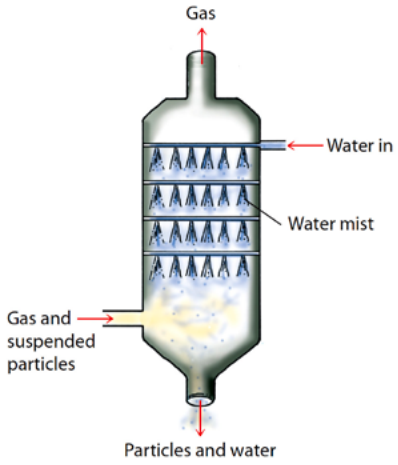
The cloud of sulfur dioxide generated by the June 15, 1991, eruption of Mount Pinatubo reached India in 4 days. (The black strips are where satellite data are missing.) By July 27, the sulfur dioxide cloud had traveled around the globe.





Λ Figure 16.17

(a) Micrograph of aerosols in the atmosphere. (b) An aerosol is the site of many chemical reactions involving pollutants. Water surrounding the solid particle attracts airborne molecules that then readily react in aqueous solution before being released back into the atmosphere.



Λ Figure 16.18

During scrubbing of industrial gaseous effluents, a fine mist of water captures and removes solid particles that have diameters as small as 0.001 millimeter.

Aerosols and Particulates Facilitate Chemical Reactions

Airborne solid particles, such as ash, soot, metal oxides, and even sea salts, play a major role in air pollution. Particles up to 0.01 millimeter in diameter (too small to be seen with the naked eye) attract water droplets and thereby form **aerosols** that may be visible as fog or smoke. Aerosol particles remain suspended in the atmosphere for extended periods of time and, as **Figure 16.17** shows, serve as sites for many chemical reactions involving pollutants.

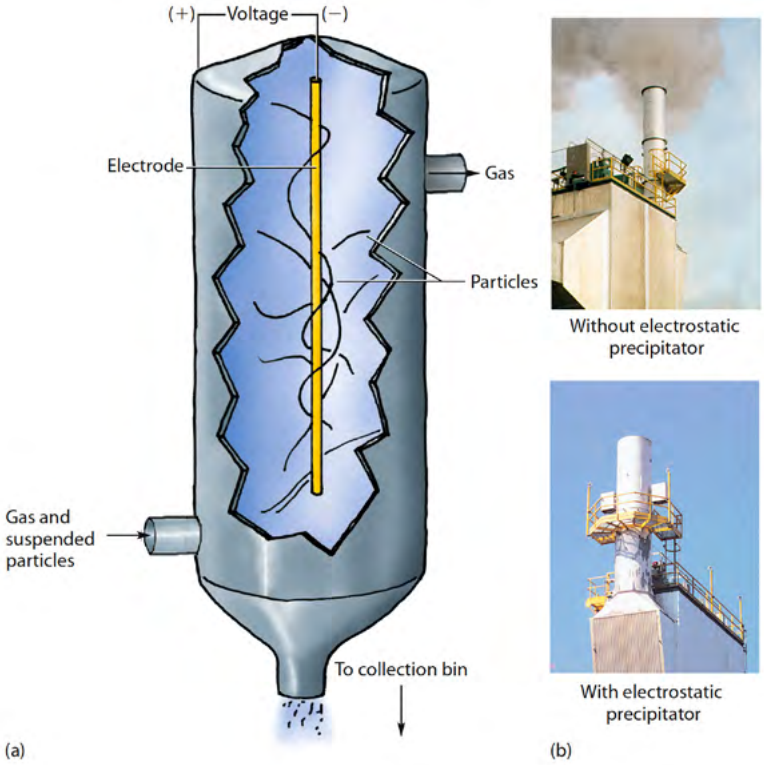
Larger solid particles, called **particulates**, tend to settle to the ground faster than the particles that form aerosols and hence do not play as big a role in facilitating atmospheric chemical reactions. While they are airborne, however, particulates obscure visibility. Atmospheric particulates (and aerosols) also have a global cooling effect because they reflect sunlight back into space. The particulates and aerosols emitted by massive volcanic eruptions have been known to have a profound impact on the weather. A series of eruptions in Indonesia around 1815, for example, led to freezing summer temperatures and brutal winters over mid-latitude regions such as New England and Europe. Crops perished and famines ensued. The effect was most pronounced during 1816, which became known as the "year without a summer."

Industries use a variety of techniques to cut back on emissions of solid particles. Physical methods include filtration, centrifugal separation, and scrubbing, which, as **Figure 16.18** shows, involves spraying gaseous effluents with water. Another method, electrostatic precipitation, shown in **Figure 16.19**, is energy intensive but more than 98 percent effective at removing particles.

CONCEPT **CHECK**

Why are temperature inversions more common during the day than at night?

CHECK YOUR ANSWER A temperature inversion occurs when a body of warm air sits above a body of denser cold air. The higher air is warmed by the heat of the Sun, which is out only during the day.



Λ Figure 16.19
(a) Particles in industrial gaseous effluents become negatively charged by an electrode and are attracted to the positively charged wall of the electrostatic precipitator. Once it touches the wall, a particle loses its charge and falls into a collection bin. (b) Smokestacks with and without electrostatic precipitators.

FOR YOUR INFORMATION

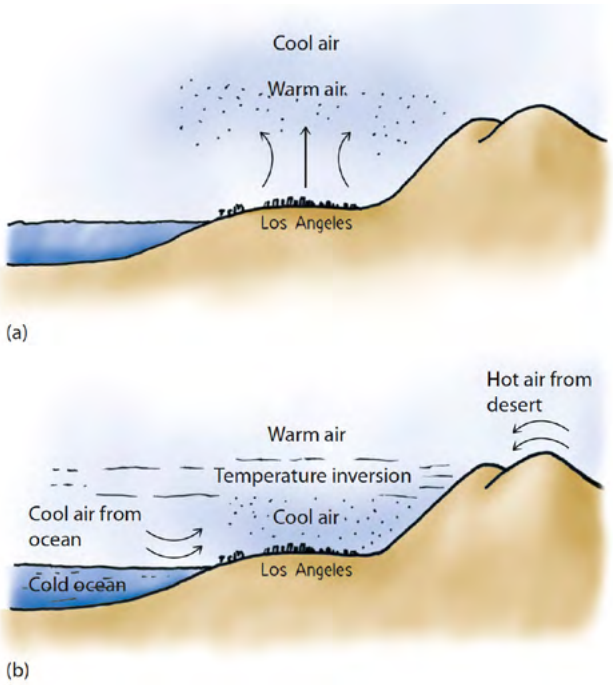
Aerosols and particulates in the atmosphere help to keep the Earth cool by reflecting solar radiation back into space. This effect, known as "global dimming," appears to have masked the full impact of global warming. Efforts to clean the air of aerosols and particulates may have the effect of hastening global warming.

Smog

The term *smog* was coined in 1911 to describe a poisonous mixture of smoke, fog, and air that settled over the city of London and killed many people. Smog has since grown to be a major problem, especially over urban areas, where industrial and human activities abound.

Weather plays an important role in smog formation. Normally, air warmed by the Earth's surface rises to the upper troposphere, where pollutants are dispersed, as shown in **Figure 16.20a.** Parcels of dense, cold air, however, sometimes settle below warm air in a *temperature inversion*, shown in **Figure 16.20b**. Now the air tends to stagnate, which allows a buildup of air pollutants. Temperature inversions may occur just about anywhere, but local geographies make some areas more prone to them than others. The smog of Los Angeles, for example, is trapped by an inversion created when low-level cold air moving eastward from the ocean is capped by a layer of hot air moving westward from the Mojave Desert.

Temperature inversions tend to disperse at night because air at higher altitudes cools more quickly than does lower air, which is closer to the Earth's warm surface. This is one reason the skies in many urban areas tend to have less smog in the early morning than in the late afternoon.



Λ Figure 16.20
Smog is removed by rising warm air. In a temperature inversion, smog is trapped as cool air settles below warm air. (The normal scheme of cool above warm is inverted.)

READING CHECK
What are the two types of smog?

There are two types of smog: industrial and photochemical. **Industrial smog**, produced largely from the combustion of coal and oil, is high in particulates. Its main chemical ingredient is sulfur dioxide, which accumulates in the water coating of aerosols and is transformed to sulfuric acid:

$$\underset{\text{Sulfur dioxide}}{2\ SO_2} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Sulfur trioxide}}{2\ SO_3}$$

$$\underset{\text{Sulfur trioxide}}{SO_3} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Sulfuric acid}}{H_2SO_4}$$

Breathing aerosols containing even very low concentrations of sulfuric acid can cause severe breathing distress. As discussed in Section 10.5, airborne sulfuric acid is also a leading cause of acid rain.

Although many industries still exceed federal standards regulating sulfur emissions, levels of industrial smog have dropped markedly since the passage of the 1970 Clean Air Act and its subsequent amendments. In the future, however, maintaining low levels of sulfur dioxide emissions will become more difficult as both national economies and world population continue to grow.

Photochemical smog consists of pollutants that participate either directly or indirectly in chemical reactions induced by sunlight. These pollutants are predominantly nitrogen oxides, ozone, and hydrocarbons, and their prime source is the internal-combustion engine. In the combustion chamber, oxygen is mixed with vaporized hydrocarbons for the production of heat, which causes an expansion of gases that drives the piston's power stroke. Atmospheric nitrogen is also present, however, and at the high temperature characteristic of internal-combustion engines, the nitrogen and oxygen form nitrogen monoxide:

$$\text{heat} + N_2 + O_2 \rightarrow 2\ NO$$

Nitrogen monoxide is fairly reactive. Once released from the engine, it reacts rapidly with atmospheric oxygen to form nitrogen dioxide:

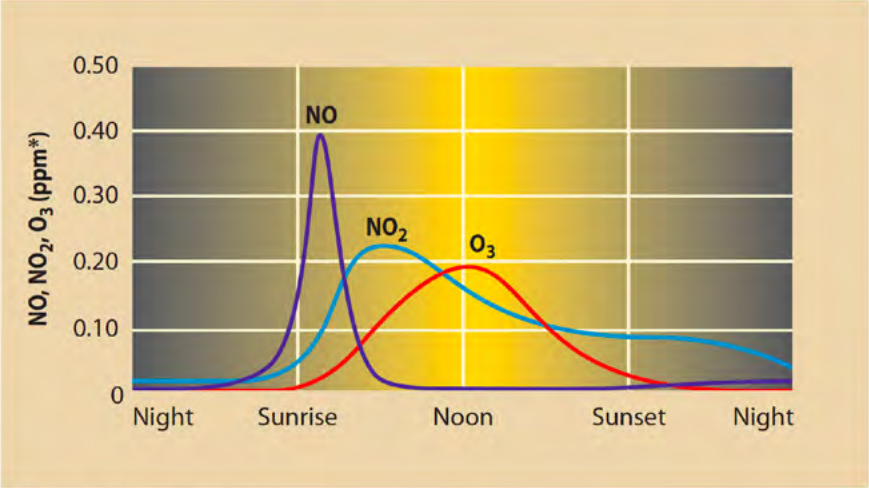
$$2\ NO + O_2 \rightarrow 2\ NO_2$$

Nitrogen dioxide is a powerful corrosive agent that acts on metal, stone, and even human tissue. Its brown color is responsible for the brown haze typically seen over a polluted city. Sunlight initiates the transformation of nitrogen dioxide to nitric acid, HNO_3, which, along with sulfuric acid, is a prime component of acid rain. In aerosols, sunlight splits nitrogen dioxide into nitrogen monoxide and atomic oxygen:

$$\text{sunlight} + NO_2 \rightarrow NO + O$$

The nitrogen monoxide reacts with atmospheric oxygen to re-form nitrogen dioxide, and the atomic oxygen reacts with atmospheric oxygen to form ozone:

$$O + O_2 \rightarrow O_3$$



*ppm = parts per million

< Figure 16.21
The average daily concentration of nitrogen monoxide, nitrogen dioxide, and ozone in Los Angeles.

Ozone is a pungent pollutant. It causes eye irritation and at high levels can be lethal. Plant life suffers when exposed to even relatively low concentrations of ozone, and it causes rubber to harden and turn brittle. To protect tires from ozone, manufacturers have incorporated paraffin wax, which reacts preferentially with the ozone, sparing the rubber. As was discussed in Section 9.7, ozone is also formed by natural processes in the Earth's stratosphere, where it filters out as much as 95 percent of the Sun's ultraviolet rays. So, at the Earth's surface, ozone is a harmful pollutant, while 25 kilometers straight up it serves as a sunscreen and is vital for the good health of all living organisms. As with many chemicals, ozone can be both harmful and helpful depending upon the situation.

A profile of average urban concentrations of nitrogen monoxide, nitrogen dioxide, and ozone is given in **Figure 16.21**. Early morning rush hour causes a rapid increase in nitrogen monoxide, which by mid-morning has largely been converted to nitrogen dioxide. On a sunny day, following nitrogen dioxide formation, ozone levels begin to peak. In the absence of a temperature inversion, late-afternoon winds clear the pollutants away. After a night of calm, the cycle begins again.

Another class of components in photochemical smog is hydrocarbons, such as those found in gasoline. In the presence of ozone, airborne hydrocarbons are transformed to aldehydes and ketones, many of which add to the foul odor of smog. Also, incomplete combustion of gasoline leads to the release of *polycyclic aromatic hydrocarbons*, which are known carcinogens. Significant amounts of hydrocarbons are also released each time a car is filled with gasoline. Because gasoline is a volatile liquid, any air in a closed tank of gasoline is loaded with gasoline vapors—even when the tank is nearly empty. Every time you fill up at the pump, these vapors, about 10 grams worth, are displaced and vented directly into the atmosphere. Newer gasoline pumps have nozzles designed to trap most of these vapors, as shown in **Figure 16.22**.

∧ Figure 16.22
Some gasoline nozzles are equipped with a jacket that keeps gasoline vapors from escaping into the atmosphere. Instead, the vapors are directed back to the main tank of the gas station through a secondary hose hidden within the nozzle.

CONCEPT **CHECK**
How does the Sun help disperse air pollutants?

CHECK YOUR ANSWER Sunlight warms the ground, which in turn warms the air, which then rises, carrying with it many air pollutants.