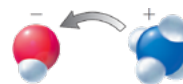


## Chapter 10

# Acids and Bases

### THE MAIN IDEA



Acids donate protons and bases accept them.

### 10.1 [Exchanging Protons](#)

### 10.2 [Acid and Base Strength](#)

### 10.3 [Acidic, Basic, or Neutral](#)

### 10.4 [Buffers Resist pH Changes](#)

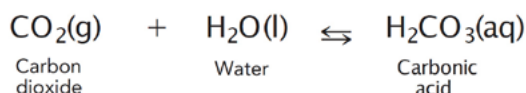
### 10.5 **Rainwater Is Acidic**



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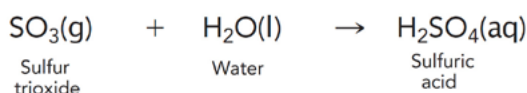
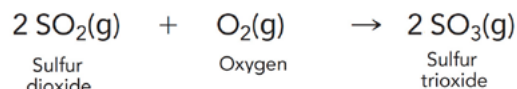
As previously mentioned, rainwater is naturally acidic. A main source of this acidity is carbon dioxide, the same gas that gives fizz to soda drinks. There are about 3,000 billion tons of  $\text{CO}_2$  in the atmosphere, most of it from such natural sources as volcanoes and decaying organic matter but a growing amount (about 1000 billion tons) from human activities. In other words, about a third of the  $\text{CO}_2$  in our present atmosphere is from ourselves.

Water in the atmosphere reacts with carbon dioxide to form *carbonic acid*:



Carbonic acid, as its name implies, behaves as an acid and lowers the pH of water. The  $\text{CO}_2$  in the atmosphere brings the pH of rainwater to about 5.6—noticeably below the neutral pH value of 7. Because of local fluctuations, the normal pH of rainwater varies between 5 and 7. This natural acidity of rainwater may accelerate the erosion of land and, under certain circumstances, can lead to the formation of underground caves.

By convention, *acid rain* is a term used for rain having a pH lower than 5. Acid rain is created when airborne pollutants, such as sulfur dioxide, are absorbed by atmospheric moisture. Sulfur dioxide is readily converted to sulfur trioxide, which reacts with water to form *sulfuric acid*:



### FOR YOUR INFORMATION

Acid rain remains a serious problem in many regions of the world. Significant progress, however, has been made toward fixing the problem. In the United States, for example, sulfur dioxide and nitrogen oxide emissions have been reduced by nearly half since 1980.



(a)



(b)



(c)

### ^ Figure 10.18

(a) and (b) These two photographs show the same obelisk in New York City's Central Park before and after the effects of acid rain. (c) Many forests downwind from heavily industrialized areas, such as in the eastern United States and in Europe, have been noticeably hard-hit by acid rain. The dead fir trees in this photo from the Great Smoky Mountains National Park are a result of both acid rain, as well as invasive beetles.

Most  $\text{SO}_2$  is released into the atmosphere by the combustion of sulfur-containing coal and oil. Sulfuric acid is much stronger than carbonic acid, and as a result, rain laced with sulfuric acid and therefore higher  $\text{H}_3\text{O}^+$  concentrations eventually corrodes metal, paint, and other exposed substances. This cumulative damage has cost billions of dollars. The cost to the environment is also high (**Figure 10.18**). Many rivers and lakes receiving acid rain become less capable of sustaining life. Much vegetation that receives acid rain doesn't survive. This is particularly evident in heavily industrialized regions.

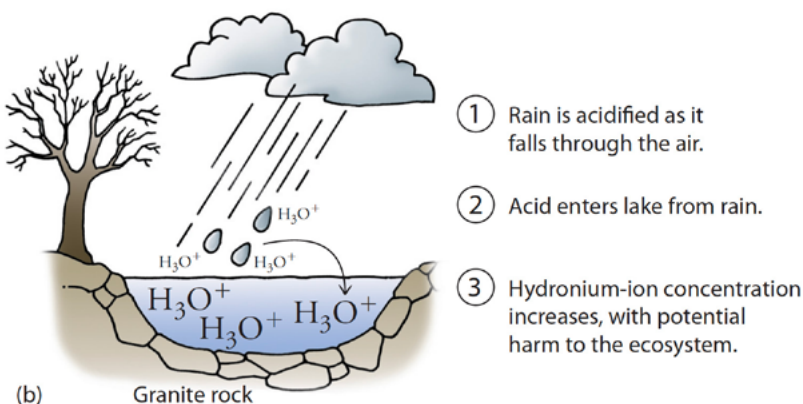
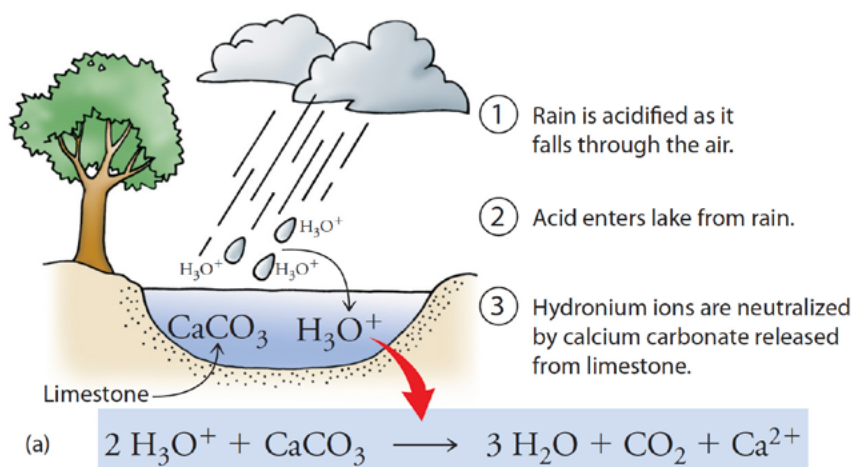
#### CONCEPT CHECK

When sulfuric acid,  $\text{H}_2\text{SO}_4$ , is added to water, what makes the resulting aqueous solution corrosive?

#### CHECK YOUR ANSWER

Because  $\text{H}_2\text{SO}_4$  is a strong acid, it readily forms hydronium ions when dissolved in water. Hydronium ions are responsible for the corrosive action.

The environmental impact of acid rain depends on local geology, as **Figure 10.19** illustrates. In certain regions, such as the midwestern United States, the ground contains significant quantities of the alkaline compound calcium carbonate (limestone), deposited when these lands were submerged under oceans, as has occurred several times over the past 500 million years. Acid rain pouring into these regions is often neutralized by the calcium carbonate before any damage is done. In the northeastern United States and many other regions, however, the ground contains very little calcium carbonate and is composed primarily of chemically less reactive materials, such as granite. In these regions, the effect of acid rain on lakes and rivers accumulates.



&lt; Figure 10.19

(a) The damaging effects of acid rain do not appear in bodies of fresh water lined with calcium carbonate, which neutralizes any acidity. (b) Lakes and rivers lined with inert materials are not protected.



#### FOR YOUR INFORMATION

If the world is able to lower its  $\text{SO}_2$  emissions, even with a growing population and greater economic activity, might we also be able to lower our  $\text{CO}_2$  emissions? Collectively we release about 100 million tons of  $\text{SO}_2$  each year. For perspective, we release about 40,000 million tons of  $\text{CO}_2$  each year, which is about 400x as much. Carbon dioxide is also less chemically reactive than  $\text{SO}_2$ , which means that capturing it at the source is more difficult. Lowering our  $\text{CO}_2$  emissions is many times more the challenge.

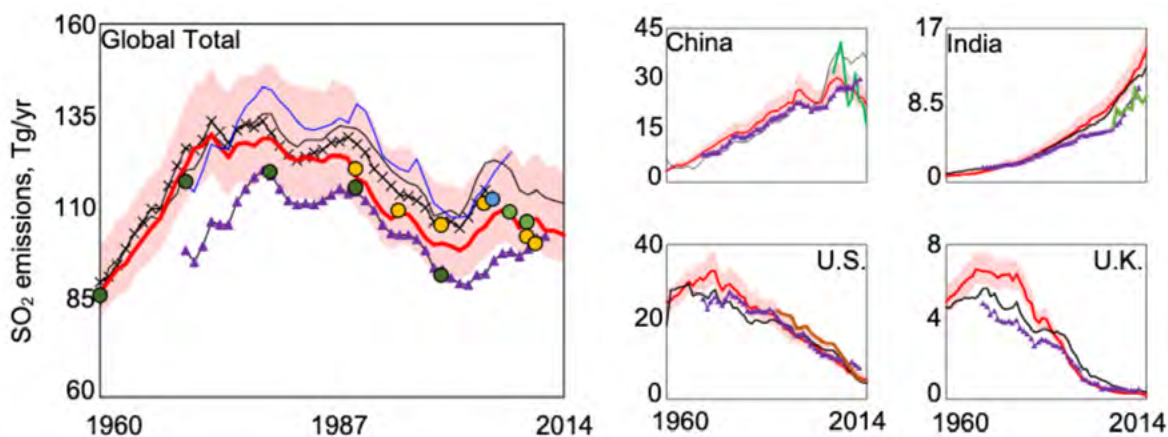
One demonstrated solution to this problem is to raise the pH of acidified lakes and rivers by adding calcium carbonate—a process known as liming. The cost of transporting the calcium carbonate, coupled with the need to monitor treated water systems closely, limits liming to only a small fraction of the vast number of water systems already affected. Furthermore, as acid rain continues to pour into these regions, the need to lime continues.

A longer-term solution to acid rain is to prevent most of the generated sulfur dioxide and other pollutants from entering the atmosphere in the first place. Toward this end, smokestacks have been designed or retrofitted to minimize the quantities of pollutants released. Although costly, the positive effects of these adjustments have been demonstrated as shown in **Figure 10.20**. An ultimate long-term solution, however, would be a shift from fossil fuels to cleaner energy sources, such as nuclear and solar energy.



#### READING CHECK

What is a longer-term solution to the problem of acid rain?



^ **Figure 10.20**

Due in great part to public attention and economics, over the past few decades, developed nations have markedly decreased their SO<sub>2</sub> emissions, primarily by capturing the SO<sub>2</sub> rather than releasing it. The world leaders in SO<sub>2</sub> emissions are now collectively with developing nations such as India. (Source: Source: [pubs.acs.org/doi/10.1021/acs.est.9b07696](https://pubs.acs.org/doi/10.1021/acs.est.9b07696))

#### CONCEPT CHECK

What kind of lakes are most protected against acid rain?

#### CHECK YOUR ANSWER

Lakes that have a floor consisting of basic minerals, such as limestone, are more resistant to acid rain, because the chemicals of the limestone (mostly calcium carbonate, CaCO<sub>3</sub>) neutralize any incoming acid.