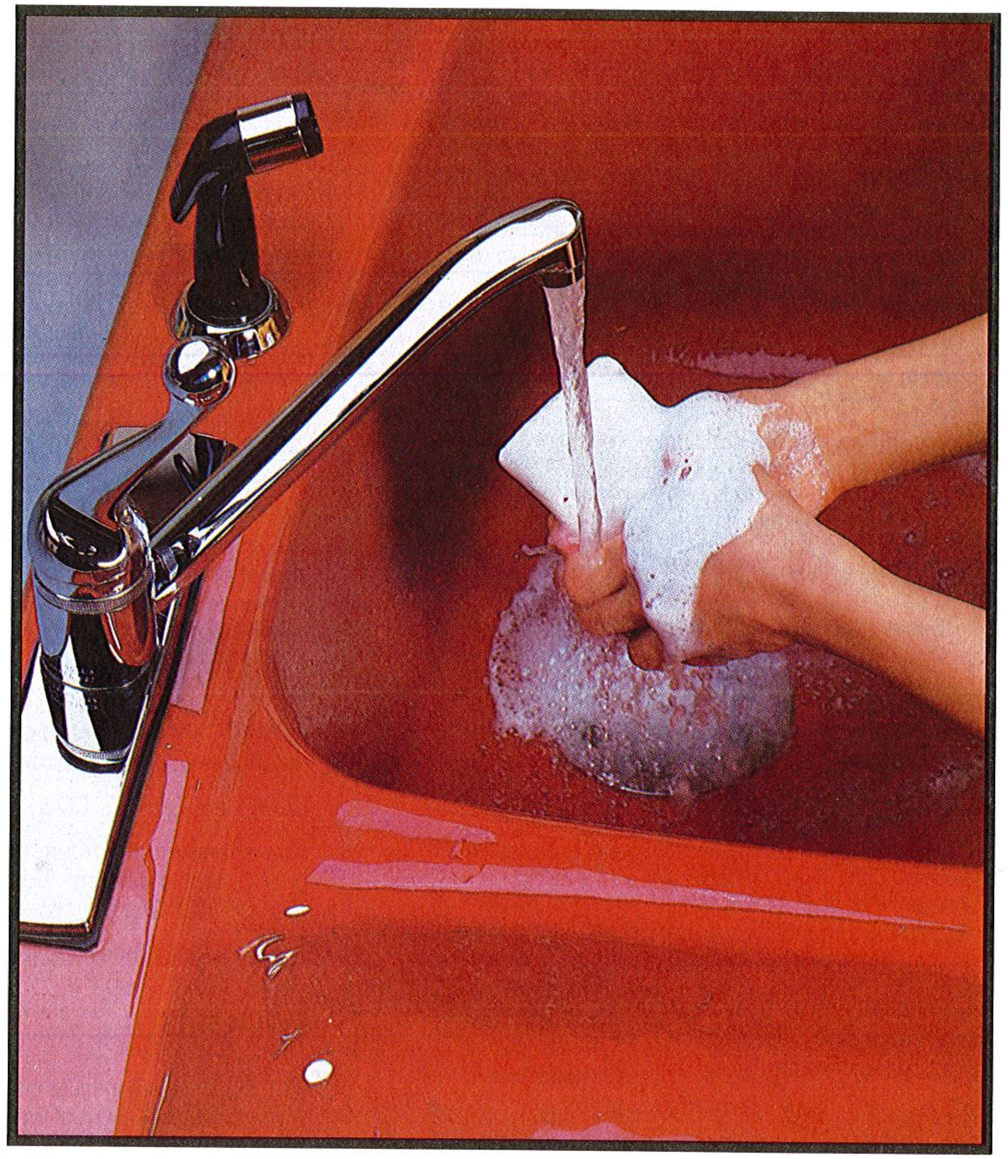
CHAPTER 20



The English word *acid* comes from *acidus,* the Latin word for sour. Sour taste is a prominent characteristic of the compounds called acids. Many fruits taste sour. You can be quite confident that foods such as cherries, lemons, grapefruit, yogurt, and tomatoes all contain compounds that are classified as acids.

Bases also have a property that is familiar to you. A substance that has a soapy or slippery feel to it generally contains a compound classified as a base. In this chapter, you will study other characteristics used to describe acids and bases and why these compounds are so important to the study of chemistry.

Acid-Base Reactions

Identifying Properties of Acids and Bases

Understanding chemical behavior helps you understand your world. However, there are too many reactions to try to remember them all individually. It would be somewhat like trying to remember the names and occupations of all the people in Vancouver! You have seen many examples of how classifying compounds into groups with similar characteristics reduces the amount of information one must remember. Acids and bases comprise two groups of substances that have been categorized by their chemical behavior.

CONCEPTS

- **classifying compounds as acids and bases**
- **Brönsted-Lowry definitions of acids and bases**
- **conjugate acid-base pairs**
- **characteristics of amphiprotic substances**
- **preparation and properties of acids**
- **preparation and properties of bases**

20-1 General Characteristics of Acids and Bases

If you have ever tasted a lemon you are aware of its very sour taste. Lemon juice contains an acid. Grapefruit and spoiled milk also are sour due to the presence of acids. Sour taste is a property common to compounds classified as acids. If you have ever gotten soap in your mouth, you have noted a bitter taste. Bitterness is common to compounds classified as bases. Do not try the taste test because some acids and bases are harmful.

One property of acids is how they behave when they contact some metals. When hydrochloric acid and magnesium metal are mixed together, bubbles are produced and the magnesium metal reacts. When tested, the bubbles are found to be hydrogen gas. A similar reaction occurs when other acids are combined with magnesium. In Figure 20-1 you can see the long glass tube that is used to measure the amount of hydrogen generated by the acid and metal. When most metals are combined with a base, no noticeable change occurs.

An electric current is not conducted through pure water, but it is conducted through an acid solution. Basic solutions also conduct electricity. The apparatus shown in Figure 20-2 is used to test conductivity. The presence of ions allows current to flow between the two electrodes, and the light bulb glows. Solutions which conduct an electric current are called electrolytes. Table 20-1 lists the characteristic properties of acids and bases which are both electrolytes.

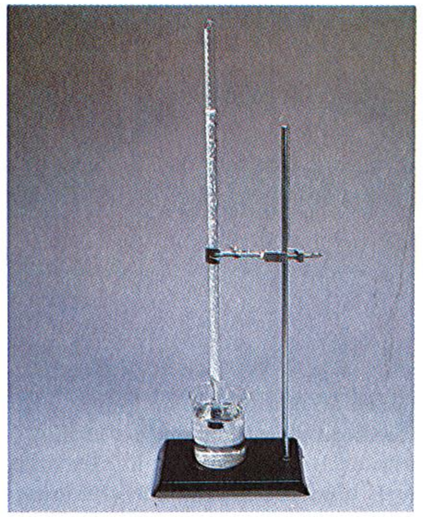


Figure 20-1 The reaction of magnesium metal with hydrochloric acid produces hydrogen gas.

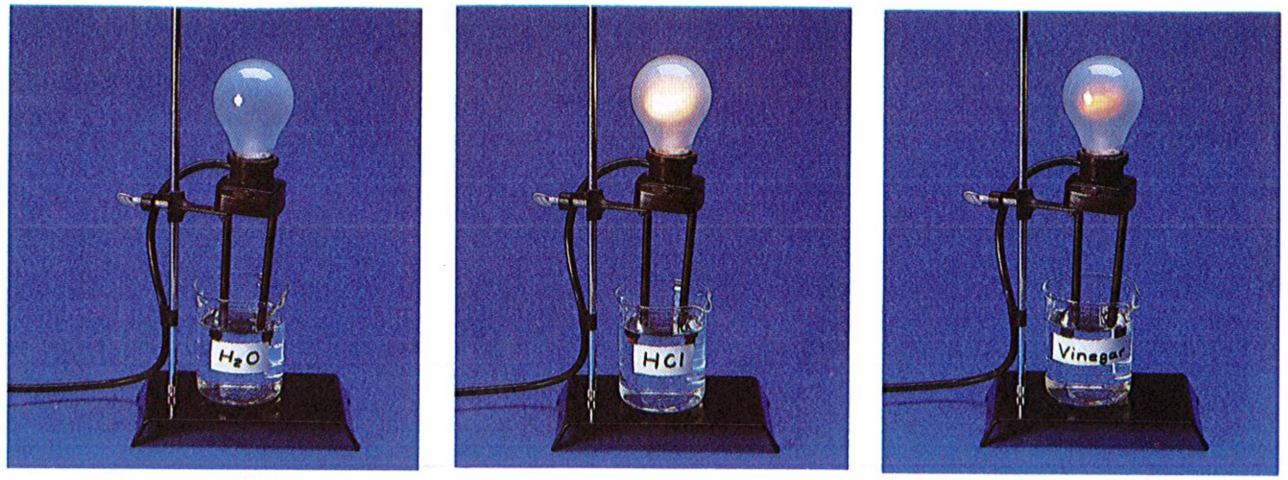


Figure 20-2 Conductivity testing of pure water on the left, hydrochloric acid in the middle, and acetic acid on the right. Note that pure water does not conduct and the conductivity of the two acid solutions varies.

Table 20-1

CHARACTERISTIC PROPERTIES OF ACIDS AND BASES

ACIDS	BASES
Dissolve in water to give a solution that:	Dissolve in water to give a solution that:
1. tastes sour	1. tastes bitter
2. conducts an electric current	2. conducts an electric current
3. causes certain dyes to change color	3. causes certain dyes to change color
4. liberates hydrogen when it reacts with certain metals	4. feels slippery
5. loses the above properties when it is reacted with a base, though the resulting solution will conduct a current	5. loses the above properties when it is reacted with an acid, though the resulting solution will conduct a current

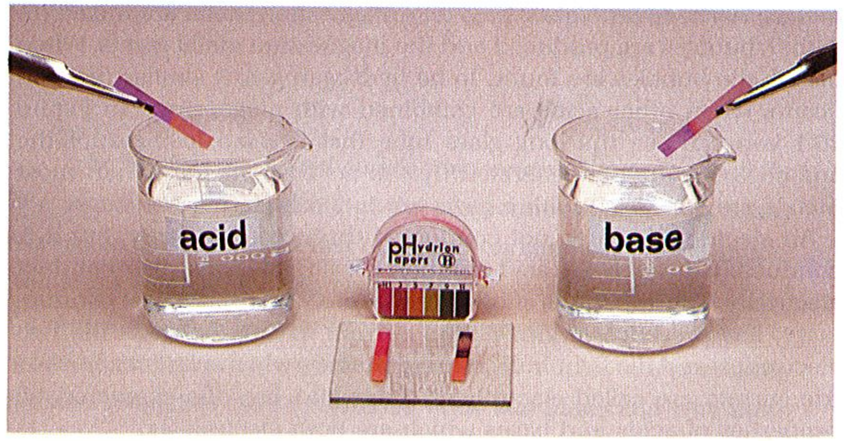


Figure 20-3 Litmus is an indicator. Blue litmus paper turns red in the presence of an acid. Red litmus turns blue in the presence of a base. Another acid-base indicator, pH hydrion paper, turns a range of colors depending on the degree of acidity or basicity.

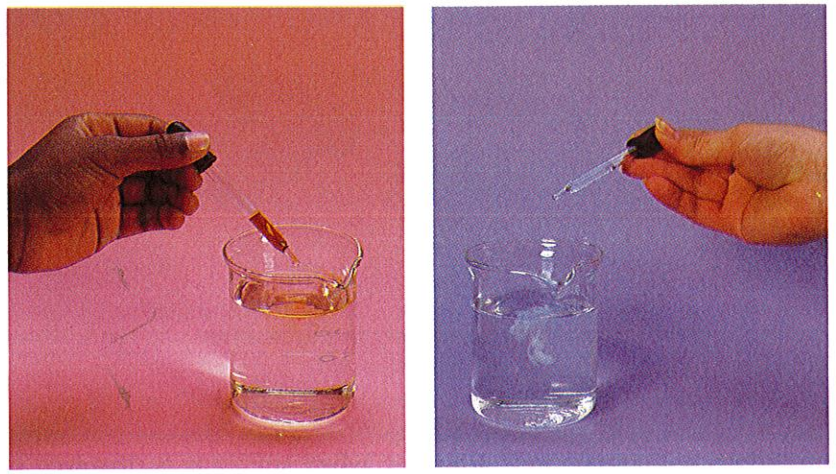


Figure 20-4 Bromthymol blue indicator turns yellow in the presence of an acid as shown in the photograph on the left. Silver nitrate is used to detect the presence of chloride ions in the beaker on the right.

20-2 Definition of Acids and Bases

Hydrogen chloride, HCl, is a choking gas at room temperature. If it is cooled below −84.9°C, it liquefies. The liquid state does not conduct an electric current so it must not contain ions. HCl readily dissolves in water, and the solution does conduct an electric current. What are the ions and from where did they come?

Certain compounds, called **indicators**, can be used to detect the presence of acids and bases. The indicator will appear as one color in the presence of high concentrations of H^+ (acid solution) and another color when the H^+ concentration is low (base solution). How indicators respond to H^+ concentration is discussed in Section 20-11. When an indicator such as bromthymol blue is added to the HCl solution, the color of the indicator changes to clear yellow. Bromthymol blue is always yellow in the presence of high concentrations of H^+. Thus you conclude that HCl in water contains H^+ ions.

If the HCl in water produced H^+, a positive ion, then the solution also must contain a negative ion. A possible candidate is the chloride ion, Cl^-. Adding silver nitrate is the qualitative test used to confirm the presence of chloride ions in a solution. If a drop of $AgNO_3(aq)$ is added to the HCl solution, a cloudy white precipitate forms as in Figure 20-4, indicating the presence of chloride ions. The precipitate is silver chloride.

$$Cl^-(aq) + Ag^+(aq) \longrightarrow AgCl(s).$$

When HCl reacts with water, it produces the H^+, which combines with the water molecule to produce a hydronium ion, H_3O^+.

$$HCl + H_2O \longrightarrow H_3O^+ + Cl^-$$

The **hydronium ion** is a hydrated proton. A model for the formation of the hydronium ion is shown in Figure 20-5. Though more than one water molecule is involved, the hydrated proton is traditionally shown with a single water molecule. A number of different experiments support the idea that the hydrogen ion is hydrated when water is the

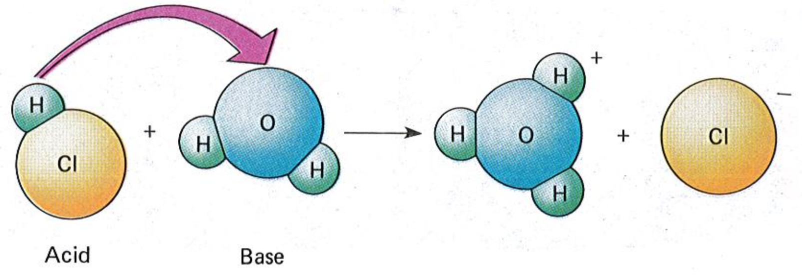
Do You Know?

One of the earliest definitions of an acid was proposed by Svente Arrhenius, a Swedish chemist. According to Arrhenius, an acid is any compound which produces hydrogen ions in solution, and a base is any compound which produces hydroxide ions in solution.

CHEM THEME

Since H_3O^+ represents a hydrated proton (H^+), the notations H_3O^+ and $H^+(aq)$ are often used interchangeably in acid-base chemistry.

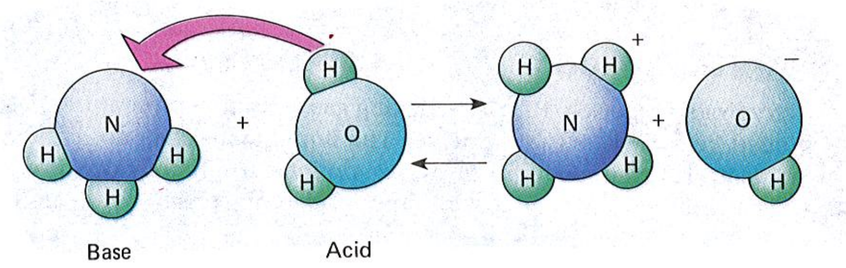
Figure 20-5 The formation of the hydronium ion involves a proton transfer from the acid to the water molecule. This reaction is a Brönsted-Lowry acid-base reaction.



solvent. Notice how the water behaved in the reaction with HCl. Water accepted the H^+ in forming the hydronium ion.

Ammonia, NH_3, also is a gas at room temperature. When it is cooled below −33.35°C, it liquefies. This liquid does not conduct electricity, so it does not contain ions. However, when ammonia is dissolved in water, the solution conducts electricity.

Figure 20-6 The formation of the ammonium ion involves the transfer of a proton from the water molecule to the ammonia molecule. This reaction is a Brönsted-Lowry acid-base reaction.



Do You Know?

Gilbert Lewis, an American chemist, expanded the definition of an acid and a base to include many compounds which do not contain hydrogen. A Lewis acid is an electron pair acceptor; a Lewis base is an electron pair donor.

The water donated a proton (H^+) which was used by NH_3 to form NH_4^+. The importance of the solvent in acid-base reactions led chemists to a specific definition of acid and base. Johannes Brönsted in Denmark, and Thomas Lowry in England, independently proposed that an **acid** is any substance that can produce (or donate) a proton, while a **base** is any substance that can accept a proton in a reaction.

Water can act as a proton acceptor or a proton donor. Compounds and ions that exhibit this dual behavior are called **amphiprotic**. How water behaves depends on what other ions are present. In the case of HCl and H_2O, water acts as a base in accepting the proton from the HCl. Water is a Brönsted-Lowry base. In the case of NH_3, water donates a proton to produce the ammonium ion and the hydroxide ion. In this case, water acts as a Brönsted-Lowry acid. Ammonia (NH_3) is also amphiprotic. In the equation above, NH_3 acts as a base, but in some reactions it can act as an acid (donate a proton) to become the amide ion (NH_2^-). All acid-base reactions can be described as competing for protons.

When an acid such as HCl and a base such as KOH combine, they react with each other to counteract their acidic and basic properties. When moles of protons donated by the acid and moles of protons accepted by the base are equal, **neutralization** occurs. A salt is produced, and if the base is OH^-, water is the other product.

$$HCl + KOH \longrightarrow KCl(aq) + H_2O$$

Figure 20-7 Bromthymol blue remains blue in the presence of a base such as aqueous ammonia. An aqueous ammonia solution causes red litmus paper to turn blue.

If an acid is accidentally spilled, a weak base may be applied to neutralize the acid and quickly nullify its effects. Likewise, if a base is accidentally spilled, a weak acid is applied to nullify the effects of the base.

If the neutralization reaction of hydrochloric acid and potassium hydroxide is written in terms of ions, you will see what happens when the salt is formed.

$$H_3O^+(aq) + Cl^-(aq) + K^+(aq) + OH^-(aq) \longrightarrow 2H_2O(l) + K^+(aq) + Cl^-(aq)$$

Notice that in this expression, there are terms common to both sides. To write the net ionic equation, the spectator ions are not included in the equation.

$$\underset{H^+\text{ from HCl}}{H_3O^+(aq)} + \underset{\text{from NaOH}}{OH^-(aq)} \longrightarrow \underset{\text{neutral water}}{2H_2O}$$

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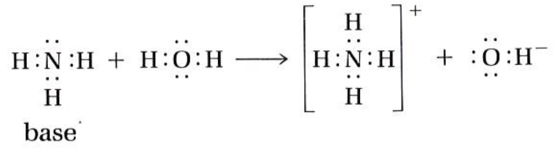
20-3 Conjugate Acid–Base Pairs

When NH_3 is combined with water, the ammonia acts as the base, accepting a proton from the water, which acts as an acid.



$$\underset{\text{base}}{H:\overset{..}{\underset{\underset{H}{..}}{N}}:H} + H:\overset{..}{\underset{..}{O}}:H \longrightarrow \left[H:\overset{\overset{H}{..}}{\underset{\underset{H}{..}}{N}}:H\right]^+ + :\overset{..}{\underset{..}{O}}:H^-$$

Once the ammonia gets the proton from the water, the NH_3 becomes the ammonium ion, NH_4^+. This ammonium ion is capable of donating a proton to some other ion if the occasion arises. Molecules and ions that differ only by a proton (hydrogen ion) are sometimes referred to as **conjugate acid–base pairs**. NH_4^+ and NH_3 are a conjugate acid–base pair. Conjugate means paired together. H_2O and OH^- are another conjugate acid–base pair.

The acid form of the pair contains a proton that is missing in the base form. The presence of a proton is the only difference between members of a conjugate acid–base pair.

CHEM THEME

In any Brönsted-Lowry acid-base equation, two conjugate pairs are present:

conjugate pair

$$HCN + H_2O \rightleftharpoons H_3O^+ + CN^-$$

acid base acid base

conjugate pair

conjugate pair

$$HCO_3^- + H_2PO_4^- \rightleftharpoons H_2CO_3 + HPO_4^{2-}$$

base acid acid base

conjugate pair

$$\underset{\text{acid}}{NH_4^+} \quad \text{and} \quad \underset{\text{base}}{NH_3}$$

$$\underset{\text{acid}}{H_2O} \quad \text{and} \quad \underset{\text{base}}{OH^-}$$

You might ask why, in this situation, NH_3 does not act like an acid, produce a proton, H^+, and become NH_2^-.

$$\underset{\text{acid}}{NH_3} \longrightarrow \underset{\text{base}}{H^+ + NH_2^-}$$

There are few molecules that attract hydrogen ions strongly enough to pull one off the ammonia molecule and form the amide ion.

Acids and bases that donate or accept one proton are called monoprotic. If a substance is capable of accepting more than one proton, it is a polyprotic base. A polyprotic acid is capable of donating more than one proton. Examples of polyprotic acids are sulfuric acid, H_2SO_4, and phosphoric acid, H_3PO_4.

Polyprotic acids ionize in steps. In each step the acid donates a proton.

1st ionization step: $\underset{\text{acid}}{H_2SO_4} + H_2O \longrightarrow \underset{\text{base}}{HSO_4^-} + H_3O^+$

2nd ionization step: $\underset{\text{acid}}{HSO_4^-} + H_2O \longrightarrow \underset{\text{base}}{SO_4^{2-}} + H_3O^+$

Phosphoric acid ionizes in three steps since it is capable of donating three protons.

1st ionization step: $\underset{\text{acid}}{H_3PO_4} + H_2O \longrightarrow \underset{\text{base}}{H_2PO_4^-} + H_3O^+$

2nd ionization step: $\underset{\text{acid}}{H_2PO_4^-} + H_2O \longrightarrow \underset{\text{base}}{HPO_4^{2-}} + H_3O^+$

3rd ionization step: $\underset{\text{acid}}{HPO_4^{2-}} + H_2O \longrightarrow \underset{\text{base}}{PO_4^{3-}} + H_3O^+$

Both HSO_4^- and $H_2PO_4^-$ may act as either an acid or base. These ions are amphiprotic like water.

20-4 Preparation and Properties of Acids

Sulfuric acid More sulfuric acid is produced yearly by industry than any other chemical in the world. Why is sulfuric acid used so widely? Primarily, it is cheap to make. Sulfur, oxygen, and water are the raw materials needed to make the acid. There are large, natural deposits of sulfur available, plus more sulfur is produced as a by-product of many metal-refining processes. Another raw material needed is oxygen, which is very plentiful in the air—another inexpensive resource. Water is necessary and it also is inexpensive. The commercial reaction to prepare the acid is simple, which also helps to keep the cost down. There are no by-products to pollute the environment, another cost-saving feature.

Do You Know?

Oleum is the Latin word for oil. Sulfuric acid was once called oil of vitriol.