Reactions in aqueous solutions

Acids, Bases and Neutralization reactions

ACIDS

Many acids and bases are industrial and household substances and some are important components of biological fluids. Hydrochloric acid (HCl), for example, is an important industrial chemical and the main constituent of gastric juice in your stomach.

Acids and bases are also common electrolytes.

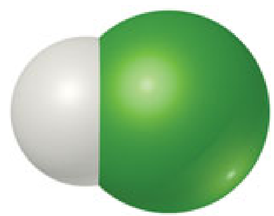
Acids are substances that ionize in aqueous solutions to form hydrogen ions H^+ (*aq*). As a hydrogen atom consists of a proton and an electron, H^+ is simply a proton.

Thus, acids are also called **proton donors**.

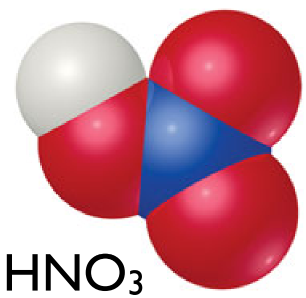
ACIDS

Protons in aqueous solution are solvated by water molecules. In writing chemical equations involving protons in water, therefore, we write H^+ (*aq*).

Molecules of different acids ionize to form different numbers of H^+ ions. Both HCl and HNO_3 are **monoprotic acids**, yielding one H^+ per molecule of acid.



HCl



HNO_3

Sulfuric acid, H_2SO_4, is a **diprotic acid**, it yields two H^+ per molecule of acid. The ionization of H_2SO_4 and other diprotic acids occurs in two steps:

1) $\mathbf{H_2SO_4}$ **(*aq*)** $\longrightarrow$ $\mathbf{H^+}$ **(*aq*) +** $\mathbf{HSO_4^-}$ **(*aq*)**

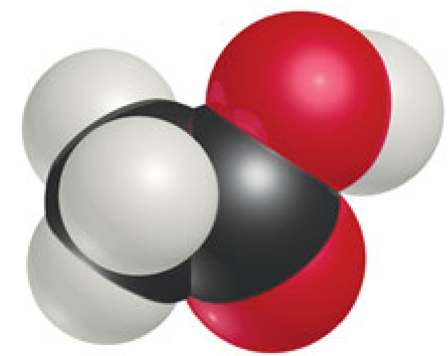
2) $\mathbf{HSO_4^-}$ **(*aq*)** $\longrightarrow$ $\mathbf{H^+}$ **(*aq*) +** $\mathbf{SO_4^{2-}}$ **(*aq*)**

ACIDS

Acetic acid (CH_3COOH) is the primary component in vinegar and is a monoprotic acid.

It has four hydrogens but only one of them, the H in the COOH group, is ionized in water. The three other hydrogens are bound to carbon and do not break their C-H bonds in water.

$$CH_3COOH\ (aq) \longrightarrow H^+\ (aq) + CH_3COO^-\ (aq)$$



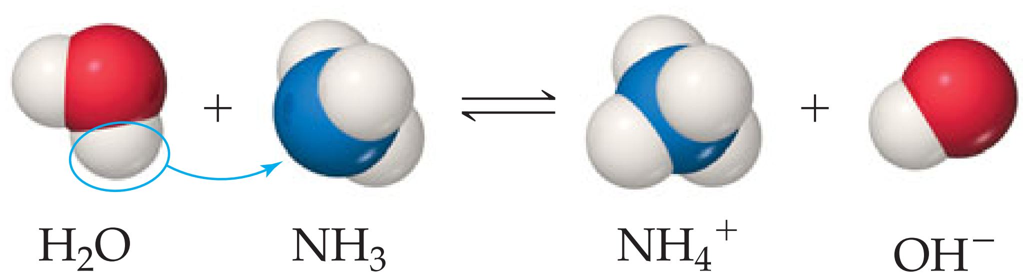
Acetic acid, CH_3COOH

BASES

Bases are substances that accept H^+ ions.
Bases produce hydroxide ions OH^- (*aq*) when they dissolve in water.

Ionic hydroxide compounds, such as NaOH, KOH, and $Ca(OH)_2$, are among the most common bases. When dissolved in water, they release OH^- ions into the solution.

Compounds that do not contain OH^- ions can also be bases. For example, ammonia (NH_3) is a common base. When added to water, it accepts an H^+ ion from a water molecule and thereby produces an OH^- ion.



$$NH_3\ (aq) + H_2O \longrightarrow NH_4^+\ (aq) + OH^-\ (aq)$$

Strong and Weak Acids and Bases

Acids and bases that are **strong electrolytes** (completely ionized in solution) are **strong acids** and **strong bases**.
Those that are **weak electrolytes** (partly ionized) are weak acids and weak bases.

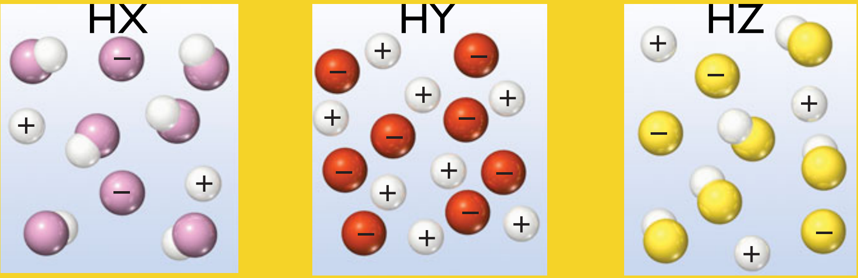
Common strong acids and bases	
Strong Acids	**Strong Bases**
Hydrochloric, **HCl**	Group 1A metal hydroxides [**LiOH**, **NaOH**, **KOH**, RbOH, CsOH]
Hydrobromic, **HBr**	Group 2A metal hydroxides [$Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$]
Hydroiodic, **HI**	
Chloric, **$HClO_3$**	
Perchloric, **$HClO_4$**	
Nitric, **HNO_3**	
Sulfuric, **H_2SO_4**	

The brevity of this list tells that most acids are weak. (For H_2SO_4 only the first proton completely ionizes). The common strong bases are the common soluble metal hydroxides. Most other metal hydroxides are insoluble in water.
The most common weak base is NH_3, which reacts with water to form OH^- ions.

Strong and Weak Acids and Bases

PRACTICE EXERCISE (Comparing Acid Strengths)

- The following diagrams represent aqueous solutions of acids HX, HY, and HZ. Rank the acids from strongest to weakest.



<u>Solution</u>

We can determine the relative numbers of uncharged molecular species in the diagrams. The strongest acid is the one with the most H^+ ions and fewest undissociated molecules in solution. The weakest acid is the one with the largest number of undissociated molecules.

The order is HY > HZ > HX.
HY is a strong acid because it is totally ionized (no HY molecules in solution), whereas both HX and HZ are weak acids, whose solutions consist of a mixture of molecules and ions. Because HZ contains more H^+ ions and fewer molecules than HX, it is a stronger acid.

- Imagine a diagram showing 10 Na^+ ions and 10 OH^- ions. If this solution were mixed with the one pictured above for HY, what species would be present in a diagram that represents the combined solutions after any possible reaction?

Answer: The diagram would show10Na^+ ions, 2OH^-ions, 8Y^- ions and 8 H_2O molecules.

Identifying Strong and Weak Electrolytes

It is possible to make predictions about the electrolytic strength of a great number of water-soluble substances. To classify a soluble substance as strong electrolyte, weak electrolyte, or non-electrolyte, we work our way down and across this table. We first ask whether the substance is ionic or molecular. If it is ionic, it is a strong electrolyte.

Summary of the Electrolytic Behavior of Common Soluble Compounds

	Strong Electrolyte	**Weak Electrolyte**	**Nonelectrolyte**
Ionic	All	None	None
Molecular	Strong acids (see table)	Weak acids, weak bases	All other compounds

Identifying Strong and Weak Electrolytes

PRACTICE EXERCISE (Identifying Strong, Weak, and Non-electrolytes)

- Classify these dissolved substances as strong, weak, or non-electrolyte: $CaCl_2$, HNO_3, C_2H_5OH (ethanol), HCOOH (formic acid), KOH.

Solution

We can predict whether a substance is ionic or molecular based on its composition.

Two compounds are ionic: $CaCl_2$ and KOH. Because the "*Summary of the Electrolytic Behavior of Common Soluble Compounds*" table tells us that all ionic compounds are strong electrolytes, that is how we classify these two substances.

The three remaining compounds are molecular. HNO_3 and HCOOH are acids.

Nitric acid, HNO_3, is a common strong acid ("*Common Strong Acids and Bases*" table), and therefore is a strong electrolyte.

Because most acids are weak acids, the best guess would be that HCOOH is a weak acid (weak electrolyte).

The remaining molecular compound, C_2H_5OH, is neither an acid nor a base, so it is a non-electrolyte.

Note: Although C_2H_5OH has an OH group, it is not a metal hydroxide and so not a base. Rather, it is a member of a class of organic compounds that have C-OH bonds, which are known as alcohols.

Neutralization Reactions and Salts

The properties of acidic solutions are quite different from those of basic solutions. Acids have a sour taste, whereas bases have a bitter taste.
In addition, acidic and basic solutions differ in chemical properties in several other important ways.

When an acid and a base are mixed, a **neutralization reaction** occurs.
The products of the reaction have none of the characteristic properties of either the acidic solution or the basic solution.
E.g. When hydrochloric acid is mixed with a solution of sodium hydroxide, the reaction is

$$\underset{\text{acid}}{HCl\,(aq)} + \underset{\text{base}}{NaOH\,(aq)} \longrightarrow \underset{\text{water}}{H_2O\,(\ell)} + \underset{\text{salt}}{NaCl\,(aq)}$$

Water and table salt, NaCl, are the products of the reaction. By analogy to this reaction, the term salt has come to mean any ionic compound whose cation comes from a base (for example, Na^+ from NaOH) and whose anion comes from an acid (for example, Cl^- from HCl).
In general, a neutralization reaction between an acid and a metal hydroxide produces water and a salt.

Neutralization Reactions and Salts

PRACTICE EXERCISE (Writing Chemical Equations for a Neutralization Reaction)

- For the reaction between aqueous solutions of acetic acid (CH_3COOH) and barium hydroxide, $Ba(OH)_2$, write the balanced molecular equation

Solution

Neutralization reactions form two products: H_2O and a salt. We examine the cation of the base and the anion of the acid to determine the composition of the salt.

The salt contains the cation of the base (Ba^{2+}) and the anion of the acid (CH_3COO^-). Thus, the salt formula is $Ba(CH_3COO)_2$. This compound is soluble in water. The unbalanced molecular equation for the neutralization reaction is

$$CH_3COOH\ (aq) + Ba(OH)_2\ (aq) \longrightarrow H_2O\ (\ell) + Ba(CH_3COO)_2\ (aq)$$

To balance this equation, we must provide two molecules of CH COOH to furnish the two CH COO- ions and to supply the two H ions needed to combine with the two OH ions of the base. The balanced molecular equation is

$$2\ CH_3COOH\ (aq) + Ba(OH)_2\ (aq) \longrightarrow 2\ H_2O\ (\ell) + Ba(CH_3COO)_2\ (aq)$$

- For the reaction of phosphorous acid (H_3PO_3) and potassium hydroxide (KOH), write the balanced molecular equation.

Answers: (a)$H_3PO_3\ (aq) + 3\ KOH\ (aq) \longrightarrow 3\ H_2O\ (\ell) + K_3PO_3\ (aq)$