LESSON

21 Neutral Territory

Neutralization Reactions

Think About It

The acid and base react in solution and neutralize each other. The chemical equation for the reaction between an acid and base is shown below.

A Neutralization Reaction

Acid Base Salt Water

$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$

Cl^- changes place with OH^-

Notice that this reaction is a double exchange reaction. The H^+ and Na^+ cations exchange anions. The result is the production of a salt, NaCl, and water. The excess H^+ from the acid combines with OH^- from the added base to form H_2O. The reaction is referred to as a **neutralization reaction.**

BIG IDEA Acids and bases neutralize each other, producing a salt and water.

So, one way to make an acidic solution safe is by adding a base. Likewise, you can make a basic solution safe by adding an acid.

Not all neutralization reactions produce neutral solutions. For example, if you use an acidic solution that is very concentrated and a basic solution that is not very concentrated, there will be leftover H^+ ions after mixing. There will not be enough OH^- ions to neutralize all of the H^+ ions. But some neutralization will have taken place. As a result of mixing, the solution will be closer to neutral than either of the starting solutions.

2 Predicting the Products of Neutralization Reactions

Several neutralization reactions are shown. Notice the patterns in the products of the reactions.

$$HCl(aq) + KOH(aq) \longrightarrow KCl(aq) + H_2O(l)$$
$$HNO_3(aq) + NaOH(aq) \longrightarrow NaNO_3(aq) + H_2O(l)$$
$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$
$$2HCl + Mg(OH)_2(aq) \longrightarrow MgCl_2(aq) + 2H_2O(l)$$
$$H_2SO_4(aq) + Ca(OH)_2(aq) \longrightarrow CaSO_4(aq) + 2H_2O(l)$$

Each reaction results in the production of an ionic compound (a salt) plus water. The salt consists of the cation of the base and the anion of the acid. For example, the cation in potassium hydroxide, KOH, is potassium, K^+. The anion in nitric acid, HNO, is nitrate, NO_3^-. The K^+ and NO_3^- produce the ionic compound, potassium nitrate, KNO_3, which is a salt.

Some acids transfer more than one H^+ ion. For example, each mole of sulfuric acid, H_2SO_4, transfers two moles of H^+ ions. This is because there are two hydrogen ions in solution for every one sulfate anion, SO_4^{2-}. Likewise, each mole of calcium hydroxide, $Ca(OH)_2$, transfers two moles of OH^- ions. There are two hydroxide ions in each formula unit of calcium hydroxide to balance the charge on the calcium cations, Ca^{2+}.

HEALTH CONNECTION

Some antacids are made of calcium carbonate. Calcium carbonate is the main component of eggshells and seashells and can also be used as an inexpensive calcium supplement.

Example

Producing Potassium Sulfate, K_2SO_4

Which of the acids and bases in this table could you mix in order to make potassium sulfate, K_2SO_4? Write a balanced chemical equation for the reaction.

Acids	Bases
HNO_3	KOH
H_2SO_4	NaOH
HBr	$Mg(OH)_2$

Solution

One way to use a neutralization reaction to make potassium sulfate is

$$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$$

Notice that you need 2 mol of KOH in order to balance the equation properly.

Relieving Stomach Acid

A common over-the-counter remedy for excess stomach acid uses a neutralization reaction. Milk of magnesia is a white mixture containing magnesium hydroxide, $Mg(OH)_2$. The mixture looks like milk because magnesium hydroxide, a white solid, does not dissolve completely in water. Instead, the white solid is suspended in the liquid.

Magnesium hydroxide is a base. It neutralizes stomach acid, HCl, to produce a salt and water as shown by this reaction.

$$2HCl(aq) + Mg(OH)_2 \longrightarrow MgCl_2(aq) + 2H_2O(l)$$

stomach acid + milk of magnesia $\longrightarrow$ magnesium chloride + water

Key Term

neutralization reaction

Lesson Summary

What happens when acids and bases are mixed?

A neutralization reaction is a reaction in which an acid and a base react in aqueous solution to produce an ionic compound (a salt) and water. The pH approaches 7 because the H^+ from the acid and the OH^- from the base combine to form H_2O. It is relatively easy to predict the products of a neutralization reaction. The salt that forms is made from the cation of the base and the anion of the acid.

EXERCISES

Reading Questions

1. Describe two ways to make a strong acidic solution safer.
2. What is a neutralization reaction?

Reason and Apply

4. Predict the products for the reactions given below. Be sure to balance each equation.

a. $HF(aq) + NaOH(aq) \longrightarrow$

b. $HCl(aq) + Mg(OH)_2(aq) \longrightarrow$

c. $HF(aq) + NH_4OH(aq) \longrightarrow$

7. Which of these substances might be useful in neutralizing a lake damaged by acid rain?

A. H_2SO_4

B. CH_3COOH

C. $CaCl_2$

D. $Ca(OH)_2$

8. Which combination of reactants would result in a neutralization reaction with sodium nitrate, $NaNO_3$, as one of the products?

A. $Mg(NO_3)_2 + NaOH$

B. $HNO_3 + NaOH$

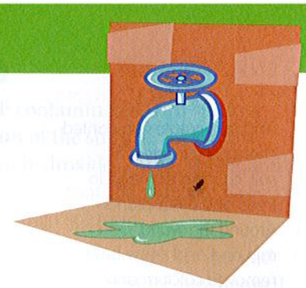
C. $CH_3OH + NaOH$

D. $HNO_3 + NaCl$

LESSON

22 Drip Drop

Titration



Think About It

When sulfur dioxide, SO_2, and nitrogen oxide, NO, two components of air pollution, come in contact with water in the atmosphere they are converted to sulfuric acid, H_2SO_4, and nitric acid, HNO_3. The acids then fall as acidic rain or snow. Acid precipitation is highly destructive, sometimes causing the complete elimination of fish and insect species from lakes or streams. Acid rain also makes the soil unsuitable for plant life, killing off whole sections of forest. Water scientists, called hydrologists, regularly study the acidity of lakes and streams to monitor the extent of the acid rain problem.

How can you use a neutralization reaction to figure out acid or base concentration?

To answer this question, you will explore

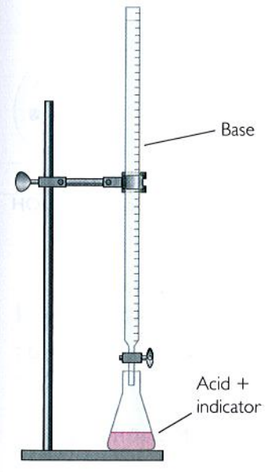
1. Titrations
2. Particle Views of Titrations
3. Titration Calculations

Exploring the Topic

1 Titrations

To track the spread of acid rain, scientists take water samples from lakes and test them for H^+ concentration. One way to determine the concentration of a strong acid in a water sample is to use a method called a **titration.** A titration is a neutralization reaction that is monitored with an acid-base indicator. For example, a strong base with a known concentration is added to a strong acid sample with an unknown concentration. The base is added until the indicator changes color.

A Titration Setup



The indicator provides a visual signal that the solution has reached the **equivalence point,** the point at which the moles of base added have neutralized the moles of acid. By keeping track of the exact volume of base that is added to a known volume of acid, you can figure out the unknown concentration of acid in the sample.

The illustration shows a titration setup. The long thin tube is a *burette.* A valve on the burette allows you to regulate how much solution goes into the beaker. During a titration, solution is added from the burette until the indicator changes color. You determine the volume of solution added by noting the change in the height of the solution in the burette.

Phenolphthalein is an indicator that changes from colorless to bright pink in a base.

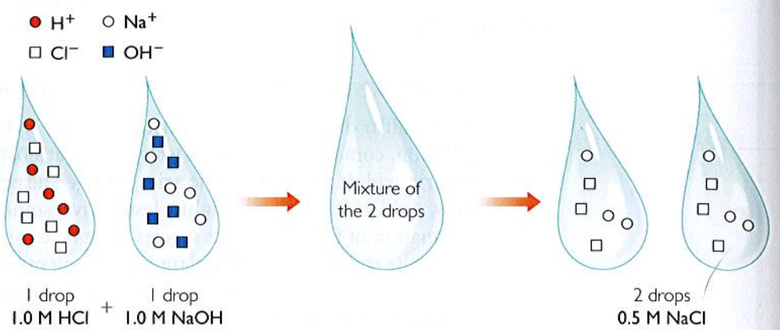
ENVIRONMENTAL CONNECTION

Acid rain creates unwanted chemical changes in soil, causing damage to trees and other plants. Around the world, acid rain and acid snow have removed calcium and magnesium from the soil and have increased levels of aluminum. When aluminum is absorbed into plants, it displaces calcium and other nutrients that the plants need.

2 Particle Views of Titrations

This illustration shows what happens as equal volumes of 1.0 M HCl, hydrochloric acid, and 1.0 M NaOH, sodium hydroxide, are mixed together.

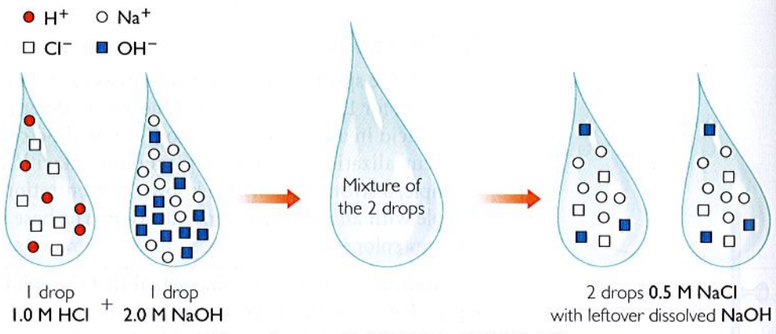
$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$



Neutralization of 1.0 M NaOH by 1.0 M HCl

When you add one drop of 1.0 M HCl to one drop of 1.0 M NaOH, H^+ ions from the acid and OH^- ions from the base combine to form H_2O. The Na^+ ions and Cl^- ions from the original drops are dissolved in the water. Notice that the concentration of Na^+ ions and Cl^- ions has decreased because each ion has spread out over twice the volume, equal to two drops of solution.

The next illustration shows what happens when equal volumes of 1.0 M HCl and 2.0 M NaOH are mixed together.

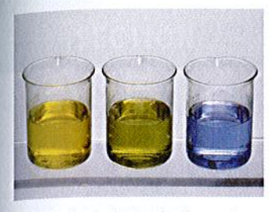


Neutralization of 1.0 M HCl by 2.0 M NaOH

In this example, the base is more concentrated than the acid so the two-drop mixture will have leftover dissolved NaOH in addition to dissolved 0.5 M NaCl.

Because the 2.0 M NaOH is twice as concentrated as the 1.0 M HCl, you only need half as much of it to neutralize the HCl.

Moles of H^+ in 1.0 M HCl (10 mL)	Moles of OH^- in 2.0 M NaOH (5 mL)
moles H^+ = molarity · volume = 1.0 M · 0.010 L = 0.005 mol	moles OH^- = molarity · volume = 2.0 M · 0.005 L = 0.005 mol



Bromothymol blue indicator is yellow in acidic solution, green in neutral solution, and blue in basic solution.

3 Titration Calculations

Suppose you take a 100 mL water sample from a lake contaminated with sulfuric acid, H_2SO_4. You want to determine the concentration of the sulfuric acid in the lake. So you titrate the sample with 2.0 molar sodium hydroxide, 2.0 M NaOH, until the solution is neutral. At the equivalence point, you know that the moles of base you added neutralized moles of acid that were in the unknown solution.

You need an indicator that changes color when the solution is neutral, so you add a drop of bromothymol blue to the lake water sample. You add NaOH slowly until the indicator turns green. Because you know the volume and molarity of the NaOH added, you can calculate the moles of acid per liter of solution in the lake water sample.

Example

Titration of H_2SO_4

A 100 mL sample of aqueous sulfuric acid, H_2SO_4, is titrated with 2.0 M NaOH. After 50 mL of NaOH are added, the indicator changes color at pH 7. What was the starting concentration of the H_2SO_4?

Solution

Begin by writing a balanced chemical equation.

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$
$$\text{sulfuric acid} + \text{sodium hydroxide} \longrightarrow \text{sodium sulfate} + \text{water}$$

Find the total number of moles of NaOH that were used to neutralize the H_2SO_4.

$$\text{moles NaOH} = (\text{molarity of NaOH})(\text{volume of NaOH added})$$
$$= (2.0 \text{ mol/L})(0.050 \text{ L}) = 0.10 \text{ mol NaOH}$$

Since 2 mol of NaOH are needed to neutralize every 1 mol of H_2SO_4, the moles of H_2SO_4 in the sample must be half the number of moles of the added NaOH.

$$\text{moles of } H_2SO_4 = \frac{1}{2}(\text{moles of NaOH}) = \frac{1}{2}(0.10 \text{ mol}) = 0.05 \text{ mol}$$

Finally, find the molarity of the sulfuric acid solution.

$$\text{molarity of sulfuric acid} = \frac{n}{V}$$
$$= 0.050 \text{ mol}/0.100 \text{ L}$$
$$= 0.50 \text{ M } H_2SO_4$$

Key Terms

titration
equivalence point

Lesson Summary

How can you use a neutralization reaction to figure out acid or base concentration?

A titration is a chemical procedure carried out between an acid and a base in order to determine the concentration of either the acid or the base. A titration is a neutralization reaction that is monitored with an indicator. The volume of acid and the volume of base used in the procedure are carefully recorded. If the molarity of either the acid or the base is known, the molarity of the other can be determined.

EXERCISES

Reading Questions

1. Describe how you might use a titration to figure out the concentration of potassium hydroxide in a water sample.
2. What is the role of an indicator in titration?

Reason and Apply

3. How many mL of 0.1 M NaOH would be required to neutralize 2.0 L of 0.050 M HCl?

5. A student mixes 100 mL of 0.20 M HCl with different volumes of 0.50 M NaOH. Are the final solutions acidic, basic, or neutral? Explain your thinking.
   a. 100 mL of 0.20 M HCl + 20 mL of 0.50 M NaOH
   b. 100 mL of 0.20 M HCl + 40 mL of 0.50 M NaOH
   c. 100 mL of 0.20 M HCl + 60 mL of 0.50 M NaOH
6. Imagine you use 0.95 M NaOH to titrate several water samples. The volume of base needed to neutralize a specified amount of acid is given. Determine the acid concentration for each.
   a. 25 mL acid, 46 mL NaOH
   b. 10 mL acid, 17 mL NaOH
   c. 25 mL acid, 12 mL NaOH