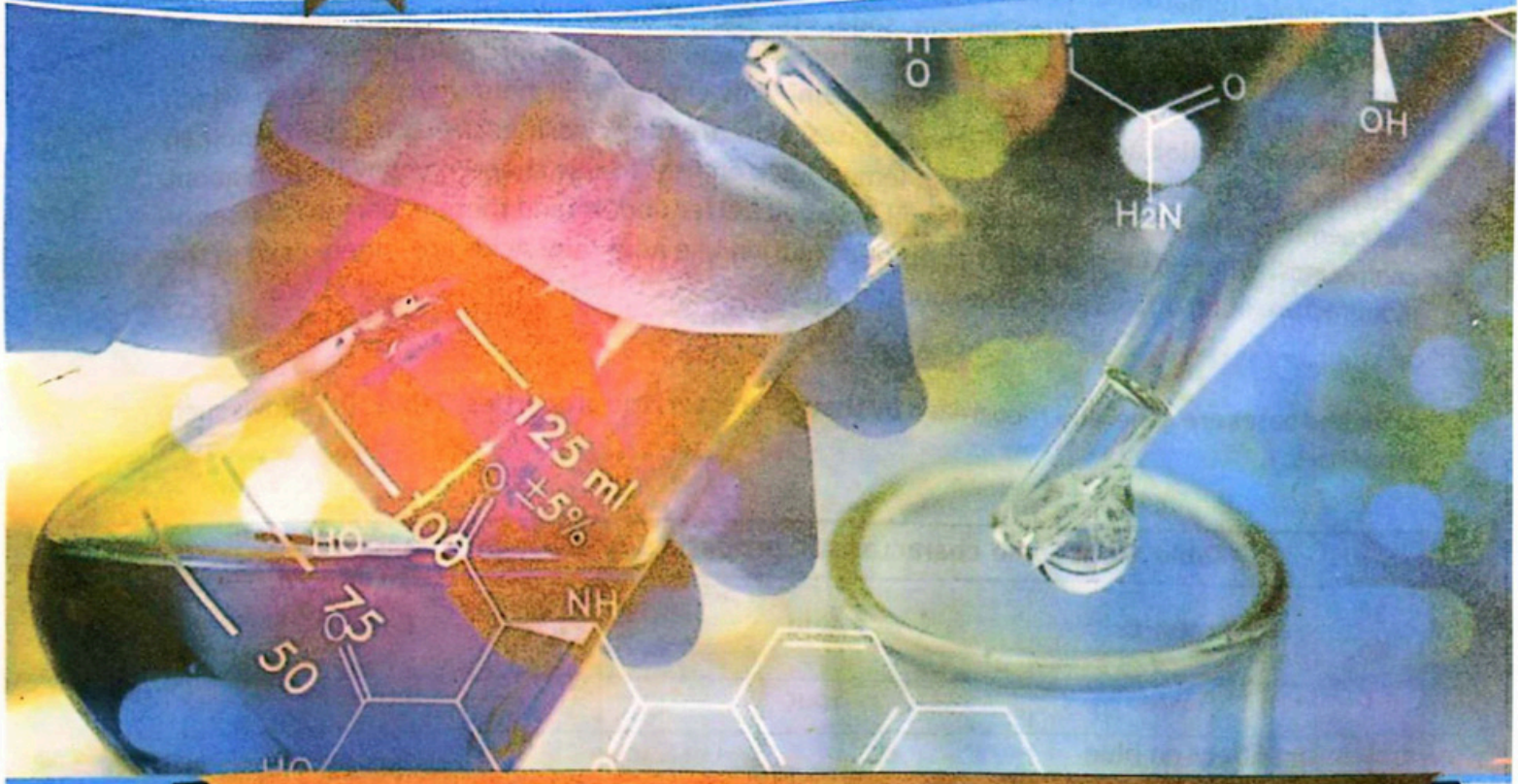
UNIT 10



ACIDS, BASES AND SALTS

Student Learning Outcomes (SLOs)

After completing this lesson, the student will be able to:

- Define Bronsted-Lowry acids as proton donors and Bronsted-Lowery bases as proton acceptors.
- Recognize that aqueous solutions of acids contain H^+ ions and aqueous solutions of alkalis contain OH^- ions.
- Define a strong acid and a base as an acid or base that completely dissociates in aqueous solution and weak acids and bases that partially dissociates in aqueous solution.(some example include: Students writing symbol equations to show these for hydrochloric acid, sulphuric acid, nitric acid, and ethanoic acid).
- Formulate dissociation equations for an acid or base in aqueous solution.
- Recognize that bases are oxides or hydroxides of metals and that alkalis are water-soluble bases.
- Describe the characteristic properties of acids in terms of their reactions with metals, bases, and carbonates.
- Identify the characteristic properties of bases in terms of their reactions with acids and ammonium salts.
- Define acid rain.
- Discuss effects of acid rain and relate them with the properties of acids.

INTRODUCTION

You often use acids and bases in all areas of life. For example, vinegar, aspirin, lemon juice, cola drinks, apple, tomato and toilet cleaners contain acids. Substances containing bases such as drain cleaner, antacid tablets, baking powder, soda, etc. You eat and drink certain acids and bases and your body produces them. From "acid indigestion" to "acid rain," the word acid appears frequently in news and advertisements. What is acid rain? This chapter will help you understand which substances are called acids and which are bases. How are they classified? What happens when an acid reacts with a base? Why do we use lemon juice on fish? In this chapter, you will learn about the chemistry of acids and bases. This will help you better understand these important classes of compounds. What do we mean by the pH of a solution like acid rain? Acids are widely used in the manufacture of fertilizers and in the food industry.

10.1 CONCEPTS OF ACIDS AND BASES

Acids and bases are generally recognized by their characteristic properties. Table 10.1 shows such properties.

Table 10.1: Some characteristic properties of acids and bases

Sr. No.	Property	Acid	Base
1	Taste	Sour	Bitter
2	Effect on blue litmus	Turns red	No effect
3	Effect on red litmus	No effect	Turns blue
4	Effect on skin	Corrosive	Corrosive
5	Electrical conductivity	Aqueous solutions conduct electricity	Aqueous solutions conduct electricity

10.1.1 Arrhenius Concept of Acids and Bases

In 1887, a Swedish chemist Svante Arrhenius proposed the first successful theory of acids and bases. According to this theory

An acid is a substance that ionizes in water to produce H^+ ion sand a base is a substance that ionizes in water to produces OH^- ions.

For example,

$$HCl_{(g)} \xrightleftharpoons{H_2O} H^+_{(aq)} + Cl^-_{(aq)}$$

$$NaOH_{(s)} \xrightleftharpoons{H_2O} Na^+_{(aq)} + OH^-_{(aq)}$$

Which substances in the following reactions are acids or bases?

$$HNO_{3\,(l)} \xrightleftharpoons{H_2O} H^+_{(aq)} + NO_3^{-1}{}_{(aq)}$$

$$H_2SO_{4\,(l)} \xrightleftharpoons{H_2O} 2H^+_{(aq)} + SO_4^{-2}{}_{(aq)}$$

$$KOH_{(s)} \xrightleftharpoons{H_2O} K^+_{(aq)} + OH^-{}_{(aq)}$$

$$NH_4OH_{(aq)} \xrightleftharpoons{H_2O} NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

Table 10.2 shows some common acids and table 10.3 shows some common bases.

Table 10.2 Some Common Acids

Name	Formula	Common use
Hydrochloric acid	HCl	Cleaning of metals, bricks and removing scale from boilers
Nitric acid	HNO_3	Manufacture of fertilizers, explosives
Sulphuric acid	H_2SO_4	Manufacture of many chemicals, drugs, dyes, paints and explosives.
Phosphoric acid	H_3PO_4	Manufacture of fertilizers, acidulant for food

Table 10.3 Some Common Bases

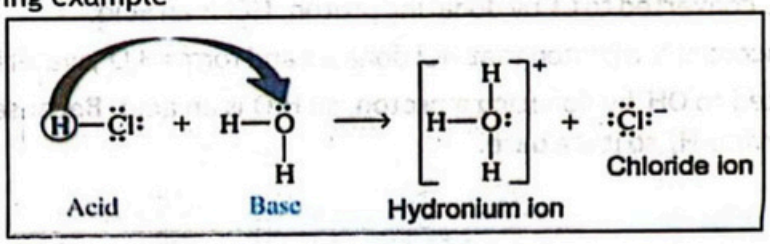
Name	Formula	Common use
Sodium hydroxide	$NaOH$	Soap making, drain cleaners
Potassium hydroxide	KOH	Making liquid soap, shaving cream
Calcium hydroxide	$Ca(OH)_2$	Making mortar, plasters, cement
Magnesium hydroxide	$Mg(OH)_2$	Antacid, laxative

10.1.2 The Bronsted-Lowery Concept of Acids and Bases

The Arrhenius theory has its limitations. This applies to aqueous solutions. This does not explain why compounds like CO_2, SO_2, etc. are acidic. Why are substances like NH_3 bases? There is no H in CO_2 and no O in NH_3.

In 1923, J. N. Bronsted and T. M. Lowery independently proposed another theory to overcome the shortcomings of the Arrhenius theory. This theory is known as the Bronsted-Lowery theory. According to this theory, an acid is a proton donor and a base is a proton acceptor.

Consider the following example



Q.1. Whichsubstance is donating proton?

_____

Q. 2. Which substance is accepting proton?

_____

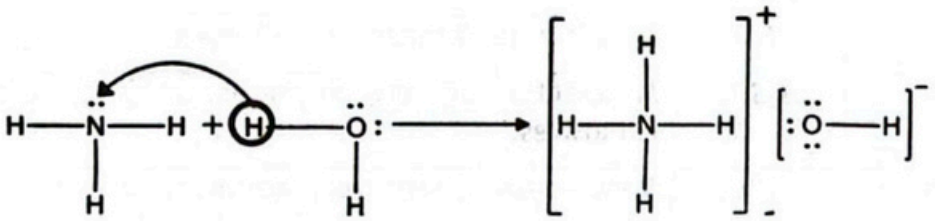
Q. 3. Which substance is acid?

_____

Q. 4. Which substance is base?

_____

Where does OH^- come from when ionizing bases such as ammonia? The Arrhenius theory is not sufficient to answer this question, but the Bronsted-Lowry theory explains how ammonia acts as a base in water. Ammonia is a gas at room temperature. When it is dissolved in water, the following reaction occurs.



Which substance is donating proton, NH_3 or H_2O? Which substance is proton acceptor? All the acids included in the Arrhenius Theory are also acids in the Bronsted-Lowery Theory. However, all the bases included in Bronsted-Lowery theory except OH^- are not Arrhenius bases. Consider above two examples. In one example, water molecule accepts a proton and in the other water donates a proton. This means water behaves like an acid as well as a base. It is amphoteric in nature. Substances that react with both acids and bases are called amphoteric substances.

Example 10.1: Classify substances as acids or bases or as proton donor or proton acceptor

Identify Bronsted-Lowery acids or bases in the following reactions.

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

$$H_2O + NH_3 \longrightarrow NH_4^+ + OH^-$$

Problem solving strategy:

1. **An acid is a proton donor. After donating proton, an acid forms a negative ion.**
2. **A base is a proton acceptor. After accepting proton from an acid it forms a positive ion.**

Solution:

1. **Because HCl is converted to Cl^- by donating proton, HCl is an acid.**
2. **Because H_2O accepts the proton that HCl donates and forms H_3O^+, wateris a base.**
3. **H_2O is converted to OH^- by donating a proton, so H_2O is an acid. Because NH_3 accepts the proton and forms NH_4^+ so it is a base.**

CONCEPT ASSESSMENT EXERCISE 10.1

Identify Bronsted acids and Bronsted bases in the following reactions.

1. $H_2SO_4 + H_2O \rightleftharpoons HSO_4^- + H_3O^+$
2. $CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$
3. $H_2S + NH_3 \rightleftharpoons NH_4^+ + HS^-$

10.2 STRENGETH OF ACIDS AND BASES

All the acids and bases do not ionize in aqueous solutions to the same degree. Therefore, they have different strengths.

10.2.1 Strong and weak acids

An acid that ionizes completely in aqueous solution is called a strong acid. For example, HCl, HNO_3, H_2SO_4 etc are strong acids. They ionize 100% in aqueous solution. All the molecules of strong acids ionizze in water.

$$HCl_{(g)} \xrightleftharpoons{H_2O} H^+_{(aq)} + Cl^-_{(aq)}$$

$$HNO_{3\,(l)} \xrightleftharpoons{H_2O} H^+_{(aq)} + NO_3^{1-}{}_{(aq)}$$

$$H_2SO_{4\,(l)} \xrightleftharpoons{H_2O} 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

Acids that do not ionize completely in aqueous solutions are called weak acids. Fewer molecules of weak acids ionize in water. For example, ethanioc acid(acetic acid) which is found in vinegar ionizes only up to 5% in water. So, etanoic acid is a weak acid.

$$CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$$

10.2.2 Strong and weak bases

Like acids, bases can also ionize in water to different degree. A base that ionizes completely or 100% in aqueous solution is termed as strong base. For example, NaOH, KOH, $Ca(OH)_2$ etc are strong bases.

$$NaOH_{(s)} \xrightleftharpoons{H_2O} Na^+_{(aq)} + OH^-_{(aq)}$$

$$KOH_{(s)} \xrightleftharpoons{H_2O} K^+_{(aq)} + OH^-_{(aq)}$$

A base that ionizes to a little extent is called a weak base.Such bases produce fewer OH^- ions in aqueous solution. $Al(OH)_3$, NH_3 etc are weak bases.

$$H_2O + NH_3 \longrightarrow NH_4^+ + OH^-$$

Alkalis

A base which is soluble in water is called an alkali. This means that all the bases are not alkalis. On the other hand all the alkalis are bases. Which is an alkali KOH or NaOH?

Many bases do not dissolve in water. For example, copper hydroxide($Cu(OH)_2$, aluminiun hydroxide$Al(OH)_3$ and ferric hydroxide$Fe(OH)_3$. All hydroxides are bases and only water soluble bases are alkalis. Many household items such as soaps, detergents, shampoos, toothpaste contain alkali.

10.3 CHARACTERISTIC PROPERTIES OF ACIDS

General properties of acids are as follows:

1. Acids have sour raste.
2. Acids change the colour of blue litmus paper to red.
3. Acids react with most metals and corrode them. Acids combine with metals like zinc, magnesium, aluminium and calcium to form their salts and hydrogen. The hydrogen gas is liberated in the form of bubbles. Zinc reacts with hydrochloric acid to produce zinc chloride with the leberation of hydrogen gas. Similarly, magnesium reacts with sulphuric acid to produce magnesium sulphate and hydrogen. The reaction of metals with acids can be described by the following equation.

Metal + Acid → Salt + Hydrogen

$Zn + HCl \rightarrow ZnCl_2 + H_2$

$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$

4. Acids react with metal carbonates to form salts, water with the liberation of carbon dioxide. The liberated carbon dioxide forms bubbles in water. For example hydrochloric acid reacts with sodium carbonate to forn sodiun chloride, carbon dioxide and water. Similarly, sulphuric acid reacrs with calcium carbonate(lime stone or marble) to produce calcium sulphate, carbon dioxide and water. The reaction of metal carbonate with acids can be represented by the following general reaction.

Metal carbonate + Acid → Salt + Water + Carbon dioxide

$Na_2CO_3 + HCl \rightarrow NaCl + H_2O + CO_2$

$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$

This reaction is used in the industrial preparation of glass, paper and soap.

5. Acids combine with bases to produce salt and water. This reaction is called as neutralization reaction. For example hydrochloric acid neuutralizes sodium hydroxide to form sodium chloride and water. Similarly sulphuric acid combines with potassium hydroxide to produce potassium sulphate and water. Neutralization reaction can be represented by the following general reaction.

Acid + Base → Salt + Water

$HCl + NaOH \rightarrow NaCl + H_2O$

$H_2SO_4 + KOH \rightarrow K_2SO_4 + H_2O$

Normal rain is slightly acidic due to dissolved carbon dioxide. As a result of human activity, many

oxides enter the atmosphere, which makes rainwater more acidic, which falls as acid rain .Acid rain contains dissolved nitric and sulphuric acid. Due to the corrosive nature of acids, acid rain can damage structures, buildings, and statues containing metals and metal carbonates. You can learn about the consequences of acid rain in the chapter on environmental chemistry.

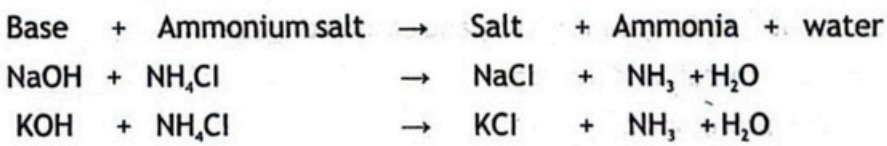
10.4 CHARACTERISTIC PROPERTIES OF BASES

General properties of bases are as follows:

1. Bases have bitter taste.
2. Bases change the colour of red litmus paper to blue.
3. Aqueous solution of bases have slippery touch.
4. Bases neutralize acids to form salt and water.

$$H_2SO_4 + NaOH \rightarrow Na_2SO_4 + H_2O$$

5. Bases decompose ammonium salts on heating and liberate ammonia gas.



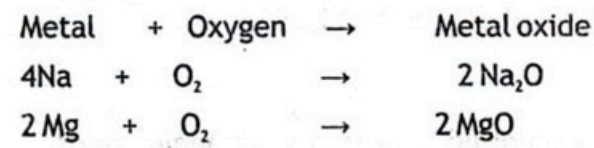
$$\text{Base} + \text{Ammonium salt} \rightarrow \text{Salt} + \text{Ammonia} + \text{water}$$

$$NaOH + NH_4Cl \rightarrow NaCl + NH_3 + H_2O$$

$$KOH + NH_4Cl \rightarrow KCl + NH_3 + H_2O$$

10.5 OXIDES AND HYDROXIDES

Bases and hydroxides of metals consists of oxides and hydroxides of metals. Metallic oxides are the compounds formed by the reaction of metals with oxygen. For example, sodium reacts with oxygen to produce sodium oxide (Na_2O). Similarly magnesium on ignition in air burns producing magnesium oxide(MgO).



$$\text{Metal} + \text{Oxygen} \rightarrow \text{Metal oxide}$$

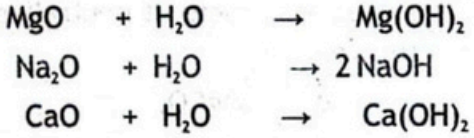
$$4Na + O_2 \rightarrow 2\,Na_2O$$

$$2\,Mg + O_2 \rightarrow 2\,MgO$$

When metal oxides dissolve in water, resulting in metal cations and oxide ions in aqueous solution. Because oxide ions are unstable in water, they immediately accept protons from water molecules and become hydroxide ions, and the water molecules also become hydroxide ions. Which species is the proton donor in this reaction?

$$O^{2-} + H\text{-}OH \rightarrow 2OH^{1-}$$

$$\textbf{Metal oxide} + \textbf{water} \rightarrow \textbf{Metal hydroxide}$$



$$MgO + H_2O \rightarrow Mg(OH)_2$$

$$Na_2O + H_2O \rightarrow 2\,NaOH$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Most metal oxides and hydroxides are very basic in nature. They show the characteristic properties of bases. However, some metal oxides and hydroxides do not dissolve in water but behave in chemical reactions like both acids and bases. Such metal oxides and hydroxides are called amphoteric oxides and hydroxides, respectively. For example, aluminium oxide (Al_2O_3), alunimium hydroxjde ,$Al(OH)_3$, zinc oxide(ZnO) and zinc hydroxide($Zn(OH)_2$,etc.

KEY POINTS

- According to Arrhenius theory, an acid is a substance that ionizes in water to produce H+ ions and a base is a substance that ionizes in water to produce OH- ions.
- A Bronsted-Lowry acid is a proton donor and a base is a proton acceptor.
- A srong acid completely dissociates in aqueous solution and a weak acid dissociate partially in aqueous solution.
- A stong base completely dissociates in aqueous solution and a weak base dissociates partially in aqueous solution.
- Bases are oxides and hydroxides of metals.
- Alkalis are water soluble bases.
- Acids neutralize bases to form salt and water.
- Acids decompose carbonates to form salt, water, and carbon dioxide.
- Acids corrode metals and form salt and hydrogen
- References for additional information
- Longman Chemistry for IGCSE.
- IGCSE Chemistry.
- Cambridge IGCSE, Chemistry.
- Theories of Acids and Base Chemiguide.

REVIEW QUESTIONS

1. Encircle the correct answer.

(I) Which of the following cannot be classified as Arrhenius acid?

(a) HNO_3 (b) H_2CO_3

(c) CO_2 (d) H_2SO_4

(ii) Which of the following is a Bronsted base?

(a) NH_3 (b) HCl

(c) CH_3COOH (d) H_3O^+

(iii) Milk of magnesia contains $Mg(OH)_2$. It is used as antacid. It neutralizes excess stomach acid. Which salt is formed in this reaction?

(a) $MgSO_4$ (b) $MgCO_3$

(c) $MgCl_2$ (d) MgO

(iv) Ammonia is a base, because it

(a) Ionizes in water to give OH^- ions (b) Contains OH group

(c) Can accept an election pair (d) Can accept proton

(v) Consider the following reaction?

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

(vii) Which species is an electron proton acceptor in this reaction?

(a) H_2O (b) HCl

(c) H_3O^+ (d) none

2. Give short answer.

(i) Write the equation for the self-ionization of water.

(ii) Define and give examples of Arrhenius acids.

(iii) Why HCl acts as a strong acid?

(iv) Why NH_3 acts as Bronsted-Lowry base?

(v) Why ammonia acts as a weak base.

3. Ammonium hydroxide and nitric acid react and produce ammonium nitrate and water. Write balanced chemical equation for this neutralization reaction.

4. Write balanced chemical equations for the following chemical reactions.

(i) Sulphuric acid + Magnesium hydroxide ⟶ magnesium sulphate + water.

(ii) Sulphuric acid + Sodium Carbonate ⟶ Soduimsulphhate + water.

(iii) Hydrochloric acid + Magnesium ⟶ Magnesoum chloride + water

5. Identify Bronsted -Lowry acids or bases in the following reactions.

(i) $HNO_3 + H_2O \longrightarrow H_3O^+ + NO_3^-$

(ii) $NH_3 + HNO_3 \longrightarrow NH_4NO_3$

6. Give the Bronsted-Lowry definition of an acid. Write an equation that illustrates the definition.

7. Identify Bronsted acids and Bronsted bases in the following reactions.
Classify water as proton donor or proton acceptor.

(i) $CH_3COOH_{(aq)} + H_2O \rightleftharpoons CH_3COO^-{}_{(aq)} + H_3O^+{}_{(aq)}$

(ii) $HCO_3^-{}_{(g)} + H_2O_{(l)} \rightleftharpoons CO_3^{-2}{}_{(aq)} + H_3O^+_{(aq)}$

(iii) $NH_{3(g)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$

(iv) $HCl_{(aq)} + HCO_3^-{}_{(aq)} \rightleftharpoons H_2CO_{3(aq)} + Cl^-{}_{(aq)}$

(v) $HS^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons S^{-2}{}_{(aq)} + H_3O^+{}_{(aq)}$

8. Write equations showing the ionization of the following as Arrhenius acids.

9. Write equations showing the ionization of the following as Arrhenius acids

(a) $HI_{(aq)}$ (b) $HNO_{2(aq)}$

THINK TANK

10. Compare the relative concentrations of hydrogen ions and hydroxide ions in each kind of solution?

(a) acidic (b) basic (c) neutral

11. Codeine, $C_{18}H_{21}NO_3$ is a commonly prescribed pain killer. It dissolves in water by the following reaction?

$$C_{18}H_{21}NO_3 + H_2O \rightleftharpoons [C_{18}H_{21}HNO_3]^+ + OH^-$$

Differentiate Codeine and water as Bronsted-Lowry acid or base.

12. Examine some ways in which you might determine whether a particular water solution contains an acid or a base.

PROJECT

Examine the labels of at least three antacid preparations. Make a list of the ingredients in each. Write a balanced chemical equation for the neutralization reaction that takes place when these antacids react with HCl in the stomach.