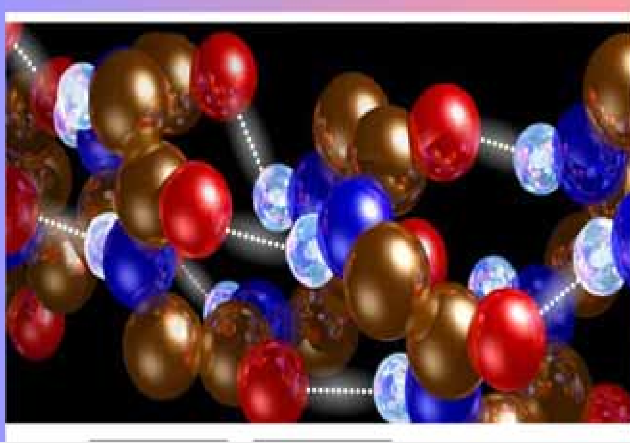
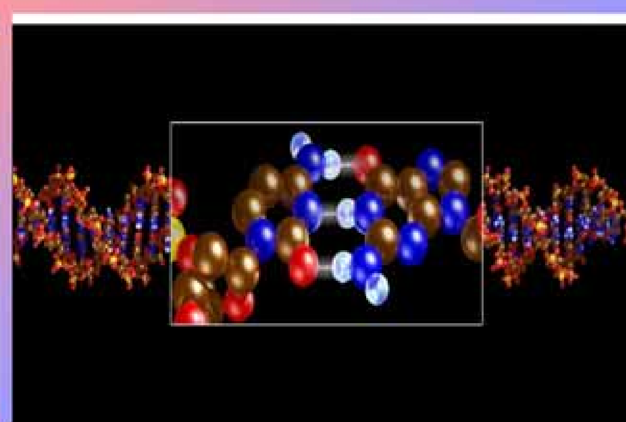
Arrhenius and Bronsted-Lowry Acid-Base Concepts

Learning Outcomes:

Students will be able to:

1. define and give examples of the Arrhenius concept of acids and bases;
2. state and explain the Bronsted-Lowry theory of acids and bases;
3. use the Bronsted-Lowry theory to classify substances as acids or bases.

Introduction:

For thousands of years people have known that vinegar, lemon juice and many other foods taste sour. However, it was until a few years ago that it was discovered why these things taste sour because they are all *acids*. The term acids, in fact, comes from the latin word *acēre*, which means "sour".

In chemistry, there are many different definitions of acids and bases. In this lesson, we will introduce the basic concepts of acid-base chemistry.

In the seventeenth century, the Irish writer and amateur chemist Robert Boyle first labeled substances as either acids or bases (he called bases as alkalies) according to the following characteristics:

Acids	Bases
■ taste sour 	■ feel slippery
■ are corrosive to metals	■ change litmus to blue 
■ change litmus to red 	■ neutralize acids
■ neutralize bases	

While Boyle and others categorized substances as acids and bases but they were not able to explain why these substances behave the way they do.

Acids	Bases
Lemon Juice	*Eggs*
Vinegar	*Calcium*
Milk	*Baking Soda*
Apple Juice	*Sea Water*
White Bread	*Blood*

- It was not until 200 years later that the first reasonable definition of acids and bases was proposed.

Arrhenius concept of Acids and Bases:

In the late 1800s, a Swedish scientist Svante Arrhenius proposed that water can dissolve many compounds by separating them into their individual ions. Arrhenius suggested that *acids are compounds that contain hydrogen and can dissolve in water to release hydrogen ions into solution.* For example, hydrochloric acid (HCl) dissolves in water as follows:

Animation

$$HCl \xrightarrow{H_2O} H^+_{(aq)} + Cl^-_{(aq)}$$

Arrhenius defined bases as *substances that dissolve in water to release hydroxide ions (OH^-) into solution.* For example, a typical base according to the Arrhenius definition is sodium hydroxide (NaOH):

$$NaOH \xrightarrow{H_2O} Na^+_{(aq)} + OH^-_{(aq)}$$

Animation

Usefulness of Arrhenius Theory:

The Arrhenius definition of acids and bases explains a number of things. Arrhenius's theory explains why all acids have similar properties to each other (and, conversely, why all bases are similar). This is because all acids release H^+ into solution (and all bases release OH^-). The Arrhenius definition also explains Boyle's observation that acids and bases counteract each other.

Acids.	Bases.
$HClO_4$	$LiOH$
H_2SO_4	$NaOH$
HCl	KOH
HI	$CsOH$
HBr	$Ca(OH)_2$
HNO_3	$Sr(OH)_2$
	$Ba(OH)_2$

This idea, that a base can make an acid weaker, and vice versa, is called neutralization.

Neutralization:

As you can see from the equations, acids release H^+ ions into solution and bases release OH^- ions. If we were to mix an acid and base together, the H^+ ion would combine with the OH^- ion to make a molecule of water (H_2O).

$H^+_{(aq)}$ + $OH^-_{(aq)}$ → H_2O

The neutralization reaction of an acid with a base will always produce water and salt, as shown below:

Acid		Base		Water		Salt
HCl	+	NaOH	→	H_2O	+	NaCl
HBr	+	KOH	→	H_2O	+	KBr
$HClO_4$	+	NaOH	→	H_2O	+	$NaClO_4$

Though Arrhenius helped explain the fundamentals of acid / base chemistry, unfortunately his theory has limits. For example, the Arrhenius definition does not explain why some substances, such as common baking soda ($NaHCO_3$), can act like a base even though they do not contain hydroxide ions. Na_2CO_3

Bronsted-Lowry Acid-Base Concept:

In 1923, the Danish scientist Johannes Brønsted and the Englishman Thomas Lowry published independent, yet similar papers, that refined Arrhenius theory. In Brønsted's words, "... acids and bases are substances that are capable of splitting off or taking up hydrogen ions, respectively." The Brønsted-Lowry definition broadened the Arrhenius concept of acids and bases.

The Brønsted-Lowry definition of acids is very similar to the Arrhenius definition, *any substance that can donate a hydrogen ion is an acid (under the Brønsted definition, acids are often referred to as proton donors because an H^+ ion, i.e.* hydrogen minus its electron, is simply a proton).

The Brønsted definition of bases is, however, quite different from the Arrhenius definition.

The Brønsted base is defined as *any substance that can accept a hydrogen ion.* In short, a base is the opposite of an acid. NaOH and KOH, as we saw earlier, would still be considered bases because they can accept an H^+ from an acid to form water. However, the Brønsted-Lowry definition also explains why substances that do not contain OH^- can act like bases.

Baking soda ($NaHCO_3$), for example, acts like a base by accepting a hydrogen ion from an acid as illustrated below:

$$\underset{\text{Acid}}{HCl} + \underset{\text{Base}}{NaHCO_3} \rightarrow H_2CO_3 + \underset{\text{Salt}}{NaCl}$$

In this example, the carbonic acid (H_2CO_3) formed undergoes rapid decomposition to produce water and gaseous carbon dioxide, and so the solution bubbles as CO_2 gas is released.

conjugate acid–Base pairs

$$HCl + NH_3 \rightleftharpoons NH_4^+ + Cl^-$$

Acid   Base   Acid   Base

conjugate acid–Base pairs

Under the Brønsted-Lowry definition, both acids and bases are related to the concentration of hydrogen ions present. Acids increase the concentration of hydrogen ions, while bases decrease the concentration of hydrogen ions (by accepting them). The acidity or basicity of something, therefore, can be measured by its hydrogen ion concentration.

Lowry-Bronsted Classification of acids and bases:

The following species may be regarded as *acids*:

Molecular Species : HCl, H_2SO_4, CH_3COOH, HCN, H_2S, H_2O etc.

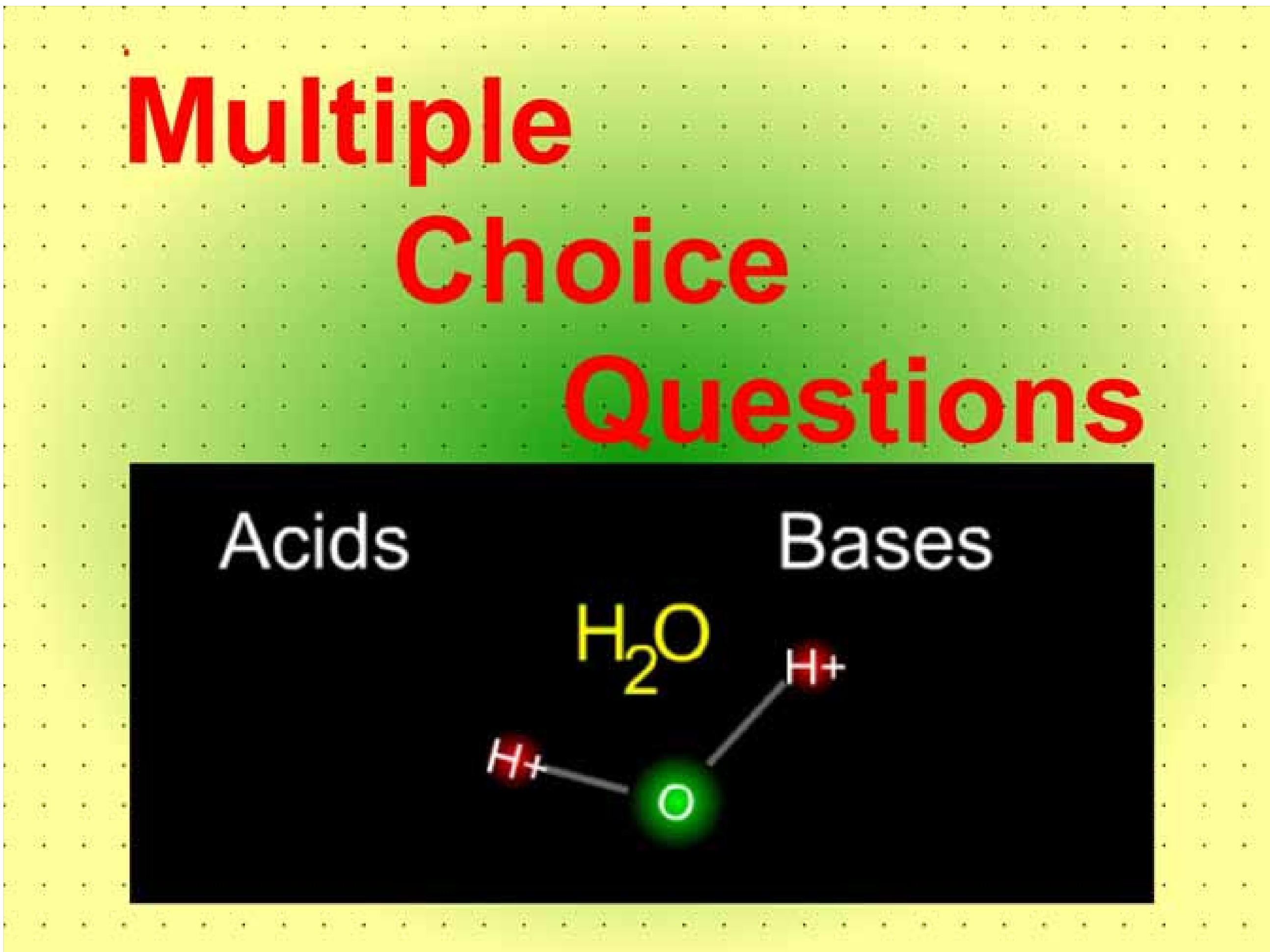
Anionic Species : HSO_4^-, HCO_3^-, $H_2PO_4^-$, HS^- etc.

Cationic Species : H_3O^+, NH_4^+ etc.

The following species may be regarded as *bases*:

Molecular Species : H_2O, NH_3, CH_3NH_2 etc.

Anionic Species : OH^-, HS^-, S^{2-}, HCO_3^-, HSO_4^-, Cl^- etc.


Multiple
Choice
Questions
Acids
Bases
H2O
H+
H+
O

1. A hydrogen ion, H^+, is the same as a/an

A. hydroxide ion.
B. electron.
C. neutron.
D. proton.

2. Which of the following species increase when acid dissolves in water?

A. Hydrogen ions
B. Hydrate ions
C. Hydroxide ions
D. Negative ions

3. Bases are the substances which can

A. accept proton.
B. donate proton.
C. accept hydrogen atom.
D. donate hydrogen atom.