

EXPERIMENT 6  
ACID AND BASE STRENGTH

PURPOSE:

1. To distinguish between acids, bases and neutral substances, by observing their effect on some common indicators.
1. To distinguish between strong and weak acids and bases, by conductivity testing.
3. To identify an unknown, as an acid (strong or weak), a base (strong or weak) or a neutral substance.

PRINCIPLES:

We frequently encounter acids and bases in our daily life. **Acids** were first associated with the sour taste of citrus fruits. In fact, the word **acid** comes from the Latin word **acidus**, which means, “**sour**”.

Vinegar tastes sour because it is a dilute solution (about 5 percent) of acetic acid; citric acid is responsible for the sour taste of a lemon. The sour tastes of rhubarb and spinach come from small amounts of oxalic acid they contain. A normal diet provides mostly acid-producing foods. Hydrochloric acid is the acid in the in the gastric fluid in your stomach, where it is secreted at a strength of about 5 percent.

Water solutions of acids are called **acidic solutions**.

**Bases** have usually a **bitter** taste and a slippery feel, like wet soap. The bitter taste of tonic water comes from natural base, quinine. Common medicinal antacides (used to relieve heartburn) and bitter tasting Milk of Magnesia, a common laxative, (a suspension of about 8 percent of magnesium hydroxide) are also bases. Other bases used around the house are cleaning agents, such as ammonia, and products used to unclog drains, such as Drano. The most important of the strong bases is sodium hydroxide, a solid whose aqueous solutions are used in the manufacture of glass and soap.

Water solutions of bases are called alkaline solutions or **basic solutions**.

Substances used to determine whether a solution is acidic or basic are known as **indicators**. Indicators are organic compounds that change color in a specific way, depending on the acidic or basic nature of the solution. A wide variety of indicators are commonly used in the chemistry laboratory, to identify the acidic or basic nature of an aqueous solution. This experiment uses only two types of indicators: litmus, a vegetable dye, and phenolphthalein.

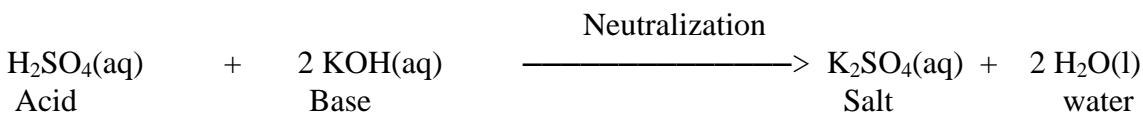
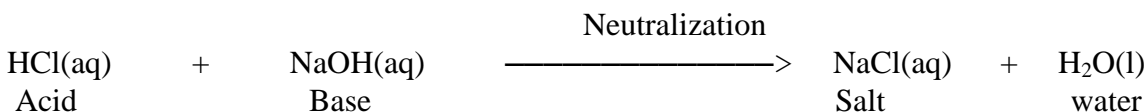
In summary, some of the characteristic properties commonly associated with acids and bases in aqueous solutions are the following:

<b>ACIDS</b>	<b>BASES</b>
Sour taste	Bitter taste
Change the color of litmus in a specific way	Change the color of litmus in a specific way
Do not change the color of phenolphthalein	Change the color of phenolphthalein
React with active metals and produce hydrogen gas	
feeling	Have a slippery, soapy
React with carbonates to produce CO <sub>2</sub>	
<b>React with bases</b>	<b>React with acids</b>

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When acids and bases react with one another in equal proportions, the result is a **neutralization reaction**, which produces neutral products: salt and water. Neutral means in this context, that these products do not change the color of litmus or phenophtalein, do not have a sour or bitter taste, therefore they are “neither acidic nor basic”.

The following equations represent two typical acid-base neutralization reactions:



Note that a salt is any compound of a cation (other than  $\text{H}^+$ ) with an anion (other than  $\text{OH}^-$  or  $\text{O}^{2-}$ ). The word **salt** in everyday conversation means sodium chloride, which is a salt under this definition.

It appears that acid properties are often opposite to base properties, and vice versa; a base is an anti-acid, and an acid is an anti-base.

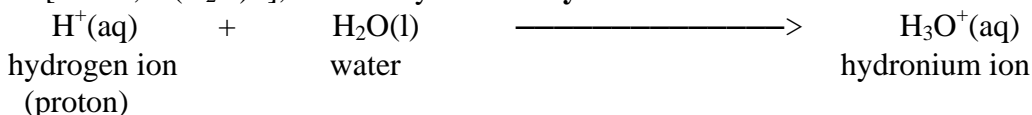
Several theories have been proposed to answer the question “What is an Acid or a Base?” One of the earliest and most significant of these theories was proposed by a Swedish scientist, Svante Arrhenius in 1884.

**According to Arrhenius:**

AN ACID	A BASE
<b>Is a hydrogen-containing substance that dissociates to produce hydrogen ions, <math>\text{H}^+</math>, in aqueous solutions</b>	<b>Is a hydroxide-containing substance that dissociates to produce hydroxide ions, <math>\text{OH}^-</math>, in aqueous solutions.</b>
<b>The hydrogen ions, <math>\text{H}^+</math>, are produced by the dissociation of acids in water</b>  $\text{HA} \text{-----}> \text{H}^+ + \text{A}^-$ <b>Acid</b>	<b>The hydroxide ions, <math>\text{OH}^-</math>, are produced by the dissociation of bases in water</b>  $\text{MOH} \text{-----}> \text{M}^+ + \text{OH}^-$ <b>Base</b>
<b>An ACID SOLUTION contains an excess of hydrogen ions, <math>\text{H}^+</math>.</b>	<b>A BASE SOLUTION contains an excess of hydroxide ions, <math>\text{OH}^-</math>.</b>
<b>Examples: <math>\text{HCl(aq)}</math>, <math>\text{H}_2\text{SO}_4\text{(aq)}</math></b>	<b>Examples: <math>\text{NaOH(aq)}</math>, <math>\text{Ca(OH)}_2\text{(aq)}</math></b>

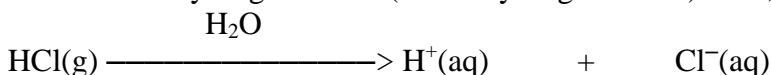
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Today we know that  $\text{H}^+$  ions cannot exist in water, because a  $\text{H}^+$  ion is a bare proton, and a charge of +1 is too concentrated for such a tiny particle. Because of this, any  $\text{H}^+$  ion in water immediately combines with a  $\text{H}_2\text{O}$  molecule to form a hydrated hydrogen ion,  $\text{H}_3\text{O}^+$  [that is,  $\text{H}(\text{H}_2\text{O})^+$ ], commonly called a **hydronium ion**.



While it is a known fact that the hydrogen ion does not exist alone, as  $\text{H}^+$ , but is stable in aqueous solution in the form of the hydronium ion,  $\text{H}_3\text{O}^+$ , it is an accepted simplification to represent the hydronium ion,  $\text{H}_3\text{O}^+$ , as a hydrogen ion,  $\text{H}^+$ .

In beginning courses, formulas for acids (and no other compounds except water) are written with the dissociable hydrogen atoms (acidic hydrogen atoms) first, as in HCl.



Methane,  $\text{CH}_4$ , ammonia,  $\text{NH}_3$ , urea,  $\text{NH}_2\text{—CO—NH}_2$ , and glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ , are examples of substances that are **not acids**, since they do not provide hydrogen ions to aqueous solutions. Their **hydrogen atoms are therefore not written first in their formulas**.

For certain acids such as acetic acid,  $\text{HC}_2\text{H}_3\text{O}_2$ , only the hydrogen atom written first is capable of being released as hydrogen ion,  $\text{H}^+$ ; the other three hydrogen atoms do not yield  $\text{H}^+$  ions in aqueous solution.

With a slight modification (the introduction of the  $\text{H}_3\text{O}^+$  ion), the Arrhenius definitions of acid and base are still valid today, as long as we are talking about aqueous solutions.

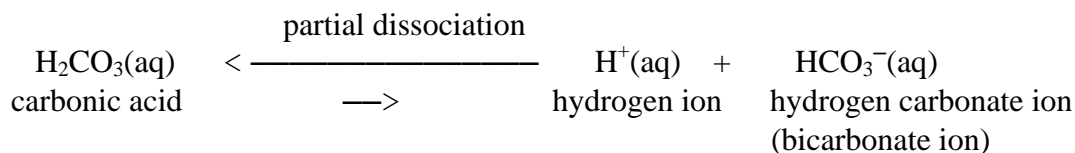
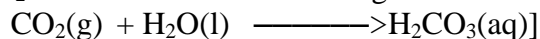
**In summary, according to Arrhenius:**

When we dissolve <b>an acid (a molecular substance)</b> in water, the molecules of acid ions, $\text{M}^+$ react with water to <b>produce <math>\text{H}_3\text{O}^+</math> ions</b> .	When we dissolve <b>a base (an ionic substance)</b> in water, the metallic and the hydroxide ions, $\text{OH}^-$ separate.
$\begin{array}{ccc} & \text{H}_2\text{O} & \\ & \xrightarrow{\hspace{2cm}} & \\ \text{HCl}(\text{g}) & & \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \\ \text{Accepted simplification:} & & \\ \text{HCl}(\text{aq}) & \xrightarrow{\hspace{2cm}} & \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \end{array}$	$\begin{array}{ccc} & \text{H}_2\text{O} & \\ & \xrightarrow{\hspace{2cm}} & \\ \text{NaOH}(\text{s}) & & \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq}) \\ \text{Accepted simplification:} & & \\ \text{NaOH}(\text{aq}) & \xrightarrow{\hspace{2cm}} & \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq}) \end{array}$
The aqueous solution of the acid contains <b>ions only</b> (no molecules)	The aqueous solution of the base contains <b>ions only</b> (no molecules)
<b>The acidic solution is a strong electrolyte</b> (Complete dissociation took place)	<b>The basic solution is a strong electrolyte</b> (Complete dissociation took place)
Acids which are <b>completely dissociated</b> in ions in aqueous solutions are called <b>strong acids</b>	Soluble <b>metallic hydroxides</b> , completely separated in aqueous solution are called <b>strong bases</b>

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Other substances, although they do in fact produce hydrogen ions,  $H^+$ , when dissolved in water, dissociate only partially. Such substances are called **weak acids**. It follows that **weak acids are weak electrolytes**.

For example, carbonic acid,  $H_2CO_3$ , found in carbonated beverages, is a weak acid. [ $H_2CO_3$  forms when  $CO_2$  reacts with water according to:



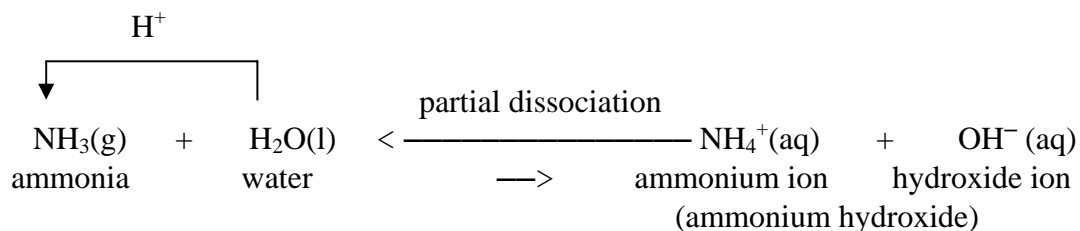
The double arrows in the equation for the partial dissociation of carbonic acid indicate that the dissociation reaction for this substance reaches **equilibrium**.

At equilibrium, a certain fixed concentration of hydrogen ion,  $H^+$ , is present. The equilibrium lies well to the left (as suggested by the size of the respective arrows) and only a few carbonic acid molecules ( $H_2CO_3$ ) are converted to bicarbonate ions  $HCO_3^-$ .

**The concentration of hydrogen ion,  $H^+$ , produced by dissolving a given amount of weak acid is much less than if the same amount of strong acid is dissolved.**

A similar situation exists with bases. Some substances, which do not contain hydroxide ions,  $OH^-$  in pure form, produce hydroxide ions,  $OH^-$ , in water by reacting with the water. The most important example of this kind of base is ammonia gas,  $NH_3$ .

Ammonia produces  $OH^-$  ions by taking  $H^+$  ions from water molecules and leaving  $OH^-$  ions behind:



This equilibrium also lies well to the left, meaning that the majority of particles present in an aqueous solution of ammonia are  $NH_3$  molecules and very few ammonium ions,  $NH_4^+$  and hydroxide ions,  $OH^-$ , are present. In a 1 M solution of  $NH_3$  in water, only about 4 molecules of  $NH_3$  out of every 1000 have reacted to form  $NH_4^+$  ions.

Nevertheless, some  $OH^-$  ions are produced, so an aqueous solution of  $NH_3$  is in fact a base, although a weak one.

**Substances that produce  $OH^-$  by partial dissociation are called weak bases. It follows that weak bases are weak electrolytes.**

As with weak acids, the concentration of hydroxide ions,  $OH^-$ , in a solution of a weak base is much smaller than if the same amount of strong base had been dissolved.

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Although the Arrhenius definitions of acids and bases have proved very useful, the theory is restricted to the situation of aqueous solutions.

In 1923 new definitions of acids and bases were proposed simultaneously by Bronsted and Lowry.

The Bronsted/Lowry theory of acids and bases extends the Arrhenius definitions to more general situations, which explain the behavior of weak bases and do not require the solvent to be water.

**According to the Bronsted/Lowry theory:**

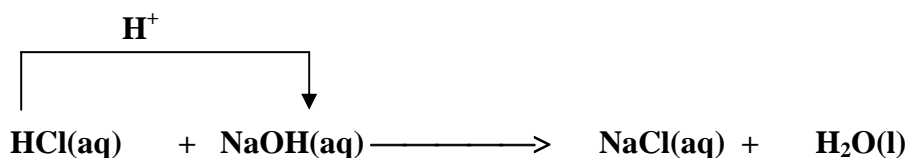
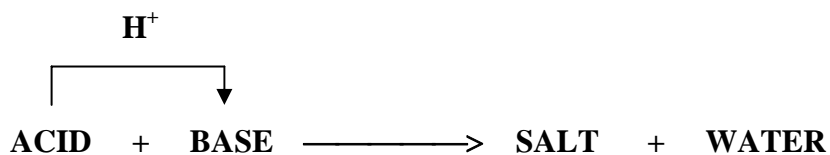
**AN ACID:**

**Is a proton,  $H^+$ , donor**

**A BASE:**

**Is a proton,  $H^+$ , acceptor**

**AN ACID-BASE REACTION (NEUTRALIZATION REACTION) IS THE TRANSFER OF A  $H^+$**



In summary, both acids and bases have characteristic properties and can either strong or weak, as shown below:

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	<b>ACIDS</b>		<b>BASES</b>	
Arrhenius definition	produce <b>H<sup>+</sup></b> ions in aqueous solution		produce <b>OH<sup>-</sup></b> ions in aqueous solution	
Bronstead/Lowry definition	<b>H<sup>+</sup> donors</b>		<b>H<sup>+</sup> acceptors</b>	
Electrolyte Strength	<b>STRONG ACIDS</b> (strong electrolytes)	<b>WEAK ACIDS</b> (weak electrolytes)	<b>STRONG BASES</b> (strong electrolytes)	<b>WEAK BASES</b> (weak electrolytes)
Extent of dissociation	completely dissociated	partially dissociated	completely dissociated	partially dissociated
Symbols used to show extent of dissociation	→	←→	→	←→
Particles present solution	ions only	mostly molecules and a few ions	ions only	mostly molecules and a few ions

Keep in mind that **strong** and **concentrated** are not interchangeable terms when applied to acids and bases:

**STRONG:** refers to the extent to which an acid or base dissociates in water.

**CONCENTRATION:** describes how much of an acidic or basic compound is present in a solution.

Strong acids and bases are 100% dissociated. Therefore we cannot interpret the relative acidic or basic strength among strong acids and bases. Strong acids and Strong bases have acidic and basic properties to an extreme.

The situation is quite different for weak acids and bases. They dissociate partially and to different degrees. The more an acid dissociates, the more free H<sup>+</sup> ions are present and the stronger the weak acid.

A similar situation exists for bases: the more a base dissociates, the more free OH<sup>-</sup> ions are present and the stronger the weak base. No attempt is made in this experiment to rank the weak acids or bases according to their relative strength.

In this experiment, you will use indicators to distinguish between acids, bases and neutral substances.

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To distinguish between strong and weak acids and bases, semi-quantitative conductance testing will be performed. The result of the conductance test should clearly distinguish between strong and weak electrolytes, and will permit you to identify the acid or the base as strong or weak. However, no attempt is made in this experiment to rank the weak acids or bases according to their relative strength.

PROCEDURE:

You will determine the conductance and the effect on indicators (Red litmus paper, Blue Litmus paper, and phenolphthalein) of a set of 10 substances and an unknown identified by a number. From the data you gather you will be able to determine: the electrolyte character, the formula of the predominant species in solution and the acidic, basic, or neutral character of the solution.

If the solution is acidic or basic, you will be able to determine if the acid or the base is strong or weak.

All your aqueous solutions (including your unknown) have the same concentration: 0.1 M

The formulas and the names of your solutions are listed below:

HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> (aq)	acetic acid	HNO <sub>3</sub> (aq)	nitric acid
D.I. H <sub>2</sub> O	deionized water	NH <sub>3</sub> (aq)	aqueous ammonia
NaOH(aq)	sodium hydroxide	KOH(aq)	potassium hydroxide
NaCl(aq)	sodium chloride	HC <sub>3</sub> H <sub>5</sub> O <sub>3</sub> (aq)	lactic acid
HCl(aq)	hydrochloric acid		

There are several stations set-up in the lab. All stations have some of the solutions available for testing. You may start working at any station and may go from station to station, in any order depending on availability.

As you move from station to station:

- DO:**
- take with you:
    - your own Chemplate (rinse very well between tests)
    - a 250 mL beaker with D.I. water, and
    - your own wash bottle, containing D.I. water
  - check if the electrodes are clean before testing (D.I. water test)
  - rinse the electrodes very well after testing.

- DO NOT:**
- remove reagents from stations
  - leave reagent bottles open
  - switch droppers from dropper bottles
  - remove or disconnect the conductivity apparatus

You will do the experiment with a partner. However the unknown will be assigned to you individually.

Do not forget the report your unknown number in your lab notebook and on your Report Form.

At each station, you will perform the following tests:

I. Conductance testing

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1. Check if the electrodes are clean (D.I. water test should give negative test).
2. Fill one depression of the Chemplate with 30 drops of the solution to be tested.
3. Perform the conductance test as it was done in a previous experiment.
4. Record the result
5. **Do not use this solution for the tests that follow**

II. Indicator testing

**Fill another depression of the Chemplate with 30 drops of the solution to be tested .**

You may want to use a sheet of white paper as a background to better distinguish the color changes.

1. Red Litmus Paper Test

Immerse the strip of “red” (actually pink) litmus paper in the solution you are testing. Remove the strip and examine its color.

You may obtain two possible results:

- (a) The “red” litmus paper turns blue (actually faint lavender), or
- (b) The “red” litmus paper stays “red”; indicate “NO CHANGE” in your lab

notebook.

(c) Do not discard the test solution.

(d) Discard the used litmus paper.

2. Blue Litmus Paper Test

Immerse the strip of “blue” (actually faint lavender) litmus paper in the solution you are testing.

Remove the strip and examine its color.

You may obtain two possible results:

- (a) The “blue” litmus paper turns “red” (actually faint lavender), or
- (b) The “blue” litmus paper stays “blue”; indicate “NO CHANGE” in your lab notebook.

(c) Do not discard the test solution

(d) Discard the used litmus paper.

3. Phenolphthalein Test

Place a sheet of white paper underneath the Chemplate, as a background.

Add 2 drops of phenolphthalein solution to the test solution.

Note any color change. If the solution remain colorless, so indicate.

Discard your test solution

Wash your Chemplate with plenty of tap water.

Rinse your Chemplate with D.I. water from your wash bottle.

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NAME: \_\_\_\_\_ PARTNER: \_\_\_\_\_

	Conductance (+, +/-, or -)	Electrolyte Character (SE, WE, or NE)	Color with Red Litmus Paper*	Color with Blue Litmus Paper**	Color with phenolphthalein solution	Formula of predominant particles	Acid, Base or Neutral***	Strong or Weak
HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> 0.1 M								
D.I. H <sub>2</sub> O								
NaOH 0.1 M								
NaCl 0.1 M								
HCl 0.1 M								
HNO <sub>3</sub> 0.1 M								
NH <sub>3</sub> 0.1 M								
KOH 0.1 M								
HC <sub>3</sub> H <sub>5</sub> O <sub>3</sub> 0.1 M								
Unknown # :								

\* The original color of "Red" Litmus paper is actually Pink

- If its color does not change, report: N.C. (No Change)
- If its color changes to Faint Lavender, report "Blue"

\*\* The original color of "Blue" Litmus paper is actually Faint Lavender

- If its color does not change, report: N.C. (No Change)
- If its color changes to Pink, report "Red"

\*\*\* If the solution is neutral, do not complete the last column (Strong or Weak)

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PART I: A STUDY OF ACIDIC BEHAVIOR

1. List below the **formulas** and the **names** of all the acids used in this experiment  
Do not forget to include the state designation "aq", after the formula.

FORMULAS                      NAMES

2. Which acids, listed in number (1) above are **strong acids**?  
Give their formulas below:

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For each strong acid listed, write an equation that illustrates its ionization reaction:

3. Which acids, listed in number (1) above are **weak acids**?  
Give their formulas below:

---

For each weak acid listed, write an equation, that illustrates its ionization reaction:

4. What do all acids (STRONG and WEAK) have in common, in terms of the particles they contain in aqueous solution ?

- 
5. What is the essential difference between STRONG ACIDS and WEAK ACIDS, in

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terms of the particles they contain in aqueous solution ?

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6. The following questions refer to the effect of Acids on Indicators.

A) What is the effect of acids on the color of red litmus paper ?

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B) What is the effect of acids on the color of blue litmus paper ?

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C) What is the color of an acidic solution to which phenolphthalein is added?

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7. What causes acids to behave the same way toward the indicators used in this experiment ?

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8. Can you distinguish between a strong and a weak acid by using **only** the indicators mentioned above ? (Assume that no conductivity apparatus is available)

\_\_\_\_\_  
Explain your answer.

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PART II: A STUDY OF BASIC BEHAVIOR

1. List below the **formulas** and the **names** of all the bases used in this experiment  
Do not forget to include the state designation "aq", after the formula.

FORMULAS                      NAMES

2. Which bases, listed in number (1) above are **strong bases**?  
Give their formulas below:

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For each strong base listed, write an equation that illustrates its dissociation reaction:

3. Which bases, listed in number (1) above are **weak bases**?  
Give their formulas below:

---

For each weak base listed, write an equation, that illustrates its ionization reaction:

4. What do all bases (STRONG and WEAK) have in common, in terms of the particles they contain in aqueous solution ?

---

5. What is the essential difference between STRONG BASES and WEAK BASES, in terms of the particles they contain in aqueous solution ?

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6. The following questions refer to the effect of Bases on Indicators.

A) What is the effect of bases on the color of red litmus paper ?

\_\_\_\_\_

B) What is the effect of bases on the color of blue litmus paper?

\_\_\_\_\_

C) What is the color of a basic solution to which phenolphthalein is added?

\_\_\_\_\_

7. What causes bases to behave the same way toward the indicators used in this experiment ?

\_\_\_\_\_

8. Can you distinguish between a strong and a weak base by using **only** the indicators mentioned above ? (Assume that no conductivity apparatus is available)

\_\_\_\_\_  
Explain your answer.

PART III: IDENTIFICATION OF THE UNKNOWN

1. Is your unknown # \_\_\_\_\_ an **ACID**, a **BASE**, or a **NEUTRAL SUBSTANCE** ?

\_\_\_\_\_

2. (A) If your unknown is an **ACID** or a **BASE**, is it **STRONG** or **WEAK** ?

(B) \_\_\_\_\_  
If your unknown is a **NEUTRAL** substance, identify the substance:

\_\_\_\_\_