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 Draino. 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:

ACIDS	**BASES**
Sour taste	Bitter taste
Change the color of litmus paper In a specific way	Change the color of litmus paper In a specific way
Do not change the color of phenolphthalein	Change the color of phenolphthalein
React with carbonates to produce CO_2	React with acids
React with bases	React with acids

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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 phenolphthalein, do not have a sour or bitter taste, therefore they are "neither acidic nor basic".
The following equations represents a typical acid-base neutralization reaction:

$$\underset{\text{Acid}}{HCl(aq)} + \underset{\text{Base}}{NaOH(aq)} \xrightarrow{\text{Neutralization}} \underset{\text{Salt}}{NaCl(aq)} + \underset{\text{water}}{H_2O(l)}$$

Note that a salt is any compound of a cation (other than H^+) with an anion (other than OH^- or 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**
Is a hydrogen-containing substance that dissociates to produce hydrogen ions, H^+, in aqueous solutions	**Is a hydroxide-containing substance that dissociates to produce hydroxide ions, OH^-, in aqueous solutions.**
The hydrogen ions, H^+, are produced by the dissociation of acids in water $\underset{\text{Acid}}{HA} \longrightarrow H^+ + A^-$	**The hydroxide ions, OH^-, are produced by the dissociation of bases in water** $\underset{\text{Base}}{MOH} \longrightarrow M^+ + OH^-$
An ACID SOLUTION contains an excess of hydrogen ions, H^+.	**A BASE SOLUTION contains an excess of hydroxide ions, OH^- .**
Examples: $HCl(aq)$, $HC_2H_3O_2(aq)$	**Examples: $NaOH(aq)$, $NH_4OH(aq)$**

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Today we know that H^+ ions cannot exist in water, because a $\mathbf{H^+}$ ion is a bare proton, and a charge of +1 is too concentrated for such a tiny particle. Because of this, any $\mathbf{H^+}$ ion in water immediately combines with a H_2O molecule to form a hydrated hydrogen ion, H_3O^+ [that is, $H(H_2O)^+$], commonly called a **hydronium** ion.

$H^+(aq)$	+	$H_2O(l)$	————>	$H_3O^+(aq)$
hydrogen ion (proton)		water		hydronium ion

While it is a known fact that that the hydrogen ion does not exist alone, as $\mathbf{H^+}$, but is stable in aqueous solution in the form of the hydronium ion, H_3O^+, it is an accepted simplification to represent the hydronium ion, H_3O^+, as a hydrogen ion, 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 (aq) Hydrochloric acid

$HC_2H_3O_2$(aq) Acetic acid

Note: Only the hydrogen written first is capable of being released as hydrogen ion, H^+; the other three hydrogen atoms do not yield H^+ ions in aqueous solution

Methane	CH_4
Ammonia	NH_3
Urea	NH_2–CO–NH_2
Glucose	$C_6H_{12}O_6$

Are not acids, since do not provide H^+ ions to aqueous solutions. Their hydrogen atoms are therefore not written first in their formulas.

With a slight modification (the introduction of the H_3O^+ 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 **an acid** (**a molecular substance**) in water, the molecules of acid react with water to produce $\mathbf{H_3O^+}$ **ions**	When we dissolve **a base** (**an ionic substance**) in water, the metallic ion and the hydroxide ions, OH^- **separate**
$HCl(g) \xrightarrow{H_2O} \mathbf{H_3O^+(aq)} + Cl^-(aq)$ Accepted simplification: $HCl(aq) \longrightarrow \mathbf{H^+(aq)} + Cl^-(aq)$	$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + \mathbf{OH^-(aq)}$ Accepted simplification: $NaOH(aq) \longrightarrow Na^+(aq) + \mathbf{OH^-(aq)}$
The aqueous solution of hydrochloric acid contains ions only (no molecules)	The aqueous solution of sodium hydroxide contains ions only (no molecules)
The acidic solution is a strong electrolyte. (Complete dissociation took place).	The basic solution is a strong electrolyte. (Complete dissociation took place)
Acids which are **completely dissociated in ions** in aqueous solutions are called **strong acids.**	Soluble metallic hydroxides, **completely separated** in aqueous solution are called **strong bases**.

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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, acetic acid, $HC_2H_3O_2$, found in vinegar, is a weak acid.

$$\underset{\text{acetic acid}}{HC_2H_3O_2\,(aq)} \;\xrightleftharpoons{\text{partial dissociation}}\; \underset{\text{hydrogen ion}}{H^+(aq)} + \underset{\text{acetate ion}}{C_2H_3O_2^-\,(aq)}$$

The double arrows in the equation for the partial dissociation of acetic 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 acetic acid molecules ($HC_2H_3O_2$) are converted to hydrogen ions (H^+) and acetate ions ($C_2H_3O_2^-$). In a 0.1 M solution of acetic acid in water, only about 1 molecule molecules of $HC_2H_3O_2$ out of every 100 have reacted to form hydrogen ions (H^+) and acetate ions ($C_2H_3O_2^-$).
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:

H^+

$$\underset{\text{ammonia}}{NH_3(g)} + \underset{\text{water}}{H_2O(l)} \;\xrightleftharpoons{\text{partial dissociation}}\; \underset{\substack{\text{ammonium ion}\\ \text{(ammonium hydroxide)}}}{NH_4^+(aq)} + \underset{\text{hydroxide ion}}{OH^-\,(aq)}$$

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:

<u>AN ACID</u>:
Is a proton, H^+, donor

<u>A BASE</u>:
Is a proton, H^+, acceptor

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

H^+

ACID + BASE ——————> SALT + WATER

H^+

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

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

	ACIDS		**BASES**	
Arrhenius definition	produce **H^+ ions** in aqueous solution		produce **OH^- ions** in aqueous solution	
Bronstead/Lowry definition	**H^+ donors**		**H^+ acceptors**	
Electrolyte Strength	STRONG ACIDS (strong electrolytes)	WEAK ACIDS (weak electrolytes)	STRONG BASES (strong electrolytes)	WEAK BASES (weak electrolytes)
Extent of dissociation	completely dissociated	partially dissociated	completely dissociated	partially dissociated
Symbols used to show extent of dissociation	$\longrightarrow$	$\rightleftarrows$	$\longrightarrow$	$\rightleftarrows$
Particles present solution	ions only	mostly molecules and a few ions	ions only	mostly molecules and a few ions

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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^+ ions are present and the stronger the weak acid.
A similar situation exists for bases: the more a base dissociates, the more free OH^- 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.
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.

<u>PROCEDURE</u>:

You will determine the conductance and the effect on indicators (Red litmus paper, Blue Litmus paper, and phenolphthalein) of a set of six substances in aqueous solution and an unknown identified by a number. The unknown is one of the six solutions tested. 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: 0.10 M.
The formulas and the names of your solutions are listed below:

1. $HC_2H_3O_2(aq)$ acetic acid
2. $NH_3(aq)$ aqueous ammonia
3. D.I. H_2O deionized water
4. $HCl(aq)$ hydrochloric acid
5. $NaOH(aq)$ sodium hydroxide
6. $NaCl(aq)$ sodium chloride

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I. Conductivity Testing

1. Connecting your "Conductivity Tester Combo"

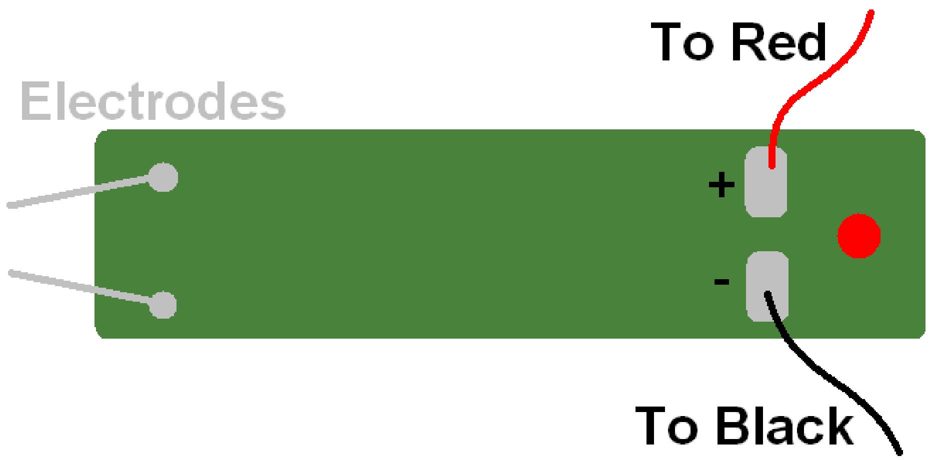
(a) Check out a "Conductivity Tester Combo", composed of a "Power Converter" connected to a "Conductivity Indicator".

(b) Make sure that the Power Converter is in the **"OFF"** position.

(c) If the dial is not already set to 9V, set the dial to 9 V.
Keep the dial in this position throughout your experiment.

(d) Connect the cords:

- Snap the alligator end of the **red** cord onto the (+) post (labeled "**R**") of the conductivity indicator and the **black** cord onto the (-) post (labeled "**B**") of the conductivity indicator.



- If not already taped, solidly tape the connections of the cords to the conductivity indicator with electrical tape (available at the instructor's desk)
- Insert the other two ends of the cords into the outlets of the Power Converter:
  - Red end of the cord into the red outlet of the Power Converter
  - Black end of the cord into the outlet of the Power Converter

(e) After ensuring one more time that the Power Converter is in the is in the "OFF" position, you may plug in the Power Converter into the power supply available at your station.

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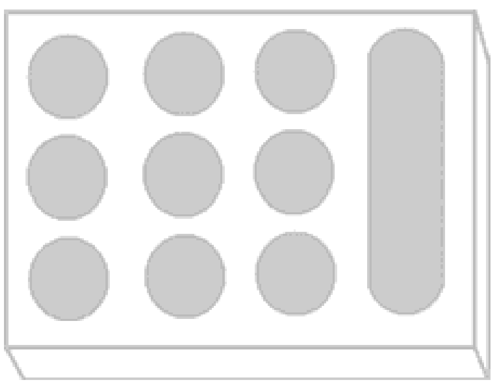
2. Checking the Conductivity Indicator

(a) Turn the Power Converter "**ON**"

(b) Test the circuit by touching the tips of the two copper electrodes to a coin or a piece of metal.
- If the conductivity indicator is working properly, the LED will light up brightly.
- If the LED light does not light up, notify your laboratory instructor

(c) Check if the copper electrodes are clean by immersing them into D.I. water (your 250 mL beaker filled with about 100 mL D.I. water may be used for this purpose)
- The electrodes are clean if the LED does not light up when the electrodes are immersed in D.I water.
- If the LED lights up, indicating that the electrodes are dirty, discard the D.I water, and immerse the electrodes again in fresh D.I. water.
- If necessary, rinse the electrodes repeatedly with fresh portions of D.I water, until you get no response from the LED.

3. Preparing your Chemplate



(a) Clean and dry your Chemplate

(b) Plan which solutions you will place in each depression and record this in your Lab Notebook
- Note that the depressions are numbered.
- To avoid contaminating the six solutions by overfilling the depressions, you may want to avoid using depressions that are next to each other.

4. Testing the conductivity of the solutions

(a) Fill completely the depressions with the seven solutions (Six known solutions and one unknown solution).
It takes about 30 drops to completely fill a depression, without overfilling.

(b) Test the first solution, by immersing the copper electrodes in the solution.
- In order to obtain consistent observations:
  - the position of the conductivity indicator should be perfectly vertical and perpendicular to the Chemplate, and
  - the two electrodes should always be immersed at the same depth.
- The response of the LED will indicate the following types of conductivity:
  - Bright Light indicates **Strong Conductivity (+)**
  - Faint Light indicates **Weak Conductivity (+/-)**
  - No Light indicates **No Conductivity (-)**
  - Observe and record the reaction of the LED

(c) Proceed and test the other solutions

- Before testing the next aqueous solution, rinse the two copper electrodes by immersing them in the beaker containing the D.I water.
  NOTE: The electrodes are clean if the LED does not light up when the electrodes are immersed in D.I. water.
- Blot the excess water from the electrodes with tissue paper.
- Continue to the next depression and repeat the previous steps of the procedure.

II. Indicator testing

NOTE:

- You may use the same seven solutions (Six known solutions and one unknown solution) and depressions of the Chemplate that have been previously used for conductivity testing
- You may want to use a sheet of white paper as a background to better distinguish the color changes.
- When using litmus paper (Red or Blue), there is no need to use a full strip of indicator paper. To avoid wasting indicator paper, use only one-third of indicator paper strip for each test.

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)
Record "**BLUE**" in your lab notebook,
OR

(b) The "red" litmus paper stays "red" (actually pink)
Record "**NO CHANGE**" in your lab notebook.

(c) Do not discard the test solution.

(d) Discard the used litmus paper in a beaker set up at your station.

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)
Record "**RED**" in your lab notebook,
OR

(b) The "blue" litmus paper stays "blue" (actually faint lavender)
Record "**NO CHANGE**" in your lab notebook.

(c) Do not discard the test solution

(d) Discard the used litmus paper in a beaker set up at your station.

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3. Phenolphthalein Test

Add 2 drops of phenolphthalein solution to each of the seven solutions to be Tested (Six known solutions and one unknown solution).

You may obtain two possible results:

(a) The solution remains colorless.
Record "**NO CHANGE**" in your lab notebook.
OR

(b) The color of the solution changes to pink
Record "**PINK**" in your lab notebook.

(c) Cleaning up:
- Discard your test solutions in the appropriately labeled waste container,
- Wash your Chemplate with plenty of tap water.
- Rinse your Chemplate with D.I. water from your wash bottle.
- Blot the excess water from the Chemplate with clean paper towel
- Store the Chemplate in your locker.
- Discard the used strips of litmus paper in the trash can.

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REPORT FORM

NAME: ______________________________ Date: _______________ Partner: ______________________________

	Conductance (+, +/ –, or –)	Electrolyte Character (SE, WE, or NE)	Color with Red Litmus Paper*	Color with Blue Litmus Paper**	Color with phenolphtalein solution	Formula of predominant particles	Acid, Base or Neutral***	Strong or Weak
$HC_2H_3O_2(aq)$ 0.10 M								
$NH_3(aq)$ 0.10 M								
D.I. H_2O								
HCl 0.10 M								
NaOH(aq) 0.10 M								
NaCl(aq) 0.10 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 the two acids used in this experiment Do not forget to include the state designation "aq", after the formula.
   FORMULAS NAMES

2. Which acid, listed in number (1) above is a **strong acids**?
   Give its formula below:

   ____

   For the strong acid listed above, write an equation that illustrates its ionization/dissociation reaction:

3. Which acid, listed in number (1) above is a **weak acid**?
   Give its formula below:

   ____

   For the weak acid listed above, write an equation, that illustrates its Ionization/dissociation reaction:

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

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

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PART II: A STUDY OF BASIC BEHAVIOR

1. List below the **formulas** and the **names** of the two bases used in this experiment Do not forget to include the state designation “aq”, after the formula.
   FORMULAS NAMES

2. Which base, listed in number (1) above is a **strong base**?
   Give its formula below:

   ____

   For the strong base listed above, write an equation that illustrates its ionization/dissociation reaction:

3. Which base, listed in number (1) above is a **weak base**?
   Give its formula below:

   ____

   For the weak base listed above, write an equation, that illustrates its Ionization/dissociation reaction:

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

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

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PART III: ASSESSING THE TESTS PERFORMED

Can you distinguish between a strong and a weak acid or a strong and a weak base by using **only** the indicators used in this experiment? (Assume that no conductivity apparatus is available)

______

Explain your answer.

PART IV: 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:

   _______________________ (formula)