NJIT RET Summer program 2014
Lesson Module

MODULE TOPIC: Two Methods of Determining the Concentration of Soluble Compounds or Analytes

LESSON TWO TOPIC: Electrical Conductivity Analysis of Soluble Compounds (1Day).

Learning Objectives
Students will be able to:
- **Measure** electrical conductivity of a few mixtures.
- **Differentiate** between covalent compounds and ionic compounds.
- **Explain** why ionic compounds conduct electricity while most covalent compounds don't.
- **Determine** if a solution is an electrolyte or a non-electrolyte.

Standard (s)
NGSS: 5-PS1-3. Make observations and measurements to identify materials based on their properties.
CCSS-Math: 8.SP.2. Know that straight lines are widely used to model relationships between two quantitative variables.

Introduction:

At swimming pools, swimmers must leave the water for a period of time after nearby lightning strikes. Why is this so? What is special about water that we are concerned about when electricity is around? What kinds of liquids would this not be true for? Does distilled water have this same status?

Consider the following:
- What do you see take place when a solute dissolves in a solvent? Does the solute disappear? How could you find out?
- What physical process is occurring at the molecular level to result in what you see happening when something dissolves?
- Does the same thing happen when all substances dissolve? Do salt and sugar both dissolve in the same way? How about all acids and all bases? Do they dissolve in the same way?

Substances that are capable of conducting an electric current in solution are known as electrolytes. Ionic compounds are electrolytes since they form positively and negatively charged ions in solution to conduct the electrical charges. Electrolytes are divided into three substances:

Acids, Bases, and Salts. Not all electrolytes conduct electricity to the same degree. Non-electrolytes are compounds that do not conduct electric currents in aqueous solutions. Most molecular (covalent) compounds are non-electrolytes since there are no positively and negatively charged ions in solution to conduct the electrical charges.

Electrolytes dissolve in water and dissociate, at least partially, into free ions. In a solution of electrolytes, several different species might be present, including intact molecules and dissociated ions. Strong electrolytes dissociate completely into ions. Weak electrolytes dissociate incompletely. Non-electrolytes do not dissociate at all. Strong electrolytes include strong acids, strong bases and soluble salts, while weak electrolytes include weak acids, weak bases and low-solubility salts. Non-electrolytes include all molecular (covalent) compounds. Any solution, even one containing ions, provides considerable resistance to the flow of current through it. Conductivity is, essentially, the reciprocal of this resistance -- high resistance means low conductivity; low resistance means high conductivity. Resistance is measured in **ohms**, so conductance is measured in **ohms^{-1}**, more commonly called **mhos** or **Siemens** (**S,** the official System International (SI) name of the unit). Chemists measure the conductivity of a solution by using the solution to complete an electrical circuit, usually by inserting a pair of electrodes into the circuit, and immersing the electrodes in the solution. The resistance that the solution adds to the circuit is converted to conductivity by a computer chip, and displayed on a meter.

Strong and Weak Electrolytes

a) Acids

Acids ionize or dissociate in aqueous solution to produce hydronium ions (H_3O^+ (aq)). The strength of an acid depends on the amount it ionizes or dissociates. Strong acids ionize almost completely, while weak acids ionize to a much lesser degree.

Examples:

Strong acid: $HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

0% **100 % Ionized**

Weak acid: $CH_3COOH(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + CH_3COO^-(aq)$

~99% **~1% ionized**

Note: The dissociation of a substance with complete ionization is shown with a single forward arrow, while the dissociation of a substance with a low % ionization is shown with a double arrow.

See animation below for illustration of a strong vs. weak acid ionizing in water:
http://preparatorychemistry.com/Bishop_Water_frames.htm (choose 'acid animation' from the menu)

b) Bases

Bases ionize or dissociate in aqueous solution to produce hydroxide ions (OH^- (aq)). The strength of a base depends on the amount it ionizes or dissociates. Strong bases ionize almost completely, while weak bases ionize to a lesser degree.
Examples:

Strong Base:	$NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$
Weak Base:	$NH_3(aq) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq)$

c) Salts
Salts dissociate in aqueous solution to produce a positive metal ion and a negative non-metal ion. Soluble salts dissociate almost completely, while low-solubility salts dissociate to a lesser degree. A table of solubilities (included) allows you to determine the solubilities of many salts.
Examples:

Soluble Salt:	$NaCl (s) \rightarrow Na^+(aq) + Cl^-(aq)$
Low-solubility Salt:	$Ca(OH)_2(s) \leftrightarrow Ca^{2+}(aq) + 2OH^-(aq)$

<u>Non-Electrolytes</u>
Sucrose, or table sugar, is a non-electrolyte. Its molecules remain intact when dissolved in water as shown in the equation below:

$$C_{12}H_{22}O_{11}(s) \rightarrow C_{12}H_{22}O_{11} (aq)$$

Ethanol is also a non-electrolyte as shown in the following equation:

$$CH_3CH_2OH (l) \rightarrow CH_3CH_2OH (aq)$$

Purpose:
In this experiment, you will construct a conductivity tester and study the electrical conductivity of water and various water solutions. You will then identify the solutions as electrolytic and non-electrolytic, and identify variations in conductivity among electrolytes.

Pre-lab Information:
Many of the materials you will be using today are found in common household items. A list of common names or uses can be found below:

Hydrochloric acid, HCl	Stomach acid
Acetic acid, CH_3COOH	Vinegar
Sodium hydroxide, NaOH	Lye; used in soaps, detergents
Ammonia(aq), $NH_3(aq)$	Household cleaners
Sodium chloride, NaCl	Common household salt
Calcium hydroxide, $CaCO_3$	Chalk.
Ethanol, CH_3CH_2OH	Found in gasoline or in alcoholic beverages.
Sucrose, $C_{12}H_{22}O_{11}$	Table sugar, beet or cane sugar

Acetone CH_3COCH_3 Nail polish remover.

Health & Safety Rule:

1. Wear eye protection throughout.

Materials:

1. Sucrose
2. Sodium Chloride
3. Calcium Carbonate
4. Cupper (II) Sulfate
5. Acetic Acid 6 M
6. Acetone
7. Ethanol 95%
8. Hydrochloric Acid 6 M
9. Ammonium Hydroxide 6 M
10. Sodium Hydroxide 6 M
11. Distilled Water
12. Tap Water

Apparatus:

1. Magnetic Stirring bar
2. Magnetic Stirrer
3. 100 mL beakers
4. Electric Balance
5. 50 mL Graduated Cylinder
6. Vernier Conductivity Sensors
7. Logger Pro Software
8. Computer
9. Safety Glasses

Procedure:

Part 1 **Measure electrical conductivity of Tap water vs. Distilled Water**

1. Predict whether distilled water or tap water will conduct electricity. Justify your answer.
2. Place 50 mL of DI water in a 100 mL beaker and record it conductivity using the Vernier conductivity electrode in the part 1 table . Was there a difference in the conductivities of each? Explain. Was your prediction correct?

Part 2: **Measure electrical conductivity of ionic and covalent compounds dissolution with time.**

1. Calculate the amount in grams of the following solids that would make 50.0 mL of 1.0 M solution in DI water.
   - Sucrose
   - Sodium Chloride

- Calcium Carbonate
- Cupper (II) Sulfate

2. Weigh out the mass of each solute separately.
3. Place 50.0 mL DI water in 100.0 mL beaker, gently insert the magnetic stirring bar.
4. Place the beaker on a magnetic stirrer, and set the stirring on the lowest speed.
5. Insert the Vernier Conductivity sensor in the solution.
6. While collecting electrical conductivity, dump the solute into the beaker.
7. Stop the collection when the measured conductivity remains constant.
8. Save the data and the graph.
9. Print the data and the graph.
10. Repeat step 2-10 for each solute.
11. Calculate the volume of the following solutions that need to be taken to make 50.0 mL of 1.0 M concentration of each in DI water.
    - Acetic Acid 6 M
    - Acetone
    - Ethanol 95%
    - Hydrochloric Acid 6 M
    - Ammonium Hydroxide 6 M
    - Sodium Hydroxide 6 M
12. Measure the calculated volume of each solution separately.
13. Place the 50.0 mL beaker on the magnetic Stirrer having a magnetic stirring bar.
14. Add the calculated DI water into the beaker, insert the Vernier electrode.
15. Start mixing process on the lowest speed.
16. Start collecting the electrical conductivity while adding the measured volume of the solution drop by drop.
17. Stop data collection as soon as the electrical conductivity value remains constant.
18. Save the data and graph.
19. Print the data and graph.

Data and Observations:

Part 1 – Record the Electrical Conductivity of DI water and Tap Water.

Substance Tested	Conductivity (µS/cm)
Distilled Water	
Tap Water	

Part 2 – From the graph of plotted data obtained from the logger pro software, obtain the slope of the linear portion. Record the slopes in the following table. By comparing the slope organize the compounds in order of increasing rate of dissolution.

Solution	Slope or dissolution rate
Hydrochloric acid solution	
Acetic acid solution	
Sodium hydroxide solution	
Aqueous ammonia	
Sodium chloride solution	
Calcium carbonate solution	
Sucrose solution	
Ethanol solution	

Record the maximum electrical conductivity of each solution made in part 2

Solution	Electrical Conductivity
Hydrochloric acid solution, 1 mol/L	
Acetic acid solution, 1 mol/L	
Sodium hydroxide solution, 1 mol/L	
Aqueous ammonia, 1 mol/L	
Sodium chloride solution, 1 mol/L	
Calcium carbonate solution, 1 mol/L	
Sucrose solution, 1 mol/L	
Ethanol solution, 1 mol/L	

Post-Laboratory Questions:
Strong and Weak Acids and Bases

1. Predict whether each of the acids and bases being tested will conduct electricity (and to what extent). Again, justify your answer.

2. Explain your results using ionization equations for each acid and base.

3. Which acid and base is considered strong? Which acid and base is considered weak?

4. How does the strength of the acid or base relate to the electrical conductivity measured?

Salts

5. Predict whether each of the salts being tested will conduct electricity (and to what extent).

6. Based on your results, which substance dissolved the most? Which substance dissolved the least? How do you know?

7. How does the solubility of the salt relate to the level of brightness observed in the bulb?

8. Write the dissociation equation for NaCl, $CuSO_4$ and $CaCO_3$ and explain what occurs at the molecular level when each substance dissolves.

9. Would pure, crystalline table salt (NaCl) have conducted an electric current? Explain your answer.

Non-Electrolytes

10. Predict whether acetone, sucrose and ethanol will conduct electricity.

11. Explain the results you observed when the conductivity electrode was placed in the non-electrolyte solutions.

12. How does dissolving occur in non-electrolytes? Write the equation for the dissolving of $C_{12}H_{22}O_{11}$ and CH_3CH_2OH and explain what occurs at the molecular level when each substance dissolves.

13. Are non-electrolytes generally covalent or ionic?

Summary Questions:

1. What effect would concentration have on the conductivity of a substance?

2. Describe the difference (macroscopically) between an ionic compound and a molecular compound?

3. Draw microscopically what happens to an ionic and a molecular compound when dissolved in water.

4. Explain why some materials are strong, weak or non-conductors.

5. What are the predominant and minor (if any) species present in each of the solutions tested?

6. What trend might you observe if you tested the conductivity of NaCl, $CaCl_2$, and $AlCl_3$ solutions? Explain why a trend might be observed.

7. Explain why 5 mol/L $HC_2H_3O_2$ would conduct electricity but pure $HC_2H_3O_2$ (called glacial acetic acid) would not.

8. Which would have more ions: 1.0 mol/L HCl or 5 mol/L $HC_2H_3O_2$? How could you find out?

9. Write an operational definition for 'electrolyte'. What is the difference between an electrolyte and a non-electrolyte?

10. If you were caught in a thunderstorm, which of the solutions tested would you least like to be standing in?

11. What would happen to the conductivity of a substance if you dilute its solution with water?

Summative Assessment: Students will write a formal laboratory report following the class rubric.

Online Resources:
Weak Acid Equilibrium:
http://www.dlt.ncssm.edu/tiger/Flash/electrochem/WeakAcidEquilibrium.html
To access the T.I.G.E.R site enter username: htaccess and password: tiger.core

Strong Acid Ionization:
http://www.dlt.ncssm.edu/tiger/Flash/electrochem/StrongAcidIonization.html
To access the T.I.G.E.R site enter username: htaccess and password: tiger.core

Conductivity Simulation #1: Greenbowe (Test Acids, Bases, Salts and Unknown Solutions with 1.0 M solutions)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/conductivity.html

Conductivity Simulation #2: Greenbowe (Test Acids, Bases, Salts and Unknown Solutions with changing molarity)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/conductivity-2.html

NaCl dissolving in Water: Greenbowe
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/thermochem/solutionSalt.html

Collision of HCl with H_2O: Greenbowe
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animations/HCl(aq).html

Collision of NH_3 with H_2O: Greenbowe
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animations/NH3eqtg.html

Solubility Rules Table:

Negative Ion (Anions)	**Positive Ions (Cations)**	**Solubility of Compounds**
All negative ions are_____with	Alkali ions (Li^+, Na^+, K^+ etc)	Soluble
All negative ions are ____ with	Hydrogen (H^+)	Soluble
All negative ions are ____ with	Ammonium ion (NH_4^+)	Soluble
Nitrate NO_3^- ions are ____ with	All positive ions are	Soluble
Acetate CH_3COO^- ions are____ with	All positive ions are	Soluble
Chloride, Cl^- Bromide Br^- Iodide I^-	Ag^+, Pb^{2+}, Hg_2^{2+}, Cu^+ → All other positive ions →	Low solubility Soluble
Sulfate SO_4^{2-}	Ba^{2+}, Sr^{2+}, Pb^{2+} → All other positive ions	Low solubility Soluble
Sulfide S^{2-}	Alkali ions, H^+, NH_4^+, Be^{2+} Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+} → All other positive ions →	Soluble Low solubility
Hydroxide, OH^-	Alkali Ions, NH_4^+, Sr^{2+}, Ba^{2+} → All other positive ions →	Soluble Low solubility
Phosphate PO_4^{3-} Carbonate CO_3^{2-} Sulfite, SO_3^{2-}	Alkali Ions, H^+, NH_4^+ → All other positive ions →	Soluble Low solubility

Assessment:

- Students a**nalyze** the printed plotted graph and table of data produced by the Vernier Software.

- Students **create a bar graph** comparing the maximum electrical conductivity of samples.
- Students **answer** the **post laboratory questions.**
- Students **answer** the **summary questions**.
- Students **write a formal lab** report following the provided rubric incorporating all the above items.

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LABORATORY REPORT FORMAT (40 points)

Laboratory reports should follow this format unless announced otherwise. It is important to recognize that when you are writing a lab report, you should be objective. Also, the lab reports are used as examples of your writing style, so when sentences are written, they must be grammatically correct. You should use a computer; use Times New Roman font size 12, double-spaced. If the calculations section of the lab report is handwritten, it should be done neatly in pencil (erase errors), on lined paper, one side only.

Lab reports are due at the beginning of the class on the due date. If you are missing class (for example, a field trip) the report should be in my mailbox before you leave. If you are absent the date it is due, you must hand it in before homeroom the day you return. Penalties: minus 1 grade per day. Lab reports are usually 40 points each.

Lab reports are collected and kept on file; for AP students, a small folder or binder is appropriate, since some colleges require a summary of the experiments done as well as the AP Test score; the collection will be returned to you when you graduate.

FORMAT:

I. **Title Page** title in the center of the page **(2 points)**

Your name, date performed, class period, and partner(s)

Abstract (should take up about 1/3 of the bottom of the page **(5 points)**

- a brief summary of a research article, thesis, laboratory report or any in-depth analysis of a particular subject
- placed prior to the introduction and procedure (on cover page of lab report)
- often used to help the reader quickly ascertain the paper's purpose

II. **Copy of the experiment with directions** **(3 points)**

This includes the Objective, Procedure, Theory, etc.

If these are not included (or stained), you need to write them yourself

III. **Data and Results**

Even if you scribbled the data on your lab directions, you **(5 points)** need to create the appropriate tables, graphs, descriptions, etc. (use your computer)

IV. **Calculations** **(10 points)**

Show all calculations that you used to get your results. Be sure to use correct significant figures and labels. If you are not using Equation Editor, the handwritten page should be done in pencil on lined paper.

If lab is qualitative and there are no calculations, points can be adjusted.

V. **Conclusion**

This section includes:

ANSWERS TO QUESTIONS given in the lab exercise. **(10 points)**

- Write question ***in italics***
- Write the answer below it.

FINAL PARAGRAPH: **(5 points)**

- **Your** answers to the objective of the experiment (the result of
- The experiment, **not what you should have gotten)**
- An explanation for all large experimental errors (in excess of 10%)
- Any error greater than 30% calls for repeating the experiment