EXPERIMENT 10: Electrical Conductivity

Chem 111

INTRODUCTION

A. Electrical Conductivity

A substance can conduct an electrical current if it is made of positively and negatively charged particles that are free to move about and is called a conductor. When an electrical current is applied between two electrodes, the positively charged electrode, the anode, will attract negatively charged particles and the negatively charged electrode, the cathode, attracts positively charged particles. So to conduct electricity mobile charged particles must be present

A substance that does not conduct electricity is a nonconductor.

B. Conductivity of Pure Substances

1. Elements

a. Metals

Metals are conductors. A metal can be viewed as an array of positive ions surrounded by a "sea" of mobile valence electrons. When an electrical current is applied to the metal, the electrons move away from the cathode and toward the anode, forming an electrical current in the metal.

b. Nonmetals

2. Compounds

a. Ionic compounds

All ionic compounds are solids at room temperature. In the solid, the ions are not free to move about, therefore the solid ionic compound does not conduct electricity. However, if the ionic compound is heated to its melting point, the ions in the molten (melted) ioni c compound become mobile. Therefore the molten ionic compound does conduct electricity.

b. Molecular compounds do not conduct electricity as solids or as liquids. When a molecular solid is melted, the molecules do become mobile, but molecules are not cha rged and do not carry an electrical current.

C. Conductivity of Solutions

1. Solvents

Water is a good solvent for many compounds, both ionic and molecular, because it is polar.

a. Solubility of Ionic Compounds

Water dissolves many ionic compounds becaus e its partially positive end is attracted to anions and its partially negative end is attracted to cations. This ion -dipole attraction allows water to pull the ions away from each other and surround them. Ionic compounds are not soluble in nonpolar solvents such as toluene.

b. Solubility of Molecular compounds

The "rule of thumb" for the solubility of molecular compounds is "like dissolves like". This means that polar compounds dissolve in polar solvents and nonpolar compounds dissolve in nonpolar solvents. Water is a good solvent for polar compounds. (Toluene, a nonpolar solvent, is a good solvent for nonpolar compounds.) Water pulls the polar molecules away from each other and surrounds them.

2. Electrolytes and Nonelectrolytes

A compound that dissolves in water to form an electrically conducting solution is called an electrolyte. A compound that dissolves in water to form an nonconducting solution is called a nonelectrolyte. A compound that dissolves in water to give a solution that conducts strongly is called a strong electrolyte and one that dissolves in water to give a solution that conducts weakly is called a weak electrolyte.

a. Soluble Ionic Compounds

When ionic compounds dissolve in water their ions dissociate (are separated from each other and then surrounded by water molecules).

$$NaCl_{(s)} \xrightarrow{H_2O} Na^+_{(aq)} + Cl^-_{(aq)}$$

Solutions of ionic compounds conduct strongly, therefore soluble ionic compounds are strong electrolytes.

b. Soluble Molecular Compounds

When molecular compounds dissolve in water their molecules dissociate (separated and surrounded by water). For example, sucrose (table sugar):

$$C_{12}H_{22}O_{11(s)} \xrightarrow{H_2O} C_{12}H_{22}O_{11(aq)}$$

The molecules in the solution do not conduct electricity, therefore most molecular compounds are nonelectrolytes.

However, there are some molecular compounds whose solutions conduct electricity because the molecules chemically react with water to form ions. The two classes of molecular compounds that undergo this Ionization Reaction are the acids and the nitrogenous bases.

(1) Acid Solutions

In an aqueous solution of an acid, the dissolved molecules react to form ions:

$$HA_{(aq)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq)} + OH^-_{(aq)}$$

It is a strong acid if <u>all</u> of its molecules react to form ions. Because its solution conducts strongly, it is a strong electrolyte. In a solution of a weak acid only a small fraction of its molecules react to form ions thus giving a solution that conducts only a little. Therefore weak acids are weak electrolytes.

(2) Nitrogenous Base Solutions

Nitrogenous bases are weak electrolytes. Few of their dissolved molecules react to form ions, so the solution conducts weakly. For example, NH_3.

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

AQUEOUS SOLUTIONS OF COMPOUNDS

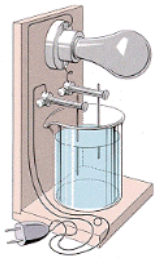
TYPE OF COMPD	PARTICLES COMPOUND MADE OF	CLASS OF COMPOUND	CRITERIA FOR SOLUBILITY IN WATER	SOLU-BILITY IN WATER	SOLUTE PARTICLES RESULTING FROM DISSOCIATION IN WATER UPON DISSOLVING	SOLUTE PARTICLES (MOLECULES) UNDERGO IONIZATION REACTION WITH WATER	COMPOUND DESCRIPTION	SOLUTE PARTICLES PRESENT IN SOLUTION	STRONG, WEAK, OR NON-ELECTRO-LYTE
IONIC	IONS	SALT	Cation is from group IA, NH_4^+, Anion is $C_2H_3O_2^-$ NO_3^- Anion is Cl^-, Br^-, I^-, or SO_4^{2-}, with exceptions	Soluble	ions	no	Soluble Salt	ions only	
			Anion is CO_3^{2-}, PO_4^{3-}, CrO_4^{2-}, or S^{2-}, with exceptions	Insoluble	___	___	Insoluble Salt	___	
		METAL OXIDE							
		METAL HYDROXIDE	Cation is from Group IA or is Ca^{2+}, Sr^{2+}, Ba^{2+}	Soluble	ions	no	Strong Base (soluble metal hydroxide)	ions only	
			All the rest of the metal hydroxides	Insoluble	___	___	Insoluble Metal Hydroxide	___	
MOLECULAR	MOLECULES	NITROGENOUS BASE	Polar	Soluble	molecules	NH_3 yes (very little)	Weak Base NH_3	molecules (plus a few ions)	
		COVALENT	Polar	Soluble	molecules		Polar Covalent	molecules only	
			Nonpolar	Insoluble	___	___	Nonpolar Covalent	___	
		ACID	Polar (all acids are polar)	Soluble	molecules	yes (100%)	HCl, HBr, HI, Strong Acid HNO_3, H_2SO_4, $HClO_4$	ions only	
						yes (very little)	Weak Acid	molecules (plus a few ions)	

PROCEDURE

CAUTION: Glacial acetic acid is corrosive and will burn the skin. If skin contact occurs, the contacted area should be washed with large amounts of water. It also has a strong odor and should be kept away from the nose while testing it. When finished, it is to be flushed with lots of water into the large sink before, while and after it is emptied.

A. Conductivity DEMONSTRATION BY INSTRUCTOR

Your instructor will test the conductivity of some substances and solutions using the light bulb conductivity apparatus.



The conductivity apparatus will be plugged into an electrical outlet. When the electrodes are placed in the material being tested, the light bulb will light if mobile ions are present. If the light bulb lights brightly, the material is a strong conductor (lots of mobile ions present to conduct the current) . If the bulb lights only dimly, it's a weak conductor (relatively few mobile ions present). If the bulb does not light at all, the material is nonconducting (no mobile ions).
Record your observations on your Report Sheet.

1. Test the conductivity of tap water
2. Test deionized water.
3. Observe the conductivity of pure acetic acid, $HC_2H_3O_{2(l)}$. There is no solvent present. (This pure liquid is also called "glacial" acetic acid because its freezing point (16.7°C) is just slightly below room temperature.)
4. The conductivity of a solution of HCl dissolved in toluene (a nonpolar solvent) will be tested.
5. Water (a polar solvent) will be added to the HCl/toluene solution and the mixture stirred. Water and toluene are immiscible and will form two layers. Toluene is less dense than water so it forms the upper layer and water the lower. The electrodes will be placed below the toluene layer and into the water layer to test its conductivity.

ALL MIXTURES CONTAINING TOLUENE WILL BE DISPOSED OF IN THE "HALOGENATED HYDROCARBONS" CONTAINER.

B. Students' Measurements of Conductivity

Students will work in pairs for this part of the experiment. Each pair will check out the following from the stockroom:

- LED Conductivity Indicator (Fragile! Handle with care.)
- Spot plate (You cannot use the spot plate in your locker.)

Oval well for deionized water (for rinsing electrodes between tests on liquid samples)

The material to be tested is placed in a well of the spot plate. When the electrodes are immersed in th e test sample, you will get one of three responses. You may need to shade the LED (light emitting diode) indicator from the bright overhead lights in the lab with your hand in order to see the response. (Alternatively, your instructor may turn off some of the lights in the lab.) Also, it is best to view the LED indicator by looking down on it from above.

LED Indicator Response	Type of Conductor
bright red light (blinking or not)	strong conductor
dim red non-blinking light	weak conductor
no light	non-conductor

1. Conductivity of Ionic Compounds and Metals

   a. Take your clean, dry spot plate to the reagent bench and add solid NaCl to one of the wells of the spot plate until it is about half full. At your bench, test the test the conductivity of the NaCl by immersing the tips of the electrodes in it. Record your observation on your report sheet.

   b. Take your conductivity indicator to the reagent bench where you will find a card with strips of Cu, Zn and Sn attached to it. Test the metals for conductivity by touching the electrodes to each of the metals. Record your observations on your report sheet.

2. Conductivity of Solutions

   a. Take the clean, dry spot plate to the reagent bench. Place about 16 drops of each of the solutions listed below in a separate well of a spot plate. Be sure that each well is at least half full to the solution to be tested.

      (1) 0.10 M NaCl
      (2) 0.10 M HCl
      (3) 0.10 M NaOH
      (4) 0.10 M $HC_2H_3O_2$
      (5) 0.10 M NH_3 (labeled NH_4OH)
      (16) 0.10 M $NaC_2H_3O_2$
      (7) sucrose, $C_{12}H_{22}O_{11}$ (solution of unknown concentration)

   b. Return to your bench, being careful to prevent the solutions from contaminating each other, and add deionized water to the oval-shaped well on the spot plate. Immerse the electrodes of the LED conductivity indicator in each solution to be tested. After each sample is tested, be sure to rinse the electrodes by dipping them into the deionized water. Record your observations on your Report Sheet.

   c. Dispose of the solutions in the spot plate by pouring them into the sink and was hing them down the drain with lots of water.

3. Conductivity of Reactant Mixtures Before and After Mixing

   a. Take the clean, dry spot plate to the reagent bench. Add about 8 drops of each of the following solutions to separate wells of the spot pl ate:

      (1) 0.10 M $HC_2H_3O_2$ } already measured above.
      (2) 0.10 M NH_3 (labeled NH4OH) }

      (3) 0.10 M $CaCl_2$
      (4) 0.10 M Na_2CO_3

   b. At your bench add deionized water to the oval well and measure the conductivities of the four solutions and record your observations on the Report Sheet. (Do n't forget to rinse electrodes between samples.)

   c. Mix the 0.10 M $HC_2H_3O_2$ and 0.10 M NH_3 by using a clean medicine dropper to transfer the contents of one well into the other. Test the conductivity of the resulting mixture and record your observations on the Report Sheet.

   d. Mix the 0.10 M $CaCl_2$ and 0.10 M Na_2CO_3 by using a clean medicine dropper to transfer the contents of one well into the other. Test the conductivity of the resulting mixture and record your observations on the Report Sheet.

   e. Dispose of the solutions by pouring them in the sink and washing them down with water.

4. Detecting the End Point of an Acid-Base Reaction by Measuring Electrical Conductivity

   a. Take the clean, dry spot plate to the reagent bench. To one well add 12 drops of 0.10 M $Ba(OH)_2$ and to another well add 6 drops of 0.10 M H_2SO_4. Test the conductivity of each solution by using the LED conductivity indicator. Record your observations on the Report Sheet.

   b. With the conductivity electrodes immersed in the 0.10 M H_2SO_4 solution, slowly add the 0.10 M $Ba(OH)_2$ solution drop by drop to the H_2SO_4 solution . Mix well after the addition of each drop by gently shaking the spot plate. Monitor the electrical conductivity until the LED shows no conductivity.

   c. Add more drops of 0.10 M $Ba(OH)_2$ solution to the non-conducting mixture until electrical conductivity is resumed. Record your observations on the Report Sheet.

Dispose of the reaction mixture in the special waste container labeled:

"$BaSO_4$ WASTE"

REPORT SHEET - EXPERIMENT 10 Name_____
Chem 111 (Last) (First)

Instructor's Approval _____

A. Conductivity Demonstrations

	Sample	Light Bulb Response Bright, Dim, No Light	Strong Conductor, Weak Conductor, or Non-Conductor
1	Tap Water		
2	Deionized Water		
3	Pure Acetic Acid, $HC_2H_30_2$ (l)		
4	HCl/toluene solution		
5	HCl/water solution		

Why did the aqueous solution of HCl conduct electricity but the HCl in toluene solution did not?

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_____

B. Student Conductivity Measurements

1. Conductivity of Ionic Compounds and Metals

	Sample	LED Response: Bright Red, Dim Non-Blinking Red, None	Strong Conductor, Weak Conductor, or Non-Conductor
1	NaCl(s)		
2	Copper		
3	Zinc		
4	Tin		

Why did the metals conduct electricity but the NaCl did not?

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_____

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_____

2. Conductivities of Aqueous Solutions of Compounds

		Classify Solute Compound: Salt, Strong Acid, Weak Acid, Strong Base, Weak Base, Covalent	LED Response: Bright Red, Dim Non-Blinking, None	Conductivity Strong Weak None	Formulas or Symbols of Solute Particles (list most abundant first)	Compound is: Stong Electrolyte Weak Electrolyte Non-Electrolyte
1	0.10 M NaCl					
2	0.10 M HCl					
3	0.10 M NaOH					
4	0.10 M $HC_2H_3O_2$					
5	0.10 M NH_3					
6	0.10 M $NaC_2H_3O_2$					
7	sucrose, $C_{12}H_{22}O_{11}$					

a. Why did the NaCl solution conduct electricity but pure NaCl did not conduct electricity?

_____ _____

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_____ _____

b. Why did the aqueous acetic acid solution conduct electricity but pure acetic acid did not?

_____

_____ _____

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3. Conductivity of Reactant Mixtures Before and After Mixing

a. Conductivity Before Reaction

		Classify Solute Compound: Salt, Strong Acid, Weak Acid, Strong Base, Weak Base, Covalent	LED Response: Bright Red, Dim Non-Blinking, None	Conductivity Strong Weak None	Formulas or Symbols of Solute Particles (list most abundant first)	Compound is: Stong Electrolyte Weak Electrolyte Non-Electrolyte
1	0.10 M $HC_2H_3O_2$					
2	0.10 M NH_3					
3	0.10 M $CaCl_2$					
4	0.10 M Na_2CO_3					

b. Conductivity After Reaction

Reaction Mixture	LED Response: Bright Red, Dim Non-Blinking, None	Conductivity Strong Weak None	Formulas or Symbols of Solute Particles (list most abundant first)
$HC_2H_3O_2$ and NH_3			
$CaCl_2$ and Na_2CO_3			

c. Reaction of $HC_2H_3O_2$ and NH_3

ME_____

TIE_____

NIE_____ _

Use the total ionic equation above to explain the before and after mixing observations.

Before Mixing: _____

_____ _____

After Mixing: _____

_____

d. Reaction of $CaCl_2$ and Na_2CO_3

ME_____

TIE_____

NIE_____

Use the total ionic equation above to explain the before and after mixing observations.

Before Mixing: _____

_____

After Mixing: _____

_____

4. Detecting the End Point of an Acid-Base Reaction by Measuring Electrical Conductivity

a. Conductivity Before Reaction

	Classify Solute Compound: Salt, Strong Acid, Weak Acid, Strong Base, Weak Base, Covalent	LED Response: Bright Red, Dim Non-Blinking, None	Conductivity Strong Weak None	Formulas or Symbols of Solute Particles (list most abundant first)	Compound is: Stong Electrolyte Weak Electrolyte Non-Electrolyte
0.10 M $Ba(OH)_2$					
0.10 M H_2S0_4					

b. Reaction of $Ba(OH)_2$ and H_2S0_4

ME_____

TIE_____

NIE_____

How do you explain the lack of electrical conductivity at th e end point?

_____

_____

c. Excess $Ba(OH)_2$

Observation of Conductivity _____

Explain in terms of the ions present in solution _____

EXERCISES:

1. Complete the table

Aqueous Solution of	Class of Compound Salt, Strong Acid, Weak Acid, Strong Base, Weak Base, Covalent	Formulas or Symbols of Solute Particles (list most abundant first)	ELECTROLYTE Strong, Weak, Non	Solute Particles that Conduct Electrical Current
NaOH				
$KC_2H_3O_2$				
$H_2C_2O_4$				
KHS				
HI				
HNO_2				
$Pb(NO_3)_2$				
C_2H_6O				
$BaCl_2$				
H_2S				
NH_3				
$NH_4C_2H_3O_2$				

2. Write molecular, total, and net-ionic equations for each of the following. Then predict if the mixtures would conduct electric current and write the formulas of ions conducting electricity.

a. Aqueous solutions of silver nitrate and hydrobromic acid

ME_____

TIE_____

NIE_____

a. After the reaction is over would you expect the solution to conduct electricity? _____

b. List the ions that would be conducting the current. _____

b. Aqueous solutions of Potassium chloride and magnesium nitrate

ME_____

TIE_____

NIE_____

a. After the reaction is over would you expect the solution to conduct electricity? _____

b. List the ions that would be conducting the current. _____

c. Aqueous solutions of sodium acetate and hydrochloric acid are mixed.

ME_____

TIE_____

NIE_____

a. After the reaction is over would you expect the solution to conduct electricity? _____

b. List the ions that would be conducting the current. _____ _____

d. Aqueous solutions of potassium hydroxide and hydrosulfuric acid are mixed.

ME_____

TIE_____ _____

NIE_____

a. After the reaction is over would you expect the solution to conduct electricity? _____

b. List the ions that would be conducting the current. ____ _____