EXPERIMENT 0

Soluble and Insoluble Salts

A. Goal

The goals of this experiment are to test the solubility rules and to investigate the changes of solubility with temperature.

B. Materials

- ☐ spot plate
- ☐ Type A reagents: NaCl(aq), Na_2SO_4(aq) and Na_3PO_4(aq)
- ☐ Type B reagents: $Ca(NO_3)_2$(aq) and $AgNO_3$(aq)
- ☐ KNO_3
- ☐ hot plate, beaker, ring and stand

C. Background

Electrolytes and insoluble compounds

On one hand, electrolytes are compounds that conduct electricity once dissolved in water. Differently, nonelectrolytes are compounds that do not conduct electricity once dissolved in water. On the other hand, insoluble compounds are not soluble in water, whereas soluble compounds can be dissolved in water. This section covers the properties of electrolytes and insoluble (and soluble) compounds. At the end of this section, you should be able to classify a chemical in terms of its electrolyte type and solubility character.

Solubility formula

Solubility (s) is the grams of a solute per 100 g of solvent:

$$\boxed{s = \frac{\text{g of solute}}{\text{100 g of solvent}}}$$

A saturated solution can be achieved when you fit the maximum amount of solute in the solvent. If you continue adding solute to a saturated solution it will precipitate and a solid will form.

Soluble and insoluble salts

Soluble compounds dissolve in water, whereas insoluble compounds do not. For example, barium chromate ($BaCrO_{4(s)}$) is an insoluble salt. How do we know that? Table 1 will help you predict the solubility of a salt. To do this, you need to start by assessing the right ion (the anion, ${CrO_4}^{2-}$) located in the left column of Table 1. After that, you need to assess the left ion (the cation, Ba^{2+}) located in the right column. If you follow this, you will see that chromate is insoluble and barium is not part of any exception. Let us predict for example the soluble/insoluble nature of $CaSO_4$, calcium sulfate. We start by looking for ${SO_4}^{2-}$ in the left column to find out is soluble. Next, we continue in the same line as ${SO_4}^{2-}$ and look for the ion in the left Ca^{2+}. In conclusion, even when ${SO_4}^{2-}$ is soluble, when combined with Ca^{2+}, we have that $CaSO_4$ is insoluble, and overall $CaSO_{4(s)}$ is insoluble.

Sample Problem 1

Predict the soluble/insoluble nature of the following compounds: (a) K_2CO_3, (b) $NaNO_3$ and (c) $Ca(OH)_2$.

SOLUTION

(a) $K_2CO_{3(aq)}$ is soluble, as ${CO_3}^{-2}$ is insoluble but when combined with K^+ the salt becomes soluble. (b) All nitrates are soluble without exceptions. (c) $Ca(OH)_{2(aq)}$ is soluble.

STUDY CHECK

Predict the soluble/insoluble nature of the following compounds: (a) Li_3PO_4 (b) Na_2S (c) AgCl

Table 1 Soluble and insoluble compounds

Ions that form *soluble* compounds...	... **except** when combined with
Group I ions (Na^+, Li^+, K^+, etc)	no exceptions
Ammonium (${NH_4}^+$)	no exceptions
Nitrate (${NO_3}^-$)	no exceptions
Acetate (CH_3COO^-)	no exceptions
Hydrogen carbonate (${HCO_3}^-$)	no exceptions
Chlorate (${ClO_3}^-$)	no exceptions
Halide (F^-, Cl^-, Br^-, I^-)	Pb^{2+}, Ag^+ and ${Hg_2}^{2+}$
Sulfate (${SO_4}^{2-}$)	Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, ${Hg_2}^{2+}$ and Pb^{2+}
Ions that form *insoluble* compounds...	... **except** when combined with
Carbonates (${CO_3}^{2-}$)	group I ions (Na^+, Li^+, K^+, etc) or ammonium (${NH_4}^+$)
Chromates (${CrO_4}^{2-}$)	group I ions (Na^+, Li^+, K^+, etc) or Ca^{2+}, Mg^{2+}or ammonium (${NH_4}^+$)
Phosphates (${PO_4}^{3-}$)	group I ions (Na^+, Li^+, K^+, etc) or ammonium (${NH_4}^+$)
Sulfides (S^{2-})	group I ions (Na^+, Li^+, K^+, etc) or ammonium (${NH_4}^+$)
Hydroxides (OH^-)	group I ions (Na^+, Li^+, K^+, etc) or Ca^{2+}, Mg^{2+}, Sr^{2+}or ammonium (${NH_4}^+$)

Strong electrolytes

Strong electrolytes completely dissociate in water. Hence, in a solution of a strong electrolyte, you will only have ions and never molecules. Strong electrolytes are typically ionic compounds such as $MgCl_2$ or NaCl (table salt). We represent the dissociation of a strong electrolyte with a single arrow, meaning that the reaction proceeds to completion, and for the example below, in the solution, we will only have ions ($Mg^{2+}_{(aq)} + 2\,Cl^-_{(aq)}$) and not molecules ($MgCl_{2(s)}$):

$$MgCl_{2(s)} \xrightarrow{H_2O} Mg^{2+}_{(aq)} + 2\,Cl^-_{(aq)}.$$

Weak electrolytes partially dissociate in water, and this is indicated using a chemical reaction with a double arrow. Hence in a solution of a weak electrolyte, you will have ions as well as molecules at the same time. Examples of weak electrolytes are hydrofluoric acid, water, ammonia, or acetic acid. The dissociation of hydrochloric acid (HF) proceeds as:

$$HF_{(l)} \xrightleftharpoons{H_2O} H^+_{(aq)} + F^-_{(aq)}$$

Acetic acid (CH_3COOH) is an important weak electrolyte and its dissociation proceeds somehow in a peculiar way:

$$CH_3COOH_{(l)} \xrightleftharpoons{H_2O} CH_3COO^-_{(aq)} + H^+_{(aq)}$$

Nonelectrolytes

Nonelectrolytes do not dissociate in water. Hence a solution of a nonelectrolyte will only contain molecules and not ions. Examples of nonelectrolytes are carbon-based chemicals such as methanol, ethanol, urea, or sucrose. The dissociation of urea for example CH_4N_2O proceeds as:

$$CH_4N_2O_{(s)} \xrightarrow{H_2O} CH_4N_2O_{(aq)}$$

Identify the electrolyte character of a chemical

You can use Table 3 to identify the electrolyte character of a chemical. Ionic compounds are in general strong electrolytes, and most acids are as well. There are four important weak electrolytes: water, acetic acid, ammonia, and hydrofluoric acid. Covalent compounds are in general nonelectrolytes. Organic compounds, compounds based on carbon atoms (e.g. $C_{12}H_{22}O_{11}$) are in general nonelectrolytes.

Sample Problem 2

For the following chemicals indicate whether you will have in the solution (a) only ions, (b) ions and some molecules, or (c) molecules: NH_3, KOH, and $C_{12}H_{22}O_{11}$.

SOLUTION

Ammonia (NH_3) is a weak electrolyte and a solution of ammonia will contain ions and well as ammonia molecules. Differently KOH is a strong electrolyte and in solution you would find only ions (K^+ and OH^-). Sucrose ($C_{12}H_{22}O_{11}$) is a nonelectrolyte and in solution you will find molecules.

STUDY CHECK

For the following chemicals indicate whether you will have in the solution only ions, ions and some molecules, or molecules: (a) H_2SO_4, HNO_3 and CH_3OH.

Table 3 Different types of electrolytess

Electrolyte Type	Dissociation	Particles in solution	Examples
Strong	Fully	Mostly ions	Ionic Compounds and most acids and bases (hydroxides): NaCl, NaOH, HCl, $MgCl_2$, H_2SO_4, etc
Weak	Partially	Ions & molecules	NH_3, CH_3COOH (acetic acid), HF, H_2O
Nonelectrolytes	No	molecules	Most covalent compounds: CH_3OH (methanol), CH_3CH_2OH (ethanol), $C_{12}H_{22}O_{11}$ (sucrose), CH_4NO_2 (urea)

D. Procedure

1. Solubility rules The goal of this mini experiment is to test the solubility rules and predict the soluble character of a chemical.

Step 1: – Find a spot plate. Arrange in the following order the set of reactants Type A: NaCl(aq), Na_2SO_4(aq) and Na_3PO_4(aq). Arrange in the following order the set of reactants Type B: $Ca(NO_3)_2$(aq) and $AgNO_3$(aq).

Step 2: – Make mixtures of each pair of compounds listed in the results table by adding 2-3 drops of each solution in the same spot of the spot plate. When the resulting mixture is cloudy that means a precipitate has formed.

Step 3: – Write down the result on the Results table as soluble (S) or insoluble (I).

2. Change of solubility with temperature The goal of this mini experiment is to investigate the change of solubility of KNO_3 with temperature. You will do so by adding different amounts of solute and measuring the temperature at what the solute dissolved. You will work in different teams and each team will share their results with the rest of the class.

Step 1: – You will be assigned an amount of solute between 3 and 7 grams. Weight the solid and write down exactly how much solute did you use. If for example you are assigned 3g you can weight 3.1g.

Step 2: – Measure 5mL of water with a measuring cylinder. Add the liquid and the solid to a test tube that should be damped to a stand inside a water bath. Use a thermometer and start warming up the water bath.

Step 3: – Heat the solution with either a hot plate or a Bunsen burner until the solid dissolves completely. If you use a hot plate, make sure you secure the beaker with a ring. At that point, stop the heating and take the tube out of the bath keeping the thermometer inside the solution. When crystals start to appear, write down the temperature of the solution. You can calculate solubility in $g \cdot mL^{-1}$ using the formula:

$$\text{Solubility} = \frac{\text{mass of KNO}_3}{\text{5 mL of H}_2\text{O}} \times 100$$

Step 4: – When you have all results from the class, plot solubility (vertical axis) vs. temperature (horizontal axis).

STUDENT INFO

Name: ______________________ Date: ______

Pre-lab Questions

Soluble and Insoluble Salts

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1. Name and predict the solubility (*soluble* or *insoluble*) of the following substances.

Compound	Name	Solubility
$CaCl_2$		
$NaNO_3$		
NH_4Br		
$AgCl$		
$Ni(OH)_2$		
Ag_3PO_4		
$Ca_3(PO_4)_2$		

2. Are salts more or less soluble in liquid at high or low temperature?

3. Think about a soda can. Are gases more or less soluble in liquid at high or low temperature?

STUDENT INFO

Name: ____________________ Date: ______

Results

EXPERIMENT

Soluble and Insoluble Salts

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1. Solubility rules

	NaCl	$Na_3PO_4(aq)$	Na_2SO_4
$Ca(NO_3)_2(aq)$			
$AgNO_3(aq)$			

(write *S* for soluble product and *I* for insoluble product.)

2. Change of solubility with temperature

Mass of KNO_3 (g)	Temperature when crystals appear (°C)	Solubility (g/ml)
–	100	13
3		
3.5		
4		
4.5		
5		
5.5		
6		
6.5		
7		

STUDENT INFO

Name: ______________________ Date: ______

Post-lab Questions

Soluble and Insoluble Salts

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1. According to your graph, estimate solubility at 37 °C.

2. Solubility for a given chemical is 0.1 $g \cdot mL^{-1}$ at 30 °C. How many grams of solute will dissolve in 25mL of water at that temperature.

3. Solubility of table salt is 0.4 $g \cdot mL^{-1}$ at 25 °C. Will 50 grams of table salt dissolve in 100mL of water at that temperature.