Note: You are responsible for remembering and being able to use EVERYTHING from CHM 0100. CHM 1100 is impossible to understand without the knowledge from CHM 0100. If you do not remember CHM 0100, you must review it immediately.

Stoichiometry is the chemistry calculation to answer the question: How much? How much of this chemical is needed to react in this reaction? How much of that chemical is produced by that reaction? How much of one chemical reacts with a certain amount of another chemical?

Stoichiometry problems are generally word problems, that never say the word "stoichiometry". That means you must interpret the ENGLISH!

When you read a stoichiometry problem, it must have three things:

1: A BALANCED CHEMICAL EQUATION. If an equation is given unbalanced,

what you need to solve for. It does not need to be a product.

If you do not have these exact three things, it is not a stoichiometry problem (or a least not a normal one)! You do not need to worry about what the reaction is used for, or why it is important in real life, because we do stoichiometry as paper-and-pencil problems.

There is a three step calculation to solve stoichiometry problems.

step 1: convert given to moles! step 2: convert given to unknown! step 3: convert unknown from moles

Notice, these are conversion calculations that use the same "dimensional analysis" fraction technique introduced back in CHM 0100. Different stoichiometry problems may skip some steps or add extra steps to these basic three steps.

If the measurements are in grams, it looks like this:

There are several important variations on stoichiometry: including PERCENT YIELD, LIMITING REAGENTS, SOLUTION STOICHIOMETRY, GAS STOICHIOMETRY, THERMOCHEMICAL STOICHIOMETRY and ELECTROCHEMICAL STOICHIOMETRY. Problem 1: When dinitrogen pentoxide, N<sub>2</sub>O<sub>5</sub>

Problem 5: Copper is a reddish-orange metal famous for pennies and electrical wiring. Pure elemental copper is rare in nature, and must be be refined from ores. The brownish mineral bornite ( $Cu_3FeS_3$ ) is an important copper ore. When roasted (heated), the following reaction occurs:

If 2.50 metric tons of  $Cu_3FeS_3$  is reacted with excess  $O_2$  and the process has an 86.3% yield of copper, what mass of copper is produced?

Problem 6: Isopropyl alcohol is the disinfectant chemical in rubbing alcohol. It is a compound that contains the elements carbon, hydrogen, and oxygen. If the complete combustion of a 1.802 g sample of isopropyl alcohol produces 3.959 g carbon dioxide and 2.162 g water, what is the empirical formula of isopropyl alcohol.

Solution 1: When dinitrogen pentoxide,  $N_2O_5$ , a white solid, is heated, it decomposes to nitrogen dioxide and oxygen.

If a sample of N<sub>2</sub>O<sub>5</sub> produces 1.381 g O<sub>2</sub>, how many grams of NO<sub>2</sub> are formed?

given is 1.381 g  $O_2$  with molar mass of 2 (16.00) = 32.00 g/ mol! unknown is NO<sub>2</sub> with molar mass of 14.01 + 2 (16.00) = 46.01 g/ mol! mole ratio is 1 mol  $O_2$  = 4 mol NO<sub>2</sub>

Solution 2: Potassium superoxide, KO<sub>2</sub>, is used in self-contained breathing apparatus used by emergency personnel as the source of oxygen. It reacts with the moisture from exhaled breaths:

Solution 5: Copper is a reddish-orange metal famous for pennies and electrical wiring. Pure elemental copper is rare in nature, and must be be refined from ores. The brownish mineral bornite ( $Cu_3FeS_3$ ) is an important copper ore. When roasted (heated), the following reaction occurs:

If 2.50 metric tons of  $Cu_3FeS_3$  is reacted with excess  $O_2$  and the process has an 86.3% yield of copper, what mass of copper is produced?

Ignoring all the extra English: given is 2.50 tons  $Cu_3FeS_3$  with molar mass of 3 (63.55) + 55.85 + 3 (32.07) = 342.7 g/ mol! unknown is Cu with molar mass = 63.55 g/ mol and percent yield = 86.3%! mole ratio is 2 mol  $Cu_3FeS_3 = 6$  mol Cu Solution 6: Isopropyl alcohol is the disinfectant chemical in rubbing alcohol. It is a compound that contains the elements carbon, hydrogen, and oxygen. If the complete combustion of a 1.802 g sample of isopropyl alcohol produces 3.959 g carbon dioxide and 2.162 g water, what is the empirical formula of isopropyl alcohol?

givens are  $3.959 \text{ g CO}_2$  with molar mass of 12.01 + 2(16.00) = 44.01 g/mol, ! $2.162 \text{ g H}_2\text{O}$  with molar mass of 2(1.008) + 16.00 = 18.02 g/mol, !and <math>1.802 g isopropyl alcohol sample

The combustion reaction equation must like this, although it cannot be balanced:

$$C_{\chi}H_{\chi}O_{Z} + O_{2} - CO_{2} + H_{2}O$$

Part 1: from combustion products to reactant mass composition:

3.959 
$$g \operatorname{CO}_2 \times \frac{1 \mod \operatorname{CO}_2}{44.01 \ g \operatorname{CO}_2} \times \frac{1 \mod \operatorname{C}}{1 \mod \operatorname{CO}_2} \times \frac{12.01 \ g \ \mathrm{C}}{1 \mod \operatorname{C}}$$
 1.080  $g \ \mathrm{C}$ 

2.161 *g* **H** 

Part 2: from mass composition to empirical formula:

step 1: convert all elements to moles

step 2: divide by smallest mole count:

the empirical formula of isopropyl alcohol is

In previous topics, we used pure substances. We used one chemical at a time. If we had more than one, we were relating them in chemical reactions.

A solution is a HOMOGENEOUS mixture. A SOLUTE is dissolved into a SOLVENT to make the SOLUTION.

If water is the solvent, the solution is called an AQUEOUS solution - abbreviated "aq." We will be using water as O

DO NOT, UNDER ANY CIRCUMSTANCE, TASTE ANY OF THE CHEMICALSIN THE LAB!

Since ionic compounds in aqueous solutions exist as ions, we don't always write balanced equations as the MOLECULAR EQUATIONS (from Chapter 3). Instead, we often write out the electrolytes in NET IONIC EQUATIONS.

lonic compounds in aqueous solution undergo some important reactions. Since many compounds are insoluble, when soluble solution reactants may produce an insoluble product in a DOUBLE DISPLACEMENT (the cations and anions switch their partners). Insoluble products PRECIPITATE; they are produced as solid grains that separate from the solution. Any remaining product ions are called SPECTATOR IONS.

Acid solutions react with base solutions in a NEUTRALIZATION REACTION.

Oxidation numbers (or states) are used to keep track of electrons during a chemical reaction. The oxidation number of an ion in an ionic compound is the same as its ion charge. The oxidation number of an atom in a covalent compound, would be its charge if it were an ion.

Some rules to find the oxidation number are:

rule 1: the oxidation number of an element is zero.

rule 2: the oxidation number of a monatomic ion is its ion charge.

rule 3: the oxidation number of fluorine in compound is always -1, oxygen in compound is almost always -2, and hydrogen is +1, except for -1 in a metal hydride.

rule 4: the total oxidation number of a compound must be zero.

rule 5: the total oxidation number of a polyatomic ion must be its charge.

rule 6: the oxidation number of uncertain atoms must be determined through the context of the molecule it is part of.

- m) n) o) p)
- q)

Problem 5: Identify the species being reduced and oxidized in the following redox reactions. Write balanced half reactions for the reduction and oxidation. (You may ignore spectator ions.)

a)

b)

- C)
- d)

Problem 6: If 39.4 g of sodium sulfate is dissolved in water to make 796 mL of solution, what is Molarity of the solution?

Problem 7: What mass of potassium nitrate is dissolved in 398 mL of a 2.14 Molar solution?

Problem 8: Solutions of nickel sulfate, , and sodium phosphate, , react to give a pale yellow-green precipitate of nickel phosphate, , and a solution of sodium sulfate,

Problem 9: Millions of tons of hydrochloric acid are used every year for "metal pickling" - removing any rust or corrosion from metal surfaces - before final finishing. The reaction with iron(III) oxide is:

$$Fe_2O_3(s) + 6 HCI_{(aq)} = 2 FeCI_3(aq) + 3 H_2O_{(/)}$$

If a steel sheet with 5.29 g  $Fe_2O_3$  rust is pickled with 27.5 mL of 2.45 M HCl, would all the rust be removed? (a) What concentration of  $FeCl_3$  would be produced, if the final volume is 89.4 mL? (b) If the rust is the excess reagent, what mass of  $Fe_2O_3$  would remain?

Solution 1: Write the balanced equations for the dissociation reactions of the following ionic compounds in aqueous solution. If the compound is insoluble, write NR, for "No reaction," in place of the products.

 $KCI_{(s)}$   $K^+_{(aq)} + CI^-_{(aq)}$ a)  $Ag_2SO_4$  (s) NR b)  $Mg(NO_3)_{2(s)}$   $Mg^{2+}_{(aq)} + 2NO_{3(aq)}^{-}$ C) d)  $AgC_2H_3O_2(s)$   $Ag^+_{(aq)} + C_2H_3O^-_{(aq)}$ e)  $NH_4NO_3(s)$   $NH_4^+(aq) + NO_3^-(aq)$ f)  $Li_{3}PO_{4(s)}$   $3Li_{(aq)}^{+} + PO^{3-}$ g) h) i) j) k) copper(II) chloride I) barium sulfate

potassium chromate

n) iron(II) sulfide

m)

Al's oxidation number decreases, it gains electrons, it is reduced (also called the oxidizing agent).

red  $2 \text{ AI}^{3+} + 6 \text{ e}^{-} 2 \text{ AI}$ ox  $3 \text{ Mg} \qquad 3 \text{ Mg}^{2+} + 6 \text{ e}^{-}$ b) Cu +  $2 \text{ AgCI} \qquad \text{CuCl}_2 + 2 \text{ Ag}$  $0 \qquad +1 \quad -1 \qquad +2 \quad -1 \qquad 0$ Cu +  $2 \text{ AgCI} \qquad \text{CuCl}_2 + 2 \text{ Ag}$ 

Cu's oxidation number increases, it loses electrons, it is oxidized (also called the reducing agent).

Ag's oxidation number decreases, it gains electrons, it is reduced (also called the oxidizing agent).

red  $2 Ag^{+} + 2 e^{-} 2$ 

C)

Cr's oxidation number decreases, it gains electrons, it is reduced (also called the oxidizing agent).

C's oxidation number increases, it loses electrons, it is oxidized (also called the reducing agent).

d)

Ca's oxidation number increases, it loses electrons, it is oxidized (also called the reducing agent).

Ni's oxidation number decreases, it gains electrons, it is reduced (also called the oxidizing agent).

$$KNO_{3}$$

$$K = 39.10$$

$$N = 14.01$$

$$O_{3} = 16.00 \times 3 = 48.00$$

$$KNO_{3} = 101.11 \text{ g/mol}$$

$$M = \frac{mol}{L}$$

$$L \times M = mol$$

$$0.398 \ L \times \frac{2.14 \ mol \ \text{KNO}_3}{L} = mol \ \text{KNO}_3$$

$$0.8517 \ mol \ \text{KNO}_3$$

0.8517 *mol* KNO<sub>3</sub> × 
$$\frac{101.11 \ g \text{ KNO}_3}{1 \ mol \text{ KNO}_3}$$
 86.1  $g \text{ KNO}_3$ 

Solution 8: Solutions of nickel sulfate, NiSO<sub>4</sub>, and sodium phosphate, Na<sub>3</sub>PO<sub>4</sub>, react to give a pale yellow-green precipitate of nickel phosphate, Na<sub>3</sub>PO<sub>4</sub>, and a solution of sodium sulfate, Na<sub>2</sub>SO<sub>4</sub>

$$3 \text{ NiSO}_{4 (aq)} + 2 \text{ Na}_{3} \text{PO}_{4 (aq)} + \text{Ni}_{3} (\text{PO}_{4})_{2 (s)} + 3 \text{ Na}_{2} \text{SO}_{4 (aq)}$$

(a) How many milliliters of 0.375 M NiSO<sub>4</sub> will completely react with 45.7 mL of 0.265 M Na<sub>3</sub>PO<sub>4</sub>?

This is a solution stoichiometry problem.

part (a) given is 45.7 mL of  $0.265 \text{ M Na}_3\text{PO}_4!$ part (a) unknown is mL of  $0.375 \text{ M Ni}_3\text{SO}_4!$ mole ratio is 3 mol Ni $\text{SO}_4 = 2 \text{ mol Na}_3\text{PO}_4$ 

$$45.7 \ mL \times \frac{0.265 \ mol \ Na_3 PO_4}{L} \times \frac{2 \ mol \ NiSO_4}{3 \ mol \ Na_3 PO_4} \times \frac{L}{0.375 \ mol \ NiSO_4}$$
 21.5 mL

It might be easier to do the three-step stoichiometry process one step at a time.

step 1: convert given to moles

$$\mathcal{M} = \frac{mol}{L}$$

$$\mathcal{L} \times \mathcal{M} = mol$$

$$0.0457 \ \mathcal{L} \times 0.265 \ \mathcal{M} \ Na_3 PO_4 = mol \ Na_3 PO_4$$

$$0.01211 \ mol \ Na_3 PO_4$$

step 2: convert given to unknown

$$0.01211 \ mo/ \ Na_{3}PO_{4} \times \frac{2 \ mo/ \ NiSO_{4}}{3 \ mo/ \ Na_{3}PO_{4}} \qquad 0.008074 \ mo/ \ NiSO_{4}$$

step 3: convert unknown from moles

$$M = \frac{mol}{L}$$

$$L = \frac{mol}{M}$$

$$= \frac{0.008074 \ mol \ NiSO_4}{0.375 \ M \ NiSO_4}$$

$$0.0215 \ L$$

$$21.5 \ mL$$

(b) What mass of  $Ni_3(PO_4)_2$  precipitate would form?

part (b) given is 0.0457 L of 0.265 M Na<sub>3</sub>PO<sub>4</sub>!

part (b) unknown is grams  $Ni_3(PO_4)_2$  with molar mass of 3 (58.69) + 2 (30.97) + 8 (16.00) = 366.0 g/ mol!

mole ratio is 2 mol  $Na_3PO_4 = 1 \text{ mol } Ni_3(PO_4)_2$ 

$$0.0457 L \times \frac{0.265 \text{ mol} \text{Na}_{3} \text{PO}_{4}}{L} \times \frac{1 \text{ mol} \text{Ni}_{3} (\text{PO}_{4})_{2}}{2 \text{ mol} \text{Na}_{3} \text{PO}_{4}} \times \frac{366.0 \text{ gNi}_{3} (\text{PO}_{4})_{2}}{1 \text{ mol} \text{Ni}_{3} (\text{PO}_{4})_{2}} = 2.22 \text{ gNi}_{3} (\text{PO}_{4})_{2}$$

Solution 9: Millions of tons of hydrochloric acid are used every year for "metal pickling" - removing any rust or corrosion from metal surfaces - before final finishing. The reaction with iron(III) oxide is:

$$Fe_2O_3(s) + 6 HCI_{(aq)} = 2 FeCI_3(aq) + 3 H_2$$

If a steel sheet with 5.29 g rust is pickled with 27.5 mL of 2.45 M HCl, would all the rust be removed? (a) What concentration of  $FeCl_3$  would be produced, if the final

step 2: convert limiting to excess. step 3: convert excess from moles

$$\begin{array}{l} 0.0674 \ \textit{mo/ HCI} \times \frac{1 \ \textit{mo/ Fe}_2O_3}{6 \ \textit{mo/ HCI}} \times \frac{159.7 \ \textit{g} \ \text{Fe}_2O_3}{1 \ \textit{mo/ Fe}_2O_3} & 1.79 \ \textit{g} \ \text{Fe}_2O_3 \ \textit{used up} \\ \\ \textbf{5.29 g Fe}_2O_3 \ \textbf{given - 1.79 g Fe}_2O_3 \ \textbf{used up} = \textbf{3.50 g Fe}_2O_3 \ \textbf{left over} \end{array}$$

There are many types of energy. They include: kinetic energy, potential energy, and electrical energy. However, in Chemistry, we are concerned with heat energy.

Chemical reactions do not only involve a change of chemicals. They also have a change of energy. Some reactions absorb energy, other reactions release energy - measured as a change of heat, and usually converted to a change of enthalpy.

The word "calor" means heat; and "meter" means measure. Therefore, CALORIMETRY literally means "measure the heat." How? By measuring the temperature, because temperature is proportional to the heat stored in a collective object.

A calorimeter is an insulated container, usually filled with water, in which a chemical reaction is run. A thermometer in the water measures any temperature changes, which is then used to calculate the heat.

There are two versions of the calorimetry equation, depending on whether the calorimeter is measured by specific heat (s) or heat capacity (C):

"Related reactions have related enthalpies."

If there are multiple reactions that are somehow related to each other, their relationship can be used to find missing enthalpies. The problem is: What is the relationship?

I recommend a four-step procedure: Compare/ Correct/ Cancel/ Combine

step 1: COMPARE each given equation, one at a time, to the unknown reaction. What chemical do they have, exclusively, in common.

step 2: CORRECT each given equation, one at a time, if the common chemical does not match exactly for number of moles, or is not on the side (reactant

Problem 1: When 10.66 kJ of heat is added to 242 g of an unknown metal, its temperature rises from 19.5 °C to 117.6 °C. What is the specific heat of this metal?

Problem 2: When a 2.946 g sample of ethanol,  $C_2H_5OH$ , is burned with excess oxygen in a bomb calorimeter, the temperature of the calorimeter rises from 24.50°C to 33.12°C. If the heat capacity of the calorimeter and contents was 10.14 kJ °C, what is the enthalpy of combustion per 1.00 mol of ethanol? The reaction is:

$$C_2H_5OH_{(/)} + 3 O_2_{(g)} - 2 CO_2_{(g)} + 3 H_2O_{(/)}$$

Problem 3: A 285 g sample of an unknown metal at 125.50 °C is placed into 527 g of water at 16.44 °C. When equilibrium is reached, the temperature is 27.81 °C. Since the specific heat of water is 4.184 J/ g °C, what is the specific heat of the metal? Assume any heat transfer to the container is negligible.

Problem 4: Although both chemicals are highly toxic, the liquids hydrazine,  $N_2H_4$ , and dinitrogen tetroxide,  $N_2O_4$  are often used as rocket fuels, because of their fail-safe exothermic reaction:

 $2 N_2 H_4 (n) + N_2 O_4 (n)$   $3 N_2 (n) + 4 H_2 O_{(n)} H^{\circ} = -1049 \text{ kJmol}$ 

How much heat is evolved when 1 gallon  $(3.01 \times 10^3 g)$  of hydrazine is completely reacted?

Problem 5: Chemical (single-use) cold packs use of a bag of ammonium nitrate crystals inside another bag of water. When the inner bag is broken, the ammonium nitrate dissolves in the water in an endothermic reaction:

$$NH_4NO_3(s)$$
  $NH_4^+(aq) + NO_3^-(aq)$   $H^\circ = 25.7 \ k J mol$ 

If a cold pack can absorb 124 kJ of heat, what mass of ammonium nitrate does the pack contain?

Solution 1: When 10.66 kJ of heat is added to 242 g of an unknown metal, its temperature rises from 19.5 °C to 117.6 °C. What is the specific heat of this metal?

given:  $q = 10.66 \text{ kJ} \times \frac{1000 \text{ J}}{\text{kJ}} = 10,660 \text{ J}, m = 242 \text{ g}, T_i = 19.5^{\circ}C, T_f = 117.6^{\circ}C$ 

unknown: S = ?

given

$$q = m s T$$
  

$$s = \frac{q}{m T}$$
  

$$= \frac{q}{m (T_f - T_i)}$$
  

$$= \frac{10,660 J}{242 g (117.6 \circ C - 19.5 \circ C)}$$
  

$$s 0.449 J/g \circ C$$

Solution 2: When a 2.946 g sample of ethanol, C<sub>2</sub>H<sub>5</sub>OH, is burned with excess oxygen in a bomb calorimeter, the temperature of the calorimeter rises from 24.50°C to 33.12°C. If the heat capacity of the calorimeter and contents was 10.14 kJ °C, what is the enthalpy of combustion per 1.00 mol of ethanol? The reaction is:

$$C_2H_5OH_{(f)} + 3 O_2(g) = 2 CO_2(g) + 3 H_2O_{(f)}$$
  
given:  $m = 2.946 g$ ,  $T_i = 24.50^{\circ}C$ ,  $T_f = 33.12^{\circ}O_1$   
unknown:  $H^{\circ} = ?$ 

Since the calorimeter's (the surroundings') temperature is measured, not the reaction's (the system's) directly, the calorimetry equation should use a negative sign.

$$H = \frac{q}{mol}$$

$$H = \frac{-87.41 \ kJ}{0.06395 \ mol \ C_2H_5OH}$$

Solution 3: A 285 g sample of an unknown metal at 125.50 °C is placed into 527 g of water at 16.44 °C. When equilibrium is reached, the temperature is 27.81 °C. Since the specific heat of water is 4.184 J/ g °C, what is the specific heat of the metal? A ssume any heat transfer to the container is negligible.

Solution 4: Although both chemicals are highly toxic, the liquids hydrazine, , and dinitrogen tetroxide, are often used as rocket fuels, because of their fail-safe exothermic reaction:

How much heat is evolved when 1 gallon ( ) of hydrazine is completely reacted?

given is , with molar mass of 2 (14.01) + 4 (1.008) = 32.05g/ mol! unknown is kJ of heat! mole ratio is 2 mol =

$$H_{rxn}^{\circ} = n_{p} H_{f}^{\circ} (\text{products}) - n_{r} H_{f}^{\circ} (\text{reactants})$$

$$H_{rxn}^{\circ} = (2 \text{ CO}_{2(g)} + 3 \text{ H}_{2}\text{O}_{(f)}) - (\text{C}_{2}\text{H}_{5}\text{OH}_{(f)} + 3 \text{ O}_{2(g)})$$

$$= (2 (-393.5 \text{ kJ/mol}) + 3 (-285.8 \text{ kJ/mol}))$$

$$- (-277.6 \text{ kJ/mol} + 3 (0 \text{ kJ/mol}))$$

$$H_{rxn}^{\circ} = -1366.8 \text{ kJ/mol}$$

Solution 7: The primary component of gasoline is the 8-carbon isooctane. The thermochemical equation for the combustion of isooctane is:

 $2 C_8 H_{18(l)} + 25 O_{2(g)}$  16 CO<sub>2(g)</sub> + 18 H<sub>2</sub>O<sub>(l)</sub>  $H_{r_{XII}}^{\circ} = -10,921.8 \ kJ$ 

What is the enthalpy of formation of isooctane? Look up the enthalpies of formation of the other chemicals.

given:  $H_{r_{XR}}^{\circ} = -10,921.8 \ k \ Jmol, \quad H_{f}^{\circ} [O_{2(g)}] = 0 \ k \ Jmol \\ H_{f}^{\circ} [CO_{2}]$ 

unknown:



Solution 8: Determine for:

Use the following data:

step 1: when comparing given reaction 1 with the unknown reaction, they have

step 3: looking at all three corrected equations together, there are 1 mol and 2 mol on both the reactant and the product sides, and can be cancelled:

step 4: looking at what's left, the remaining 1 mol and 2 mol reactants and 1 mol

repeat step 1: in comparing given reaction 2 with the unknown reaction, they have exclusively in common. (Ignore the oxygen, because it also appears in the other

There are three physical PHASEs of matter: SOLIDs, LIQUIDs and GASes.

- A solid has a definite volume and a definite shape.
- A liquid has a definite volume, but no definite shape. A liquid will flow to take the shape of the bottom of its container.

do the atoms/ molecules of a gas behave: gas atoms/ molecules have approximately zero size (compared to the whole); have negligible forces with each other; are always in random motion and collide elastically with surroundings to produce pressure; their velocity/ kinetic energy is proportional to Kelvin temperature

These postulates are the starting point for a huge amount of theoretical work - that we don't worry about, because it's mostly Physics.

We do use a gas law for root-mean-squared velocity, which is the average speed of gas

Problem 1: A weather balloon is inflated with helium gas to a volume of 158 L at sea level at 30 °C and 770 torr. The balloon rises into the stratosphere, where it is -30 °C and 180 torr. What will be the ballon's volume?

Problem 2: Formic acid can be decomposed with sulfuric acid to produce carbon

$$\mathcal{A} = \frac{m}{V} = \frac{P}{RT}$$
  
=  $\frac{mRT}{VP}$   
=  $\frac{0.564 \ g (0.0821 \ L \ atm/mol \ K) (363 \ K)}{0.356 \ L (0.9908 \ atm)}$   
47.7 g/mol

Solution 4: The carbon dioxide exhaled by astronauts is absorbed from the spacecraft air by lithium hydroxide:

 $2 \text{ LiOH}_{(s)} + \text{ CO}_{2(q)}$ 

A person exhales about 5.8 10<sup>2</sup> L of carbon dioxide (at STP) every day. What mass of lithium hydroxide is required to absorb this carbon dioxide for each astronaut per day?

This is a gas stoichiometry problem.

given is V = 5.8 10<sup>2</sup> L with STP meaning T = 273 K and P = 1 atm! unknown is with molar mass = 23.95 g/ mol! mole ratio is 1 mol = 2 mol

step 1: convert given to moles - use Ideal Gas Law

step 2: convert given to unknown - use mole ratio;! step 3: convert unknown from moles - use molar mass Solution 5: A high explosive is any chemical that undergoes an extremely rapid,

given is C<sub>3</sub>H<sub>8 (g)</sub> at V = 5.0 L, T = 30.0 °C + 273 = 303 K ! and  $P = 2.50 \times 10^4 \text{ mm Hg} \times \frac{1 \text{ atm}}{760 \text{ mm Hg}}$  32.89 atm;!

unknown is H = ?;!

mole ratio is 1 mol  $C_3H_8$  (g) = -2219.0 kJ

step 1: convert given to moles - use Ideal Gas Law:

$$PV = nR I$$

$$n = \frac{PV}{RT}$$

$$n_{C_3H_8} = \frac{32.89 \ atm(5.0 \ L)}{0.0821 \ L \ atm/mol \ K (303 \ K)}$$

$$n_{C_3H_8} = \frac{6.61 \ mol \ C_3H_8}{6.61 \ mol \ C_3H_8}$$

step 2: convert given to unknown - use mole ratio:

6.61 *mol* 
$$C_3H_8 \times \frac{-2219.0 \ kJ}{1 \ mol} - 1.5 \times 10^4 \ kJ$$

This topic begins with a detour into Physics. We start with the question: What is light? Light is an electromagnetic wave. In Chemistry, we don't care about about light's electric and magnetic properties, but we do discuss wave behavior.

A wave is an OSCILLATION (a vibration) that TRAVELS forward and carries ENERGY with it. Light travels at a known CONSTANT SPEED OF LIGHT:

The FREQUENCY is the number of vibrations per second. The abbreviation is the Greek letter, lower case nu - ; the unit is called Hertz - Hz. Since a wave travels and vibrates at the same time, the WAVELENGTH is the distance the wave travels during one oscillation. The abbreviation is the Greek letter, lower case lambda - , measured in meters.

Since these three thing refer to one wave, the speed of light, the frequency and the wavelength must be related. The wave equation is:

(Be careful, if you search for "wave equation" on the interweb, you will discover a much more complex version of the wave equation, which we don't care about.)

Some vocabulary: the VALENCE SHELL is the last or outermost shell; VALENCE ELECTRONS are the electrons in the valence shell; INNER CORE are the shells closer to the nucleus than the valence shell; PARAMAGNETIC means at least one electron is not paired off up spin/ down down in the orbitals, DIAMAGNETIC means all the electrons are paired off up spin/ down down in the orbitals.

Problem 1: The top radio station in New York is usually the sports talk station WFAN. It broadcasts at a frequency of 660 kHz. What are the wavelength and energy per photon of the station? Since WFAN broadcasts with a power of 50,000 Joules per second, how many photons does the station transmitter produce every second?

Problem 2: What is the wavelength of light (in nanometers) emitted when an electron transitions fr7 ((in) -54.8h()n = 5tr ((in) uong-0.2 (hen a) -0.2 (r ((in)) 0.2 (i)] TJET Q EMC

Solution 1: The top radio station in New York is usually the sports talk station WFAN. It broadcasts at a frequency of 660 kHz. What are the wavelength and energy per photon of the station? Since WFAN broadcasts with a power of 50,000 Joules per second, how many photons does the station transmitter produce every second?

given:  $\nu = 660 \text{ kHz} = 660 \times 10^3 \text{ Hz}$ , c  $2.998 \times 10^8 \text{ m/s}$ , h  $6.626 \times 10^{-34} \text{ J s}$ power = 50,000 J/ s

$$C = \lambda \nu$$
  

$$\lambda = \frac{C}{\nu}$$
  

$$E = h \nu$$
  

$$= \frac{2.998 \times 10^8 \text{ m/s}}{660 \times 10^3 \text{ Hz}}$$
  

$$k = 4.37 \times 10^{-28} \text{ J/photon}$$
  

$$E = 4.37 \times 10^{-28} \text{ J/photon}$$

$$\frac{50,000 \ J}{s} \times \frac{photon}{4.37 \times 10^{-28} \ J} = 1.14 \times 10^{32} \ photonsls$$

Solution 2: What is the wavelength of light (in nanometers) emitted when an electron transitions from n = 5 to n = 3 in a hydrogen atom?

given:  $n_i = 5$ ,  $n_f = 3!$ unknown:  $\lambda = ?$  in nanometers.

$$E = -R_{H} \left( \frac{1}{n_{f}^{2}} - \frac{1}{n_{f}^{2}} \right)$$
$$= -2.179 \times 10^{-18} J \left( \frac{1}{3^{2}} - \frac{1}{5^{2}} \right)$$
$$= -2.179 \times 10$$

Solution 3: Of the following electron configurations:

1)			
2)			
3)			
4)			

(5)

which is the ground-state configuration for an element (a) in Group 2A, (b) in Period 3, (c) th

(d) single-electron paramagnetic = (5)

(e) excited state = (2)

Solution 4: What is the electron configuration of the iron (III) ion?

This is the iron atom configuration:

Since, iron is a transition metal, the 3d electrons are not valence. The iron (III) ion loses

In addition, the IE to "reach into" the inner core is always much, much higher than the IE to remove from valence.

Francium has the lowest IE. Helium (or fluorine) has the highest IE. In comparing elements: moving from left to right across a Period, IR increases, and moving from top to bottom of a Group, IR decreases. Elements closer to francium have lower IE, and elements closer to helium have higher IE.

• ELECTRON AFFINITY (EA) - the energy (per mole) gained when an electron is added to an atom - producing a -1 anion.

Francium has the lowest EA. Fluorine has the highest EA. In comparing elements: moving from left to right across a Period, EA increases, and moving from top to bottom of a Group, EA decreases. Elements closer to francium have lower EA, and elements closer to fluorine have higher EA. The EA trend has important exceptions.

• ELECTRONEGATIVITY (e.n.) - a number on a scale of zero (0) to four (4) that measures how strongly an atom attracts electrons to itself when it forms chemical bonds

Francium has the lowest e.n.. Fluorine has the highest e.n., with a perfect 4.0. In comparing elements: moving from left to right across a Period, e.n. increases, and moving from top to bottom of a Group, e.n. decreases. Elements closer to franciumcosElem

- Problem 1: Arrange the following atoms in order of increasing atomic radius: ! AI, Na, Si, Ar, P
- Problem 2: Arrange the following atoms in order of decreasing first ionization energy: ! Te, Se, O, S, Po
- Problem 3: Arrange the following atoms in order of increasing second ionization energy: ! Na, Mg, Al
- Problem 4: Arrange the following species in order of decreasing radius: ! S, S<sup>+</sup>, S<sup>2+</sup>, S<sup>-</sup>, S<sup>2-</sup>
- Problem 5: Arrange the following ions in order of increasing ionic radius: !  $$\rm Ca^{2+}$$

# Solution 1: Arrange the following atoms in order of increasing atomic radius: ! AI, Na, Si, Ar, P

Solution 5: Arrange the following ions in order of increasing ionic radius: ! Ca^{2+}, Mg^{2+}, Ba^{2+}, Be^{2+}

increasing order means smallest IR first and largest IR last. Since these ions have the same charge, and are all in the same Group, only the Period matters - radius increases moving down a Group:

 $Be^{2+} < Mg^{2+} < Ca^{2+} < Ba^{2+}$ 

Lewis (electron dot) diagrams/ structures are pictures that Chemists draw of a molecule to show the bonding between the atoms. It is most useful for covalent bonding - the diagram for ionic compounds is usually considered trivial (too simple to worry about).

Covalent bonding is a sharing of electrons. One atom contributes one electron, another atom contributes another electron, and the two electrons end up being shared between the two atoms. It is usually possible to draw the diagrams for two atoms and immediately see how single (unpaired) electrons for each atom would pair off to form the bond, and redraw the molecule.

However, it is usually faster to draw the molecule, without drawing the atoms. I recommend a five-step procedure:

As stated before: covalent bonding is a sharing of electrons. However, the sharing does not have to be fair or equal. If the sharing is equal, it is called a NONPOLAR COVALENT BOND. If the sharing is unequal, it is called a POLAR COVALENT BOND. Chemists use the word "polar" to say that one side of an unequal bond is slightly negative ( –) in charge. It is the negative pole (because the negative electrons are more on that side). The other side is slightly positive ( +) in charge. It is the positive pole (because the negative electrons are more on that side). The other side is slightly positive ( +) in charge. It is the positive pole (because the negative electrons are more on that side). The other side is slightly positive ( +) in charge. It is the positive pole (because the negative electrons are less on that side). – and + is called DELTA NOTATION - is the Greek lower-case letter delta. An arrow is often drawn pointing toward the negative pole.

The simplest way to determine whether a bond is polar or nonpolar covalent bond, is to compare the ELECTRONEGATIVITY of the two atoms. Electronegativity is a number from zero (0) to four (4), that measures how strongly an atom attracts electrons to itself when it bonds. A nonpolar covalent bond has a very small electronegativity difference; while a polar covalent bond has a large electronegativity difference. (Ionic bonds have a very large electronegativity difference.)

Check with your professor, but a 0.0 to 0.4 e.n. difference should indicate a nonpolar covalent bond. A 0.5 to 1.8 e.n. difference indicates a polar covalent bond. A 1.9 or greater difference indicates an ionic bond. Remember, the diatomic elements must have a nonpolar covalent bond, because the atoms are identical.

Remember also that electronegativity is a periodic property; there is a Periodic Table pattern to electronegativity. The electronegativity increases toward the top, right corner of the Table, and electronegativity decreases toward the bottom, left corner of the Table. Therefore, atoms closer to each other on the Table are less polar, while atoms further apart on the Table are more polar.

You are not expected to memorize exact electronegativity numbers; except that fluorine (F) is the highest, with a perfect 4.0. Oxygen (O) is second highest. The periodic property trend is often enough.

One interesting application of Lewis diagrams is the use of bond energy to estimate the enthalpy change of a chemical reaction. The "strength" of a chemical bond can be measured by the amount of energy required to "break" the chemical bond (completely separate the atoms). Since a chemical reaction requires breaking chemical bonds in the

reactants and the formation of new bonds in the products, the bond energy (BE) difference is equivalent to the enthalpy change.

 $H_{r_{XR}}^{\circ}$   $n_r BE$  (reactants) –  $n_p BE$  (products)

Notice: this formula is similar to the enthalpy of formation formula, except this is reactants subtract products.

Bond energies have been measured and published in tables. But, a table is useless if you don't know what bonds to look up. You need to draw Lewis diagrams of all the chemicals in the reaction to identify the bonds.

Chapter 8 and Chapter 9 problems are grouped together.

See attached table.

The Lewis diagram is extremely useful in Chemistry. They are a 99% accurate practical representation of the bonding in a molecule - impressive, since they're just simple dotsand-dashes pencil-and-paper drawings. This knowledge can be extended to determine many other properties of a molecule - including VSEPR geometry, the 3-dimensional shape of a molecule. We do not expect you to draw the 3-D geometry, because we do not expect you to be an artist. Instead, we want you to remember the shape name. Remember, the Lewis diagram is not an accurate representation of the molecular 3-D Problem 1: Using these electronegativity values: P = 2.1, As = 2.0, CI = 3.0, Br = 2.8, ! arrange the following bonds in order of increasing polarity:

Problem 2: Using these electronegativity values: C = 2.5, N = 3.0, O = 3.5, F = 4.0, ! arrange the following bonds in order of decreasing polarity:

Problem 3: Use an arrow and delta notation to indicate the polarity of the following bonds: (a) C—N, (b) O—S, (c) CI—Si, (d) Br—F. Hint: the arrow points toward the negative pole.

Problem 4: Draw Lewis structures for the following species that obey the octet rule. State their VSEPR geometry name. What is the center atom's hybridization? Is the species polar or nonpolar?

- (a)  $CH_4$
- (b) NH<sub>3</sub>
- (c) OF<sub>2</sub>
- (d)  $BF_4^-$
- (e)  $CH_3CI$
- (f) HF
- (g)  $PCI_3$
- (h)  $PCI_2^-$
- (i)  $H_2CO$
- (j) HCN
- (k) HOCI
- (I) CO<sub>2</sub>

- (m) CO
- (n)  $C_2H_4$
- (o)  $CH_3OH$
- (p) CH<sub>3</sub>CHO

Problem 5: Draw two resonance Lewis structures for the nitrite ion,  $NO_2^-$ :

Problem 6: Draw Lewis structures for the following species that have incomplete octets. State their VSEPR geometry name. What is the center atom's hybridization? Is the species polar or nonpolar?

- (a) AICI<sub>3</sub>
- (b)  $GeCl_2$

Problem 7: Draw Lewis structures for the following species that have expanded octets. State their VSEPR geometry name. What is the center atom's hybridization? Is the species polar or nonpolar?

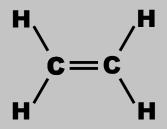
- (a)  $PCI_5$
- (b)  $POCI_3$
- (c)  $SO_2F_2$
- (d) SF<sub>4</sub>
- (e)  $ICI_5$
- (f)  $SO_4^{2-}$
- (g)  $XeF_2$

Problem 8: Draw three resonance Lewis structures for the cyanate ion OCN<sup>-</sup> (carbon is the center atom). Compute each atom's formal charge for the three diagrams. Which structure is the most stable?

(d) has 32 valence electrons

(g) has 26 valence electrons

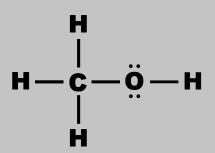
(n) C<sub>2</sub>H<sub>4</sub> has 12 valence electrons



Both C have 3 bond + 0 lone = 3 total domains.

VSEPR is trigonal planar (for both C), sp<sup>2</sup> hybridization (for both C), nonpolar molecule (in whole).

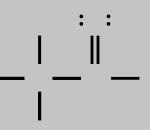
(o) CH<sub>3</sub>OH has 14 valence electrons



The C has 4 bond + 0 lone = 4 total domains. The O has 2 bond + 2 lone = 4 total domains.

VSEPR is tetrahedral (for C) and bent at less than 109.5° (for O), sp<sup>3</sup> (for C) and sp<sup>3</sup> (for O) hybridization, polar molecule (in whole).

(p) CH<sub>3</sub>CHO has 18 valence electrons



The left C has 4 bond + 0 lone = 4 total domains. The right C has 3 bond + 0 lone = 3 total domains.

VSEPR is tetrahedral (for left C) and trigonal planar (for right C), sp<sup>3</sup> (for left C) and sp<sup>2</sup> (for right C) hybridization, polar molecule (in whole).

:

Solution 5: Draw two resonance Lewis structures for the nitrite ion,

has 18 valence electrons

Solution 6: Draw Lewis structures for the following species that have incomplete octets. State their VSEPR geometry name. What is the center atom's hybridization? Is the species polar or nonpolar?

(a)

(a)  $PCI_5$  has 40 valence electrons



The P has 5 bond + 0 lone = 5 total domains.

VSEPR is trigonal bipyramidal, sp<sup>3</sup>d hybridization, nonpolar molecule.

(b) has 32 valence electrons

The P has 4 bond + 0 lone = 4 total domains.

VSEPR is tetrahedral, sp<sup>3</sup> hybridization, polar molecule.

(c) has 32 valence electrons

The Shas 4 bond + 0 lone = 4 total domains.

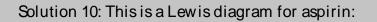
VSEPR is tetrahedral, sp<sup>3</sup> hybridization, nonpolar molecule.

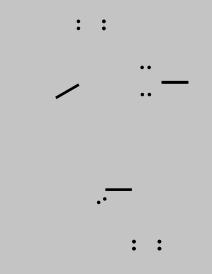
(d) has 34 valence electrons

The Shas 4 bond + 1 lone = 5 total domains.

VSEPR is seesaw, sp<sup>3</sup>

(g)





How many sigma () and pi () bonds does this molecule have?

I

There are twenty-one (21) sigma () bonds and five (5) pi () bonds.

Recall: a gas has neither a definite volume nor shape, while solids have definite volume and shape, and liquids has a definite volume, but no definite shape. What holds solids and liquids into their shapes or volumes?

Solids and liquids have INTERMOLECULAR FORCES. (Intermolecular means between one molecule (or atom) and other molecules (or atoms. Intramolecular means inside a molecule - chemical bonds.) We will not worry much about the electrical Physics of the forces. We want to recognize the kinds of intermolecular forces in different chemicals.

• nonpolar molecules (or monatomic elements) have London DISPERSION FORCES only. Dispersion forces are very weak, and these chemicals are expected to be gases (have low melting and boiling points, and high vapor pressure) under normal conditions, unless the molar mass is high. Recall: calorimetry says that when heat is added to a solid, its temperature will increase.

However, the temperature will not increase forever - at some point the solid will melt at a fixed melting point temperature. The HEAT OF FUSION ( ) accounts for the "loosening" of the atoms/ molecules in the solid-to-liquid PHASE CHANGE.

After the solid completely liquifies, the temperature of the liquid will increase again if heat continues to be added, but once again, the temperature increase will not continue forever. At some point, the temperature will plateau at a fixed boiling point as the liquid vaporizes (boils), before the temperature increase can continue. The HEAT OF VAPORIZATION ( ) accounts for the "separation" of the atoms/ molecules in the liquid-to-gas phase change.

A HEATING CURVE is the five-step graph of heat added (x-axis) versus temperature change (y-axis) showing the five-step solid/ melt/ liquid/ boil/ gas process. Note, the process is reversible - removing heat reverses the process - a cooling curve.

When Chemists say that the freezing point of water is 0 °C and the boiling point is 100 °C, this is only correct at a pressure of 1 atm. The freezing and boiling points of chemicals changes - sometimes a lot - at different external pressures.

The PHASE DIAGRAM plots temperature (x-axis) versus pressure (y-axis), showing the freezing and boiling points of chemicals at different pressures. It shows a "Y" shape, that separates the solid, liquid and gas phases into different zones. Be aware: some substances have much more complex phase diagrams because of their allotropes.

The phase diagram also shows the triple point - the one pressure and temperature, where solid, liquid and gas coexist in equilibrium. You have probably never seen this, because the triple point of most substances is at such a low pressure, you would be unable to breathe - you'd be long since dead.

Remember: solid to liquid is melting;! liquid to solid is freezing;! liquid to gas is boiling;! gas to liquid is condensing

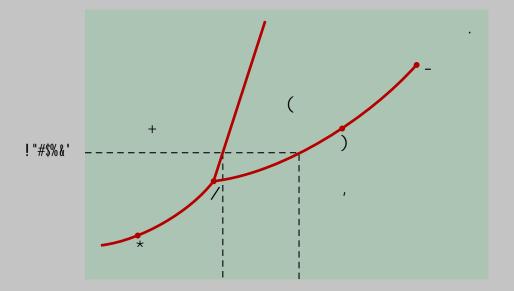
Special note: it is possible for a solid to directly change into a gas, without ever passing through the liquid phase. This is called SUBLIMATION. You may have never seen this either, because sublimation occurs at a very low temperature and pressure for most common substances. The only sublimation that most non-Chemists have ever seen is "dry ice". Solid carbon dioxide will sublimate to gas at normal conditions, which is why it's called "dry" - there's never any liquid. Also: gas directly to solid is called deposition.

Problem 1: Which of the following pair of substances, has the given property. Explain your answer.

- (a) higher boiling point: HBr, or Kr.
- (b) higher freezing point: H<sub>2</sub>O, or NaCl.
- (c) lower vapor pressure at  $258^{\circ}$ C: Cl<sub>2</sub>, or l<sub>2</sub>.
- (d) lowest melting point: CO, or CO<sub>2</sub>.

Problem 2: What mass of water ice originally at -20°C can be heated to hot liquid water at 90°C by the burning of one gallon (3785 mL) of gasoline (isooctane  $C_8H_{18(/)}$ )? The density of gasoline is 0.740 g/ mL and the enthalpy of combustion of gasoline is -5461 kJ mol. The heat of fusion of H<sub>2</sub>O is 333 J g, the specific heat of solid H<sub>2</sub>O is 2.10 J g  $\cdot$  °C and the specific heat of liquid H<sub>2</sub>O is 4.18 J g  $\cdot$  °C.

Problem 3: In this phase diagram:



Which letter indicates (a) the solid region, (b) the liquid region, (c) the gas region, (d) the triple point, and (e) a sublimation? Some of the letters are not correct answers.

Solution 1: Which of the following pair of substances, has the given property. Explain your answer.

(a) higher boiling point: HBr, or Kr.

HBr has the higher boiling point. HBr is a polar compound, with dipole-dipole forces (plus dispersion forces), stronger than Kr, a nonpolar noble gas with only dispersion forces.

(b) higher freezing point: H<sub>2</sub>O, or NaCl.

NaCl has the higher freezing point. H<sub>2</sub>O is a very polar molecule with has hydrogen bonding (plus dispersion forces), but NaCl is an ionic compound that has stronger ionic forces.

(c) lower vapor pressure at  $258^{\circ}$ C: Cl<sub>2</sub>, or l<sub>2</sub>.

 $I_2$  has the lower vapor pressure.  $CI_2$ , or  $I_2$  are both diatomic halogen elements, both are nonpolar, but  $I_2$  has the larger molar mass.

(d) lowest melting point: CO, or  $CO_2$ .

CO<sub>2</sub> has the lower melting point. CO is a polar molecule with dipole-dipole forces (plus dispersion forces), while CO<sub>2</sub> is a nonpolar molecule with weak dispersion forces only.

Solution 2: What mass of water ice originally at -20.°C can be heated to hot liquid water at 90.°C by the burning of one gallon (3785 mL) of gasoline (isooctane  $C_8H_{18(/)}$ )? The density of gasoline is 0.740 g/ mL and the enthalpy of combustion of gasoline is -5461 kJ mol. The heat of fusion of H<sub>2</sub>O is 333 J g, the specific heat of solid H<sub>2</sub>O is 2.10 J g  $\cdot$  °C and the specific heat of liquid H<sub>2</sub>O is 4.18 J g  $\cdot$  °C.

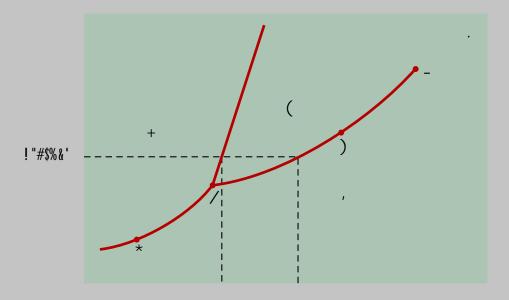
given: the gasoline is the system and the water is the surroundings, that obey conservation of energy - heat transfers from the gasoline to the water.

 $V_{gas} = 3785 \ mL, \ d_{gas} = 0.740 \ g/mL, \ H_{gas} = -5461 \ kJ/mol, = 114.2 \ g/mol$  $s_{ice} = 2.10 \ J/g \ C, \ T_{i \ ice} = -20.^{\circ}C,$ 

unknown:

Note: the combustion reaction is not important, because this is not stoichiometry.

Solution 3: In this phase diagram:



Which letter indicates (a) the solid region, (b) the liquid region, (c) the gas region, (d) the triple point, and (e) a sublimation? Some of the letters are not correct answers.

- a) the solid region = B
- (b) the liquid region = D
- (c) gas region = F
- (d) the triple point = C
- (e) a sublimation = A"

Recall: A solute is dissolved into a solvent to make a solution. However, not every solute will dissolve into any solvent.

A easy-to-use rule on what solutes and solvents are MISCIBLE (mixable) and IMMISCIBLE (not mixable) is "Like dissolves like." Usually, two polar chemicals OR two nonpolar chemicals will mix together to make a solution, but if one is polar and one is nonpolar, they will not make a solution. The saying "Oil and water don't mix" is true, chemistry-wise, because, oil molecules are nonpolar hydrocarbons, while water is highly polar.

Also recall: the concentration of the solute in a solution is measured by Molarity, defined:

$$Molarity = \frac{moles \ solute}{Liters \ solution}$$
$$M = \frac{mol}{l}$$

However, just like any other measurement, there are other ways to measure the concentration of a solution. We have already mentioned mole fraction, introduced for gas mixtures. Percent of solute in solution is commonly used in medicine.

We now introduce molality:

$$molality = \frac{moles \ solute}{kilograms \ solvent}$$
$$m = \frac{mol}{kg}$$

Be careful, "m" abbreviates for molality, not mass in this topic.

A solution of any solute in a liquid solvent has properties related to, but the same as, the solvent by itself. These COLLIGATIVE PROPERTIES of solutions include boiling point elevation (BPE), freezing point depression (FPD), vapor pressure depression (VPD), and osmotic pressure.

Problem 1: The concentration of industrial grade hydrochloric acid (sometimes called muriatic acid) is 12.4 M, with a density of 1.18 g/mL. What is the molality of this solution?

Problem 2: Calcium chloride is the chemical in "sno-melt." It is more effective than the cheaper rock salt because its van't Hoff factor is higher. What would be the freezing point of the electrolytic solution prepared by dissolving 125 g of calcium chloride in 500. mL of water? The freezing point constant of water is 1.86 °C kg/mol.

Problem 3: A 1.07 mg sample of a nonelectrolyte compound is dissolved in 78.1 mg of camphor. The resulting solution melts at 176.0 °C. What is the molecular weight of the compound? The freezing point of pure camphor is 179.5 °C and its freezing point constant is 40. °C kg/ mol.

Solution 1: The concentration of industrial grade hydrochloric acid (sometimes called muriatic acid) is 12.4 M, with a density of 1.18 g/mL. What is the molality of this solution?

solute = 12.4 mol HCI, ! = 36.46 g/molgiven is: + solvent = water= solution = 1 L, d = 1.18 g/mL

unknown is: solution molality (m = ?)

$$d = \frac{IIIASS}{V}$$

$$mass = d V$$

$$= \frac{1.18 g}{mL} \times \frac{1000 mL}{L} 1 L$$

$$mass = 1180 g \times \frac{kg}{1000 g}$$

$$mass = 1.18 kg \text{ solution}$$

12.4 *mol* HCI 
$$\times \frac{35.46 \text{ g HCI}}{1 \text{ mol HCI}}$$

Solution 2: Calcium chloride is the chemical in "sno-melt." Is is more effective than the cheaper rock salt because its van't Hoff factor is higher. What would be the freezing point of the electrolytic solution prepared by dissolving 125 g of calcium chloride in 500. mL of water? The freezing point constant of water is 1.86 °C kg/ mol.

$$solute = 125 \ g \ CaCl_2, ! = 110.98 \ g/mol \\ + \ solvent = 500. \ mL \ water \ ( = 500. \ g = 0.500 \ kg, since \ d = 1 \ g/mL) \\ K_f = 1.86^{\circ}C \ kg/mol, \ T_f = 0^{\circ}C$$

= solution

unknown is solution freezing point ( $T_f = ?$ )

The problem is done in three steps:

step 1: convert to moles

125 
$$g \operatorname{CaCl}_2 \times \frac{1 \text{ mol CaCl}_2}{110.98 \text{ } g \operatorname{CaCl}_2} = 1.126 \text{ mol CaCl}_2$$

step 2: calculate molality

$$m = \frac{mol}{kg}$$
$$m = \frac{1.126 \ mol \ CaCl_2}{0.500 \ kg}$$
$$m = \frac{2.252 \ mol \ CaCl_2/kg}{0.500 \ kg}$$

step 3: find temperature depression

$$CaCl_{2(s)} \qquad Ca_{(aq)}^{2+} + 2 Cl_{(aq)}^{-}$$
$$i = 3$$