Chapter 7 Goals

Major Goals of Chapter 7:

1 Counting - by numbers, by weighing and by volume.

2. Summing atomic masses for elements in correctly written chemical formulas.

3. Recognizing the difference between a formula mass (amu) & atomic mass (g/mol)

4. Converting grams to moles & Converting moles to grams.

5. Calculating percentage composition need in determining an empirical formula.

Before viewing, read the Chapter 7 Review:

7.1 Atomic Mass and Formula Mass

7.2 The Mole

7.3 Molar Mass

7.4. Calculations Using Molar Mass

7.5 Percent Composition and Empirical Formulas

7.6 Molecular Formulas

Chapter 7 summary

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COUNTING

Physical Methods
for counting amounts

by numbers

1 pr = 2
1 doz = 12
1 case = 12 or 24
1 hand = 5 fingers
1 foot = 12 inches

by weighing

1 gummy bear = 1 gram
1 penny = 1 gram
1 proton = 1 amu
1 neutron = 1 amu
1 hydrogen-1 atom = 1 amu
1 carbon-12 atom = 12 amu

by volume

1 mole any gas = 22.4 L
@ 0°C,1atm

Avogadro's number

1 mole anything = $6.02\text{x}10^{+23}$ anything

1 mole carbon-12 = 12 grams carbon-12 exactly
($6.02\text{x}10^{+23}$) ($6.02\text{x}10^{+23}$)

numbers to amounts
by weighing

molar masses
defined

Chemical Methods
for counting amounts

by balanced reaction

$$2\ H_2O \longrightarrow 2\ H_2 + 1\ O_2$$

2 molecule | 2 molecules | 1 molecule

multiply through by A number

2 x A number | 2 x A number | 1 x A number

A number equals Avogadro's #

2 x $6.02\text{x}10^{+23}$ | 2 x $6.02\text{x}10^{+23}$ | 1 x $6.02\text{x}10^{+23}$

Avogadro's # equals 1 mole

2 x 1 mole | 2 x 1 mole | 1 x 1 mole

count by weighing

2 x 18 grams H_2O per 1 mole H_2O | 2 x 2 grams H_2 per 1 mole H_2 | 1 x 32 grams O_2 per 1 mole O_2

the eletrolysis of 36 grams of water will produce

4 grams of hydrogen and 32 grams oxygen

COUNTING

In chemistry there are two general methods to count particles:

A. Physical Methods for counting amounts

- by numbers
- by weighing
- by volume

Chapter 7 deals with the physical measuring of amounts

• mole, and the mole mass ratio.

B. Chemical Methods for counting amounts

- by a balanced reaction

Chapter 8 deals with the chemical measuring of amounts

• balancing a chemical reaction

Section 7.2 - The Mole (amounts)

COUNTING

Physical Methods for counting amounts

by numbers

1 pr = 2
1 doz = 12
1 case = 12 or 24
1 hand = 5 fingers
1 foot = 12 inches

Avogadro's number

1 mole anything = $6.02x10^{+23}$ anything

Counting by numbers:

- one pair of anything is the same as <u>two</u> of anything.
- one dozen of anything is the same as twelve of anything.
- one case of wine is the same as twelve bottles of wine.
- one case of soda is the same as twenty four cans of soda.
- one hand is the same as five fingers.
- one foot is the same as twelve inches.

The mole is a counting device like those given above:

- one mole of anything is the same as $6.023x10^{+23}$ anything
- one mole of anything equals Avogadro’s number of anything

Section 7.2 - The Mole (amounts)

COUNTING

Physical Methods for counting amounts

by weighing

1 gummy bear	=	1 gram
1 penny	=	1 gram
1 proton	=	1 amu
1 neutron	=	1 amu
1 hydrogen-1 atom	=	1 amu
1 carbon-12 atom	=	12 amu

Counting by weighing using a <u>mass to amount</u> ratio:

- one gummy bear weighs the same as one gram
- one penny weighs the same as one gram
- one proton weighs the same as one amu (atomic mass unit)
- one neutron weighs the same as one amu (atomic mass unit)
- one hydrogen-1 atom weighs the same as one amu (exactly)
- one carbon-12 atom weighs the same as twelve amu (exactly)

An atomic mass unit has a mass of 1.67×10^{-24} grams (rounded)

$$12 \text{ pennies} \times \frac{1 \text{ gram}}{1 \text{ penny}} = 12 \text{ grams}$$

$$12 \text{ amu} \times \frac{1.67\text{x}10^{-24} \text{ grams}}{1 \text{ amu}} = 2.00\text{x}10^{-25} \text{ grams}$$

Section 7.2 - The Mole (amounts)

COUNTING

Physical Methods for counting amounts

by volume

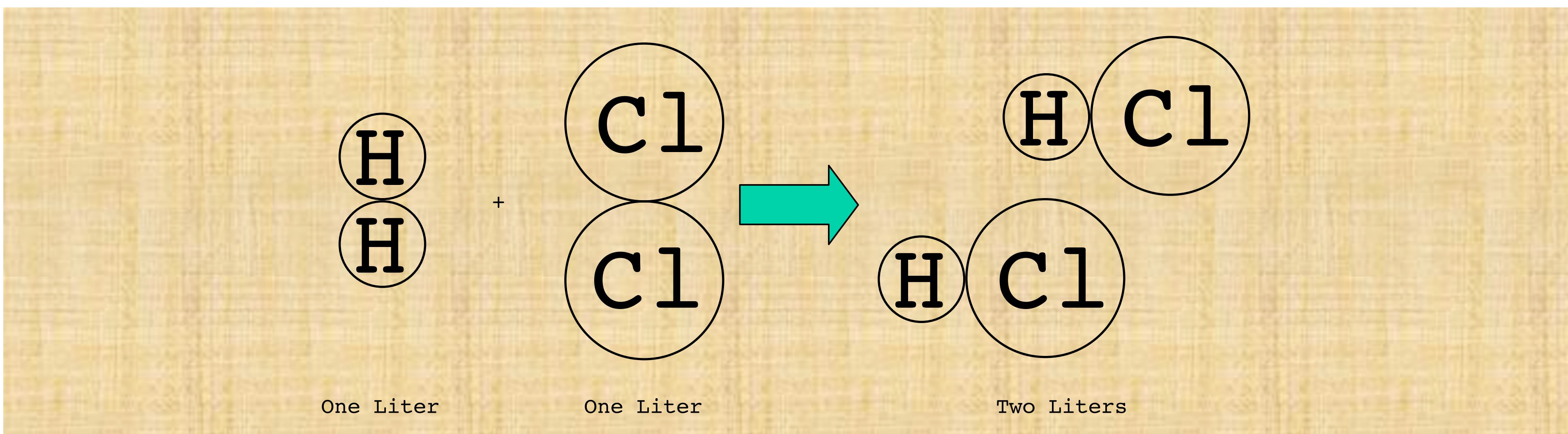
1 mole any gas = 22.4 L @ 0°C,1atm

Counting by volume using a volume to amount ratio:

•one mole of any gas is the same as 22.4 liters @ 0°C and 1 atm.

•1 mole of any gas @0°C and 1 atm contains $6.023 \times 10^{+23}$ particles.

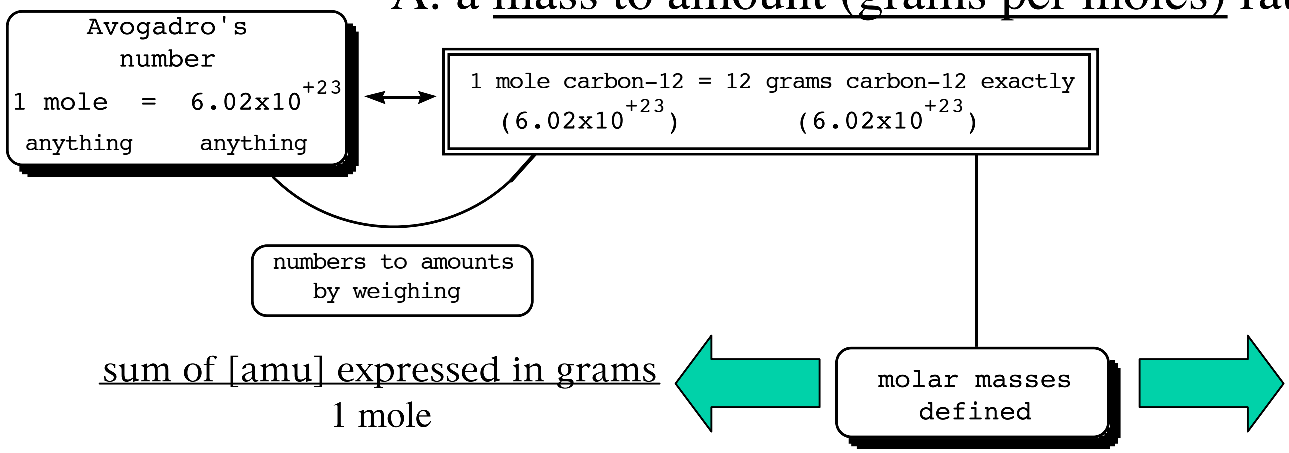
•EQUAL volumes of any gas contain EQUAL amounts of particles.



Section 7.1 - Atomic Mass and Formula Mass (mass to amount ratio)

Counting by weighing using a mass to amount ratio

A. a <u>mass to amount (grams per moles)</u> ratio is called a <u>molar mass</u>



$$\frac{\text{sum of [amu] expressed in grams}}{\text{1 mole}}$$

For HCl, 1 H = 1.007 amu
1Cl = 35.45 amu
1 mole HCl = 36.457 grams

$$12.0 \text{ mole C} \times \frac{12.01 \text{ grams C}}{1 \text{ mole C}} = 144 \text{ grams C}$$

$$12.0 \text{ moles HCl} \times \frac{36.457 \text{ grams HCl}}{1 \text{ mole HCl}} = 437 \text{ grams HCl}$$

molar mass ratio

Section 7.1- Atomic Mass and Formula Mass (mass to amount ratio)

Summary:
Be sure to know that "moles of substance" multiplied by a molar mass ratio equals grams.

$$12.0 \text{ mole C} \times \frac{12.01 \text{ grams C}}{1 \text{ mole C}} = 144 \text{ grams C}$$

grams of substance

$$12.0 \text{ moles HCl} \times \frac{36.457 \text{ grams HCl}}{1 \text{ mole HCl}} = 437 \text{ grams HCl}$$

molar mass ratio

Section 7.2 - The Mole

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I. Counting Devices

A. Familar counting devices for counting physical objects larger than atoms:

1 dozen of __anything____ = __twelve____ units of anything

A basket has 18 eggs. How many dozen eggs are contained in the basket?

$$18 \text{ eggs} \times \frac{1 \text{ dozen eggs}}{12 \text{ eggs}} = 1.5 \text{ dozen eggs}$$

B. In chemistry, our counting device is the mole:

1 mole of __anything____ = __6.023×10^{23}____ units of anything

1 mole of __Gummy bears____ = __6.023×10^{23}____ __Gummy bears____

1 mole of __atoms____ = __6.023×10^{23}____ __atoms____

1 mole of __pennies____ = __6.023×10^{23}____ __pennies____

Called Avogadro's Number

Section 7.1 - Atomic Mass and Formula Mass

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C. In chemistry, we can't physically count atoms by inspection, so we like to count the total number of atoms, and molecules by weighing.

- Counting atoms - The mole has been given a precise definition as the number of atoms contained in 12.000000 grams "exactly" of pure carbon-12.

1 mole of $^{12}_{6}C$ = 12.000000 grams of $^{12}_{6}C$ = 6.023 x 10^{23} atoms of $^{12}_{6}C$

- <u>Molar</u> <u>Mass</u> is the mass in grams of one mole of any substance, and is also numerically equal to atomic mass unit [amu] expressed in grams.

1Fex55.85 = 55.85

3Nx14.00 = 42.00

9□=x16.00 = 144.00

241.85

1 mole of carbon = 12.01 grams of carbon

1 mole of iron = 55.85 grams of iron

1 mole of $Fe(NO_3)_3$ = 241.85 grams of iron

D. Molar Mass is numerically equal to atomic mass unit (amu) expressed in grams.

Section 7.4 - Calculations Using Molar Mass

I. How can Avogadro's number be used in calculating the:

A. number of atoms for a given number of **moles** of an pure element?

How many grams is the same as 18 moles of lead, Pb?

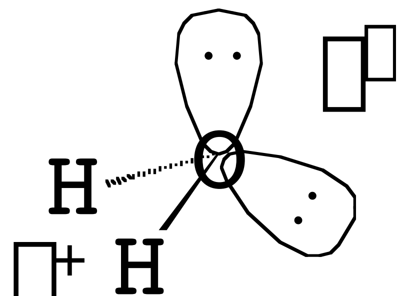
$$\frac{18 \text{ moles Pb}}{} \times \frac{6.023\text{x}10^{23} \text{ atoms}}{1 \text{ mole atoms}} = 1.0841\text{x}10^{25} \text{ atoms Pb}$$

$\boxed{1.1\text{x}10^{25} \text{ (correct Sig Figs)}}$

B. number of molecules for a given number of **moles** of a pure substance?

How many molecules is the same as 18 moles of moles?

$$18 \text{ moles} \times \frac{6.023\text{x}10^{23} \text{ molecules}}{1 \text{ mole molecules}} = 1.1\text{x}10^{25} \text{ molecules}$$



C. number of atoms for a given number of **grams** of a pure substance?

How many atoms is the same as 18 grams of water?

$$18 \text{ grams } H_2O \times \boxed{\frac{1 \text{ mole } H_2O}{18.02 \text{ g } H_2O} \text{ molar mass ratio}} \times \frac{6.023\text{x}10^{23} \text{ molecule}}{1 \text{ mole}} \times \frac{3 \text{ atoms}}{1 \text{ molecule of } H_2O} = 4.8\text{x}10^{24} \text{atoms}$$

D. number of molecules for a given number of **grams** of a pure substance?

$$18.0 \text{ grams } H_2O \times \frac{1 \text{ mole } H_2O}{18.02 \text{ g } H_2O} \times \frac{6.023\text{x}10^{23} \text{ molecules}}{1 \text{ mole}} = 6.02\text{x}10^{23} \text{ molecules } H_2O$$

Supplemental packet page 121 Counting Atoms

How many iron atoms are present in 3.00 moles of iron metal?

1 mol Fe = 55.85 g Fe = 6.02×10^{23} atoms Fe

x atoms Fe = 3.00 mol Fe 1 mol Fe = 6.02×10^{23} atoms Fe

$$x \text{ mol Fe} = 3.00 \text{ mol Fe} \times \frac{6.02 \times 10^{23} \text{ atoms Fe}}{1 \text{ mol Fe}} = 1.81 \times 10^{24} \text{ atoms Fe}$$

Work out the following problems (show math set-ups)

x atoms S = 0.174 mol S

$$0.174 \text{ mol S} \times \frac{6.02 \times 10^{23} \text{ atoms S}}{1 \text{ mol S}} =$$

<u>How many sulfur atoms</u> are present in 0.174 moles of S nonmetal?

ANS: 1.05×10^{23} mol S

x mol K = 5.92×10^{24} atoms K

$$5.92 \times 10^{24} \text{ atoms K} \times \frac{1 \text{ mol K}}{6.02 \times 10^{23} \text{ atoms K}} =$$

<u>How many moles of K</u> are present in 5.92 x10^{24} atoms of K metal?

ANS: 9.83 atoms K

Let's go over this example together

x atoms C = 27.4 g C

<u>How many atoms of C</u> are present in 27.4 grams of

$12.01 \text{ g C} = 6.02 \times 10^{23} \text{ atoms C}$

Combined we have a grams to particles equivalent statement

$$27.4 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} \times \frac{6.02 \times 10^{23} \text{ atoms C}}{1 \text{ mol C}} = 1.37 \times 10^{24} \text{ atoms C}$$

(grams) x (mol per grams) Avogradro's number

$$\text{moles} \times \frac{6.02 \times 10^{23} \text{ atoms}}{1 \text{ mole}}$$

How many atoms are present in a formula unit of sodium sulfate Na_2SO_4?

Just as a mole of atoms is based on the atomic mass or atomic weight, a mole of a compound is based upon the formula mass or formula weight.

sodium sulfate, Na_2SO_4	
First:	How many atoms are there present per formula unit of Na_2SO_4? 7 atoms
Second:	What is the mass in amu of one molecule of sodium sulfate? 142.06 amu
Third:	What is the mass—in grams—of one mole of sodium sulfate? 142.06 g
Fourth:	How many moles of Na_2SO_4 are in 16.0 g Na_2SO_4? 1.13×10^{-1} mol

Na_2SO_4

2 Na
1 S
4 O
7 atoms

2 Na x 22.99 = 45.98
1 S x 32.07 = 32.07
4 O x 16.00 = 64.00
142.06 g Na_2SO_4

$$\mathbf{x} \text{ mol } Na_2SO_4 = 16.0 \text{ g } Na_2SO_4 \times \frac{1 \text{ mol } Na_2SO_4}{142.06 \text{ g } Na_2SO_4} = 1.13 \times 10^{-1} \text{ mol } Na_2SO_4$$

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Molar Mass Calculations; one mole amount of a substance in grams

CH_4 1 C x 12.0 = 12.0 4 H x 1.0 = 4.0 ANS: 16.0	$CuSO_4 \bullet 5H_2O$ This is called a pentahydrate 1 Cu x 63.6 = 63.6 1 S x 32.0 = 32.0 4 O x 16.0 = 64.0 5 H_2O x 18.0 = 90.0 ANS: 249.6
$C_3H_5Br_2$ 3 C x 12.0 = 36.0 5 H x 1.0 = 5.0 2 Br x 78.9 = 157.8 ANS: 200.9	aluminum nitrate $Al(NO_3)_3$ 1Al x 27.0 = 27.0 3 N x 14.0 = 42.0 9 0 x 16.0 = 144.0 Note you must be able to derive correct formulas from names ANS: 213.0
C_3H_7OH 3 C x 12.0 = 36.0 8 H x 1.0 = 8.0 1 O x 16.0 = 16.0 ANS: 60.0	calcium dihydrogen phosphate $Ca(H_2PO_4)_2$ 1 Ca x 40.1 = 40.1 4 H x 1.0 = 4.0 2 P x 31.0 = 62.0 8 O x 16.0 = 128.0 ANS: 234.1

Supplemental page 123 Grams to Moles and Moles to Grams

How many moles are there in 41.7 g of $NaNO_3$?

1. In every calculuation problem ALWAYS Calculate molar mass; MAKE a Table and Do it

1 mol $NaNO_3$ = 85.0 g $NaNO_3$

1 Na x 23.0	=	23.0
1 N x 14.0	=	14.0
3 O x 16.0	=	48.0
molar mass		85.0 g/mol

2. Then, the grams to moles conversion set-up

$$x \text{ moles} = 41.7 \text{ g } NaNO_3 \times \frac{1 \text{ mol } NaNO_3}{85.0 \text{ g } NaNO_3} = 0.491 \text{ mol } NaNO_3$$

$$\frac{\text{(grams)}}{\text{(molar mass; g/mol)}}$$

moles

Quickly convert to moles by dividing grams by molar mass

Memorize this!!!!

Calculate the number of moles in :

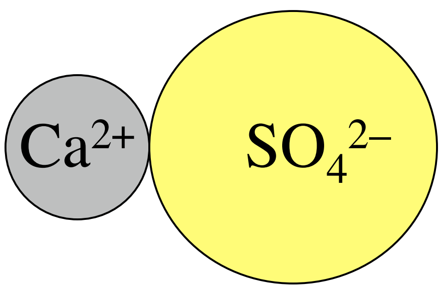
12.6 grams calcium sulfate	6.18×10^3 grams ammonium carbonate
$CaSO_4$	$(NH_4)_2CO_3$
1 Ca x 40.1 = 40.1 1 S x 32.1 = 32.1 4 O x 16.0 = 64.0	1 C x 12.0 = 12.0 2 N x 14.0 = 28.0 8 H x 1.0 = 8.0 48.0 96.0
ANS: 9.25×10^{-2} mol $CaSO_4$	ANS: 64.4mol $(NH_4)_2CO_3$

How many moles of ... **salt?**

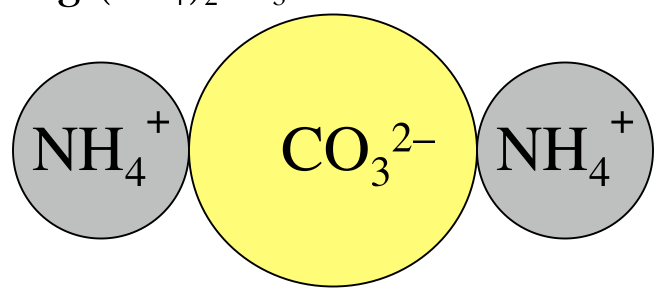
Most students fail in the second half of the semester because they cannot correctly calculate a molar mass

MAKE at TABLE when calculating molar mass

$$6.18 \times 10^3 \text{ g } (NH_4)_2CO_3 \times \frac{1 \text{ mol } (NH_4)_2CO_3}{96.01 \text{ g } (NH_4)_2CO_3} =$$



$CaSO_4$



$(NH_4)_2CO_3$

<u>How many moles of calcium sulfate atoms</u> are present in 12.6 grams of calcium sulfate ionic salt?

<u>How many moles of ammonium carbonate</u> are present in 6.18 x 10^3 grams of <u>ammonium carbonate</u> ionic salt?

<u>grams to moles</u>!!!!!!!

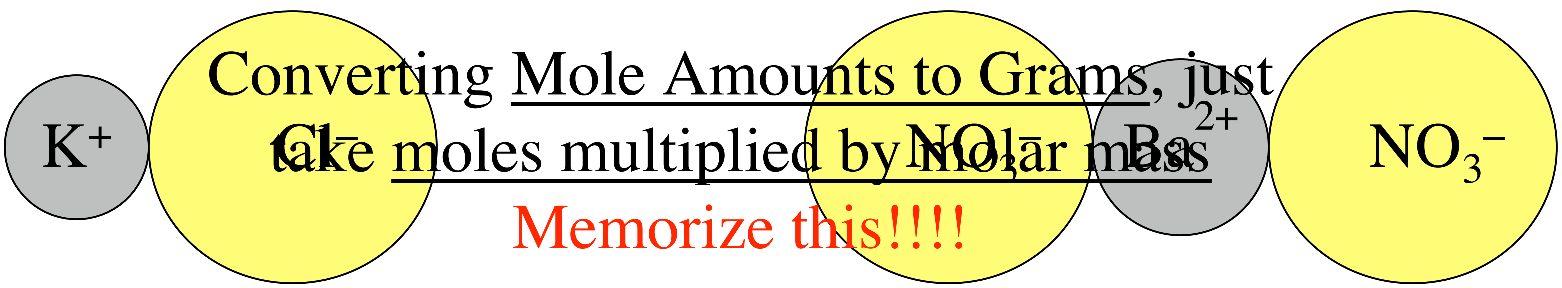
Converting Mole Amounts to Grams

Calculate the number of grams in (show math set-ups):

4.22 moles of KCl	0.0196 moles barium nitrate
KCl: 1 K x 39.1 = 39.1; 1 Cl x 35.5 = 35.5; total 74.6 g/mol	$Ba(NO_3)_2$: 1 Ba x 137.3 = 137.3; 2 N x 14.0 = 28.0; 6 O x 16.0 = 96.0; total 261.3 g/mol
$4.22 \text{ mol KCl} \times \dfrac{74.6 \text{ g KCl}}{1 \text{ mol KCl}} =$	$0.0196 \text{ mol Ba(NO}_3)_2 \times \dfrac{261.3 \text{ g Ba(NO}_3)_2}{1 \text{ mol Ba(NO}_3)_2} =$
ANS: 3.15×10^2 grams KCl	ANS: 5.12 grams $Ba(NO_3)_2$

Converting Mole Amounts to Grams, just take moles multiplied by molar mass

Memorize this!!!!



KCl $Ba(NO_3)_2$

Section 7.5 - Percent Composition and Empirical Formulas

$$\frac{\text{Part}}{\text{Whole}} \times 100\% = \text{percentage composition}$$

What is the percentage of potassium in potassium chloride?

1. Write the correct formula for the substance
2. Calculate the molar mass of the substance (the whole)
3. Divide the individual parts by the whole times 100%

KCl	1 K x 39.1 =	39.1	÷	74.6	=	52.4%
	1 Cl x 35.5 =	35.5	÷	74.6	=	47.6%
		74.6 g/mol				

What is the percentage of barium in barium nitrate?

$Ba(NO_3)_2$	1 Ba x 137.3 =	137.3	÷	261.3	=	52.5%
	2 N x 14.0 =	28.0	÷	261.3	=	10.7%
	6 O x 16.0 =	96.0	÷	261.3	=	36.7%
		261.3 g/mol				

Section 7.5 - Percent Composition and Empirical Formulas

1. Explain the difference between the empirical formula and the molecular formula of a compound.

   An empirical formula is the smallest whole number ratio for a molecular formula. For example, $C_6H_{12}O_6$ would have an empirical formula $C_1H_2O_1$

2. The molecular formula of the gas acetylene is C_2H_2. What is the empirical formula?

   C_2H_2 is divisible by "n ratio factor" of two; thus C_1H_1 is the empirical formula.

$$\text{"n ratio factor"} = \frac{\text{molar mass}}{\text{empirical mass}}$$

$$2 = \frac{C_2H_2}{C_1H_1}$$

3. The empirical formula for a compound used as a green paint pigment is $C_2H_3As_3Cu_2O_8$.
The molar mass is 1013.71 grams. What is the molecular formula?

Solve for the "n ratio factor"

$$\text{"n ratio factor"} = \frac{\text{molar mass}}{\text{empirical mass}}$$

<u>by first</u> calculating the empirical mass

2C x	12.0	=	24.0
3H x	1.0	=	3.0
3As x	74.9	=	224.7
2Cu x	62.9	=	125.6
8O x	16.0	=	128.0
empirical mass			505.3 g/mol

$$\text{"n ratio factor"} = \frac{1013.71\text{ g/mol}}{\text{empirical mass}}$$

<u>then</u>, by dividing molar mass by empirical mass

$$\text{"n ratio factor"} = \frac{1013.71\text{ g/mol}}{505.3\text{ g/mol}} \Rightarrow \text{"n ratio factor"} = 2$$

Continued on the next slide

Section 7.5 - Percent Composition and Empirical Formulas

Continued from the previous slide

Finally, multiply empirical by n

$[C_2H_3As_3Cu_2O_8] \times 2$
empirical formula

$C_4H_6As_6Cu_4O_{16}$
molecular formula 1013.71 g/mol

molecular formula exists as two empirical formulas

Section 7.5 - Percent Composition and Empirical Formulas

4. A sugar which is broken down by the body to produce energy has the following percent composition (C = 39.99 %, H = 6.713 % and O = 53.29 %) and a molar mass of 210.18 g. What is the empirical formula? What is the molecular formula?

Consider the following, if you had a 100 gram sample of this substance, how many grams of it would be carbon, hydrogen and oxygen?

39.99% C x 100 gram sample = 39.99 grams carbon in sample
6.713% H x 100 gram sample = 6.713 grams hydrogen in sample
53.29% O x 100 gram sample = 53.29 grams oxygen in sample

On the next slide, we'll convert grams of sample to moles.

From knowing the number of moles, a mole ratio of atoms in the chemical formula will be calculated.

Section 7.5 - Percent Composition and Empirical Formulas

MAKE A TABLE!!!!!! And convert grams to moles which will be the mole ratio

4. A sugar which is broken down by the body to produce energy has the following percent composition (C = 39.99 %, H = 6.713 % and O = 53.29 %) and a molar mass of 210.18 g. What is the empirical formula? What is the molecular formula?

grams divided by molar mass

Mole ratio of atoms in the substance

analysis	C = 39.99 %	H = 6.713 %	O = 53.29 %
grams assume 100 g sample	39.99 grams	6.713 grams	53.29 grams
MM (molar mass)	12.0 g/mol	1.0 g/mol	16.0 g/mol
mole	3.33 mol	6.71 mol	3.33 mol
ratio / divide by the smallest	$\frac{3.33\text{ mol}}{3.33\text{ mol}}$	$\frac{6.71\text{ mol}}{3.33\text{ mol}}$	$\frac{3.33\text{ mol}}{3.33\text{ mol}}$
whole number ratio	C_1	H_2	O_1

1C to 2H to 1O is a 1 : 2: 1mole ratio of carbon to hydrogen to oxygen in the empirical formula for a substance of 39.99g C, 6.713gH, 53.29 C by mass

Section 7.5 - Percent Composition and Empirical Formulas

To check your work, consider calculating a percentage composition

The empirical formula for the sugar used in the analysis is $C_1H_2O_1$. Calculate a percentage composition of each element in the formula.

1. calculate the empirical mass

			parts							
1C x	12.0	=	12.0	÷ 30.0	=	0.400	x	100 %	=	40.0 %
2H x	1.0	=	2.0	÷ 30.0	=	0.67	x	100 %	=	6.7 %
1O x	16.0	=	16.0	÷ 30.0	=	0.400	x	100 %	=	53.3 %
empirical mass			30.0 g/mol							
			whole							

2. Divide the parts by the whole and times by 100 %

C_1 H_2 O_1

This type of analysis always produces the lowest whole number ratio, thus we have now just calculated the empirical formula

5. Using the empirical formula and molar mass that was given determine the molecular formula for the substance given the molar mass is 210.18 g/mol

The empirical formula for a compound used in the past as $C_1H_2O_1$
The molar mass is 210.18 g/mol . What is the molecular formula?

first, calculate the "n ratio factor"

$$\text{"n ratio factor"} = \frac{\text{molar mass}}{\text{empirical mass}}$$

second, calculate the empirical mass

1C	x	12.0	=	12.0
2H	x	1.0	=	2.0
1O	x	16.0	=	16.0
empirical mass				30.0 g/mol

$$\text{"n ratio factor"} = \frac{\text{210.18 g/mol}}{\text{empirical mass}}$$

third, divide molar mass by empirical mass

$$\text{"n ratio factor"} = \frac{\text{210.18 g/mol}}{\text{30.0 g/mol}} \Rightarrow \text{"n ratio factor"} = 6$$

Continued on the next slide

Section 7.6 - Molecular Formulas

Continued from the previous slide

fourth, multiply empirical formula by the "n ratio factor"

"n ratio factor" = $\frac{210.18 \text{ g/mol}}{30.0 \text{ g/mol}}$

$[C_1H_2O_1]$ x 6
empirical formula

"n ratio factor" = 6
$C_6H_{12}O_6$

molecular formula 210.18 g/mol

The molecular formula is $C_6H_{12}O_6$