Objective 4. Perform mole-mass calculations with compounds and reactions. Determine chemical formula from elemental analysis (% composition). Determine masses of reactants/product from mass of products/reactants in chemical reaction.

Quiz Practice problems:

Key ideas: Measure mass to determine number of atoms or moles (*Counting by weighing*). Molar mass is used as a mass-moles conversion factor. Compounds combine in whole number ratios.

Chemical reactions occur in whole number ratios. Law of conservation of mass - Balance a chemical equation using coefficients. Same number of atoms of each element in reactants and products. Chemical reaction occurs when bonds break and form.

Use mole ratios based on coefficients - know moles of one substance tells you moles of every other substance.

Theoretical yield of product may not be the same as the Actual yield of product. The reactant that completely reacts is the Limiting reactant and limits the amount of products produced. The reactant that does not completely react is the excess reactant.

Skills: Identify mole ratios of elements in a compound.
Balance a chemical equation.
Identify mole ratios of substances in a reaction.
Given molar mass = mass/moles equation, use algebra to solve for mass or moles.
Convert Mass to mole and vice versa using molar mass. Use algebra.
Determine chemical formula of a compound from % composition data.
Given mass of a reactant, calculate theoretical yield of a product.
Calculate % yield of a product from actual yield and theoretical yield.
Give masses of reactants, determine Limiting reactant and excess reactant.

Questions 1-4 are a review of Conversion factors from Objective 1. Identify the conversion factor in each question.

1. Common table salt is NaCl.
a. The molar mass of NaCl is ____.
b. How many g of sodium are in 0.5 mole of NaCl?
c. You measure 1 tablespoon (18 g) of NaCl. How many moles of NaCl are in 1 Tbsp of NaCl? (Answer: between 0.25 and 0.35 moles)
d. You buy 7.7 moles of NaCl. How many lbs (1 lb = 454 g) of NaCl did you buy?
e. ¼ teaspoon of NaCl has a mass of 1.5 g and contains 590 mg of sodium. Confirm this calculation.

Answers:
a. 58.5 g/mole
b. Convert moles NaCl --> moles Na --> g Na
0.5 mole NaCl (1 mole Na/1 mole NaCl) (23 g Na /mole Na) = 0.0217 g Na
Round to 1 significant figure based on 0.5 mole NaCl, which has 1 significant figure ==> 0.02 g Na
c. Convert tablespoon --> g NaCl --> moles NaCl
1 tablespoon NaCl (18 g NaCl/1 tablespoon NaCl)(1 mole NaCl/58.5 g NaCl) = 0.307 moles NaCl
Round to 1 significant figure based on 1 tablespoon NaCl, which has 1 significant figure ==> 30 g Na
d. Convert moles NaCl --> g NaCl --> lb NaCl
7.7 moles of NaCl (58.5 g NaCl/1 mole NaCl) (1 lb/454 g) = 0.992 lbs
Round to 2 significant figures based on 7.7 moles NaCl, which has 2 significant figures ==> 0.99 g NaCl
e. Convert teaspoons NaCl --> g NaCl --> moles NaCl --> moles Na --> g Na --> mg Na
¼ teaspoons NaCl (1.5 g NaCl/¼ teaspoon NaCl)(1 mole NaCl/58.5 g NaCl)(1 mole Na/1 mole NaCl)(23 g Na/1 mole Na)(1000 mg/1 g) = 589.7 mg Na
Round to 2 significant figures based on 1.5 g NaCl, which has 2 significant figures ==> 590 mg Na

2. You buy a 4 lb bag of sugar (sucrose, $C_{12}H_{22}O_{11}$).
a. The molar mass of $C_{12}H_{22}O_{11}$ is ____.
b. 1 tsp sugar = 4 g sugar. How many moles of sugar are in 1 tsp? How many moles of carbon are in 1 tsp of sugar?
c. How many moles of sugar are in 4 lb of sugar?
d. Your tea is not sweet so you add 0.012 moles of sugar to your tea. How many g of sugar did you add?
e. How many teaspoons of sugar did you add?

Answers:
a. 342 g/mole = 12 mole C(12 g C/mole C)+22 moles H(1 g H/mole H)+11 moles O (16 g O/mole O)
b. Convert tsp sugar --> g sugar --> moles sugar --> moles C
1 tsp sugar (4 g sugar/1 tsp sugar)(1 mole sugar/342 g sugar) = 0.0117 moles sugar
Round to 1 significant figure based on 1 tsp sugar, which has 1 significant figure ==> 0.01 moles sugar
0.0117 moles sugar (12 moles C/1 mole sugar) = 0.140 moles C
Round to 1 significant figure based on 1 tsp sugar, which has 1 significant figure ==> 0.1 moles C
c. Convert lb sugar --> g sugar --> moles sugar
4 lb sugar (454 g/1 lb)(1 mole sugar/342 g sugar) = 5.31 moles sugar

Round to 1 significant figure based on 4 lb sugar, which has 1 significant figure ==> 5 moles sugar
d. Convert moles sugar --> g sugar
0.012 moles sugar (342 g sugar/1 mole sugar) = 4.104 g sugar
Round to 2 significant figure based on 0.012 moles sugar, which has 2 significant figure ==> 4.1 g sugar
e. 4.1 g sugar (1 tsp sugar / 4 g sugar) = 1.026 tsp sugar
Round to 2 significant figures based on 4.1 g sugar, which has 2 significant figures ==> 1.0 tsp sugar

3. You measure 1 tablespoon (18 g) of NaCl.
a. What is the mole ratio of Na to NaCl?
b. How many moles of Na are in 1 tablespoon of NaCl?
c. How many g of Na are in 1 tablespoon of NaCl?
Answers:
a. 1 mole Na to 1 mole NaCl
b. Convert tablespoon NaCl --> g NaCl --> moles NaCl --> moles Na
1 tablespoon NaCl (18 g NaCl/1 tablespoon NaCl)(1 mole NaCl/58.5 g NaCl)(1 mole Na/1 mole NaCl) = 0.3077 moles Na
Round to 1 significant figure based on 1 tablespoon NaCl, which has 1 significant figure ==> 0.3 moles Na
c. Convert moles Na from (b) --> g Na
0.3077 moles Na (23 g Na/1 mole Na) = 7.077 g Na
Round to 1 significant figure based on 1 tablespoon NaCl, which has 1 significant figure ==> 7 g Na

4. Calcium carbonate is the active ingredient in Tums antacid. Tums is also used as a calcium supplement.
What is the chemical formula of calcium carbonate? Calculate the molar mass of calcium carbonate.
One Tums tablet has 500 mg of calcium carbonate. How many g of calcium are in 500 mg of calcium carbonate?
Answers:
Calcium carbonate = $CaCO_3$
Molar mass = 100 g/mole
400 mg $CaCO_3$ (1 g/1000 mg)(1 mole $CaCO_3$/100 g $CaCO_3$)(1 mole Ca/1 mole)(40 g Ca/1 mole Ca) = 0.16 g Ca
Round to 1 significant figure based on 500 mg of calcium carbonate, which has 1 significant figure ==> 0.1 g Ca

Chemical Formula and % composition
5. Iron oxide exists as FeO or Fe_2O_3. If you were given a sample of iron oxide, you could do an elemental analysis, which tells you the %Fe and %O, to determine which form of iron oxide you have.
FeO has a molar mass of 71.85 g/mole (55.85 g/mole for Fe and 16.00 g/mole for O)
Remember % = (part/total) x 100
%Fe = (mass of Fe/total mass) x 100 = (55.85 g/71.85 g) x 100 = 77.73% Fe.
%O = (mass of O/total mass) x 100 = (16.00 g/71.85 g) x 100 = 22.27% O.
%Fe + %O should equal ___.
Calculate the % composition of Fe_2O_3.
Answers:
%Fe + %O should equal 100%.
%Fe = (mass of Fe/total mass) x 100 = (2 x 55.85 g/159.7 g) x 100 = 69.94% Fe.
%O = (mass of O/total mass) x 100 = (3 x 16.00 g/159.7 g) x 100 = 30.06% O.

6. If your lawn isn't green, it may need fertilizer (or water). Fertilizer is added to soil to supply one or more elements needed for plant growth. The three major elements are nitrogen (N), phosphorus (P), and potassium (K). On fertilizer labels, you'll see the three NPK numbers " #-#-#". The first number gives the % nitrogen, the second number gives the % phosphorus as P_2O_5, and the third number gives the % potassium as K_2O. So Miracle Grow fertilizer label that shows "20-20-20" is 20% N, 20% P_2O_5, and 20% K_2O. Fertilizers may contain other elements like calcium, sulfur, magnesium, boron, manganese, iron, zinc, copper, and molybdenum (reference: http://www.chemicalland21.com/arokorhi/industrialchem/inorganic/NPK.htm). Table 1 shows fertilizer material compositions.
a. Analysis of a fertilizer material gives a % composition of 13.9% N, 38.6% K, and 47.5% O. Determine the chemical formula and give the chemical name of this compound.
b. Fill in the blanks in Table 1. Compare your calculated %N to the %N in the label. If the %N is different, what could be a reason?

Table 1. Fertilizer Composition. (Reference: http://www.canr.msu.edu/vanburen/e-896.htm)

Fertilizer Material and NPK from Label	Chemical Formula	Name of Ions	Chemical Formulas of Each Ion	Molar Mass	Calculated %N	Calculated %P	Calculated %K
Potassium chloride	KCl	Potassium ion, chloride	K^+ Cl^-	74.5 g/mole	0	0	39/74.5 = 52.3%

(0-0-60)		ion					
Potassium nitrate (10-0-44)							
Potassium sulfate (0-0-50)							
Anhydrous ammonia (82-0-0)							
Urea (46-0-0)							
Ammonium nitrate (33.5-0-0)							
Sodium nitrate (16-0-0)							
Diammonium phosphate (16 to 21 - 48 to 53 - 0)							
Monoammonium phosphate (11-48-0)							

Answers:
a. 13.9% N = 13.6 g N (1 mole N/14 g N) = 0.971 moles N
38.6% K = 38.6 g K (1 mole K/39 g K) = 0.990 moles K
47.5% O = 47.5 g O (1 mole O/16 g O) = 2.97 moles O
Divide by the lowest factor ==> 0.971
0.971 moles N/0.971 = 1
0.990 moles K/0.971 = 1
2.97 moles O/0.971 = 3
Chemical formula = KNO_3. Note this is an ionic compound so write the metal first followed by the non-metal polyatomic ion.
KNO_3 = potassium nitrate
b.
Table 1. Fertilizer Composition. (Reference: http://www.canr.msu.edu/vanburen/e-896.htm)

Fertilizer Material and NPK from Label	Chemical Formula	Name of Ions	Chemical Formulas of Each Ion	Molar Mass	Calculated %N	Calculated %P	Calculated %K
Potassium chloride (0-0-60)	KCl	Potassium ion, chloride ion	K^+ Cl^-	74.5 g/mole	0	0	39/74.5 = 52.3%
Potassium nitrate (10-0-44)	KNO_3	Potassium ion, nitrate ion	K^+ NO_3^-	101	13.9	0	38.6
Potassium sulfate (0-0-50)	K_2SO_4	Potassium ion, sulfate ion	K^+ SO_4^{-2}	174	0	0	44.8
Anhydrous ammonia (82-0-0)	NH_3			17	82.4	0	0
Urea (46-0-0)	N_2H_4CO			60	46.7	0	0
Ammonium nitrate (33.5-0-0)	NH_4NO_3	ammonium ion, nitrate ion	NH_4^+ NO_3^-	80	35	0	0
Sodium nitrate (16-0-0)	$NaNO_3$	sodium ion, nitrate ion	Na^+ NO_3^-	85	16.5	0	0
Diammonium phosphate (16 to 21 - 48 to 53 - 0)	$(NH_4)_2HPO_4$	ammonium ion, hydrogen phosphate ion	NH_4^+ HPO_4^{-2}	132	21.2	23.5	0

Monoammonium phosphate (11-48-0)	$NH_4H_2PO_4$	ammonium ion, dihydrogen phosphate ion	NH_4^+ $H_2PO_4^-$	115	12.2	27.0	0

Calculated %N is different from fertilizer label for:
KNO_3 = 13.9%N calculated vs. 10% on label. Fertilizer label is likely for Potassium nitrate dihyrate, which gives a %N = 10.2%.
NH_4NO_3 = 35%N calculated vs. 33.5% on label. %N is pretty close.

7. A friend returns from the dentist and tells you what a kick it was to be under the influence of laughing gas. Your friend knows that laughing gas is a nitrogen oxygen compound but doesn't know the chemical formula. Your friend also knows that nitrogen oxides are produced in the exhaust of automobiles and somehow collects a pure sample of nitrogen oxide from a car.
a. You do an elemental analysis of laughing gas and find 1.27 g of N and 0.73 g of O in 2.0 g of laughing gas.
(i) What is the % composition of laughing gas?
(ii) What is the chemical formula of laughing gas? (Subscripts in a chemical formula represent moles. Convert mass to moles: 1.27 g N = 0.091 moles, 0.73 g O = 0.046 moles. Divide the moles of each element by the smallest moles: 0.091 moles N/0.046 moles = 2.0 moles N, 0.046 moles O/0.046 moles = 1.0 moles O. So chemical formula = $N_{2.0}O_{1.0}$ or N_2O.)
b. You do an elemental analysis of the nitrogen oxide from car exhaust and find 0.61 g of N and 1.39 g of O in 2.0 g of the nitrogen oxide.
(i) What is the chemical formula of this nitrogen oxide?
(ii) What is the % composition of this compound?
Answers:
a. (i) %N = (mass N/mass of laughing gas) x 100 = (1.27 g N/2.0 g) x 100 = 73.5%N
%O = (mass O/mass of laughing gas) x 100 = (0.73 g O/2.0 g) x 100 = 36.5% O
(ii) convert g to moles:
1.27 g N (1 mole N/14 g N) = 0.0907 moles N
0.73 g O (1 mole O/16 g O) = 0.0456 moles O
divide by smallest factor = 0.0456
0.0907 moles N/0.0456 = 2 N
0.0456 moles O/0.0456 = 1 O
So chemical formula = N_2O
OR
Use % composition
73.5%N = 73.5 g N (1 mole N/14 g N) = 5.25 moles N
36.5% O = 36.5 g O (1 mole N/16 g O) = 2.28 moles O
divide by smallest factor = 2.28
5.25 moles N/2.28 = 2 N
2.28 moles O/2.28 = 1 O
So chemical formula = N_2O
b. (i) %N = (mass N/mass of compound) x 100 = (0.61 g N/2.0 g) x 100 = 30.5%N
%O = (mass O/mass of compound) x 100 = (1.39 g O/2.0 g) x 100 = 69.5% O
(ii) convert g to moles:
0.61 g N (1 mole N/14 g N) = 0.0436 moles N
1.39 g O (1 mole O/16 g O) = 0.0869 moles O
divide by smallest factor = 0.0436
0. 0436 moles N/0.0436 = 1 N
0. 0869 moles O/0.0436 = 2 O
So chemical formula = NO_2

8. Ethylene glycol is a sweet smelling and sweet tasting liquid used in antifreeze in the cooling system in cars. Elemental analysis of ethylene glycol gives 38.7%C, 9.7%H, and 51.6%O. The molar mass of ethylene glycol is 62 g/mole. What is the chemical formula of ethylene glycol? (The molar mass of the chemical formula should be the same as the experimental molar mass.)
Answers:
38.7%C = 38.7g C (1 mole C/14 g C) = 3.22 moles C
9.7%H = 9.7 g H (1 mole H/1 g H) = 9.7 moles H
51.6%O = 51.6 g O (1 mole O/16 g O) = 3.22 moles O
divide by smallest factor = 3.22
3.22 moles C/3.22 = 1 C

9.7 moles H/3.22 = 3 H
3.22 moles O/3.22 = 1 O
CH_3O has a molar mass of 31 g/mole.
The molar mass of ethylene glycol is 62 g/mole. This molar mass is twice the molar mass of CH_3O.
So multiple each subscript in CH_3O by 2 ==> $C_2H_6O_2$.