Supplemental Questions
for
General Stoichiometry

1a. Dimethylglyoxime is a molecular compound with many uses. An elemental analysis of dimethylglyoxime shows it to be 41.37% carbon, 6.94% hydrogen, 24.12% nitrogen, and 27.56% oxygen by weight. If dimethylglyoxime contains only these elements, what is its empirical formula?

Assume 100.000 g of the compound.

Element	% by Weight	Mass (g)	Moles	Ratio Moles of Element to Moles of N
C	**41.37**	**41.37**	**3.444_{34}**	**2.000**
H	**6.94**	**6.94**	**6.88_{56}**	**4.00**
N	**24.12**	**24.12**	**1.722_{0}**	**1.000**
O	**27.56**	**27.56**	**1.722_{61}**	**1.000**

Determine moles of each element and then find the ratio of moles of each element to moles of the element that has the fewest number of moles.

$$41.37gC\left(\frac{1mole}{12.011g}\right) = 3.444_{34}\,moleC$$

$$6.94gH\left(\frac{1mole}{1.0079g}\right) = 6.88_{56}\,moleH$$

$$24.12gN\left(\frac{1mole}{14.007g}\right) = 1.722_{0}\,moleN$$

$$27.56gO\left(\frac{1mole}{15.999g}\right) = 1.722_{61}\,moleO$$

Since the ratios of moles of each element to moles of N for all the elements are within 0.1, we know that the empirical formula is C_2H_4NO.

b. Another student tells you that the molecular formula of dimethylglyoxime is $C_4H_8N_2O_2$. Is this molecular formula consistent with the elemental analysis given in part a? Explain why or why not.

It is consistent with the empirical formula because the proposed molecular formula is twice the empirical formula.

2a. The compound cryolite, a compound used in the production of aluminum, is 32.79% Na, 13.02% Al and 54.19% F. What is the empirical formula of cryolite?

Assume 100.000 g of the compound.

Element	% by Weight	Mass (g)	Moles	Ratio Moles of Element to Moles of Al
Na	**32.79**	**32.79**	**1.426_{27}**	**2.955_{75}**
Al	**13.02**	**13.02**	**0.4825_{4}**	**1.000**
F	**54.19**	**54.19**	**2.852_{41}**	**5.911_{24}**

Determine moles of each element.

$$32.79gNa\left(\frac{1mole}{22.990g}\right)=1.426_{27}\,moleNa$$

$$13.02gAl\left(\frac{1mole}{26.982g}\right)=0.4825_{4}\,moleAl$$

$$54.19gF\left(\frac{1mole}{18.998g}\right)=2.852_{41}\,moleF$$

The ratios are all within 0.1 of a whole number, so we can round to the nearest whole number, which makes the empirical formula of cryolite to be Na_3AlF_6.

b. Is this empirical formula the same as the chemical formula of cryolite? Explain.

Cryolite contains metals and a non-metal. So, it is likely that it is an ionic compound. The chemical formula of an ionic compound is the simplest ratio of cations and anions that give an overall charge of zero. We know that Na ion is +1, aluminum ion is +3 and fluoride is -1; summing these up gives an overall charge of zero. Although other combinations are possible, this formula satisfies the requirement of both a formula unit and an empirical formula. So, it is likely that the empirical and chemical formulas of cryolite are the same.

c. There is a compound related to cryolite in which the sodium is replaced by potassium. Will the percent by weight of Al in this compound be greater than, less than or equal to the percent by weight of Al in cryolite? Explain. (No calculation necessary.)

Potassium has a higher molar mass than sodium. Replacing sodium with potassium means that the molar mass of cryolite goes up, but the mass of aluminum remains the same. So, the percent by weight of Al in this compound will be less than that in cryolite.

3. Hydrated copper(II) sulfate is 36.07% water by weight. Write the proper chemical formula for the hydrated copper(II) sulfate. You are given that the molar mass of anhydrous copper(II) sulfate is 159.610 g/mole and the molar mass of water is 18.012 g/mole.

In 100.00 g of the hydrate there is 36.07 g H_2O and 63.93 g $CuSO_4$.

Convert these masses to moles.

$$36.07 gH_2O\left(\frac{1 mole}{18.012 g}\right) = 2.002_{55} moleH_2O$$

$$63.93 gCuSO_4\left(\frac{1 mole}{159.610 gCuSO_4}\right) = 0.4005_4 moleCuSO_4$$

The ratio of moles of H_2O to moles of $CuSO_4$ gives the chemical formula

$$\frac{2.002_{55} moleH_2O}{0.4005_4 moleCuSO_4} = 4.999_{64}\frac{moleH_2O}{moleCuSO_4} = 5.000\frac{moleH_2O}{moleCuSO_4}$$

There are 5 moles of H_2O per mole of $CuSO_4$. Therefore, the correct chemical formula for this hydrate is $CuSO_4{\cdot}5H_2O$ (name is copper(II) sulfate pentahydrate).

4a. The action of bacteria on meat and fish produces a compound called cadaverine, which is responsible for the wonderful odor of spoiled food. Cadaverine is known to be 58.77% C, 13.81% H and 27.40% N. What is its empirical formula?

Assume 100.000 g of the compound.

Element	**% by Weight**	**Mass (g)**	**Moles**	**Ratio Moles of Element to Moles of N**
C	**58.77**	**58.77**	**4.893_{01}**	**2.501**
H	**13.81**	**13.81**	**13.70_{176}**	**7.004_{63}**
N	**27.40**	**27.40**	**1.956_{10}**	**1.000**

Determine moles of each element and then find the ratio of moles of each element to moles of the element that has the fewest number of moles.

$$58.77 gC\left(\frac{1 mole}{12.011 g}\right) = 4.893_{01} moleC$$

$$13.81 gH\left(\frac{1 mole}{1.0079 g}\right) = 13.70_{176} moleH$$

$$27.40 gN\left(\frac{1 mole}{14.007 g}\right) = 1.956_{16} moleN$$

Since the ratio for moles C to moles N is not within 0.1 of a whole number, must multiply everything by 2 to clear the fraction.

This gives the empirical formula of cadaverine as $C_5H_{14}N_2$.

b. Cadaverine's molar mass is 102.2 g/mole. What is the chemical formula of cadaverine?

The molar mass of the empirical formula is

Element	Mass
5 C	5(12.011) = 60.055 g
14 H	14(1.0079) = 14.110_6 g
2 N	2(14.007) = 28.014 g
	102.179_6 g/mole

The molar mass of the empirical formula for cadaverine is the same as its true molar mass. So the chemical formula is the same as the empirical formula, $C_5H_{14}N_2$.

c. Is the chemical formula of cadaverine you wrote above a *molecular formula* or a *formula unit*? Explain.

The chemical formula indicates that only non-metals are present in cadaverine. With no evidence for any polyatomic ions being present in cadaverine, we must conclude that cadaverine is a molecular compound and the formula is a molecular formula.

5a. You have synthesized a hydrate of zinc sulfate. If 1.374 g of the hydrated zinc sulfate releases 0.251 g of water when heated, what is the chemical formula of the zinc sulfate hydrate that you have synthesized?

By the Law of Conservation of Mass the mass of the anhydrous $ZnSO_4$ must be

1.374 g – 0.251 g = 1.123 g

The molar mass of $ZnSO_4$ is

Element	Mass
Zn	65.39 g
S	32.065 g
4 O	4(15.999) = 63.996 g
	161.45 g/mole

Convert the mass to moles

$$0.251 g H_2O \left(\frac{1 mole}{18.012 g} \right) = 0.0139_4 mole H_2O$$

$$1.123 g ZnSO_4 \left(\frac{1 mole}{161.45 g ZnSO_4} \right) = 0.006955_{71} mole ZnSO_4$$

The ratio of moles H_2O to moles $ZnSO_4$ is

$$\frac{0.0139_4 mole H_2O}{0.006955_{71} mole ZnSO_4} = 2.00 \frac{mole H_2O}{mole ZnSO_4}$$

There are 2 moles H_2O per mole $ZnSO_4$. So, the chemical formula is $ZnSO_4 \cdot 2H_2O$.

b. What is the name of the hydrate in part a (as we would say it)?

The hydrate's name is zinc sulfate dihydrate.

c. If you had 100.0 g of the zinc sulfate hydrate in part a, how many grams of water would you have? You don't need an answer to part a to do this problem!

We could calculate the percent water by weight in $ZnSO_4 \cdot 2H_2O$, but there is an easier way. The mass of water in 1.374 g of $ZnSO_4 \cdot 2H_2O$ was given. We can use this as a conversion factor from g of $ZnSO_4 \cdot 2H_2O$ to g H_2O.

$$100.0 g ZnSO_4 \cdot 2H_2O \left(\frac{0.251 g H_2O}{1.374 g ZnSO_4 \cdot 2H_2O} \right) = 18.3 g H_2O$$

In 100.0 g of $ZnSO_4 \cdot 2H_2O$ there is 18.3 g H_2O.

6. Disulfur dichloride, S_2Cl_2 is used to vulcanize rubber. S_2Cl_2 can be made by treating molten sulfur with gaseous chlorine. The chemical equation for this reaction is:

$$S_8\ (l) + Cl_2\ (g) \rightarrow S_2Cl_2\ (l)$$

If you start with 32.0 g sulfur and 71.0 g Cl_2, what is the percent yield for this reaction if 50.0 g S_2Cl_2 are obtained?

Balance the chemical equation.

$$S_8\ (l) + \mathbf{4}\ Cl_2\ (g) \rightarrow \mathbf{4}\ S_2Cl_2\ (l)$$

	S_8 (l)	4 Cl_2 (g)	→	4 S_2Cl_2 (l)
Mass (g)	32.0	71.0		?
Molar Mass (g/mole)	256.52	70.906		135.036
Moles				

Long Way
Determine moles of each reactant and then moles of S_2Cl_2 to determine limiting reagent. Use moles of limiting reagent to calculate mass of S_2Cl_2.

$$32.0gS_8\left(\frac{1moleS_8}{256.52gS_8}\right)\left(\frac{4moleS_2Cl_2}{1moleS_8}\right)=0.498_{99}moleS_2Cl_2$$

$$71.0gCl_2\left(\frac{1moleCl_2}{70.906gCl_2}\right)\left(\frac{4moleS_2Cl_2}{4moleCl_2}\right)=1.00_{133}moleS_2Cl_2$$

Since S_8 gives fewer moles of the product, it is the limiting reagent.

$$0.498_{99}moleS_2Cl_2\left(\frac{135.036g}{1moleS_2Cl_2}\right)=67.4gS_2Cl_2$$

Somewhat Shorter Way
Determine grams of S_2Cl_2 that each reactant will give. Whichever one gives the smallest amount is the limiting reagent.

$$32.0gS_8\left(\frac{1moleS_8}{256.52g}\right)\left(\frac{4moleS_2Cl_2}{1moleS_8}\right)\left(\frac{135.036gS_2Cl_2}{1moleS_2Cl_2}\right)=67.4gS_2Cl_2$$

$$71.0gCl_2\left(\frac{1moleCl_2}{70.906gCl_2}\right)\left(\frac{4moleS_2Cl_2}{4moleCl_2}\right)\left(\frac{135.036gS_2Cl_2}{1moleS_2Cl_2}\right)=135.gS_2Cl_2$$

Since S_8 gives fewer moles of the limiting reagent, it is the limiting reagent.

The theoretical yield for this reaction is 67.4 g S_2Cl_2.

The percent yield is given by

$$\%Yield = \frac{actual}{theoretical} \times 100 = \frac{50.0g}{67.4g} \times 100 = 74\%$$

The percent yield for this reaction is 74%.

7a. The mineral dolomite has the chemical formula $CaMg(CO_3)_2$. What would be the percent by weight of calcium in a pure sample of dolomite?

Determine molar mass of dolomite.

Element	Mass (g)
Ca	**40.078**
Mg	**24.305**
2 C	**2(12.011) = 24.022**
6 O	**6(15.999) = 95.994**
Molar mass	**184.399 g/mole**

Percent calcium in dolomite by mass is given by

$$\%Ca = \frac{massCa}{massdolomite} \times 100 = \frac{40.078g}{184.399g} \times 100 = 21.734\%$$

Dolomite is 21.734% by weight Ca.

b. Calcite, $CaCO_3$, is mineral that is related to dolomite. Calcite is 40.04% by weight calcium. A mineral that could be either calcite or dolomite is analyzed by a student in a quantitative analysis class. They report their result as 35. ± 6% calcium by weight at the 95% confidence limit. What can you conclude about this mineral sample at this point? Explain.

Unless there is a systematic error, it is unlikely to be dolomite because the percent by weight Ca for dolomite lies outside the confidence interval for the measurement. It could be calcite because the percent by weight Ca for calcite does lie within the confidence interval.

We do not know the identity of the mineral, so we cannot use percent error to measure our accuracy. And since the precision is very poor, we cannot use precision to assess accuracy.

At this point we can't say anything about the identity of the mineral because of poor precision and we don't know whether there was a systematic error.

c. The student reanalyzes their mineral sample. This time the result for the six measurements is 35.05 ± 0.01% calcium by weight at the 95% confidence limit. From the information given to this point, what can you now conclude about this mineral sample?

The precision is much better now, but we still don't know anything about systematic error. This means that we are more confident that the true value for the percent calcium by weight is 35.05%, but because we don't know whether there is a systematic error, we can't really conclude anything. However, we are more confident than before that the mineral is not dolomite.

d. This mineral sample is known to be pure calcite. Calculate the percent error for the more precise analysis (either the result from part b or the result from part c, whichever is appropriate). Given that the goal in quantitative analysis lab is to be both accurate and precise; will this student receive a good grade for this experiment?

The 35.05% calcium by weight value is more precise, so use it to calculate the percent error.

$$\% Error = \frac{measured - true}{true} \times 100 = \frac{35.05 - 40.04}{40.04} \times 100 = -12.46\%$$

The percent error for the measurement is -12.46%.

e. Another mineral related to dolomite and calcite is magnesite, $MgCO_3$. Some people consider dolomite to be a mixture of calcite and magnesite; others consider it to be a pure compound. What are the criteria for dolomite being a pure compound?

To be a pure compound dolomite must not be separable by physical means into magnesite and calcite and it must have its own distinct and reproducible physical properties.

8. Camphor is a pleasant smelling compound that contains only carbon, hydrogen and oxygen. Elemental analysis of camphor shows it to be 78.90% C and 10.59% H by weight. Mass spectroscopy shows the molecular weight of camphor to be 152.2 g/mole. What is the chemical formula of camphor?

The percent oxygen by mass must be *100.00 – 78.90 – 10.59 = 10.51%.*

Assume 100.000 g of the compound.

Element	**% by Weight**	**Mass (g)**	**Moles**	**Ratio Moles of Element to Moles of O**
C	**78.90**	**78.90**	**6.568_{98}**	**10.00**
H	**10.59**	**10.59**	**10.50_{699}**	**15.99**
O	**10.51**	**10.51**	**0.6569_{2}**	**1.000**

Determine moles of each element and then find the ratio of moles of each element to moles of the element that has the fewest number of moles.

$$78.90gC\left(\frac{1mole}{12.011g}\right) = 6.568_{98}\,moleC$$

$$10.59gH\left(\frac{1mole}{1.0079g}\right) = 10.50_{699}\,moleH$$

$$10.51gO\left(\frac{1mole}{15.999g}\right) = 0.6569_{2}\,moleO$$

Since all of the ratios are within 0.1 of whole numbers, round to the nearest whole numbers to give the empirical formula of camphor as $C_{10}H_{16}O$.

The molar mass of the empirical formula is

Element	**Mass (g)**
10 C	**10(12.011) = 120.11**
16 H	**16(1.0079) = 16.126**
O	**15.999**
Molar mass	**152.24 g/mole**

The molar mass of the empirical formula is the same as the true molar mass, so the chemical formula of camphor is $C_{10}H_{16}O$.