Teaching Stoichiometry as Algebraic Word Problems, Part 3

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Abstract

This paper presents the subject of stoichiometry as a collection of algebraic methods of solving chemistry word problems. It should be clear by now that the central object of stoichiometry is the mole proportion.

1 Introduction

Stoichiometry is a basic topic of chemistry, concerned with solving for certain quantities of products and/or reactants in a balanced chemical equation,[1] given knowledge of other quantities in the equation. Such quantities of interests are typically moles, grams, and/or liters of particular substances.

In Appendix A, you'll find a compilation of molar masses of common chemicals. In Appendices B and C are problems providing the reader with additional experience in dealing with percentages.

2 Problem 1: Working with the amu (atomic mass unit)

This problem is taken from the YouTube chemistry course presented by the The Organic Chemistry Tutor at

`https://www.youtube.com/watch?v=9fSiy7-JurA`

PROBLEM: #6 (video time stamp 46:05)

Calculate the [average] mass of 25 carbon atoms in amu (atomic mass units) and in grams.

SOLUTION: Step 1.

[1] It seems that certain types of problems do not require the chemical equation to be balanced, so long as enough information is given to setup a relevant stoichiometric ratio.

We begin with the definition of the amu: In the modern definition of amu, it is defined as 1/12 the mass of a single ^{12}C atom. Now, I interjected the word ‘average’ into the question because the author of this question is using the periodic table to get the molar mass of carbon, which is itself an average over all carbon isotopes.

Let’s first solve for the mass of 1 carbon atom in terms of amu. Let R stand for the following ratio:

$$R = \frac{\text{mass of one C atom [amu]}}{\text{mass of one } {}^{12}\text{C atom [amu]}} = \frac{\text{mass of one C atom}}{12\,\text{amu}}\,. \tag{1}$$

But the ratio of the mass of carbon to mass of ^{12}C is independent of the units used. Hence, we can employ moles of atoms instead of individual atoms, to get:

$$R = \frac{\text{mass of 1 mole C atoms [g]}}{\text{mass of 1 mole } {}^{12}\text{C atoms [g]}} = \frac{12.01\text{g}}{12\,\text{g}} = 1.0008\,. \tag{2}$$

On equating the R’s from the last two equations and then solving for the mass of one carbon atom, we get

$$\text{mass of one C atom} = (1.0008)(12\,\text{amu}) = 12.01\,\text{amu}\,. \tag{3}$$

So, what I’ve accomplished is to prove what the YouTube author takes for granted as his starting point in solving this problem. Anyway, the mass of 25 carbon atoms (again, on the average) is 300.25 amu.

The (average) mass in grams of 25 carbon atoms is

$$\begin{aligned} \text{mass} &= 25 \times 12.01\,\text{g}\cdot\text{mol}^{-1} \times \frac{1 \text{ mole}}{6.022\ \times 10^{23}\ \text{[particles]}} \\ &= 4.99 \times 10^{-22}\,\text{g}\,. \end{aligned} \tag{4}$$

3 Problem 2: Mystery Metal

This next problem is taken from the online chemistry pdf file found at

`https://www.alvinisd.net/cms/lib03/TX01001897/Centricity/Domain/4240/practice%20test%20stoich.pdf`

PROBLEM 13, p. 2

11.2 g of metal carbonate, containing an unknown metal, M, were heated to give the metal oxide and 4.4 g CO_2.

$$\text{MCO}_3\,(\text{s}) \xrightarrow{\Delta} \text{MO}\,(\text{s}) + \text{CO}_2\,(\text{g}) \tag{5}$$

What is the identity of the metal M?

a. Mg b. Pb c. Ca
d. Ba e. Cr

Ans: e.

SOLUTION: Step 1.

Once we know the molar mass, say m, of M, we can look up the most likely element in the periodic table.

Step 2.

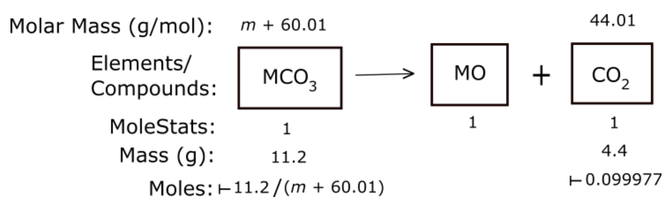

Figure 1. There's no need to clutter the diagram with superfluous information in column 2, as we only need one equation to calculate m, and that is furnished by the stoichiometric proportion between columns 1 and 3.

Next, we write down our stoichiometric proportion on columns 1 and 3:

$$\frac{1}{1} = \frac{\text{moles MCO}_3}{\text{moles CO}_2} = \frac{11.2/(m+60.01)}{0.099977}\,. \tag{6}$$

Solving for m, we get a molar mass of about 52 g$\cdot$mol^{-1}. The closest-fit element is therefore Chromium, Cr.

4 Problem 3: Mystery Hydrocarbon C_xH_y

This next problem is taken from the online chemistry pdf file found at

`https://www.alvinisd.net/cms/lib03/TX01001897/Centricity/Domain/4240/practice%20test%20stoich.pdf`

PROBLEM 14, p. 2

A given sample of some hydrocarbon is burned completely and it produces 0.44 g of CO_2 and 0.27 g of H_2O. Determine the empirical formula of the compound.

a. CH b. C_2H_3 c. CH_2
d. C_2H_5 e. CH_3

Ans: e.

SOLUTION: Step 1.

We'll begin by finding a balanced equation, starting with

$$C_xH_y + aO_2 \rightarrow bCO_2 + cH_2O\,, \tag{7}$$

where a, b, c are positive integer coefficients to be solved for in terms of unknowns x and y. To that end, we must have the coefficients cooperate with balancing the carbon, hydrogen, and oxygen:

$$\begin{array}{lcl} \mathrm{C} & : & x = b \\ \mathrm{H} & : & y = 2c \\ \mathrm{O} & : & 2a = 2b + c \end{array} \tag{8}$$

On solving a, b, c in terms of x and y, we get

$$\begin{array}{lcl} a & = & x + y/4 \\ b & = & x \\ c & = & y/2 \end{array} \tag{9}$$

Step 2. Once again, a diagram.

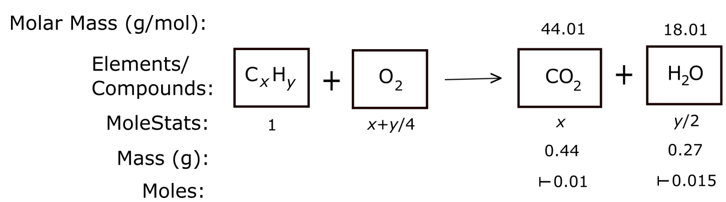

Figure 2. This sparse diagram is enough to find the ratio of x to y.

Step 3.

Next, we write down our mole proportion between columns 3 and 4:

$$\frac{x}{y/2} = \frac{0.01}{0.015} \tag{10}$$

But this is only one equation for two variables. No, we don't need another equation because all we need is the ratio of the two variables this time. Solving for x/y, we get a 1/3. Therefore, the empirical formula is CH_3.

5 Problem 4:

PROBLEM 24, p. 3

$$6H^+ + 5H_2O_2 + 2MnO_4{}^- \rightarrow 5O_2 + 2Mn_2{}^+ + 8H_2O \tag{11}$$

According to the balanced equation above, how many moles of the permanganate ion are required to react completely with 25.0 ml of 0.100 M hydrogen peroxide?

a. 0.000500 mol b. 0.00100 mol c. 0.00500 mol
d. 0.00625 mol e. 0.0100 mol

Ans: b.

SOLUTION: Step 1.

There's more than one way to get to moles in the stoich diagram. Usually, we divide grams by grams/mole, but this time we multiply moles/liter by milliliters and convert units appropriately.

Step 2. Once again, a diagram.

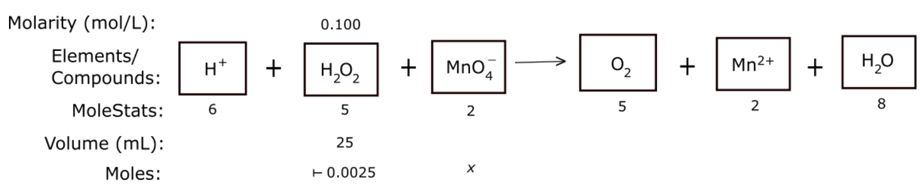

Figure 3. We can calculate x by employing the stoichiometric proportion between columns 2 and 3.

Step 3.

Next, we write down our fundamental proportion between columns 2 and 3:

$$\frac{2}{5} = \frac{\text{moles } {MnO_4}^-}{\text{moles } H_2O_2} = \frac{x}{0.0025} \tag{12}$$

Solving for x, we get a 0.001 mole, or, rather to three decimal places 0.00100 mole.

6 Problem 5: Empirical formula oxide of nitrogen

This next problem is taken from the online chemistry pdf file found at

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http://msmorrischemistry.weebly.com/uploads/3/8/9/5/38951057
      /stoichiometry__ap_mc_.pdf
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Problem 25:

The simplest formula for an oxide of nitrogen that is 36.8 percent nitrogen by weight is . . .

(A) N_2O (B) NO (C) NO_2
(D) N_2O_3 (E) N_2O_5

Ans: (D).

SOLUTION: Step 1.

To begin with, we'll denote our mystery compound as N_xO_y, and set its mass to 100.0 grams. Hence, we set the mass of the nitrogen to 36.8 grams and the mass of the oxygen to 63.2 grams.

Step 2. Next, a diagram:

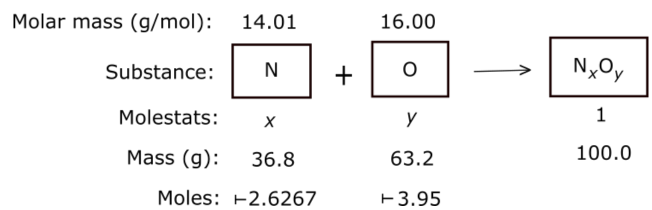

Figure 4. This figure depicts a pseudo-chemical reaction. Since we are only given the percentage of nitrogen in the mystery compound, we are free to pick the mass of the unknown compound as any convenient value we like, so I chose it to be 100.0 grams.

Step 3. Apply the stoichiometric proportion

All we need is the ratio of x to y, and we can use our stoichiometric proportion to get that:

$$\frac{x}{y} = \frac{2.6267}{3.95} = 0.665 \approx 2/3\,, \qquad (13)$$

Therefore, the empirical formula of the compound is N_2O_3.

7 Problem 6: Moles of H_2O from Burning Alkene

This next problem is taken from the online chemistry pdf file found at

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http://msmorrischemistry.weebly.com/uploads/3/8/9/5/38951057
      /stoichiometry__ap_mc_.pdf
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Problem 45:

The alkenes are compounds of carbon and hydrogen with the general formula C_nH_{2n}. If 0.561 gram of any alkene is burned in excess oxygen, what number of moles of H_2O is formed?

(A) 0.0400 mole (B) 0.0600 mole (C) 0.0800 mole
(D) 0.400 mole (E) 0.800 mole

Ans: (A).

SOLUTION: Step 1.

I'll begin with a presumptive balanced chemical equation for the reaction:

$$C_nH_{2n} + \tfrac{3}{2}nO_2 \rightarrow nH_2O + nCO_2\,. \qquad (14)$$

Step 2. First, what's the grams/mole of C_nH_{2n}? It's n times the grams/mole of the logical compound CH_2, which equals $n(12.01 + 2.02) = 14.03n$ [g·mol^{-1}].
Next, a diagram:

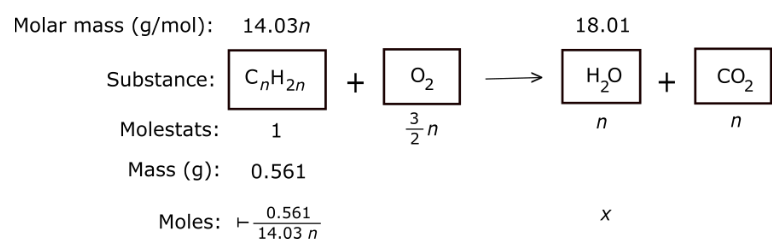

Figure 5. This sparse figure depicts the presumptive balanced equation for the burning of a general alkene in excess oxygen.

Step 3. Apply the stoichiometric proportion

All we need is the ratio of x to y, and we can use our stoichiometric proportion between columns 1 and 3:

$$\frac{n}{1} = \frac{x}{0.561/14.03n}\,\mathrm{mol}\,. \qquad (15)$$

On solving for x, we get (after rounding up)

$$x = 0.0400\,\mathrm{mol}\,. \qquad (16)$$

8 Problem 7: Mystery Carbohydate (Vit C)

This next problem is taken from the online chemistry pdf file found at http://www.uh.edu/~chem1p/c3/C3F99.pdf

PROBLEM 3–5, p. 23–25

Vitamin C (M= 176.12 g·mol^{-1}) contains C, H and O. A 1.000 g sample was placed in a combustion apparatus [and the following are facts about the masses of the products, derived by 'weighing'[2]]:

Mass of CO_2 is 1.50 grams.
Mass of H_2O is 0.41 grams.

What is the molecular formula of vitamin C?

SOLUTION: Step 1.

We'll begin with an unbalanced equation to work with

$$C_xH_yO_z + O_2 \to CO_2 + H_2O\,. \tag{17}$$

Next, by inspection we can balance this equation on elements C and H in terms of unknowns x and y, leaving a to be determined by balancing on element O:

$$C_xH_yO_z + aO_2 \to xCO_2 + \frac{y}{2}H_2O\,. \tag{18}$$

yielding:

$$z + 2a = 2x + y/2\,, \tag{19}$$

which, when solved for a, yields

$$a = x + y/4 - z/2\,. \tag{20}$$

Step 2. Once again, a diagram.

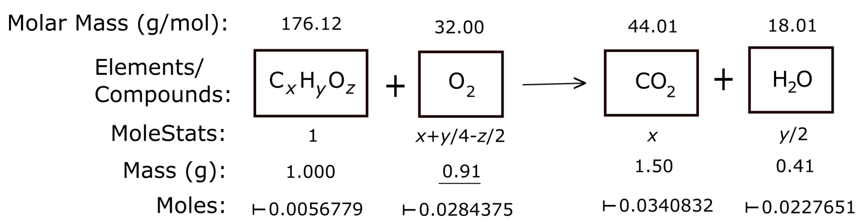

Figure 6. The 0.91 grams of O_2 in column 2 is determined by the conservation of mass between the reactants and products; hence, the underlining used in column 2, according to the markup rules we've adopted.

[2]Or, the mass can be calculated by use of knowledge of moles and molar mass of the compound.

Step 3. We can easily calculate x by using columns 1 and 3:

$$\frac{x}{1} = \frac{0.0340832}{0.0056779} \approx 6\,. \tag{21}$$

So, we'll accept the integer value of x to be six. We can also easily calculate y by using columns 1 and 4:

$$\frac{y/2}{1} = \frac{0.0227651}{0.0056779} \approx 4\,. \tag{22}$$

So, we'll accept the integer value of y to be eight. Finally, we can calculate z by using columns 1 and 2, and by substituting in the values of x and y we've just found:

$$\frac{x + y/4 - z/2}{1} = 8 - z/2 = \frac{0.0284375}{0.0056779} \approx 5\,. \tag{23}$$

Hence, $z = 6$.

We can calculate the molar mass of $C_6H_8O_6$ and find it to be $176.12\,\mathrm{g{\cdot}mol^{-1}}$ — the same value for the given value of the molar mass of the compound. Therefore, the molecular formula of the compound is $C_6H_8O_6$.

9 Problem 8: Calcium in Calcium Phosphate

This next problem is taken from the online chemistry problem found at

`(At the moment, the source is unknown.)`

PROBLEM 8(b)

How many grams of calcium are present in 890 grams of calcium phosphate?

SOLUTION: Step 1. The formula for calcium phosphate is $Ca_3(PO_4)_2$.

Step 2. Once again, a diagram.

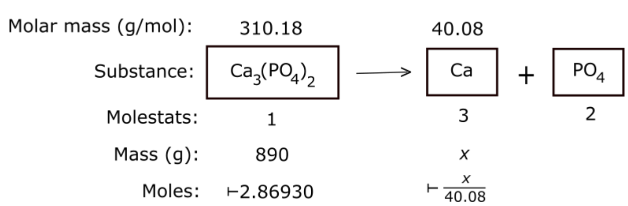

Figure 7. This figure does not represent a chemical reaction. It represents the calcium phosphate as a 'total equaling the sum of its logical parts', and that includes my treating PO_4 as a logical part.

Step 3. We can calculate x by using a mole proportion on columns 1 and 2:

$$\frac{3}{1} = \frac{x/40.08}{2.86930}\,. \tag{24}$$

Thus,

$$x = 345\,\mathrm{g}\,. \tag{25}$$

10 Problem 9: Hydrate of $BaCl_2$

This next problem is taken from the online chemistry problem found at

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https://www.chemteam.info/Mole/Determine-formula-of
             -hydrate-prob1-10.html
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PROBLEM #3

A 5.00 g sample of hydrated barium chloride, $BaCl_2 \cdot nH_2O$, is heated to drive off the water. After heating, 4.26 g of anhydrous barium chloride, $BaCl_2$, remains. What is the value of n in the hydrate's formula?

SOLUTION: Step 1.

The chemical reaction is as follows:

$$BaCl_2 \cdot nH_2O \rightarrow BaCl_2 + nH_2O\,. \tag{26}$$

Step 2. Once again, a diagram.

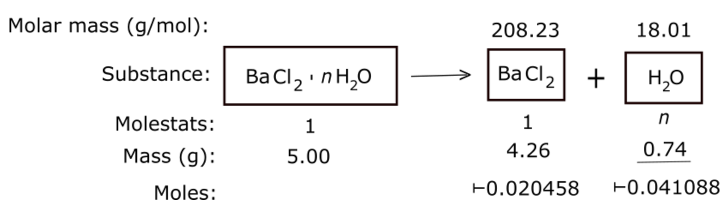

Figure 8. At this point, the problem is most easily finished by choosing the best two columns to form the mole proportion.

Step 3.

We can calculate n by using a mole proportion on columns 2 and 3:

$$\frac{n}{1} = \frac{0.041088}{0.020458} \approx 2\,. \tag{27}$$

Thus, we choose $n = 2$, resulting in the formula to be $BaCl_2 \cdot 2H_2O$.

11 Problem 10: Hydrate of $LiClO_4$

This next problem is taken from the online chemistry problem found at

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https://www.chemteam.info/Mole/Determine-formula-of
              -hydrate-prob1-10.html
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PROBLEM #1

Anhydrous lithium perchlorate (4.78 g) was dissolved in water and re-crystalized. Care was taken to isolate all the lithium perchlorate as its hydrate. The mass of the hydrated salt obtained was 7.21 g. What hydrate is it?

SOLUTION: Step 1.

The chemical reaction is as follows:

$$LiClO_4 + nH_2O \to LiClO_4 \cdot nH_2O\,, \tag{28}$$

where n is to be determined.

Step 2. Once again, a diagram.

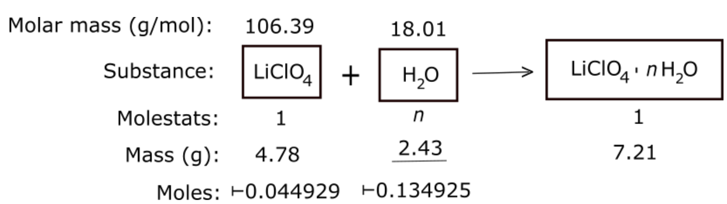

Figure 9. The mass of the water is determined by $7.21 - 4.78 = 2.43$.

Step 3.

We can calculate n by using a mole proportion on columns 1 and 2:

$$\frac{n}{1} = \frac{0.134925}{0.044929} \approx 3\,. \tag{29}$$

Thus, we choose $n = 3$, resulting in the formula to be $LiClO_4 \cdot 3H_2O$.

12 Problem 11: Hydrate of Na_2CO_3

This next problem is taken from the online chemistry problem found at

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https://www.chemteam.info/Mole/Determine-formula-of
              -hydrate-prob1-10.html
```

PROBLEM #5a

A solution was made by dissolving 52.0 g of hydrated sodium carbonate in water and making it up to 5.00 dm^3 of solution. The concentration of the solution was determined to be 0.0366 M. Determine the formula of hydrated sodium carbonate.

SOLUTION: Step 1.

Note: 1 dm^3 = 1 liter.

The chemical reaction is as follows:

$$Na_2CO_3 \cdot nH_2O \rightarrow Na_2CO_3 + nH_2O\,, \tag{30}$$

where n is to be determined.

Step 2. Once again, a diagram.

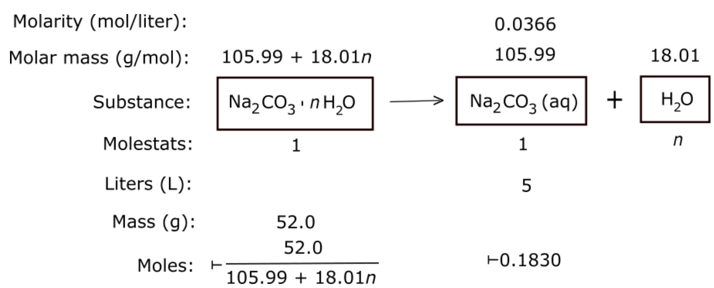

Figure 10. In this problem there are two ways to arrive at moles.

Step 3. We can calculate n by using a mole proportion on columns 1 and 2:

$$\frac{1}{1} = \frac{52.0/(105.99 + 18.01n)}{0.1830}\,. \tag{31}$$

On solving this for n, we get, after rounding to the nearest integer, $n = 10$, resulting in the formula $NaCO_3 \cdot 10H_2O$.

13 Problem 12: Precipitating Silver

This next problem is taken from the online chemistry problem found at

`https://www.calstatela.edu/sites/default/files/dept/chem/07winter/ 201-lec/201-l-4-gravimetric-analysis.pdf (p.\ 9)`

PROBLEM

How many mL of 1% potassium chloride would be needed to precipitate all of the silver in a 0.5 g ore sample that contains 1.5 parts per thousand silver? Allow for 50% excess of the chloride solution.

SOLUTION: Step 1.

First we calculate the mass of the silver in the ore sample:

$$\text{mass of Ag} = \frac{1.5}{1000} \times 0.5\,\text{g} = 7.5 \times 10^{-4}\,\text{g}\,. \tag{32}$$

Step 2. Now, a diagram showing the replacement of the potassium (K) in KCl by Silver (Ag) to form the precipitate silver chloride (AgCl).

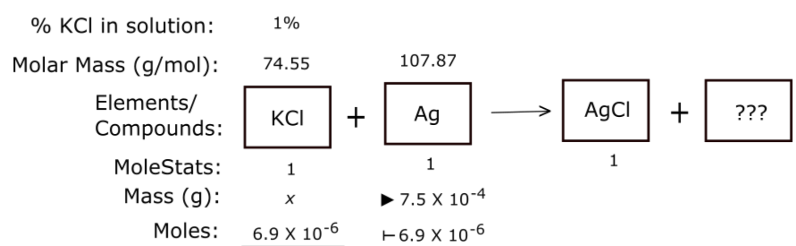

Figure 11. In column 2, the mass of the silver is a derivative result, calculated from the given data. Then the moles of Ag is easily calculated. Then, by column hopping, the moles of KCl is calculated by one-to-one molar correspondence between columns 1 and 2.

Step 3.

We can calculate x in column 1:

$$x = (6.9 \times 10^{-6}\,\text{moles}\,)(74.55\,\text{g}\cdot\text{mol}^{-1}) = 5.14 \times 10^{-4}\,\text{g}\,. \tag{33}$$

Now, 1% KCl solution by mass is formed by taking one part KCl to 99 parts water. Since 1 gram of water is 1 mL water,[3] the volume V needed is given by

$$V = \frac{5.14 \times 10^{-4}\ \text{g KCl}}{1\,\text{g KCl}/99\,\text{mL H}_2\text{O}} = 0.0509\,\text{mL [solution]}\,. \tag{34}$$

Now, adding another 50% to that volume yields $V = 0.0764\,\text{mL}$.

14 Problem 13: Making Ammonia Gas

This next problem is taken from the online chemistry problem found at

[3] This is true to a very close approximation.

https://answers.yahoo.com/question/index?qid=20100413231838AAIl4qf

PROBLEM

If water is added to magnesium nitride, ammonia gas is produced when the mixture is heated.

$$Mg_3N_2(s) + 3H_2O(l) \rightarrow 3MgO(s) + 2NH_3(g) \tag{35}$$

If 13.7 g of magnesium nitride is treated with water, what volume of ammonia gas would be collected at 28°C and 737 mm Hg?

SOLUTION: Step 1.

First, we treat the ammonia evolved as an ideal gas and expect to employ the ideal gas law:

$$PV = nRT\,, \tag{36}$$

where n is the number of moles of the gas. Now, since the Ideal Gas Constant R can be given in various unit systems, let's make that choice right now.

$$R = 8.2057 \times 10^{-2}\,\tfrac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}}\,. \tag{37}$$

Thus,

$$P = (737 \text{ mm Hg})\,\frac{1 \text{ atm}}{760 \text{ mm Hg}} = 0.9697 \text{ atm}\,, \tag{38}$$

and, of course, $T = (273 + 28)\text{K} = 301\text{K}$.

Step 2. Now, a diagram.

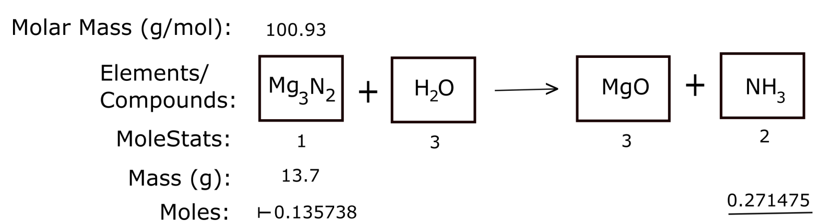

Figure 12. In column 4, the moles of NH_3 is calculated by one-to-two mole proportion between columns 1 and 4.

Step 3.

Lastly, we solve (36) for V, using $n = 0.271475$ mol from the diagram above, and write

$$V = \frac{nRT}{P} = \frac{(0.271475\,\text{mol})(8.2057 \times 10^{-2}\,\tfrac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}})(301\,\text{K})}{0.9697 \text{ atm}} = 6.92\,\text{L}\,. \tag{39}$$

15 Appendix A: Relative Molecular Masses

Atomic masses are given in terms of grams per mole ($g{\cdot}mol^{-1}$). For the compounds, I used the values given by
https://www.convertunits.com/

Ag — 107.87 (Silver)
AgBr — 187.77 (silver bromide)
AgCl — 143.32 (silver chloride)
Ag_2CrO_4 — 331.73 (silver chromate)
$AgNO_3$ — 169.87 (silver nitrate)

Al — 26.98 (Aluminum)
Al_2O_3 — 101.96
$Al(OH)_3$ — 78.00 (aluminum hydroxide)
AlC_3 — 133.34
$Al_2(CrO_4)_3$ — 401.94
$Al_2(SO_4)_3$ — 342.15

As — 74.92 (Arsenic)
As_4O_6 — 395.68

B — 10.81 (Boron)
B_2H_6 — 27.67
B_2O_3 — 69.62

Ba — 137.33 (Barium)
$BaCl_2$ — 208.23 (barium chloride)
$Ba(OH)_2$ — 171.34
$Ba(NO_3)_2$ — 545.80
$BaSO_4$ — 233.39 (barium sulfate)

Be — 9.01 (Beryllium)

Br — 79.90 (Bromine)
Br_2 — 159.81

C — 12.01 (Carbon)
CCl_4 — 153.82 (Carbon tetraflouride)
$CHCl_3$ — 119.38 (Chloroform)
CBr_2Cl_2 — 242.72
CH_3OH — 32.04

CH_3COOH — 60.05
CO — 28.01
CO_2 — 44.01
COC_2 — 98.92 (phosgene)
CH_2O — 30.03
CH_5NO_2 — 63.01 (ammonia formate)
C_2H_2 — 26.04 (acetylene)
C_2H_6 — 30.07 (ethane)
C_2H_4O — 44.53 (...)
C_3H_6O — 50.08
$C_3H_6O_3$ — 90.08 (lactic acid)
$C_3H_8O_3$ — 92.09
$C_6H_{12}O_6$ — 180.16
$C_6H_5CO_2K$ — 160.21 (potassium benzoate)
$C_3H_5(ONO_2)_3$ — 227.09 (nitroglycerin)
$C_7H_5(NO_2)_3$ — 227.13
CH_3 — 15.03 (methyl radical)
CH_4 — 16.04 (methane)
CH_3OH — 32.04
C_3H_8 — 44.10 (propane)
C_4H_8 — 56.11 (butene)
C_4H_{10} — 58.12 (butane)
C_5H_{10} — 70.13 (?)
C_5H_{12} — 72.15 (pentane)
C_8H_{18} — 114.23 (octane)

Ca — 40.08
$CaBr_2$ — 199.89
CaC_2 — 64.10
$CaCl_2$ — 110.98
$CaCl_2 \cdot 2\,(H_2O)$ — 128.99
CaO — 56.08 (calcium oxide)
$Ca(OH)_2$ — 74.09
$Ca_2(PO_3)_2$ — 270.10
$Ca_3(PO_3)_2$ — 310.18 (calcium phosphate)
$CaCO_3$ — 100.09
$CaSO_4$ — 136.14
$CaSiO_3$ — 116.16 (calcium metasilicate)

Cl — 35.45 (Chlorine)
Cl_2 — 70.91

Co — 58.93 (Cobalt)
$CoCl_2$ — 129.84 (cobalt chloride)

Cr — 52.00 (Chromium)
Cr_2O_3 — 152.00
$Cr(NO_3)_2$ — 176.01

Cs — 132.91 (Cesium)

Cu — 65.39
$CuCl_2$ — 134.45
$Cu(OH)_2$ — 97.56
$Cu(NO_3)_2$ — 183.56 (copper(II) nitrate)
Cu_2S — 159.16 (copper(I) sulfide)
Cu_2O — 143.09 (copper(I) oxide)
$CuSO_4$ — 159.61

F — 19.00
F_2 — 38.00

Fe — 55.93 (Iron)
$FeCl_2$ — 126.75
$FeCl_3$ — 162.20
Fe_2O_3 — 159.69 (iron(III) oxide)
$FeSO_4$ – 151.91
$Fe_2(SO_4)_3$ – 399.88
FeS – 87.91 (iron(II) sulfide)
$FeTiO_3$ – 151.71 (iron(II) titanate)

Ga — 69.73
Ga_2O_3 — 187.44 (gallium(III) oxide)

H — 1.01
H_2 — 2.02
HBO_2 — 43.82
HBr — 80.91 (hydrobromic acid)
$H_2C_2O_4$ — 90.03
$H_2C_4H_4O_6$ — 150.087
HCN — 27.06
H_3BO_2 — 45.83
HCl — 36.46
$HClO_4$ — 100.56 (perchloric acid)
HF — 20.01

HI — 127.91 (hydrogen iodide)
H_2O — 18.01
H_2O_2 — 34.01
HNO_3 — 63.01
H_3PO_4 — 24.31
H_2S — 34.08
H_2SO_4 — 98.08
H_2SO_3 — 82.01

Hf — 178.49 (Hafnium)

Hg — 200.59 (Mercury)
Hg_2Br_2 — 560.99 (mercurous bromide)
Hg_2Cl_2 — 472.09 (mercurous chloride)

I — 126.90 (Iodine)
I_2O_5 — 333.81 (diiodine pentoxide)

K — 39.10
KCl — 74.55
K_2CrO_4 — 194.19
$K_2Cr_2O_7$ — 294.18
KCN — 65.21
$K_4Fe(CN)_6$ —v368.34
K_2HPO_4 — 174.18
KIO_3 — 214.00 (potassium iodate)
K_3PO_4 — 212.27
KO_2 — 71.10
KOH — 56.10
$KMnO_4$ — 158.03
KNO_2 — 85.10 (potassium nitrite)
KNO_3 — 101.10 (potassium nitrate)
K_2SO_3 — 158.26 (potassium sulfite)
K_2SO_4 — 174.26 (potassium sulfate)

Li — 6.94
LiBr — 86.85 (lithium bromide)
LiCl — 42.39 (lithium chloride)
$LiClO_4$ — 106.39 (lithium perchlorate)
Li_2CO_3 — 73.89
L_3N — 34.83
$LiNO_3$ — 68.95

$LiOH$ — 23.95 (lithium hydroxide)
Lil_2SO_4 — 109.94

Mg — 24.31
$MgCl$ — 59.76
$MgCl_2$ — 95.21
MgF — 43.30 (magnesium flouride)
$MgCO_3$ — 83.31 (magnesium carbonate)
Mg_3N_2 — 100.93 (magnesium nitride)
MgO — 40.30 (magnesium oxide)
$Mg(OH)_2$ — 58.32
$MgSO_4$ — 120.37

Mn — 54.94 (manganese)
MnO_2 — 86.94
$Mn(NO_3)_3$ —240.95 (manganese (III) nitrate)
Mn_2S_3 —206.07 (manganese (III) sulfide)

N — 14.01
N_2 — 28.01
N_2l_2 — 30.03
NH_3 — 17.03
NH_4 — 18.01
$(NH_4)_2Cr_2O_7$ — 252.06
$(NH_4)_2CO_3$ — 96.09 (ammonium carbonate)
$(NH_4)Cl$ — 53.49
$(NH_4)ClO_4$ — 117.49
NH_4OH — 35.05
NH_4NO_3 — 80.04
NO — 30.01
NO_2 — 46.01
N_2O_5 — 108.01

Na — 23.00
$NaBr$ — 102.89 (sodium bromide)
$NaCl$ — 58.44 (sodium chloride)
$NaClO_4$ — 58.44 (sodium perchlorate)
$NaCN$ — 49.01 (sodium cyanide)
Na_2CO_3 —105.99 (sodium carbonate)
$Na_2C_2O_4$ — 134.00
Na_2CrO_4 — 161.97
$Na_3C_6H_5O_7$ — 258.07
NaF — 41.99 (sodium flouride)

Na_3PO_4 — 163.94
$NaHCO_3$ — 84.01
$NaIO_3$ — 197.89 (sodium iodate)
NaN_3 — 65.01
$NaNO_3$ — 84.99
$NaKC_4H_4O_6$ — 210.16
NaOH — 40.00
Na_2SO_4 — 142.04
$Na_2S_2O_3$ — 158.11

Ne —20.18

O —16.00
O_2 —32.00
O_3 —48.00

P — 30.97
P_4 — 123.90
P_4H_{10} — 133.97 (phosphorus pentoxide)
PH_3 — 34.00 (phosphine)
PH_4I — 161.91
P_2I_4 — 569.57

Pb —207.20
$PbCl_2$ — 278.11 (lead(II) chloride)
$PbCrO_4$ — 323.19
PbS — 239.27
PbO — 223.20
$Pb(SO_4)_2$ — 399.33
$Pb(NO_3)_2$ — 331.21 (lead(II) nitrate)
$Pb(NO_3)_4$ — 455.22

Ra —226.03 (Radium)

Rb — 84.87

S — 32.07
SO_2 — 64.06
$SO_4{}^{2-}$ — 96.06

Sb — 121.76 (Antinomy)

Sb_2O_3 — 291.52

Sc — 44.96 (Scandium)

Si — 28.09
SiO_2 — 60.08

Sr — 87.62 (strontium)
SrO — 103.62 (strontium oxide)

Ti — 47.88
$TiCl_4$ — 198.68 (titanium (IV) chloride)
Ti_2O_2— 127.73

U — 238.03
UF_6 — 352.02
U_3O_8 — 842.08

Y — 88.91 (Yttrium)

Zr —91.22

Zn — 65.39
$ZnCl_2$ — 136.29
$Zn(NO_3)_2$ — 189.39

16 Appendix B: Coin Problem, Percent Quantities Given

Problem:

A jar contains a collection of less than 40 coins of two types, Type1 and Type2, valuing \$4.85. The possible coin types are penny, nickel, dime, and quarter. Find the types of coins and the number of each type of coin, if the following claims are true:

a) The percentage of Type1 coins by number is 41.37931%, and

b) The percentage of Type1 coins by value is 12.371134%.[4]

Solution:

We begin with a diagram:

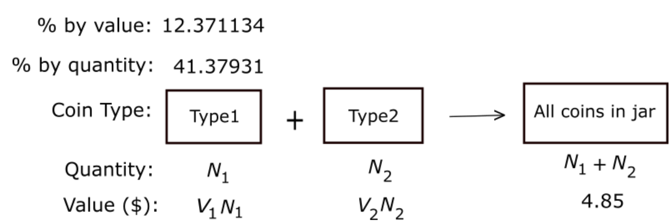

Figure B1. We add to the information in the diagram that the total number of coins is less than 40, or $N_1 + N_2 < 40$. V_1 and V_2 are the values per unit coin.

Now, using the information in the diagram, we present the obvious 'total equals the sum of its parts':

$$V_1 N_1 + V_2 N_2 = 4.85\,. \tag{40}$$

Next, we can convert the information in claim a) to

$$\frac{N_1}{N_1 + N_2} = 0.4137931\,, \tag{41}$$

and, from claim b)

$$\frac{V_1 N_1}{V_1 N_1 + V_2 N_2} = 0.12371134\,. \tag{42}$$

To solve this system, let's begin with a simplification of (41) by dividing both numerator and denominator on the left hand side by N_1:

$$\frac{N_1}{N_1 + N_2} \to \frac{1}{1 + x} = 0.4137931\,, \tag{43}$$

[4]These percentages are approximate values.

where $x = N_2/N_1$. Then we can use Wolframalpha (or some other means) to solve (43) for x:

$$x = \frac{N_2}{N_1} = 1.41667\,. \tag{44}$$

Next, we can do something similar for (42) which we did for (41), by dividing through by $V_1 N_1$.

$$\frac{V_1 N_1}{V_1 N_1 + V_2 N_2} = \frac{1}{1+xy} = \frac{1}{1+1.41667y} = 0.12371134\,, \tag{45}$$

where $y = V_2/V_1$. Solving for y, we get

$$y \approx 5\,. \tag{46}$$

Therefore, we take V_2 to be exactly five times V_1. Thus, we have two choices: Either the Type1 coin is a penny and the Type2 coin is a nickel, or the Type1 coin is a nickel and the Type2 coin is quarter. But the former case is ruled out because there is no combination of pennies and nickels that will equal \$4.85 if the total number of those coins is less than 40. Therefore,

$$V_1 = \$0.05 \quad \text{and} \quad V_2 = \$0.25\,. \tag{47}$$

Hence, (40) becomes

$$0.05N_1 + 0.25N_2 = 4.85\,. \tag{48}$$

On solving this last equation simultaneously with (41), we get

$$N_1 \approx 12\,, \quad N_2 \approx 17\,. \tag{49}$$

Therefore, we conclude that there are 12 nickels and 17 quarters in the jar.

17 Appendix C: Mystery Two-Element Compound Problem, Percent Quantities Given

Problem:

A sample of a compound contains two types of elements, Type1 and Type2. Find the empirical formula of the compound if the following claims are true:

a) The percentage of Type1 element by mass is 84.80%.[5]

b) The percentage of Type1 element by moles of atoms in the compound is about 27.27%.

c) When decomposed, the compound releases a gas (the Type2 element) that is able to ignite a smoldering flint.

[5]These percentages are approximate values.

Solution:

We begin with Claim c) to conclude that the gaseous element/compound evolved is oxygen, O_2. Let's label the Type1 element E1. Thus, the compound is $E1_aO_b$.

Next, a diagram:

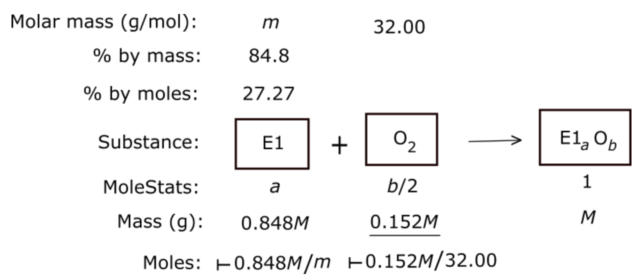

Figure C1. We are free to represent the molar mass of E1 as m, and the total mass of $E1_aO_b$ as M. The information in Claim a) is already incorporated. I regard the diagram as a 'parts-to-whole' construction, not a chemical reaction, per se, but either interpretation works.

Next, we can utilize the information in Claim b) to

$$\frac{0.848M}{m} = 0.2727\Big(\frac{0.848M}{m} + 2\frac{0.152M}{32.00}\Big)\,, \tag{50}$$

where the 2 arises in the second term on the right because we are counting moles of oxygen atoms, not moles of oxygen molecules. So, on solving (50) for m, we get

$$m = 238.07\,\mathrm{g{\cdot}mol^{-1}}\,. \tag{51}$$

Hence, we conclude that E1 is uranium, U.

Now we can calculate the ratio b/a by use of the mole proportion between columns 2 and 1:

$$\frac{b/2}{a} = \frac{\dfrac{0.152M}{32.00}}{\dfrac{0.848M}{m}} = 1.3335\,. \tag{52}$$

Therefore, $b/a = 2.667$, which is about $8/3$. Hence, the empirical formula of the compound is U_3O_8.

Comment: This problem is meant to be an exercise in algebra and logic within the domain of chemistry, but I'm too ignorant of real chemistry to know whether or not this kind of problem would ever come up in real chemistry.

References

[1] P. Atkins and L, Jones. *Chemical Principles: Quest for Insight*, 3rd Ed. Freeman (2005).

[2] M. Hein and S. Arena *Foundations of College Chemistry*, alternate 12th ed, John Wiley & Sons (2007), 421–422.

[3] M. S. Silberberg. *Chemistry: The Molecular Nature of Matter and Change* 4th Ed. McGraw-Hill (2006).