Teaching Stoichiometry as Algebraic Word Problems, Short Version

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Abstract

This paper presents the subject of stoichiometry as a collection of algebraic methods of solving chemistry word problems. The regular algebra word problems that might be useful, to make learn this easier problems, are in the long version of this paper.

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, given knowledge of other quantities in the equation. Such quantities of interests are typically moles, grams, and/or liters of particular substances.

Author's Admission: I'm still in need of much more learning myself on the rudiments of chemistry, so please bear with my inevitable naive mistakes on chemistry that will likely occur from time to time in this paper.

For an example of a simple stoichiometry problem, if one wants to make a certain amount of ammonia (NH_3), say 200 liters, by the Haber Process:

$$N_2 + 3H_2 = 2NH_3\,, \tag{1}$$

how many liters of nitrogen gas (N_2) at Standard Temperature and Pressure (STP) would be required?

In the nomenclature of *Scheme* — the name I gave to the methods of algebra problem solving I developed over the years — Eq. (1) is referred to as a 'before-and-after' type problem. Every 'before-and-after' type problem has something conserved in the process, and it's this conserved quantity (or quantities) that is (or are) the basis of an algebraic equation (or system of equations) that must be solved algebraically. Examples of conserved quantities in (1) are overall mass and the mass of each particular element. Another conserved quantity is the molar amount (or individual amount) of each element in the reaction. It's on the basis of this conservation principle that the unbalanced chemical equation can be balanced in the first place.

In stoichiometric Scheme, a typical way to diagram the reaction given in (1), could be as in Figure 0 (which I'll refer to as a *Stoich diagram* for short):

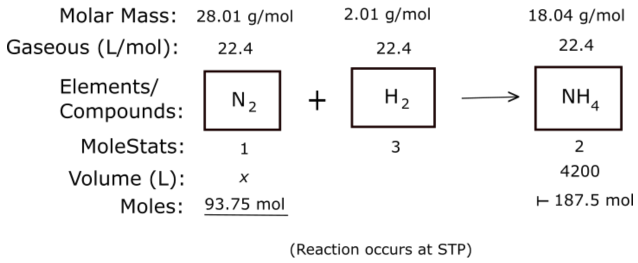

Figure 0. Diagram of the Haber Process, revealing an orderly system for keeping track of relevant information. In stoichiometric 'bookkeeping' in Scheme, we see the relevant data placed in column form. Quantities in the same column are usually related to each other by multiplication or division, whereas, quantities in the same row are often related to each other by conservation rules or by mole proportions.

The first thing I want to say about Figure 0 is a comment on the general layout of the data placed in the diagram. To begin with, typically, I place rates above the boxes and simple quantities below the boxes (following the habit I formed in solving algebra word problems). Immediately below the boxes I place the coefficients of the balanced chemical equation under investigation. I refer to this line of coefficients as the *MoleStats line.* Warning: These molestats numbers are *not* true quantities, per se, but, rather, represent mole proportions.

The second thing to say about a Scheme stoich diagram is that it contains information of two broad types: *nonderived* and *derived.* The nonderived information is in three subtypes: Given, tabular, or physical law. The given information is obviously specifically given in the problem statement. The tabular information comes from look-up tables, such as the molar masses of elements or compounds (in this paper, see Appendix A)[1]. The physical law information can also be looked up, such as the volume of a mole of an ideal gas at STP.

The derived information comes in three forms: 1) Values derived from information residing only in the same column. These values are usually prefaced by a turnstile $\vdash$ (see the figure). 2) Values derived using at least one piece of information from a column other than that in which it resides. These values are usually underlined (see figure). 3) Values derived from information (given in the problem statement or found somewhere). Such values are usually prefaced by

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[1] Yes, I know that in some educational situations, one must calculate molar massed from scratch, but in this paper, one can use the appendix if one wishes.

a solid right arrowhead ► (not shown in figure).[2] Values derived from information lying outside the diagram should be explicitly calculated outside the stoich diagram, or at least alluded to, for the reader's benefit. As a final comment on these markup symbols, they play a role in stoich diagrams similar to comments placed in computer code, i.e., they help to clarify, at a glace, the origin of the data.

Referring to the diagram, the first and easiest calculation to do is to derive the moles of NH_3:

$$\text{moles NH}_3 = \frac{4200\ \text{L}}{22.4\ \text{L}\cdot\text{mol}^{-1}} = 187.5\ \text{mol}\,, \tag{2}$$

where all the information needed to perform this calculation came from the same column as the value that was derived — hence the turnstile indicator.

Now, the way to use this new mole information toward the goal of finding the liters of N_2 gas, is to use what I refer to as the *mole proportion*[3] between the respective columns (*column hopping*): *The ratio of actual moles of substances from two columns is equal to the ratio of their respective Molestats numbers.* This ratio is sometimes referred to as the *stoichiometric ratio.* Hence,

$$\frac{\text{moles N}_2}{\text{moles NH}_3} = \frac{1}{2}\,. \tag{3}$$

On solving this for the moles of N_2 (with moles NH_3 = 187.5 mol), we get 93.75 mol. And now we're ready to solve for x, the number of liters of N_2 gas we need to solve for.

$$x = 93.75\ \text{mol} \times 22.4\,\text{L}\cdot\text{mol}^{-1} = 2100\,\text{L}\,. \tag{4}$$

I refer to the use of information in one column to be used, directly or indirectly, for making calculations in another column as *column hopping.* In this last problem, we were column hopping between columns 1 and 3. Various authors make diagrams to reveal this notion of column hopping. I'll refer the reader to just one:

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http://www.oneonta.edu/faculty/viningwj/Chem111/
          Chapter_03_bv.pdf     (p. 3-28)
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However, note that there is no equation to solve in this version of column hopping, just a set of consecutive conversion factors to apply. One of the objectives of this paper is to reveal that those modifications of one expression by a number of conversion factors to derive a final result, always begins with an equation.

Now, if a fairly good high-school algebra student were to open a chemistry textbook for the first time and thumb through the section on stoichiometry, he or she would not be too far off to conclude that the subject apparently has no

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[2] For example, in a gravimetric analysis in which a precipitate is collected, the given information could be the weight of the precipitate on a collection sheet and the weight of the sheet alone. But the value we need to put into the stoich diagram is the difference of these two numbers.

[3] A *proportion* is defined as the stated equality of two ratios.

need for algebraic equations, but rather relies on a trick of multiplying some given quantity by a number of conversion factors to derive a final result, one of those factors often being the stoichiometric ratio.

If this baffled student were to read on and learn that the basis of stoichiometry is the conservation of mass and moles of substances in a comparison of before-and-after states of what is referred to as a *chemical reaction*, he or she might wonder, rightly, if this book presentation hasn't actually hidden the conservation equations that underlie the computations.

One purpose of this paper is to reveal these 'hidden' conservation equations and reveal them as mere algebraic equations similar to those found in algebra word problems that the student is, or rather, should, already familiar with.

For a warmup to the subject, I'll present a number of word problems done in *Scheme* that will foreshadow those in typical stoichiometry problems. But if you're impatient to get to real stoichiometry problems, you can skip down to Section 10, and go from there.

2 Word Problem 9: The Boron Problem

► Naturally occurring Boron (molar mass of 10.81 g/mol = $10.81\,\text{g}\cdot\text{mol}^{-1}$) is the mixture of two of its isotopes: Boron 10 (^{10}B) and Boron 11 (^{11}B), of atomic masses 10.01 g/mol and 11.01 g/mol, respectively. Find the relative abundances of ^{10}B and ^{11}B in natural Boron, expressed in percentages.

SOLUTION:

Conceptualizing the problem

First, take note that the mixing of these two isotopes to form natural Boron is a physical, not a chemical, mixing. We shall model this problem as mixing the two isotopes in the right proportions to yield naturally occurring Boron. We lose nothing by assuming one mole of natural boron to begin with.[4]

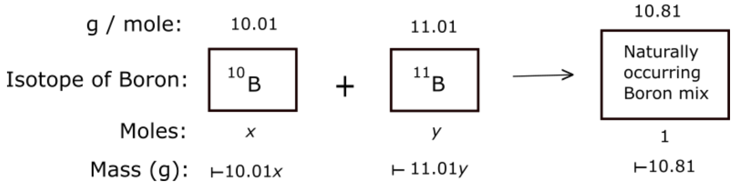

Figure 9. This graphic represents our imagined sorting of 1 mole of naturally occurring Boron into logical piles of ^{10}B and ^{11}B.

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[4] If this were not the case, then the relative percentages of these two isotopes of boron in natural boron would be functions of the macroscopic amount of natural boron collected, all other things being equal. But if this were true, then claiming that natural boron has the fixed molar mass of 10.81 would be untrue and/or meaningless.

Referring to the figure above, it should be clear, after a little comparison with the coin problem at the beginning of this paper, that the two problems are very similar. In the coin problem, we had two conservation equations: one for the conservation of the total number of coins, and another for the conservation of the total value of the coins.

In this problem, we have one equation for the conservation of the total number of moles of isotopes, and another for the conservation of the total grams of the isotopes, from which we get the pair of equations to be solved simultaneously:

$$x + y = 1\,, \tag{5a}$$

$$10.01x + 11.01y = 10.81\,. \tag{5b}$$

Getting the Numbers.

Wolframalpha gives the approximate values for x and y as $x \approx 0.2$ and $y \approx 0.8$. Converting these values to percentages, we have that in naturally occurring Boron, the relative abundance of ^{10}B as about 20% and ^{11}B as about 80%.

3 Preparing for Stoichiometry

One of the first things to do in a typical stoichiometry problem is to balance an unbalanced chemical equation. We won't go into the strategies for accomplishing that in this paper. But let's do one of them now for practice. Consider the unbalanced chemical equation

$$\mathrm{Li} + \mathrm{N}_2 \longrightarrow \mathrm{Li}_3\mathrm{N}\,. \tag{6}$$

The end objective of balancing any chemical equation is to have, for each element, the same number of each on the left side of the equation as on the right side. Clearly, 'equation' (6) is unbalanced because there are three lithiums on the right for every one lithium on the left. The nitrogens are also unbalanced. One possible first step to balancing this is the following

$$3\mathrm{Li} + \tfrac{1}{2}\mathrm{N}_2 \longrightarrow \mathrm{Li}_3\mathrm{N}\,. \tag{7}$$

This certainly completed the task of balancing each element in one step; however, convention is (usually) to clear the equation of fractions. So, we'll multiply through by 2, to get

$$6\mathrm{Li} + \mathrm{N}_2 \longrightarrow 2\mathrm{Li}_3\mathrm{N}\,. \tag{8}$$

Notice that we did not place a 1 in front of the N_2 term on the left, since its presence is implied by convention.

Say that our problem is to determine the grams of N_2 that must be supplied to react with 41.64 grams of lithium to produce 69.66 grams of $\mathrm{Li}_3\mathrm{N}$? Let's start by forming a graphic of this process:

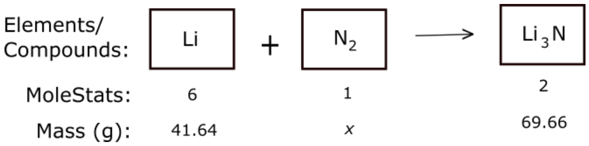

Figure 10. This graphic represents the conservation of mass when of 41.64 grams of lithium react with x grams of nitrogen to produce 69.66 grams of Li_3N.

The line labeled *MoleStats* refers to the coefficients of the terms in the balanced equation; however, we won't be using it this time, but it will play a crucial role in most problems we encounter later. Now, it may seem obvious how to proceed at this point. We merely assume that the grams are conserved in this reaction and therefore write down that

$$41.64\,\text{g} + x = 69.66\,\text{g} \tag{9}$$

and solve for x to get $x = 28.02$ grams. This is correct, but since chemistry is a science, we need more than intuition or common sense to justify this train of thought.

One of the fundamental laws of chemistry is the Law of Conservation of Mass, stated in a form fit for chemistry:

`In a closed system, the sum of all masses of the reactants in a chemical reaction is equal to the sum of all masses of the products of the reaction.`

This law justifies our calculation, but the reader should know that this kind of problem is a bit too simplistic to be seen often in stoichiometry.

The last comment I wish to make before we enter into solving for more typical stoichiometry problems is the role played by the numbers in the MoleStats line of the figures we draw.[5] Since this paper is meant to present stoichiometry as algebra, it uses the fact that the elements and/or compounds that react and produce products, do so by fixed ratios. For example, referring back to Figure 10, the ratio of lithium to Li_3N is 6 : 3. And the ratio of N_2 to Li_3N is 1 : 2. We'll see in the next problem how to form an algebraic equation out of this by finding the Fundamental Proportion to the problem (relative to any two particular terms of the balanced equation).

Thus, more important to stoichiometry, and in particular for our algebraic treatment of it, is the fundamental *Law of Fixed Molar Ratios*, stated as:[6]

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[5] I use the term 'Molestats' in reference to the statistical characteristic of 'organization and presentation of data', admittedly the weakest sense of the word *statistics*, but 'MoleStats' does have a nice sound to it.

[6] A similar notion is The Law of Definite Proportions.

`In a chemical reaction, the ratio of the coefficients of any two terms is a fixed rational number which is equal to the ratio of the moles of the respective chemical substances in the reaction.`

For example, look again at chemical equation (8). From it we can conclude that the moles of Li to the moles of N_2 is 6 : 1, which can be written in algebraic form as the proportion[7]:

$$\frac{\text{moles Li}}{\text{moles N}_2} = \frac{6}{1}\,. \tag{10a}$$

Similarly, we can conclude a similar proportion:

$$\frac{\text{moles Li}_3\text{N}}{\text{moles Li}} = \frac{2}{6}\,. \tag{10b}$$

And also:

$$\frac{\text{moles Li}_3\text{N}}{\text{moles N}_2} = \frac{2}{1}\,. \tag{10c}$$

Of course, we know that we can invert the fractions of both sides of any of the last three equations and still have a valid equation.

4 Problem 1: Kilograms to kilograms

This first problem is taken from the chemistry textbook *Chemical Principles: The Quest for Insight* ([1], p. F82):

PROBLEM:

► What mass of aluminum is needed to reduce 10.0 kg of chromium (III) oxide to produce chromium metal? The chemical equation for the reaction is

$$2\text{Al(l)} + \text{Cr}_2\text{O}_3\text{(s)} \xrightarrow{\Delta} \text{Al}_2\text{O}_3\text{(s)} + 2\text{Cr(l)}\,. \tag{11}$$

SOLUTION:

As a note to the reader: Appendix A contains a list of molar masses of various compounds for the problems in this paper, although, slight differences can occur in these molar masses depending on differences existing in various source references.

Conceptualizing the problem

First, we make a figure (below) that contains all relevant data:

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[7] Remember that a proportion is the claimed equality of two ratios, and in this context, the ratio is called the *stoichiometric ratio*.

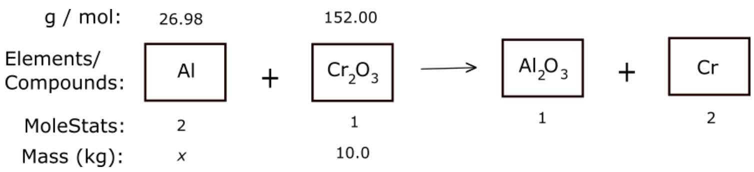

Figure 11. A kilograms-to-kilograms problem.

Next, we formulate the fundamental (mole) proportion[8] of this problem:

$$\frac{\text{moles Al}}{\text{moles } \mathrm{Cr_2O_3}} = \frac{2}{1}\,. \tag{12a}$$

But now we have to relate moles to kilograms, which is simple. Switching sides and expanding with the given information, yields:

$$\frac{2}{1} = \frac{\text{moles Al}}{\text{moles } \mathrm{Cr_2O_3}} = \frac{x[\text{kg Al}]/26.98\,\text{g/mol}}{10.0\ \text{kg}[\mathrm{Cr_2O_3}]/152.00\,\text{g/mol}}\,. \tag{12b}$$

where the information in the square brackets is parenthetical.

Now, I must explain that I pulled a fast one in Eq. (12b). There is actually nothing incorrect about what I did in writing this proportion; however, your chemistry teacher may not think so. For purists, I should have written

$$\frac{2}{1} = \frac{\text{moles Al}}{\text{moles } \mathrm{Cr_2O_3}} = \frac{x[\text{kg Al}]/26.98\times 10^{-3}\,\text{kg/mol}}{10.0\ \text{kg}[\mathrm{Cr_2O_3}]/152.00\times 10^{-3}\,\text{kg/mol}}\,. \tag{13}$$

This is the kind of subtlety with units that trips-up new students. Anyway, the reason (13) is just as good as (12b) is because we can go between them by merely multiplying both numerator and denominator by the same conversion factor. However, if we needed to know the moles of Cr_2O_3, given that we know there are 10.0 kg of it, then the correct units in the calculation would be

$$\text{moles } \mathrm{Cr_2O_3} = \frac{10.0\ \cancel{\text{kg}}[\mathrm{Cr_2O_3}]}{152.00\times 10^{-3}\ \cancel{\text{kg}}/\text{mol}}\,. \tag{14}$$

Solving (12b) for x and canceling units where possible, we get

$$x = \frac{2}{1}26.98\frac{10.0\ \text{kg}}{152.00} = 3.55\ \text{kg}\,. \tag{15}$$

Now that we've finished our first real stoichiometry problem, what have we learned about the solution? We've learned that the solution to this problem is

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[8] I refer to this proportion as involving moles, but it could just as easily refer to ratios of numbers of molecules. However, the masses of compounds are usually given in terms of molar masses, not molecular masses.

much the same as the solutions seen above to ordinary algebra word problems, especially those that include conversion factors and proportional reasoning.

A website that sets up the setting of the mole proportions similarly to how it's done here is at

`http://www.chembuddy.com/?left=balancing-stoichiometry`
`          &right=ratio-proportions`

5 Problem 2: Titration of Oxalic Acid

This second problem is taken from the same textbook *Chemical Principles: The Quest for Insight* ([1], p. F84):

PROBLEM: (Paraphrased) 25.00 mL of oxalic acid is titrated with 0.100 M NaOH(aq) until all the acid is consumed. If it required 38.00 mL of base to reach this point, what was the molarity (moles/liter) of the acid?

SOLUTION: First, the base referred to is NaOH. The chemical equation for the reaction is

$$H_2C_2O_4 + 2\text{NaOH} \longrightarrow Na_2C_2O_4 + 2H_2O \tag{16}$$

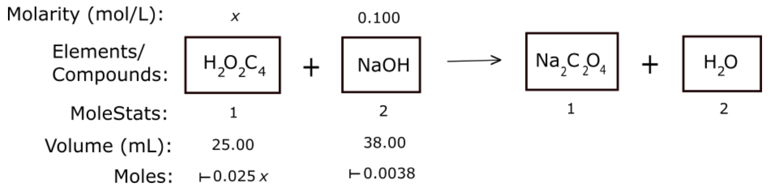

Figure 12. Oxalic acid titration by NaOH.

Next, we write down our mole proportion on columns 1 and 2:

$$\frac{1}{2} = \frac{\text{moles } H_2C_2O_4}{\text{moles NaOH}} = \frac{0.025x}{0.0038}\,. \tag{17}$$

On solving for x (to three decimal places), we get

$$x = 0.0760\,\text{mol}\cdot\text{L}^{-1}\,. \tag{18}$$

6 Problem 3: Grams-to-liters

This third problem is taken from the textbook *Chemistry: The Molecular Nature of Matter and Change* ([5], p. 120).

PROBLEM:

Given 0.10 grams of $Mg(OH)_2$ (a base) reacts completely with how many liters of 0.10 M HCl? The chemical equation for the reaction is

$$Mg(OH)_2(s) + 2HCl(aq) \longrightarrow MgCl(aq) + 2H_2O(l)\,. \tag{19}$$

SOLUTION:

First, the diagram:

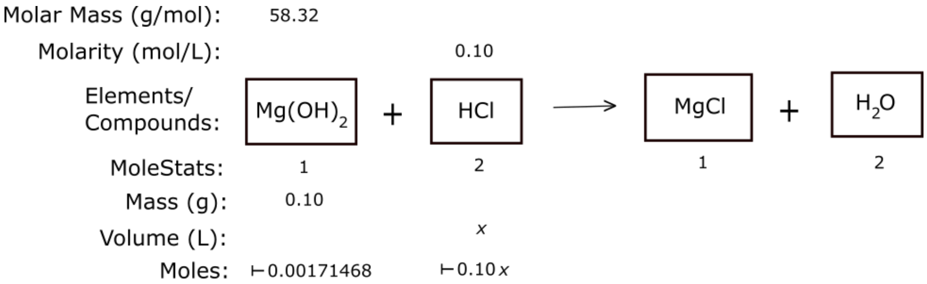

Figure 13. This graphic represents the neutralization of HCl acid with the base $Mg(OH)_2$. Note that x has unit of liters.

Next, we write down the mole proportion between columns 2 and 1:

$$\frac{2}{1} = \frac{\text{moles HCl}}{\text{moles } Mg(OH)_2} = \frac{0.10x}{0.00171468}\,. \tag{20}$$

On solving for x, we get

$$x = 3.4 \times 10^{-2}\,\mathrm{L}\,. \tag{21}$$

7 Problem 10: Analyzing Vitamin C

This problem is taken from *Chemical Principles: The Quest for Insight* ([1], Problem L16, p. F87).

PROBLEM:

A tablet of vitamin C was analyzed to determine whether it did in fact contain, as the manufacturer claimed, 1.0 g of the vitamin. One tablet was dissolved in water to form 100.00 mL of solution, and 10.0 mL of solution was titrated with iodine (as potassium triiodide). It required 10.1 mL of 0.0521 M I_3^-(aq) to reach the stoichiometric point[9] in the titration. Given that 1 mol I_3^- reacts with 1 mol vitamin C in the reaction, is the manufacturer's claim correct?

SOLUTION:

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[9] That is, when all the vitamin C was consumed.

We begin with recognizing what we must actually show. We must show 1) that our calculation of the quantity of vitamin C in the original solution must be 10 times that in the titrated solution, and 2) that our calculation for the vitamin C contents of the titrated solution must lie between 1.04 g and 0.95 g in order to round to 1.0 g.

Normally, at this point I'd produce a balanced chemical equation of the reaction, but this time I won't, principally because the products of the reaction aren't given because they're not needed. What we are given instead is the stoichiometric ratio of vitamin C consumption to I_3^- consumption being 1 : 1. But we can, and should, still produce a diagram of the reaction.

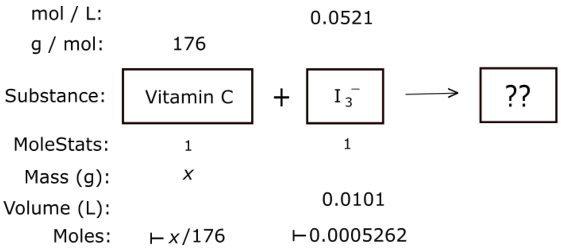

Figure 22. Note: The volume has been converted from mL to L.

But first a word about the notation in the diagram: When I use the double question mark '??', I refer to a quantity that I'm **not** interesting in knowing, probably because it's irrelevant to the problem.

Next, we write down the mole proportion between columns 1 and 2:

$$\frac{1}{1} = \frac{\text{moles Vit C}}{\text{moles } I_3^-} = \frac{x/176}{0.0005262}\,. \tag{22}$$

Solving for x, we get

$$x_{10} = 0.0926\,\text{g}\,, \tag{23}$$

where x_{10} is the mass corresponding to the 10.0 mL volume. Therefore, we multiply it by ten to get the 100.00 mL mass (approximately):

$$x_{100} = 0.926\,\text{g}\,. \tag{24}$$

However, this values lies outside the predetermined appropriate range. Therefore, the answer to the question posed is No.

8 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

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