

Homework #1

September 9 (to be tested September 15)

from Averill:

Chapter 1

Topic	Problems
Elements VS Compounds	14, 15
Periodic Table, Reading Information of the	32, 36, 38, 39, 42, 44
Periodic Table, Patterns in the	47, 48
Isotopes	73, 76
Ions and Oxidization States	34, 82
Concept of Mole	25
Molecular Mass	65, 80

Chapter 3

Topic	Problems
Molecular Mass	33
Unit Conversions (mass to moles to molecules and vice versa)	35, 43, 44
Balancing Chemical Reactions	72
Agents in a Chemical Reaction (Limiting, in excess, etc)	90, 103

Chapter 1

14. (a) compound (d) compound
 (b) element (e) element
 (c) compound
15. (a) compound (d) compound

- (b) element (e) compound
 (c) element

32. The table is:

Element	Symbol	Number of Electrons
Molybdenum	Mo	42
Potassium	K	19
Titanium	Ti	22
Boron	B	5
Iodine	I	53
Samarium	Sm	62
Helium	He	2
Silicon	Si	14

36. To one decimal place, the proton and the neutron have equal masses, 1.0 amu. If the mass of a Be atom is roughly 9.0 amu and the atom has $Z = 4$, the other five amu must come from 5 neutrons, giving $A = 9$. We can make this simple addition, however, only because we are told that these isotopes exist as only a single isotope. Therefore, the 9.0 mass for Be from the periodic table is not an average of several isotopes. It is simply the mass of every Be atom. Likewise for the rest.

Element	Symbol
Beryllium	${}^9_4\text{Be}$
Rhodium	${}^{103}_{45}\text{Rh}$
Phosphorus	${}^{31}_{15}\text{P}$
Aluminum	${}^{27}_{13}\text{Al}$
Cesium	${}^{133}_{55}\text{Cs}$
Praseodymium	${}^{141}_{59}\text{Pr}$
Cobalt	${}^{59}_{27}\text{Co}$

Yttrium	${}_{39}^{89}\text{Y}$
Arsenic	${}_{33}^{75}\text{As}$

38. The element X is given directly by the atomic number Z.

Symbol	${}_{26}^{55}\text{X}$	${}_{33}^{74}\text{X}$	${}_{12}^{24}\text{X}$	${}_{53}^{127}\text{X}$	${}_{18}^{40}\text{X}$	${}_{63}^{152}\text{X}$
X	Fe	As	Mg	I	Ar	Eu

39. The table is:

Element	Classification	Type of metal
Molybdenum	metal	transition
Potassium	metal	alkali
Titanium	metal	transition
Boron	semimetal	—
Iodine	nonmetal	—
Samarium	metal	transition
Helium	nonmetal	—
Silicon	semimetal	—

42. The “periods” of the periodic table are the horizontal rows. The “groups” are the vertical columns. Thus, the sets in (c) and (d) are in the same period.

- (a) P: period 3; V: period 4; Ru: period 5
- (b) Li and C: period 2; Cl: period 3
- (c) Na, Mg, and S: period 3
- (d) Cr, Ni, and Kr: period 4

44. The “periods” of the periodic table are the horizontal rows. The “groups” are the vertical columns. Thus, the sets in (b) and (c) are in the same group. Note, in particular, Sm.

- (a) Na and Rb: Group 1; Ba: Group 2

- (b) N, P, and Bi: Group 15
- (c) Cu, Ag, and Au: Group 11
- (d) Mg and Sr: Group 2; Sm: Group 3

47. All except phosphorus are found in the “metals” section of the periodic table. Since malleability is a property of metals, all of those listed, except phosphorus, are *predicted* to be malleable.

48. All except sulfur and arsenic are metals. Since most metals have a shiny appearance, all are predicted to be lustrous, except sulfur and arsenic. Note that arsenic is a semimetal, and such a prediction is questionable.

73. See Example 1.6 in the text. The atomic mass of each element on the periodic table is the weighted average of all isotopes for a given element. The “weighting” is done with respect to the *fractional* abundance of each isotope. For copper:

$$\text{atomic mass of Cu} = (62.9298 \text{ amu})(0.6909) + (64.9278 \text{ amu})(0.3092) = 63.55 \text{ amu}$$

76. Problems 68 through 71 detail how to determine the needed information. See those solutions. Note that $^{40}\text{X} = ^{40}\text{Ca}$. The table is

Isotope	^{57}Fe	^{40}X	^{36}S
Number of protons	26	20	16
Number of neutrons	31	20	20
Number of electrons	26	20	16

34. A cation’s mass is slightly less than the mass of the parent atom, whereas an anion’s mass is slightly greater than the mass of the parent atom. The mass difference is, of course, due to the loss or gain of electrons, respectively. The mass change is slight, however, because the mass of an electron is only 1/1836 the mass of a proton. In stoichiometry calculations, which we will soon encounter, this difference is *very* often ignored, and a Ca^{2+} ion and a Ca atom are assumed to have a mass of 40.078 amu. To a very good approximation, this is true.

- 82.** The charge on ions is due to the loss or gain of *electrons* by the neutral atom. Remember that in any *chemical* reaction the number of protons does *not* change. In each case, then, first determine the number of electrons in the neutral atom. Next, add electrons to form anions or subtract electrons to form cations. For example, a neutral oxygen atom has 8 electrons. To form an O^{2-} ion, one must add two electrons to O. Therefore, O^{2-} has 10 electrons. Likewise for the rest: Ca^{2+} , 18 electrons; Ag^+ , 46 electrons; Se^{4+} , 30 electrons; Fe^{2+} , 24 electrons; Cl^- , 18 electrons.
- 25.** Avogadro's hypothesis, equal volumes of different gases contain equal numbers of gas particles, tells us that the answer is yes. As with the law of conservation of mass, this hypothesis is not strictly true. It is *very* nearly true, however, and it was a critical step in chemistry, allowing for *diatomic molecules*, such as H_2 and O_2 . The acceptance of diatomic molecules by chemists was, nonetheless, slow.
- 65.** A silicon atom has 14 electrons and 14 protons. Thus, the mass of the electrons in a silicon atom is $14m_e = 14(0.0005486 \text{ amu}) = 7.680 \times 10^{-3} \text{ amu}$, and the mass of the protons in a silicon atom is $14m_p = 14(1.007276 \text{ amu}) = 14.10186 \text{ amu}$. Since a silicon atom has a mass of 28.09 amu, the percentage of a silicon atom's mass due to the electrons is $(7.680 \times 10^{-3} \text{ amu} / 28.09 \text{ amu}) \times 100\% < 0.02734\%$. Likewise, the percentage of a silicon atom's mass due to the protons is $(14.10186 \text{ amu} / 28.09 \text{ amu}) \times 100\% < 50.20\%$.
- 80.** It is important to note that a sample of KBr contains all the isotopes of K and Br. As Exercise 1.5 and Example 1.6 in the text show, there are two isotopes of Br, but when solving problems such as this, assume that you can use the atomic mass from the periodic table, unless the problem specifies isotopes. Thus, the ratio of the mass of Br to K in every formula unit of KBr is $79.904 / 39.0983 = 2.0437$. Thus, the proportion of bromine is roughly 2 times greater than that of K.

Chapter 3

33. We will use the one step, unit conversion method. The atomic masses are from the periodic table in the text, and the rules for significant figures are observed. With practice you will find that obtaining molecular or formula masses is very easy.

(a) V_2O_4 contains 2 V atoms and 4 O atoms. Thus,

$$\begin{aligned} \text{FM} &= \left[2 \text{ atoms V} \left(\frac{50.9415 \text{ amu}}{1 \text{ atom V}} \right) + 4 \text{ atoms O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right] \\ &= 165.8806 \text{ amu} \end{aligned}$$

(b) $CaSiO_3$ contains 1 Ca atom, 1 Si atom, and 3 O atoms. Thus,

$$\begin{aligned} \text{FM} &= \left[1 \text{ atom Ca} \left(\frac{40.078 \text{ amu}}{1 \text{ atom Ca}} \right) + 1 \text{ atom Si} \left(\frac{28.0855 \text{ amu}}{1 \text{ atom Si}} \right) \right. \\ &\quad \left. + 3 \text{ atoms O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right] = 116.162 \text{ amu} \end{aligned}$$

(c) $BiOCl$ contains 1 Bi atom, 1 O atom, and 1 Cl atom. Thus,

$$\begin{aligned} \text{FM} &= \left[1 \text{ atom Bi} \left(\frac{208.98040 \text{ amu}}{1 \text{ atom Bi}} \right) + 1 \text{ atom O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right. \\ &\quad \left. + 1 \text{ atom Cl} \left(\frac{35.453 \text{ amu}}{1 \text{ atom Cl}} \right) \right] = 260.433 \text{ amu} \end{aligned}$$

(d) CH_3COOH contains 2 C atoms, 4 H atoms, and 2 O atoms. Thus,

$$\begin{aligned} \text{MM} &= \left[2 \text{ atoms C} \left(\frac{12.0107 \text{ amu}}{1 \text{ atom C}} \right) + 4 \text{ atoms H} \left(\frac{1.00794 \text{ amu}}{1 \text{ atom H}} \right) \right. \\ &\quad \left. + 2 \text{ atoms O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right] = 60.0520 \text{ amu} \end{aligned}$$

(e) Ag_2SO_4 contains 2 Ag atoms, 1 S atom, and 4 O atoms. Thus,

$$\text{FM} = \left[2 \text{ atoms Ag} \left(\frac{107.8682 \text{ amu}}{1 \text{ atom Ag}} \right) + 1 \text{ atom S} \left(\frac{32.065 \text{ amu}}{1 \text{ atom S}} \right) + 4 \text{ atoms O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right] = 311.799 \text{ amu}$$

(f) Na_2CO_3 contains 2 Na atoms, 1 C atom, and 3 O atoms. Thus,

$$\text{FM} = \left[2 \text{ atoms Na} \left(\frac{22.98976928 \text{ amu}}{1 \text{ atom Na}} \right) + 1 \text{ atom C} \left(\frac{12.0107 \text{ amu}}{1 \text{ atom C}} \right) + 3 \text{ atoms O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right] = 105.9884 \text{ amu}$$

(g) $(\text{CH}_3)_2\text{CHOH}$ contains 3 C atoms, 8 H atoms, and 1 O atom. Thus,

$$\text{MM} = \left[3 \text{ atoms C} \left(\frac{12.0107 \text{ amu}}{1 \text{ atom C}} \right) + 8 \text{ atoms H} \left(\frac{1.00794 \text{ amu}}{1 \text{ atom H}} \right) + 1 \text{ atom O} \left(\frac{15.9994 \text{ amu}}{1 \text{ atom O}} \right) \right] = 60.0950 \text{ amu}$$

- 35.** The number of mol n of A in a sample of compound A is determined from its mass and molar mass as follows:

$$n = \text{mass of A (g)} \left(\frac{1}{\text{molar mass of A (g/mol)}} \right)$$

The number of molecules N or formula units in a sample of compound A is determined from its mass and molar mass as follows:

$$N = \text{mass of A (g)} \left(\frac{1}{\text{molar mass of A (g/mol)}} \right) \left(\frac{6.0221 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \right)$$

The same formula is used for all parts. The first step, then, is to calculate the molar mass or formula mass of the compound in question. This process is shown in explicit detail in Examples 3.1 and 3.2 in the text and in the solution to Problem 33. If you are unsure how to determine a

molar or formula mass, refer to those areas. The molar masses are calculated from the periodic table in the text, following the rules for significant figures.

(a) We calculate n as follows:

$$n = 5.00 \times 10^2 \text{ g CaO} \left(\frac{1 \text{ mol CaO}}{56.077 \text{ g CaO}} \right) = 8.92 \text{ mol CaO}$$

We calculate N as follows:

$$N = 5.00 \times 10^2 \text{ g CaO} \left(\frac{1 \text{ mol CaO}}{56.077 \text{ g CaO}} \right) \left(\frac{6.0221 \times 10^{23} \text{ formula units}}{1 \text{ mol}} \right)$$
$$= 5.37 \times 10^{24} \text{ formula units CaO}$$

(b) We calculate n as follows:

$$n = 5.00 \times 10^2 \text{ g CaCO}_3 \left(\frac{1 \text{ mol CaCO}_3}{100.087 \text{ g CaCO}_3} \right) = 5.00 \text{ mol CaCO}_3$$

We calculate N as follows:

$$N = 5.00 \times 10^2 \text{ g CaCO}_3 \left(\frac{1 \text{ mol CaCO}_3}{100.087 \text{ g CaCO}_3} \right)$$
$$\times \left(\frac{6.0221 \times 10^{23} \text{ formula units}}{1 \text{ mol}} \right) = 3.01 \times 10^{24} \text{ formula units CaCO}_3$$

(c) We calculate n as follows:

$$n = 5.00 \times 10^2 \text{ g C}_{12}\text{H}_{22}\text{O}_{11} \left(\frac{1 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11}}{342.2965 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}} \right)$$

$$= 1.46 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11}$$

We calculate N as follows:

$$N = 5.00 \times 10^2 \text{ g C}_{12}\text{H}_{22}\text{O}_{11} \left(\frac{1 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11}}{342.2965 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}} \right)$$
$$\times \left(\frac{6.0221 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \right) = 8.80 \times 10^{23} \text{ molecules C}_{12}\text{H}_{22}\text{O}_{11}$$

(d) We calculate n as follows:

$$n = 5.00 \times 10^2 \text{ g NaOCl} \left(\frac{1 \text{ mol NaOCl}}{74.442 \text{ g NaOCl}} \right) = 6.72 \text{ mol NaOCl}$$

We calculate N as follows:

$$N = 5.00 \times 10^2 \text{ g NaOCl} \left(\frac{1 \text{ mol NaOCl}}{74.442 \text{ g NaOCl}} \right) \\ \times \left(\frac{6.0221 \times 10^{23} \text{ formula units}}{1 \text{ mol}} \right) = 4.04 \times 10^{24} \text{ formula units NaOCl}$$

(e) We calculate n as follows:

$$n = 5.00 \times 10^2 \text{ g CO}_2 \left(\frac{1 \text{ mol CO}_2}{44.0095 \text{ g CO}_2} \right) = 11.4 \text{ mol CO}_2$$

We calculate N as follows:

$$N = 5.00 \times 10^2 \text{ g CO}_2 \left(\frac{1 \text{ mol CO}_2}{44.0095 \text{ g CO}_2} \right) \left(\frac{6.0221 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \right) \\ = 6.84 \times 10^{24} \text{ molecules CO}_2$$

- 43.** (a) False. $\frac{1}{2}$ of a mol is 3.02×10^{23} particles, regardless of whether they are Cl_2 or H_2 molecules.
- (b) False. 1 mol of H_2 contains one mol of H_2 *molecules* and 2 mol H *atoms*.
- (c) True. Simply add atomic masses to verify.
- (d) False. Benzene is a covalent (molecular) compound. Therefore, chemists say that the *molecular* mass of benzene is 78 amu.

44. The solutions to Problems 32 through 43 demonstrate how to complete the table. Review the methods shown there if you get stuck. (Note that we have added the formula or

Substance	FM or MM	Mass, g	Number of Moles	Number of Molecules or Formula Units	Number of Atoms or Ions
MgCl ₂	95.211	37.62	0.3951	2.379×10^{23}	7.138×10^{23}
AgNO ₃	169.8731	482	2.84	1.71×10^{24}	8.55×10^{24}
BH ₄ Cl	50.296	7460	148	8.93×10^{25}	5.36×10^{26}
K ₂ S	110.262	46900	426	2.56×10^{26}	7.69×10^{26}
H ₂ SO ₄	98.078	127	1.29	7.77×10^{23}	5.44×10^{24}
C ₆ H ₁₄	86.1754	11.8	0.1374	8.274×10^{22}	1.655×10^{24}
HClO ₃	84.459	34400	407	2.45×10^{26}	1.23×10^{27}

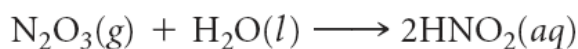
molecular mass to the table for convenience.) The values are obtained by rounding only at the end of the calculation needed to get to the appropriate column. For example, the K₂S mass is obtained without rounding at the intermediate columns along the way.

72. Pages 105 through 108 list the steps one can use to balance a chemical equation. Balancing by sight or *brief* trial and error can also be used. If you are randomly guessing for too long, you are wasting time. Use the steps of the uniform approach. Some equations, particularly oxidation-reduction equations, are impossible to balance by sight, or sometimes a single step is all that is needed.

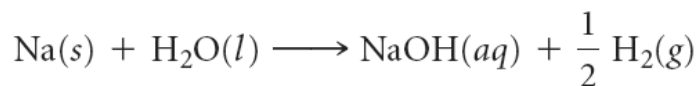
(a) A fractional coefficient (step 4) gets us to $\text{Be}(s) + \frac{1}{2}\text{O}_2(g) \rightarrow 2\text{BeO}(s)$.

Multiplication by two completes the equation: $2\text{Be}(s) + \text{O}_2(g) \rightarrow 2\text{BeO}(s)$

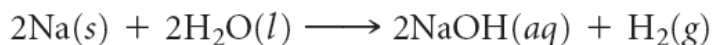
(b) Steps 1 and 2 indicate that we balance N first, which balances the equation:



(c) Na and O are already balanced, so a fractional coefficient (step 4) gets us to



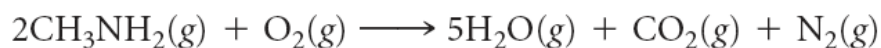
Multiplication by two completes the equation:



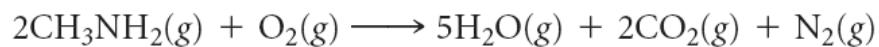
(d) Steps 1 and 2 suggest that we look at Ca and Cl first. Ca is balanced, and we balance Cl and the equation with a 2 as follows:



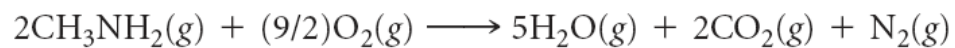
(e) H appears in only one reactant and product (steps 1 and 2). Balancing the H atoms also balances the N atoms and gives



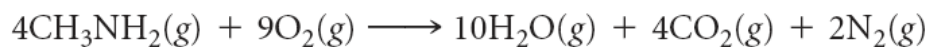
We turn to C now, not O, because C appears in only one reactant and product *and* is in the most complex substance (steps 1 and 2). A 2 in front of CO₂ does the trick:



Next, we balance O with a fraction (step 4):



Lastly, multiply through by 2 to get the completed equation:



(f) This equation is already balanced.

90. This is a limiting reactant problem, the kind discussed in Section 3.4 and Example 3.12. Balancing the equations will be up to you! Note that the phase labels on the first two equations are not a simple matter. In a sense, there is no “correct” answer in some cases. Consider the I_2 of part (b). I_2 is slightly soluble in water, allowing one to reasonably write $I_2(aq)$. If there is a lot of I_2 present, however, most of the product is $I_2(s)$, yet there is still a small amount of I_2 in solution. Focus on the balancing and the limiting reactant aspect in these cases. Lastly, note the water does *not appear in the reaction*, but you could write it over the arrow to indicate its presence.

(a) This is typical metal/nonmetal behavior, leading to: $Ba(s) + Br_2(aq) \rightarrow BaBr_2(aq)$. The mol n of each reactant are:

$$n(Ba) = \frac{2.46 \text{ g Ba}}{137.327 \text{ g/mol}} = 0.0179 \text{ mol Ba}$$

$$n(Br_2) = \frac{3.89 \text{ g Br}_2}{159.808 \text{ g/mol}} = 0.0243 \text{ mol Br}_2$$

The balanced equation indicates a 1:1 mole ratio, meaning that equal amounts (mol) of Ba and Br_2 will be consumed, leaving 0.0064 mol Br_2 . Br_2 is in excess.

(b) The reaction is $Br_2(aq) + 2KI(aq) \rightarrow 2KBr(aq) + I_2(aq)$. The mol n of each reactant are:

$$n(Br_2) = \frac{1.44 \text{ g Br}_2}{159.808 \text{ g/mol}} = 0.00901 \text{ mol Br}_2$$

$$n(KI) = \frac{2.42 \text{ g KI}}{166.0028 \text{ g/mol}} = 0.0146 \text{ mol KI}$$

The balanced equation indicates a 1:2 mole ratio, meaning that twice as many mol of KI will be consumed as mol of Br₂ during the course of the reaction. Thus, 2(0.00901 mol) = 0.0180 mol of KI are needed to consume 0.00901 mol Br₂. Since there is less KI than that, Br₂ is in excess.

- (c) The reaction is $\text{Zn}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{ZnSO}_4(aq) + \text{H}_2(g)$. See Problem 92. The mol n of each reactant are:

$$n(\text{Zn}) = \frac{1.852 \text{ g Zn}}{65.409 \text{ g/mol}} = 0.02831 \text{ mol Zn}$$

$$n(\text{H}_2\text{SO}_4) = \frac{3.62 \text{ g H}_2\text{SO}_4}{98.078 \text{ g/mol}} = 0.0369 \text{ mol H}_2\text{SO}_4$$

The balanced equation indicates a 1:1 mole ratio, meaning that equal amounts (mol) of Zn and H₂SO₄ will be consumed, leaving 0.0086 mol H₂SO₄. H₂SO₄ is in excess.

- (d) (We'll see more of this in Section 4.8 and Table 4.4.) The reaction is $\text{Fe}(s) + 2\text{AgC}_2\text{H}_3\text{O}_2(aq) \rightarrow \text{Fe}(\text{C}_2\text{H}_3\text{O}_2)_2(aq) + 2\text{Ag}(s)$. The mol n of each reactant are:

$$n(\text{Fe}) = \frac{0.147 \text{ g Fe}}{55.845 \text{ g/mol}} = 0.00263 \text{ mol Fe}$$

$$n(\text{AgC}_2\text{H}_3\text{O}_2) = \frac{0.924 \text{ g AgC}_2\text{H}_3\text{O}_2}{166.9122 \text{ g/mol}} = 0.00554 \text{ mol AgC}_2\text{H}_3\text{O}_2$$

The balanced equation indicates a Fe:AgC₂H₃O₂ mole ratio of 1:2, meaning that twice as much AgC₂H₃O₂ will be consumed as Fe. To consume 0.00263 mol Fe, we need 2(0.00263) = 0.00526 mol AgC₂H₃O₂. Thus, we have more than enough AgC₂H₃O₂ to consume all of the iron; AgC₂H₃O₂ is in excess by 0.00028 mol.

- (e) (We'll see much more on this in Section 4.5 and Table 4.1.) The reaction is $2(\text{NH}_4)_3\text{PO}_4(aq) + 3\text{Ba}(\text{OH})_2(aq) \rightarrow 6\text{NH}_4\text{OH}(aq) + \text{Ba}_3(\text{PO}_4)_2(s)$. The mol n of each reactant are:

$$n((\text{NH}_4)_3\text{PO}_4) = \frac{3.142 \text{ g } (\text{NH}_4)_3\text{PO}_4}{149.0867 \text{ g/mol}} = 0.02107 \text{ mol } (\text{NH}_4)_3\text{PO}_4$$

$$n(\text{Ba}(\text{OH})_2) = \frac{1.648 \text{ g Ba}(\text{OH})_2}{171.342 \text{ g/mol}} = 0.009618 \text{ mol Ba}(\text{OH})_2$$

The balanced equation indicates a (NH₄)₃PO₄:Ba(OH)₂ mole ratio of 2:3, meaning that two moles of (NH₄)₃PO₄ are required to consume 3 moles of Ba(OH)₂. The ratio of mol present is

$$\frac{n((\text{NH}_4)_3\text{PO}_4)}{n(\text{Ba}(\text{OH})_2)} = \frac{0.02107 \text{ mol}}{0.009618 \text{ mol}} = 2.191$$

Since a ratio of 0.667 (2:3) is present in the balanced equation, (NH₄)₃PO₄ is in excess. This reaction will consume all of the Ba(OH)₂, leaving 0.01466 mol (NH₄)₃PO₄.

103. (a) Limiting reactant problems are discussed in Section 3.4 and Example 3.12. Accounting for the impurity in the chlorobenzene, the mol n of each reactant are:

$$n(\text{C}_6\text{H}_5\text{Cl}) = \frac{0.92(20.0 \text{ g C}_6\text{H}_5\text{Cl})}{112.557 \text{ g/mol}} = 0.16 \text{ mol C}_6\text{H}_5\text{Cl}$$

$$n(\text{NH}_3) = \frac{8.30 \text{ g NH}_3}{17.0305 \text{ g/mol}} = 0.487 \text{ mol NH}_3$$

The balanced equation indicates that 2 mol of ammonia are needed for every 1 mol of $\text{C}_6\text{H}_5\text{Cl}$. Thus, 0.16 mol $\text{C}_6\text{H}_5\text{Cl}$ requires 0.32 mol NH_3 for stoichiometric equivalence. Since we have 0.487 mol NH_3 , all of the $\text{C}_6\text{H}_5\text{Cl}$ will be consumed; $\text{C}_6\text{H}_5\text{Cl}$ is the limiting reactant.

(b) From (a), NH_3 is in excess.

(c) Since $\text{C}_6\text{H}_5\text{Cl}$ is limiting, we calculate the theoretical yield (TY) of NH_4Cl as follows:

$$\begin{aligned} \text{TY}(\text{NH}_4\text{Cl}) &= 0.92(20.0 \text{ g C}_6\text{H}_5\text{Cl}) \left(\frac{1 \text{ mol C}_6\text{H}_5\text{Cl}}{112.557 \text{ g C}_6\text{H}_5\text{Cl}} \right) \left(\frac{1 \text{ mol NH}_4\text{Cl}}{1 \text{ mol C}_6\text{H}_5\text{Cl}} \right) \\ &\quad \times \left(\frac{53.491 \text{ g NH}_4\text{Cl}}{1 \text{ mol NH}_4\text{Cl}} \right) = 8.74 \text{ g NH}_4\text{Cl} \end{aligned}$$

(d) Equation 3.23 then gives

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{4.78 \text{ g}}{8.74 \text{ g}} \times 100\% = 54.7\%$$

(e) The general equation can be evaluated partially, incorporating the molar masses and mole ratio into a single number. First, the full general equation:

$$\begin{aligned} \text{TY}(\text{NH}_4\text{Cl}) &= 0.92(x \text{ g C}_6\text{H}_5\text{Cl}) \left(\frac{1 \text{ mol C}_6\text{H}_5\text{Cl}}{112.557 \text{ g C}_6\text{H}_5\text{Cl}} \right) \left(\frac{1 \text{ mol NH}_4\text{Cl}}{1 \text{ mol C}_6\text{H}_5\text{Cl}} \right) \\ &\quad \times \left(\frac{53.491 \text{ g NH}_4\text{Cl}}{1 \text{ mol NH}_4\text{Cl}} \right) = \text{g NH}_4\text{Cl} \end{aligned}$$

Evaluating this expression as much as we can gives:

$$\text{TY}(\text{NH}_4\text{Cl}) = (x \text{ g C}_6\text{H}_5\text{Cl}) \times 0.4372 = \text{g}(\text{NH}_4\text{Cl})$$

x is any initial amount of 92% pure $\text{C}_6\text{H}_5\text{Cl}$ that you might be given when ammonia is in excess.