Chapter 12
Stoichiometry

SCSh5.e: Solve scientific problems by substituting quantitative values, using dimensional analysis and/or simple algebraic formulas as appropriate.

SC2.d: Identify and solve different types of stoichiometry problems, specifically relating mass to moles and mass to mass.

SC2.e: Demonstrate the conceptual principle of limiting reactants.

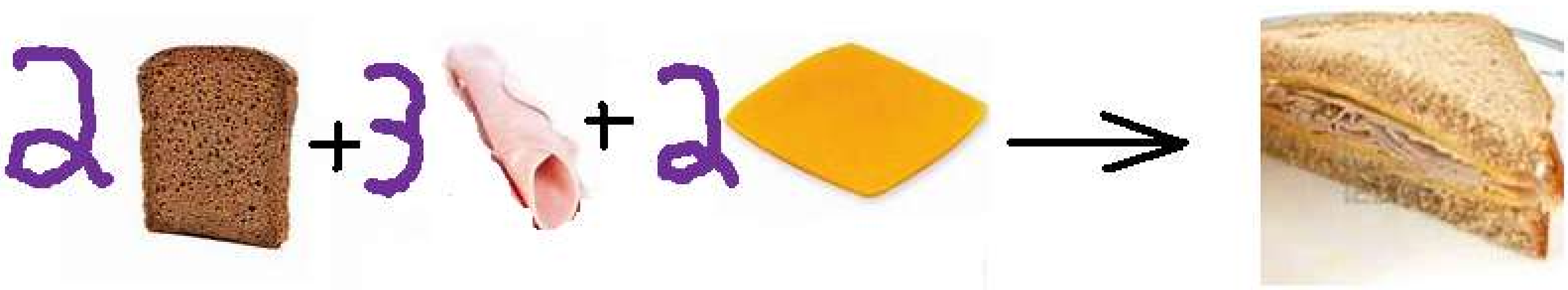
Online Resources:

Stoichiometry Practice Problems: http://mailer.fsu.edu/~rlight/stoich/

Click Stoichiomentry: http://misterguch.brinkster.net/explains2.html

Stoichiometry

- A balanced chemical equation provides the same kind of quantitative information that a recipe does.



- **Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or product is formed in a reaction.**

Stoichiometry

- Stoichiometry is the calculation of quantities in chemical reactions.
- When you know the quantity of one substance in a reaction, you can calculate the quantity of another substance consumed or created in the reaction.
- A quantity can be grams, moles, liters, molecules, atoms, ions, formula units or particles.

Stoichiometry

- A balanced equation indicates the number and type of each atom, molecules, and/or moles that makes up each reactant and each product
- A balanced chemical equation obeys the law of conservation of mass
  - The total number of grams of reactants DOES equal the total number of grams of product
- Assuming standard temperature and pressure, a balanced equation also tells you about the volume of gases.
- **Mass and atoms are conserved in every chemical reaction**

Stoichiometry

- Mole ratio is a conversion factor derived from **coefficients** of a balanced chemical equation interpreted in terms of moles.
- In chemical calculations, mole ratios are used to convert between
  - moles of reactants and moles of product,
  - or moles of products and moles of reactants
  - or between moles of two products, or two reactants
- **In the mole ratio you MUST use the COEFFICIENTS of the BALANCED chemical reaction**

Mole to Mole Conversion

- In order to do stoichiometry conversions you MUST have a balanced chemical reaction.
- Use our basic dimensional analysis set up…
  - Unit getting rid of on bottom, unit going to on top
  - NOT just the units, it is ALSO the chemical formulas

Example 1: If you decompose 6.50 moles of ammonia (NH3) how many moles of each product do you produce?

Skeleton equation: $NH_3 \rightarrow N_2 + H_2$

Balanced equation: $2NH_3 \rightarrow 1\ N_2 + 3\ H_2$

Mole to Mole Conversion

Example 1: If you decompose 6.50 moles of ammonia (NH_3) how many moles of each product do you produce?

Balanced equation: $2NH_3 \rightarrow 1\ N_2 + 3\ H_2$

$$6.50\ mol\ NH_3 \times \frac{1\ mol\ N_2}{2\ mol\ NH_3} = 3.25\ mol\ N_2$$

$$6.50\ mol\ NH_3 \times \frac{3\ mol\ H_2}{2\ mol\ NH_3} = 9.75\ mol\ H_2$$

Mole to Mole Conversion

$3\ Na_2S + 2AlP \rightarrow 2Na_3P + Al_2S_3$

Example 2: 72.50 mol of Na_2S would produce how many moles of Na_3P?

$$72.50\ mol\ Na_2S \times \frac{2\ mol\ Na_3P}{3\ molNa_2S} = 48.33\ mol\ Na_3P$$

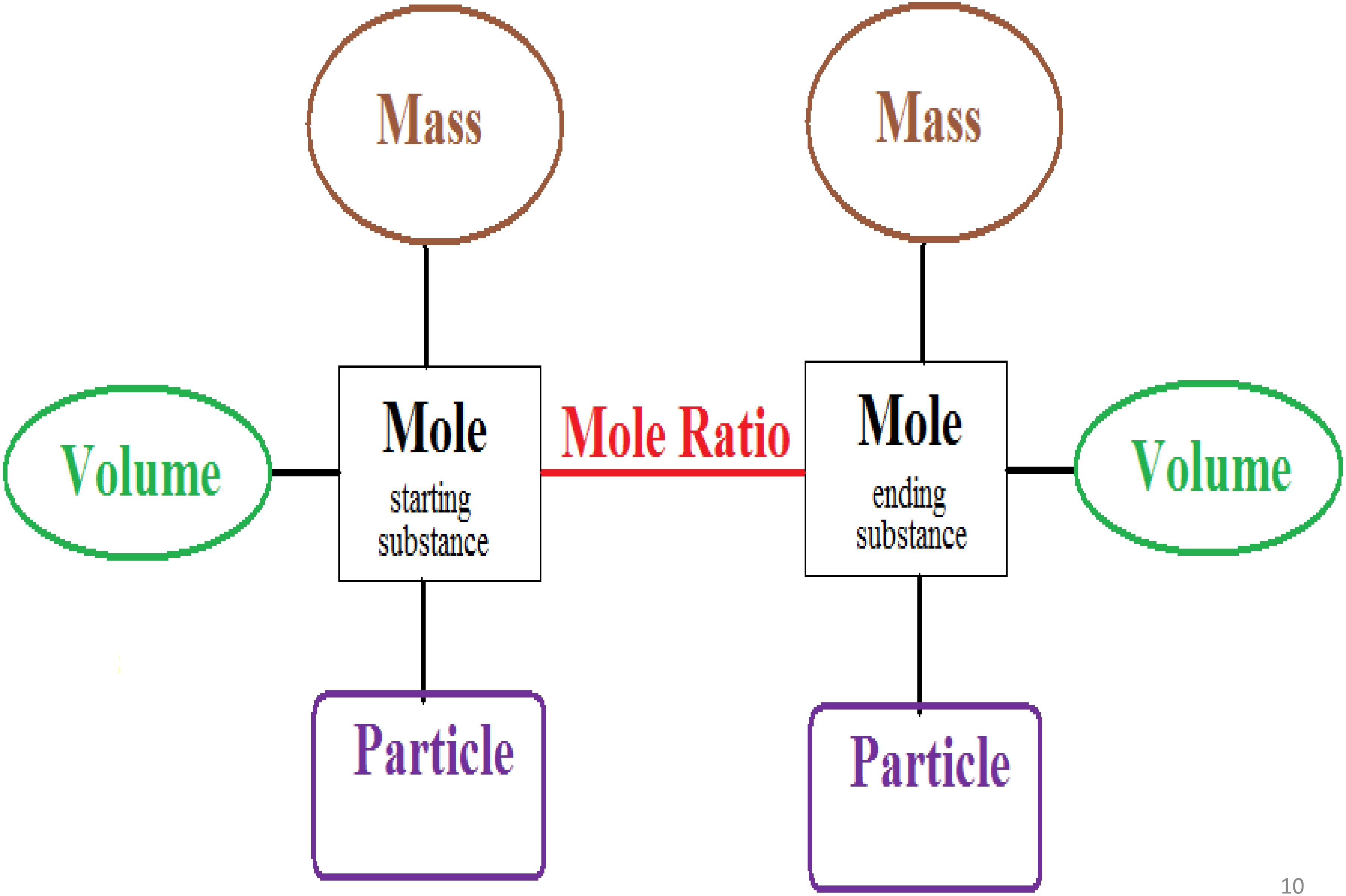
Example 3: 14.45 mol Al_2S_3 was produce by how many moles of AlP?

$$14.45\ mol\ Al_2S_3 \times \frac{2\ molmol\ AlP}{1\ mol\ Al_2S_3} = 28.90\ mol\ AlP$$

Things to remember

- You MUST have a balanced chemical equation to do ANY mole to mole conversions.
- The coefficients in the balanced chemical reaction are used in the mole ratio ONLY
- Mole ratios are the ONLY place that you can switch substances. Can do this [$\frac{gNaCl}{g\,HF}$], you can only go from gram to mole, volume to mole, particles to mole
- The starting amount (# given in the problem) is only written ONE time, and never in a conversion fraction.
- Any time you have a reactant in excess it does NOT affect calculations (you can ignore it)

New Mole Map


Mass
Mass
Volume
Mole
starting
substance
Mole Ratio
Mole
ending
substance
Volume
Particle
Particle

Terminology

- Theoretical yield is the maximum amount of product that will form during a reaction.
- Any time you are calculating the amount of product produced you are calculating theoretical yield.
- Actual yield is the amount of product that actually forms when the reaction is carried out in a *laboratory*.

Stoichiometry Calculations

1. the first step is to convert the give substance measurement to moles. (if not starting with moles)
2. Next use the mole ratio to switch between substances
3. Finally convert to the desired substance to the correct unit for the final answer.

Use your mole map to help determine the number of fractions needed to do conversion.

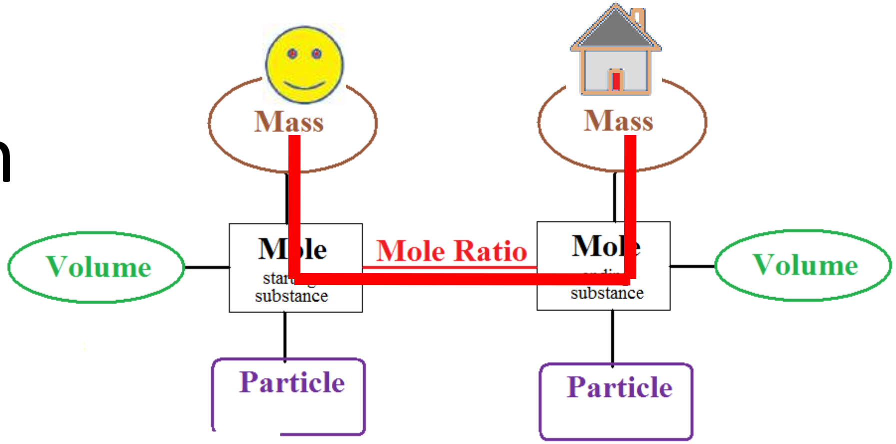
Mass to Mass Conversion

$2NH_3 \rightarrow 1\ N_2 + 3\ H_2$

Example 1: 48.38 g NH_3 would produce how many grams of nitrogen.

Use map to lay out our path

3 bridges = 3 fractions



$$48.38\ g\ NH_3 \times \frac{1\ mol\ NH_3}{17.04\ g\ NH_3} \times \frac{1\ mol\ N_2}{2\ mol\ NH_3} \times \frac{28.02\ g\ N_2}{1\ mol\ N_2} = 39.78\ g\ N_2$$

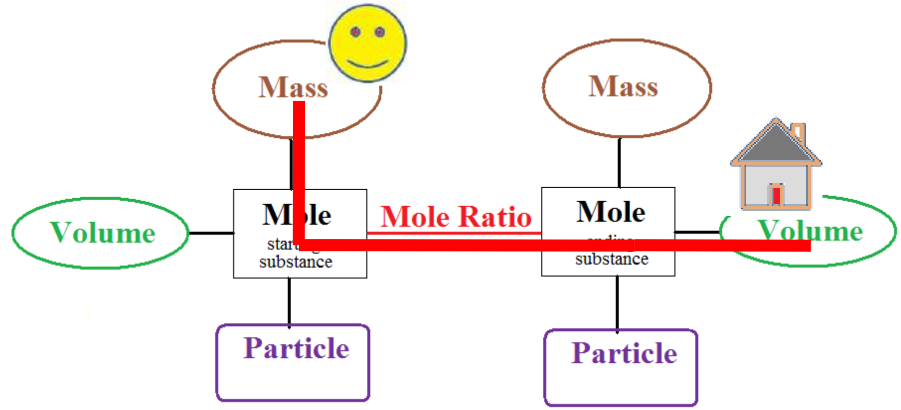
Example 2: 48.38 g NH_3 would produce how many grams of hydrogen

$$48.38\ g\ NH_3 \times \frac{1\ mol\ NH_3}{17.04\ g\ NH_3} \times \frac{3\ mol\ H_2}{2\ mol\ NH_3} \times \frac{2.02\ g\ H_2}{1\ mol\ H_2} = 8.603\ g\ H_2$$

Mass to Volume Conversion

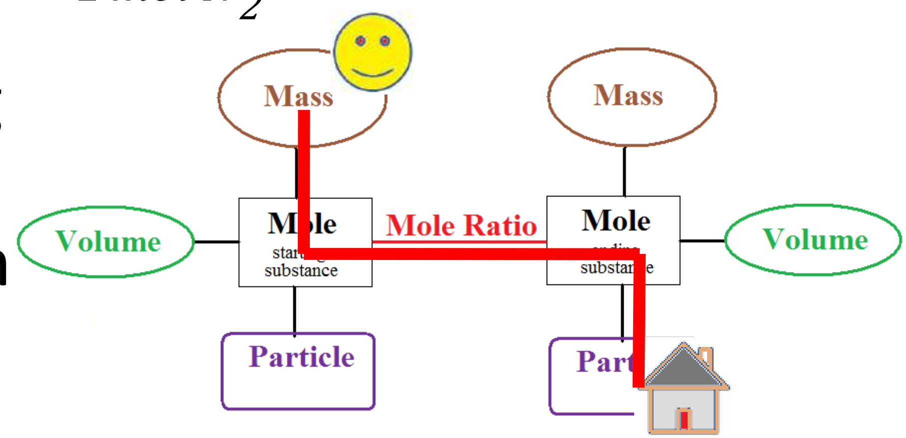
$2NH_3 \rightarrow 1\ N_2 + 3\ H_2$

Example 3: 48.38 g NH_3 would produce how many liters of nitrogen.



$$48.38\ g\ NH_3 \times \frac{1\ mol\ NH_3}{17.04\ g\ NH_3} \times \frac{1\ mol\ N_2}{2\ mol\ NH_3} \times \frac{22.4\ L\ N_2}{1\ mol\ N_2} = 31.80L\ N_2$$

Example 4: If you have 68.92 g NH_3 what would the theoretical yield of hydrogen be in molecules?



$$68.92g\ NH_3 \times \frac{1\ mol\ NH_3}{17.04\ gNH_3} \times \frac{3\ mol\ H_2}{2\ mol\ NH_3} \times \frac{6.02 \times 10^{23}\ mlcs\ H_2}{1\ mol\ H_2}$$

$$= 3.659 \times 10^{24} mlcs\ H_2$$

Things to remember

- UNLESS it is a mole ratio mole always has a 1 in front of it.
- The numbers for the mole ratio come from the BALANCED chemical equation.
- Use your mole map to see how many steps it will take
- There are only 4 valid possible options.
  - 1 mole = (molar mass) g
  - 1 mole = 22.4 L
  - 1 mole = 6.02 x 1023 particles
  - __ mole X = _____ mole Y (___ come from equation)

Terminology Part II

- Limiting reagent is the reagent that determines the amount of product that can be formed by a reaction.
- Excess reagent is the reactant that is not completely used up in a reaction.
  – To determine the limiting reactant convert one reactant into grams of second reactant
  – Compare the two values
    - If you won't have enough of the second reactant it is the limiting
    - If you have enough of the second reactant it is the excess reagent

Limiting Reactant example 1

If starting with 6.25 g Na_3P and 5.88 g CaF_2 what is the limiting reactant?

__ Na_3P + __ CaF_2 → __ NaF + __ Ca_3P_2

Balanced: 2 Na_3P + 3 CaF_2 → 6 NaF + 1 Ca_3P_2

$$6.25 g\ Na_3P \times \frac{1\ mol\ Na_3P}{99.94\ g\ Na_3P} \times \frac{3\ mol\ CaF_2}{2\ mol\ Na_3P} \times \frac{78.08\ g\ CaF_2}{1\ mol\ CaF_2}$$

$$= \mathbf{7.32\ g\ CaF_2}$$

This says we NEED 7.32 g CaF_2 but we only have 5.88 g CaF_2
Since we don't have enough of it CaF_2 is the limiting
And Na_3P is the excess reagent

Limiting Reactant example 2

If starting with 25.0 grams of each reactant determine the limiting reagent : $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

$$25.0g\ C_3H_8 \times \frac{1\ mol C_3H_8}{44.11\ g C_3H_8} \times \frac{5\ mol\ O_2}{1\ mol C_3H_8} \times \frac{32.00\ g\ O_2}{1\ mol\ O_2}$$

$$= 90.7\ g\ O_2$$

We have 25.0 grams of oxygen

we need 90.7 g oxygen

Oxygen is the limiting reagent because we don’t have enough of it.

The excess reagent is the C_3H_8

Limiting Reactant example 3

If starting with 2.50g S_8 and 3.54 g O_2 determine the limiting reagent : $S_8 + 12\ O_2 \rightarrow 8SO_3$

$$2.50g\ S_8 \quad \times \frac{1\ mol S_8}{256.56\ g\ S_8} \times \frac{12\ mol\ O_2}{1\ mol S_8} \times \frac{32.00\ g\ O_2}{1\ mol\ O_2}$$

$$= 3.74\ g\ O_2$$

We have 3.54 grams of oxygen

we need 3.74 g oxygen

Oxygen is the limiting reagent because we don’t have enough of it.

The S_8 is the excess reagent

Limiting Reactant (Reagent)

- Just by looking at the starting masses it is IMPOSSIBLE to determine the limiting reactant
- Just by looking at the coefficients it is IMPOSSIBLE to determine the limiting reactant
- **You can only determine limiting reactant IF you are comparing the same COMPOUND and same UNIT.**

Terminology Part III

- Excess reagent is the reactant that is not completely used up in a reaction.
  - To determine the excess remaining covert the limiting reactant to excess reactant and subtract that number from the stating amount of excess reactant.

Amount of Excess Remaining

If starting with 6.25 g Na_3P and 5.88 g CaF_2. How much excess remains after reaction?

2 Na_3P + 3 CaF_2 → 6 NaF + 1 Ca_3P_2

Recall that the limiting in this reaction was the CaF_2

$$5.88\ g\ CaF_2 \quad \times \frac{1\ mol\ CaF_2}{78.08\ g\ CaF_2} \times \frac{2\ mol Na_3P}{3\ mol\ CaF_2} \times \frac{99.94\ g\ Na_3P}{1\ mol Na_3P}$$

We used 5.02 grams of Na_3P

$$= 5.02\ g\ Na_3P$$

Excess remaining = Starting amount – amount used

Excess Remaining = 6.25 g Na_3P – 5.02 g Na_3P = 1.23 g Na_3P

Limiting and Excess Example

If starting with 15.0g C_2H_8 and 75.0 g O_2

$$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$$

a) determine the limiting reagent

b) the grams of excess reagent left after the reaction:

$$15.0g\ C_2H_6 \times \frac{1\ mol C_2H_6}{30.08\ g\ C_2H_6} \times \frac{7\ mol\ O_2}{2\ mol C_2H_6} \times \frac{32.00\ g\ O_2}{1\ mol\ O_2} = 55.9\ g\ O_2$$

We have 75.0 grams of oxygen

we need 55.85g oxygen

We have more than we need so Oxygen is the excess.

a) So The limiting reagent is the C_2H_6

b) excess remaining: 75.0 O_2 – 55.9 g O_2 = 19.1 g O_2

Terminology Part IV

- Percent yield is the ratio of the actual yield to the theoretical yield expressed as a percent.
- $$Percent\ yield = \frac{actual\ yield}{theoretical\ yield} x\ 100\ \%$$
- **The percent yield is a measurement of the efficiency of a reaction carried out in the laboratory.**
- Unless you are actually conducting the experiment the actual yield would have to be give to you in the problem.

Percent Yield

- What is the theoretical yield of P_2O_5 if you have 5.25 g O_2? What is the percent yield if you actually produced 8.34 g P_2O_5? $4P + 5O_2 \rightarrow 2P_2O_5$

$$5.25\, g\, O_2 \times \frac{1\, mol\, O_2}{32.00\, gO_2} \times \frac{2\, mol\, P_2O_5}{5\, molO_2} \times \frac{141.94\, g\, P_2O_5}{1\, mol\, P_2O_5} = 9.31\, g\, P_2O_5$$

- Theoretical yield of P_2O_5 is 9.31g

Percent yield = $\frac{actual}{theoretical} \times 100$

Percent yield = $\frac{8.34\, g}{9.31\, g} \times 100 = 89.6$

$\%\ yeild\ of\ P_2O_5$

Everything combined

$2Na_3PO_4 + 3CaCl_2 \rightarrow Ca_3(PO_4)_2 + 6NaCl$

If you have 2.38 g Na_3PO_4 and 6.98 g $CaCl_2$

a. determine the limiting reagent
b. Calculate the theoretical yield of NaCl (you MUST use the limiting as your starting point)
c. Calculate the mass of excess reagent left after the reaction
d. If you actually produced 1.56 g NaCl what is the percent yield for this reaction?

Everything combined

$$2Na_3PO_4 + 3CaCl_2 \rightarrow Ca_3(PO_4)_2 + 6NaCl$$

If you have 2.38 g Na_3PO_4 and 6.98 g $CaCl_2$

a. determine the limiting reagent

Turn grams of one reactant into grams of the other

$$2.38\ g\ Na_3PO_4 \times \frac{1\ mol\ Na_3PO_4}{163.94 g Na_3PO_4} \times \frac{3\ mol\ CaCl_2}{2\ mol\ Na_3PO_4} \times \frac{110.98\ g\ CaCl_2}{1\ mol\ CaCl_2}$$

$$= 2.42\ g\ CaCl_2$$

We have 6.98 g $CaCl_2$ and we need 2.42 g $CaCl_2$ so it is the excess reagent

Na_3PO_4 is the limiting reagent

Everything combined

$2Na_3PO_4 + 3CaCl_2 \rightarrow Ca_3(PO_4)_2 + 6NaCl$

If you have 2.38 g Na_3PO_4 and 6.98 g $CaCl_2$

b. Calculate the theoretical yield of NaCl (you MUST use the limiting as your starting point)

$$2.38\ g\ Na_3PO_4 \times \frac{1\ mol\ Na_3PO_4}{163.94 g Na_3PO_4} \times \frac{6\ mol\ NaCl}{2\ mol\ Na_3PO_4} \times \frac{58.44\ g\ NaCl}{1\ mol\ NaCl}$$

$$= 2.55\ g\ NaCl$$

Everything combined

$$2Na_3PO_4 + 3CaCl_2 \rightarrow Ca_3(PO_4)_2 + 6NaCl$$

If you have 2.38 g Na_3PO_4 and 6.98 g $CaCl_2$

c) Calculate the mass of excess reagent left after the reaction

$$2.38\ g\ Na_3PO_4 \times \frac{1\ mol\ Na_3PO_4}{163.94 g Na_3PO_4} \times \frac{3\ mol\ CaCl_2}{2\ mol\ Na_3PO_4} \times \frac{110.98\ g\ CaCl_2}{1\ mol\ CaCl_2}$$

$$= 2.42\ g\ CaCl_2$$

Excess remaining

6.98 $CaCl_2$ – 2.42 g $CaCl_2$ = 4.56 g $CaCl_2$

Everything combined

$2Na_3PO_4 + 3CaCl_2 \rightarrow Ca_3(PO_4)_2 + 6NaCl$

If you have 2.38 g Na_3PO_4 and 6.98 g $CaCl_2$

d) If you actually produced 1.56 g NaCl what is the percent yield for this reaction?

$$\frac{1.56\ g\ NaCl}{2.55\ g\ NaCl} \times 100 = 61.2\ \%$$

NaCl