

## Unit 7

On completion of the unit you should be able to:

1. interpret balanced equations in terms of moles, mass units and number of particles.
2. given the number of moles (or mass or number of particles) of one substance calculate the number of moles ( or mass or number of particles) of another substance in the balanced equation.
3. define limiting and excess reactants.

### CALCULATIONS INVOLVING CHEMICAL REACTIONS

#### 7.1 Coefficients of a chemical reaction

Reading: Hebden – page 123-124

#### 7.2 Calculations based on chemical equations

- Mole-mole calculation
- Mass-mass calculation
- Mass-mole calculation
- Limiting reagent calculation
- Calculations involving neutralization reactions

Reading: Hebden – page 125-133

#### PROBLEMS:

Practice Calculations

Today's focus.



# Calculations based on Chemical equations

Given moles, calculate moles

## 2. Mole-mole calculation

[[http://nobel.scas.bcit.ca/wiki/index.php/Calculations\\_based\\_on\\_chemical\\_equations\\_-\\_mole-mole\\_calculation](http://nobel.scas.bcit.ca/wiki/index.php/Calculations_based_on_chemical_equations_-_mole-mole_calculation)]

How many moles of oxygen gas is required to burn 3.60 moles of ethyl alcohol,  $C_2H_5OH$ ?

### Step 1: Identify the chemical equation involved

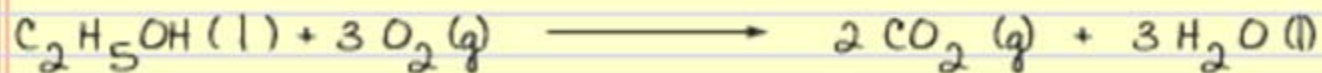
#### Step 1:

This is a combustion reaction involving a compound containing Carbon, Hydrogen and Oxygen.  
The products of the reaction are carbon dioxide and water.

### Step 2: Write the balanced chemical equation.

#### Step 2:

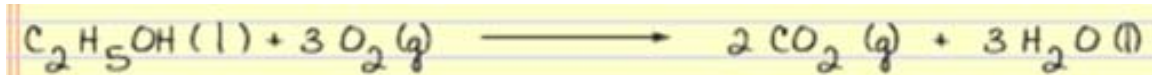
The balanced chemical equation is:



# Calculations based on Chemical equations

Given moles, calculate moles

## 2. Mole-mole calculation



How many moles of oxygen gas is required to burn 3.60 moles of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ ?

**Step 3:** Determine the mole ratio of the substances that you are working with specifically between ethyl alcohol and oxygen.

**Step 3:**  
For this question, I'm interested in the mole ratio of  $\text{C}_2\text{H}_5\text{OH}$  and  $\text{O}_2$ .  
3 moles of  $\text{O}_2$  is required to burn 1 mole of  $\text{C}_2\text{H}_5\text{OH}$   
Mole ratio is 3:1  $\text{O}_2$ :  $\text{C}_2\text{H}_5\text{OH}$

**Step 4:** Calculate the number of moles of oxygen by making the ratio specifically for 3.60 moles of ethyl alcohol.

**Step 4:**  
if 3 moles of  $\text{O}_2$  is required to burn 1 mole of  $\text{C}_2\text{H}_5\text{OH}$   
then x moles of  $\text{O}_2$  is required to burn 3.60 moles of  $\text{C}_2\text{H}_5\text{OH}$   
Set up the ratio mathematically  
$$\frac{3}{x} = \frac{1}{3.60}$$
  
$$x = 3(3.60) = \underline{\underline{10.8 \text{ moles of } \text{O}_2(\text{g})}}$$

# Calculations based on Chemical equations

Given mass, calculate mass

## 3. Mass-mass calculation

[[http://nobel.scas.bcit.ca/wiki/index.php/Calculations\\_based\\_on\\_chemical\\_equations\\_-\\_mass-mass\\_calculation](http://nobel.scas.bcit.ca/wiki/index.php/Calculations_based_on_chemical_equations_-_mass-mass_calculation)]

How many grams of oxygen gas is required to burn 20.5 grams of ethyl alcohol,  $C_2H_5OH$ ?

**Step 1:** Identify the chemical equation involved: a combustion reaction.

**Step 2:** Write the balanced chemical equation.

**Step 1:**  
This is a combustion reaction involving a compound containing Carbon, Hydrogen and Oxygen.  
The products of the reaction are carbon dioxide and water.

**Step 2:**  
The balanced chemical equation is:

$$C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)$$

**Step 2a:** Convert the mass of  $C_2H_5OH$  to moles of  $C_2H_5OH$ .

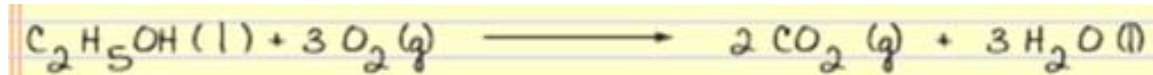
**Step 2a:**  
Molar mass of  $C_2H_5OH$  is 46.0 g/mole

$$\frac{20.5 \text{ grams}}{46.069 \text{ grams/mole}} = 0.444987 \text{ moles (calculation answer)}$$

# Calculations based on Chemical equations

Given mass, calculate mass

## 3. Mass-mass calculation



How many grams of oxygen gas is required to burn 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ ?

**Step 3:** Determine the mole ratio of the substances that you are working with specifically between ethyl alcohol and oxygen.

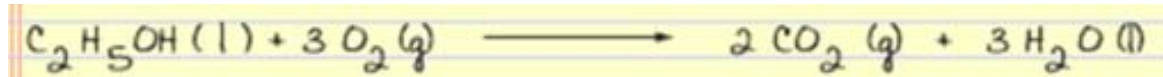
**Step 3:**  
For this question, I'm interested in the mole ratio of  $\text{C}_2\text{H}_5\text{OH}$  and  $\text{O}_2$ .  
3 moles of  $\text{O}_2$  is required to burn 1 mole of  $\text{C}_2\text{H}_5\text{OH}$   
Mole ratio is 3:1  $\text{O}_2$ :  $\text{C}_2\text{H}_5\text{OH}$



# Calculations based on Chemical equations

Given mass, calculate mass

## 3. Mass-mass calculation



How many grams of oxygen gas is required to burn 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ ?

**Step 4:** Calculate the number of moles of oxygen by making the ratio specifically for the number of moles of  $\text{C}_2\text{H}_5\text{OH}$ .

**Step 4:**

if 3 moles of  $\text{O}_2$  is required to burn 1 mole of  $\text{C}_2\text{H}_5\text{OH}$   
then  $x$  moles of  $\text{O}_2$  is required to burn 0.444987 moles of  $\text{C}_2\text{H}_5\text{OH}$

Set up the ratio mathematically

$$\frac{3}{x} = \frac{1}{0.444987}$$
$$x = 3 (0.444987) = 1.334961 \text{ moles of } \text{O}_2(\text{g})$$

**Step 5:** Convert the number of moles of oxygen obtained in step 4 to mass of oxygen.

**Step 5:**

Molar mass of  $\text{O}_2(\text{g})$  is 31.998 g/mole

$$1.334961 \text{ moles} \times 31.998 \frac{\text{grams}}{\text{mole}} = \underline{42.7 \text{ grams of } \text{O}_2(\text{g})}$$

(3 significant figures)

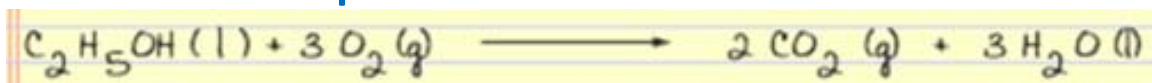
42.7 grams of oxygen gas is required to completely burn 20.5 grams of ethyl alcohol.

# Calculations based on Chemical equations

Given mass, calculate mole

## 4. Mass-mole calculation

[[http://nobel.scas.bcit.ca/wiki/index.php/Calculations\\_based\\_on\\_chemical\\_equations\\_-\\_mass-mole\\_calculation](http://nobel.scas.bcit.ca/wiki/index.php/Calculations_based_on_chemical_equations_-_mass-mole_calculation)]



How many moles of  $\text{CO}_2$  gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , is burned?

**Step 1:** Identify the chemical equation involved: a combustion reaction.

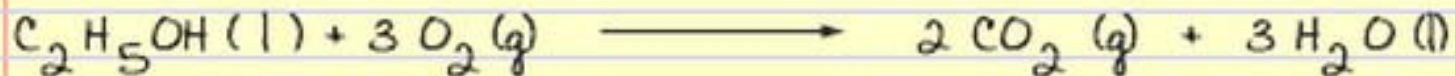
**Step 2:** Write the balanced chemical equation.

Step 1:

This is a combustion reaction involving a compound containing Carbon, Hydrogen and Oxygen.  
The products of the reaction are carbon dioxide and water.

Step 2:

The balanced chemical equation is:



**Step 2a:** Convert the mass of  $\text{C}_2\text{H}_5\text{OH}$  to moles of  $\text{C}_2\text{H}_5\text{OH}$ .

Step 2a:

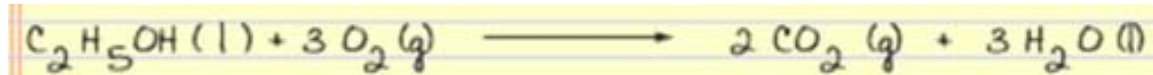
Molar mass of  $\text{C}_2\text{H}_5\text{OH}$  is 46.0 g/mole

$$\frac{20.5 \text{ grams}}{46.069 \text{ grams/mole}} = 0.444987 \text{ moles (calculation answer)}$$

# Calculations based on Chemical equations

Given mass, calculate mole

## 4. Mass-mole calculation



How many moles of  $\text{CO}_2$  gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , is burned?

**Step 3:** Determine the mole ratio of the substances that you are working with specifically between ethyl alcohol and oxygen.

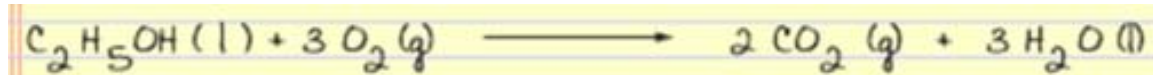
**Step 3:** Mole ratio of  $\text{CO}_2 : \text{C}_2\text{H}_5\text{OH}$  is 2:1.



# Calculations based on Chemical equations

Given mass, calculate mole

## 4. Mass-mole calculation



How many moles of  $\text{CO}_2$  gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , is burned?

**Step 4:** Calculate the number of moles of  $\text{CO}_2$  by making the ratio specifically for the number of moles of  $\text{C}_2\text{H}_5\text{OH}$  from step 2a.

Step 4:

if 2 moles of  $\text{CO}_2$  is produced for 1 mole of  $\text{C}_2\text{H}_5\text{OH}$  burned, then  $x$  moles of  $\text{CO}_2$  is produced for 0.444987 moles of  $\text{C}_2\text{H}_5\text{OH}$  burned.

Set up the ratio mathematically

$$\frac{2}{x} = \frac{1}{0.444987}$$
$$x = 2 (0.444987) = \underline{0.890 \text{ moles of } \text{CO}_2(g)}$$

(3 significant figures)

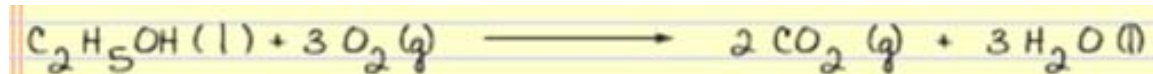
0.890 moles of carbon dioxide is produced when 20.5 grams of ethyl alcohol is burned.

# Calculations based on Chemical equations

## 5. Limiting reagent calculation

[[http://nobel.scas.bcit.ca/wiki/index.php/Limiting\\_Reactant\\_Calculations](http://nobel.scas.bcit.ca/wiki/index.php/Limiting_Reactant_Calculations)]

One reactant is in excess and the other is used up.



- (a) How many grams of carbon dioxide gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , burns with 100.0 grams of oxygen,  $\text{O}_2$ ?
- (b) Identify the limiting reagent and how much of the other reactant is left over?

**Step 1:** Identify the chemical equation involved: a combustion reaction.

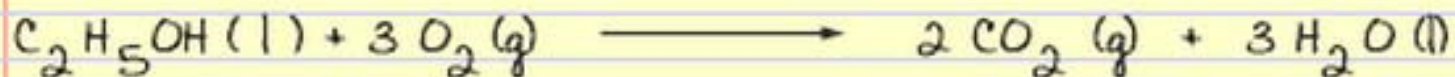
**Step 2:** Write the balanced chemical equation.

### Step 1:

This is a combustion reaction involving a compound containing Carbon, Hydrogen and Oxygen.  
The products of the reaction are carbon dioxide and water.

### Step 2:

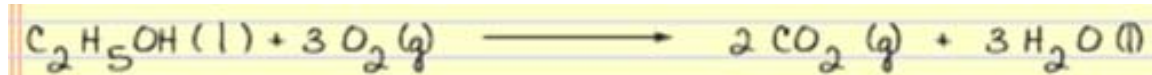
The balanced chemical equation is:



# Calculations based on Chemical equations

One reactant is in excess and the other is used up.

## 5. Limiting reagent calculation



- (a) How many grams of carbon dioxide gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , burns with 100.0 grams of oxygen,  $\text{O}_2$ ?
- (b) Identify the limiting reagent and how much of the other reactant is left over?

**Step 2a:** Convert the mass of  $\text{C}_2\text{H}_5\text{OH}$  to moles of  $\text{C}_2\text{H}_5\text{OH}$ .

Step 2a:

Molar mass of  $\text{C}_2\text{H}_5\text{OH}$  is 46.0 g/mole

$$\frac{20.5 \text{ grams}}{46.069 \frac{\text{grams}}{\text{mole}}} = 0.444987 \text{ moles (calculation answer)}$$

**Step 2b:** Convert the mass of  $\text{O}_2$  to moles of  $\text{O}_2$ .

Step 2b:

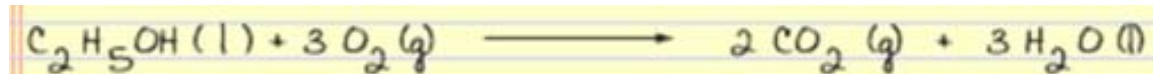
Molar mass of  $\text{O}_2(\text{g})$  is 31.998 g/mole

$$\frac{100.0 \text{ grams}}{31.998 \frac{\text{grams}}{\text{mole}}} = 3.1251953 \text{ moles (calculator answer)}$$

# Calculations based on Chemical equations

## 5. Limiting reagent calculation

One reactant is in excess and the other is used up.



- (a) How many grams of carbon dioxide gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , burns with 100.0 grams of oxygen,  $\text{O}_2$ ?
- (b) Identify the limiting reagent and how much of the other reactant is left over?

**Step 3:** Determine the mole ratio of the substances that you are working with.

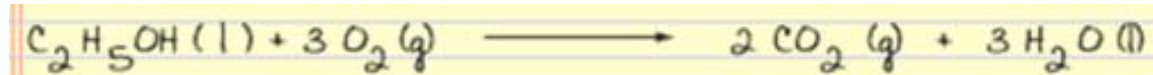
**Step 3:** Mole ratio of the substances that you are working with, specifically:

- between  $\text{C}_2\text{H}_5\text{OH}$  and  $\text{O}_2$  1:3
- between  $\text{C}_2\text{H}_5\text{OH}$  and  $\text{CO}_2$  1:2
- between  $\text{O}_2$  and  $\text{CO}_2$  3:2

# Calculations based on Chemical equations

One reactant is in excess and the other is used up.

## 5. Limiting reagent calculation



- (a) How many grams of carbon dioxide gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , burns with 100.0 grams of oxygen,  $\text{O}_2$ ?
- (b) Identify the limiting reagent and how much of the other reactant is left over?

**Step 4:** Determine which is present as the limiting reagent and which is present in excess.

Step 4:

From Steps 2a and 2b, the mole ratio of  $\text{O}_2 : \text{C}_2\text{H}_5\text{OH}$  is

100.0 g oxygen and 20.5 g ethyl alcohol has this mole ratio!  $\rightarrow 3.1251953 : 0.444987$

divide by 0.444987, to ratio it to 1 mole of  $\text{C}_2\text{H}_5\text{OH}$

$3.125195 : 0.444987$   
 $0.444987 : 0.444987$

$7.023116 : 1$

From the balanced chemical equation,  
3 moles of  $\text{O}_2$  is required to burn 1 mole of  $\text{C}_2\text{H}_5\text{OH}$  for ease of comparison

Mole ratio is  $(3:1) \text{O}_2 : \text{C}_2\text{H}_5\text{OH}$

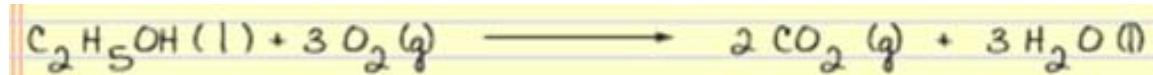
From the  $\sim 7 : 1$  mole ratio, we conclude that we have an excess amount of oxygen. In other words, we will run out of  $\text{C}_2\text{H}_5\text{OH}$  first.



# Calculations based on Chemical equations

One reactant is in excess and the other is used up.

## 5. Limiting reagent calculation



- (a) How many grams of carbon dioxide gas is produced when 20.5 grams of ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , burns with 100.0 grams of oxygen,  $\text{O}_2$ ?
- (b) Identify the limiting reagent and how much of the other reactant is left over?

**Step 5:** Calculate the amount of reactant that is left over.

Step 5:  
Recap from Step 4 -  $\text{C}_2\text{H}_5\text{OH}$  is the limiting reagent  
 $\text{O}_2$  is in excess  
- 20.5 grams ethyl alcohol is 0.444987 moles of ethyl alcohol (step 2a)  
- 100.0 g of oxygen is 3.1251953 moles of oxygen (step 2b)

$$0.444987 \text{ moles } \text{C}_2\text{H}_5\text{OH} \times \frac{2 \text{ moles } \text{CO}_2}{1 \text{ mole } \text{C}_2\text{H}_5\text{OH}} \times \frac{44.009 \text{ g}}{1 \text{ mole } \text{CO}_2}$$

$$= 39.2 \text{ grams } \text{CO}_2 \text{ produced}$$

The balanced chemical equation tells us that the ratio of  $\text{O}_2 : \text{C}_2\text{H}_5\text{OH}$  is 3:1

Therefore,  
 $0.444987 \times 3 = 1.334961$  moles of oxygen was used up to produce the  $\text{CO}_2$ .

At the start of the reaction, we had 3.1251953 moles of oxygen (100.0 g)

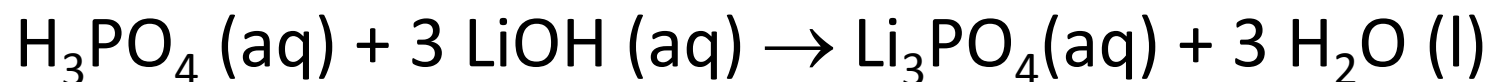
What remains must be

$$3.1251953 \text{ moles} - 1.334961 \text{ moles} = 1.79 \text{ moles}$$

(3 significant figures)

Q: A student performs a titration to determine the concentration of a LiOH solution. 20.00 mL of a 0.0820 M  $\text{H}_3\text{PO}_4$  solution was used in the titration. The student observed that when 32.45 mL of the base is added, the phenolphthalein colour indicator turned pale pink. What is the concentration of the LiOH solution?

Balanced chemical reaction:



32.45 mL  
? M LiOH  
dispensed

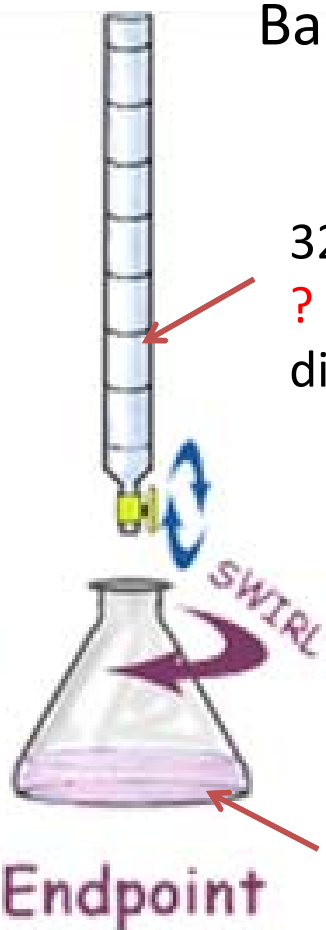
Mole ratio of  $\text{H}_3\text{PO}_4$  : LiOH

$$\frac{1}{0.001640} = \frac{3}{x}$$

$$x = 0.004920 \text{ moles LiOH}$$

$$\text{Concentration of LiOH} = \frac{0.004920 \text{ moles}}{0.03245 \text{ L}} = \mathbf{0.152 \text{ M}}$$

$$0.02000 \text{ L} \times 0.0820 \text{ moles/L} = 0.001640 \text{ moles } \text{H}_3\text{PO}_4$$





20.00 mL of a 0.0820 M  $\text{H}_3\text{PO}_4$

Endpoint

Q: 25.00 mL of a 0.243 M *acetic acid* solution is combined with 12.75 mL of a 0.250 M KOH solution.

- (a) What are the products of the reaction?
- (b) How many moles of each product are formed?
- (c) Is the final solution acidic or basic?
- (d) What volume of which solution is needed to neutralize the solution in (c)?

(a) This is a neutralization reaction. Products are  $\text{KCH}_3\text{COO (aq)} + \text{H}_2\text{O (l)}$   
 $\text{CH}_3\text{COOH (aq)} + \text{KOH (aq)} \rightarrow \text{KCH}_3\text{COO (aq)} + \text{H}_2\text{O (l)}$

25.00 mL of a 0.243 M $\text{H}_3\text{PO}_4$	12.75 mL of a 0.250 M KOH	(b) 0.00319 moles $\text{KCH}_3\text{COO}$	(b) 0.00319 moles $\text{H}_2\text{O}$
			
$0.02500 \text{ L} \times 0.243 \text{ moles/L}$ $= 0.00608 \text{ moles } \text{CH}_3\text{COOH}$	$0.01275 \text{ L} \times 0.250 \text{ moles/L}$ $= 0.00319 \text{ moles KOH}$		

This is the limiting reagent.

$0.00608 - 0.00319 = 0.002888 \text{ moles } \text{CH}_3\text{COOH} \text{ left.}$

0.002888 moles KOH is needed to neutralize the acid.

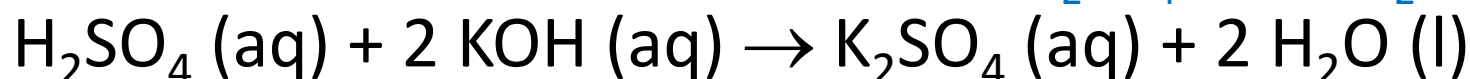
(c) Since acetic acid is in excess, the solution is acidic.

(d)  $0.002888 \text{ mole} \cdot \frac{1 \text{ L}}{0.250 \text{ mole}} = 11.6 \text{ mL}$

Q: 25.00 mL of a 0.243 M *sulfuric acid* solution is combined with 12.75 mL of a 0.250 M KOH solution.

- What are the products of the reaction?
- How many moles of each product are formed?
- Is the final solution acidic or basic?
- What volume of which solution is needed to neutralize the solution in (c)?

(a) This is a neutralization reaction. Products are  $\text{K}_2\text{SO}_4$  (aq) +  $\text{H}_2\text{O}$  (l)



25.00 mL of  
a 0.243 M  $\text{H}_2\text{SO}_4$



$$0.02500 \text{ L} \times 0.243 \text{ moles/L} \\ = 0.00608 \text{ moles } \text{H}_2\text{SO}_4$$

12.75 mL of  
a 0.250 M KOH



$$0.01275 \text{ L} \times 0.250 \text{ moles/L} \\ = 0.00319 \text{ moles KOH}$$



This is the limiting reagent.

(Note: only need 0.00158 moles  $\text{H}_2\text{SO}_4$  to use it up)

$$0.00608 - 0.00158 = 0.00450 \text{ moles } \text{H}_2\text{SO}_4 \text{ left.}$$

(b) 0.00158 moles  
 $\text{K}_2\text{SO}_4$

(b) 0.00319 moles  
 $\text{H}_2\text{O}$



(c) Since sulfuric acid is  
in excess, the solution is acidic.

(d)  $0.00900 \text{ mole} \cdot \frac{1 \text{ L}}{0.250 \text{ mole}} = 36.0 \text{ mL}$

$0.00450 \times 2 = 0.00900$  moles KOH is needed to neutralize the acid.

Try some practice problems in Maple TA.

Use Dimensional Analysis in ALL your  
calculations!!