Worksheet on excess and limiting reactants/reagents.

When dealing with questions where the mol of more than one reactant is known, students must determine which reactant is in excess. There are two possibilities, the reactants are in the right stoichiometric ratio or that one of them is in excess. If the latter is the case then the limiting reagent/reactant is the one used to perform stoichiometric calculations.

Eg Methane undergoes complete combustion, at SLC, in atmospheric oxygen to produce carbon dioxide and water. The balanced chemical equation is given below.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2\ (g) + 2H_2O(l)$$

If 97.6 litres of methane was mixed with 150 litres of oxygen gas and ignited what mass, in grams, of CO_2 is formed at the completion of the combustion reaction.

Step 1 find the limiting reactant.

Reactant	mol	Limiting quotient Mol/coefficient
CH_4	97.6 / 24.8 = 3.94	3.94/1 = 3.94
O_2	150/24.8 = 6.05	6.05/2 = 3.02

=> Identify the reactant with the lowest limiting quotient as being the limiting reactant, in this case it is O_2.

Step 2 Using the limiting reactant find the mol of CO_2 produced.

=> 6.05 X ½ = 3.03 mol

Step 3 Find the mass of CO_2

=> 3.03 X 44.0 = 133 grams

1. 50.00 mL of a 0.200 M barium hydroxide solution is mixed with 50.00 mL of a 0.300 M nitric acid solution and allowed to react
   a. Give the overall balanced chemical equation for the reaction, states included.

      $Ba(OH)_2(aq) + 2HNO_3(aq) \rightarrow Ba(NO_3)_2(aq) + 2H_2O(l)$

b. Identify the excess reactant and calculate the amount, in grams, by which it is in excess. Show all working out and give the answer to the right number of significant figures.

Reactant	mol	Limiting quotient Mol/coefficient
$Ba(OH)_2$	*0.05000 X 0.200 = 0.0100*	0.0100/1 = 0.0100
HNO_3	*0.05000 X 0.300 = 0.0150*	0.0150/2 = 0.00750

Step 1 calculate the mol of each reactant.

mol of $Ba(OH)_2$ = 0.05000 X 0.200 = 0.0100

Mol of HNO_3 = 0.05000 X 0.300 = 0.0150

Step 2 To identify the excess reactant divide the mol of each reactant by its coefficient in the balanced chemical equation given in part a. above to determine its limiting quotient. Take the reactant with the highest limiting quotient as the one in excess.

$Ba(OH)_{2\ (limiting\ quotient)}$ = 0.0100/1 = 0.0100

$HNO_{3\ (limiting\ quotient)}$ = 0.0150 / 2 = 0.00750

$Ba(OH)_2$ is the reactant in excess.

How much is it in excess by?

Step 1 using the limiting reactant calculate how much, in mol, of the excess is used up.

Mol of $Ba(OH)_2$ used up = 0.0150 X ½ = 0.0075 mol is used up.

Step 2 Find the mol of $Ba(OH)_2$ remaining

=> 0.0100 – 0.0075 = 0.0025

Step 3 mass of $Ba(OH)_2$ in excess = 0.0025 X 171.34 = 0.428g

2. Methane is reacted with oxygen gas at SLC to provide heat to increase the temperature of 5.00 kilograms of pure water.
   a. Give the balanced chemical equation for the combustion of methane gas. Include states
      $CH_4(g) + 2O_2 \rightarrow CO_2(g) + 2H_2O(l)$
   b. A mixture of 20.50 litres of methane and 40.0 litres of oxygen gas was ignited.
      i. Calculate the total volume of gas produced if the temperature and pressure remained at SLC.

Reactant	mol	Limiting quotient Mol/coefficient
$Ba(OH)_2$	*20.5 / 24.8 = 0.827*	*0.827/1 = 0.827*
HNO_3	*40.0 X 24.8 = 1.613*	*1.613 / 2 = 0.807*

Step 1 calculate the mol of each reactant.

mol of CH_4 = 20.5 / 24.8 = 0.827

Mol of O_2 = 40.0 X 24.8 = 1.613

Step 2 Identify the limiting reactant

$CH_{4\ (limiting\ quotient)}$ = 0.827/1 = 0.827

$O_{2\ (limiting\ quotient)}$ = 1.613 / 2 = 0.807

O_2 is the limiting reactant.

Using the limiting reactant (O_2) calculate the amount of CO_2 produced. At SLC, water is a liquid.

Step 1 mol of CO_2 produced = 0.807 X ½ = 0.4035 mol

Step 2 find the volume at SLC = 0.4035 X 24.8 = 10.0 L

ii. What is the total volume, in litres, of gas remaining after the reaction is complete at SLC.

Step 1 – the total volume of gas is made up of the excess gas and product gas. Since the volume of product gas has already been calculated in b i. above the excess gas needs to be calculated.

=> mol of CH_4 reacted = 0.807 X ½ = 0.4035

=> mol of CH_4 remaining = 0.827 – 0.4035 = 0.424

=> volume of CH_4 remaining = 0.424 X 24.8 = 10.5

Step 2 – total volume of gas is therefore

10.0 + 10.5 = 20.5 L

c. Calculate the final temperature of the 5.00 kg of water assuming that all the energy produced during the combustion reaction was absorbed by the water?

Step 1 – from previous calculations, of the mol of CH_4 that reacted, obtain the total energy given out by the combustion reaction.

From the data book the molar heat of combustion of methane is given as 890 kJ mol^-

=> 0.4035 X 890 = 359.1 kJ

Step 2 – Find the change in temperature.

=> ΔT = 359100 / (4.18 X 5000) = 17.2 °C

Step 3 final temp

=> 25.0 + 17.2 = 42.2 °C.

3. An amount of 2.50 grams of calcium carbonate ($CaCO_3$) pellets was placed in a beaker containing 500 mL of a 0.100 M HCl solution.

   a. Give the balanced chemical equation for the reaction between $CaCl_2$ and HCl, states included, where products are either in aqueous, liquid or gaseous states.

   $CaCO_3(s) + 2HCl \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

   b. This reaction was conducted at SLC. Find the mass, in grams, of gaseous product that is formed?

Reactant	mol	Limiting quotient Mol/coefficient
$CaCO_3$	*2.50 / 100 = 0.0250*	*0.0250/1 = 0.0250*
HCl	*0.500 X 0.100 = 0.0500*	*0.0500 / 2 = 0.0250*

Step 1 calculate the mol of each reactant.

mol of $CaCO_3$ = 2.50 / 100 = 0.0250

Mol of HCl = C X V = 0.100 X 0.500 = 0.0500

Step 2 To identify the excess reactant divide the mol of each reactant by its coefficient in the balanced chemical equation given in part a. above to determine its limiting quotient. Take the reactant with the highest limiting quotient as the one in excess.

$CaCO_{3\ (limiting\ quotient\ t)}$ = 0.0250/1 = 0.0250

$HCl_{(limiting\ quotient)}$ = 0.0500 / 2 = 0.0250

Both reactants have the same limiting quotient so they are in the exact stoichiometric ratio. We can use any one of the two reactants to perform stoichiometric calculations.

=> Find the mol of CO_2 formed
=> If 0.0500 mol of HCl reacts then 0.0250 mols of CO_2 is formed.
=> mass of CO_2 = 0.0250 X 44.0 = 1.10 g

4. Vapourised bioethanol is used as a fuel to propel a new hybrid-vehicle. The engine consumes 3.00 litres of gaseous ethanol and mixes it with 50.0 litres of air, which is composed of 20.0% oxygen gas. The mixture is ignited at SLC.

   a. Write a balanced chemical equation for the complete combustion of ethanol at SLC. States included.
   $C_2H_6O(g) + 3O_2(g) \rightarrow 3H_2O(l) + 2CO_2(g)$
   b. Identify the reactant in excess, show all working out.

Reactant	mol	Limiting quotient Mol/coefficient
C_2H_6O	3.00 / 24.8 = 0.121	0.121 / 1 = 0.121
O_2	50.0 X (20/100) / 24.8 = 0.403	0.403 / 3 = 0.134

   c.
   Step 1 calculate the mol of each reactant.
   mol of C_2H_6O = 3.00 / 24.8 = 0.121
   Mol of O_2 = 50.0 X (20/100) / 24.8 = 0.403
   Step 2 To identify the excess reactant divide the mol of each reactant by its coefficient in the balanced chemical equation given in part a. above to determine its limiting quotient. Take the reactant with the highest limiting quotient as the one in excess.
   $C_2H_6O_{(limiting\ quotient)}$ = 0.121 / 1 = 0.121
   $O_{2\ (limiting\ quotient)}$ = 0.403 / 3 = 0.134
   Oxygen is in excess so ethanol is the limiting reactant and should be used for all calculations .
   d. Calculate the amount of heat energy, in kJ, produced during the complete combustion of 3.00 litres of gaseous bioethanol with 50.0 litres of air at SLC.
   Using the limiting reactant and data-booklet calculate the heat energy released.
   => mol of C_2H_6O that reacted fully = 0.121, molar heat of combustion = 1360 kJ mol^{-}
   => Energy (kJ) = 0.121 X 1360 = 165kJ.
   e. Biothanol is relatively expensive to produce and transport.
      i. Suggest a way that car manufacturers can guarantee that the amount of ethanol pumped into the engine is totally burnt to release the maximum possible heat energy.
      Always mix the fuel with excess oxygen to ensure that ethanol is completely burnt in the engine and not expelled as unburnt fuel. Air is relatively cheap so using excess air will not increase the cost of operating the vehicle.
      ii. Give one advantage of using bioethanol as a fuel. Provide at least one chemical reaction to support your answer.
      It can be replaced in a reasonably short period of time so that it does not run out. It is renewable. It adds less CO_2 to the atmosphere than fossil fuels due to the fact that the CO_2 produced during combustion was originally absorbed from the atmosphere during photosynthesis.
      $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

5. Butane gas undergoes complete combustion when mixed with oxygen.
   a. Write the balanced chemical equation for the complete combustion of butane gas in the presence of atmospheric oxygen at SLC. States included.

   $2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2 + 10H_2O(l)$

   b. A mixture made up of 20.0 litres of butane gas and 100 litres of pure oxygen gas is ignited.
      i. Calculate the total volume, in litres, of product gas.

Reactant	mol	Limiting quotient Mol/coefficient
C_4H_{10}	*20.00 / 24.8 = 0.806*	*0.806 / 2 = 0.403*
O_2	*100.0 / 24.8 = 4.03*	*4.03 / 13 = 0.310*

Step 1 calculate the mol of each reactant.
mol of C_4H_{10} = 20.00 / 24.8 = 0.806
Mol of O_2 = 100.0 / 24.8 = 4.03
Step 2 To identify the excess reactant divide the mol of each reactant by its coefficient in the balanced chemical equation given in part a. above to determine its limiting quotient. Take the reactant with the highest limiting quotient as the one in excess.
$C_4H_{10\,(limiting\ quotient)}$ = 0.806 / 2 = 0.403
$O_{2\,(limiting\ quotient)}$ = 4.03 / 13 = 0.310
butane is in excess so oxygen is the limiting reactant and should be used for all calculations .

Step 2 using the mol of oxygen calculate the mol of CO_2 produced. At SLC water is a liquid.
=> 4.03 X (8/13) = 2.48 mol
Step 3 Volume of CO_2 = 2.48 X 24.8 = 61.5 L

      ii. What is the total volume, in litres, of gas left over after the combustion reaction is complete.

The total volume includes the unreacted gas as well as product gas.
mol of butane used = 4.03 X 2/13 = 0.62
mol of butane in excess = 0.806 – 0.62 = 0.19
Volume occupied by butane at SLC = 0.19 X 24.8 = 4.61 litres
Total volume = 4.61 + 61.5 = 66.1 L.

6. In another experiment 5.80 grams of butane was mixed with 16.0 grams of oxygen gas in a sealed 5.00 litre vessel and ignited. The balanced chemical equation for the reaction is shown below.

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2 + 10H_2O(l)$$

Calculate the pressure, in kPa, exerted on the walls of the container if the temperature of the gaseous mixture is allowed to reach 70.0 °C.

Reactant	mol	Limiting quotient Mol/coefficient
C_4H_{10}	*5.80 / 58.0 = 0.100*	*0.100 / 2 = 0.0500*
O_2	*16.0 / 32.0 = 0.500*	*0.500 / 13 = 0.0385*

Step 1 calculate the mol of each reactant.

mol of C_4H_{10} = 5.80 / 58.0 = 0.100

Mol of O_2 = 16.0 / 32.0 = 0.500

Step 2 To identify the excess reactant divide the mol of each reactant by its coefficient in the balanced chemical equation given in part a. above to determine its limiting quotient. Take the reactant with the highest limiting quotient as the one in excess.

$C_4H_{10\ (limiting\ quotient)}$ = 0.100 / 2 = 0.0500

$O_{2\ (limiting\ quotient)}$ = 0.500 / 13 = 0.0385

butane is in excess so oxygen is the limiting reactant and should be used for all calculations .

Step 2 using the mol of oxygen calculate the mol of CO_2 produced. At 70 °C water is a liquid.

=> 0.500 X (8/13) = 0.308 mol

Step 3 Calculate the amount, in mol, of butane remaining.

=> calculate the amount of butane reacting

=> 0.5 X (2/13) = 0.0770

=> calculate the amount of butane remaining.

=> 0.100 – 0.0770 = 0.0230

Step 4 Calculate the total mol of gas present after ignition.

=> 0.0230 + 0.308 = 0.331 mol

Step 5 Calculate the pressure in kPa

=> PV =nRT

=> P = nRT / V

=> P = 0.331 X 8.31 X 343 / 5.00 = 189 kPa