Limiting Reactant

Lab 4

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Work Individually
What is a limiting reactant?

• It is the reactant that limits the product that can be formed.

• Stoichiometry allows us to compare the amounts of various species involved in a reaction.

• If you have the balanced chemical equation and the quantity of one of the reactants or a product produced, the quantities of the other species produced or required can be evaluated.

• In order to determine which of the reactants is the limiting reactant, both amounts present must be considered and how they relate stoichiometrically to the balanced equation.
**Method for determining limiting reactant**

1. You know the amount of two (or more) of the reactants involved.
2. Treat each as a separate stoichiometry problem.
3. Evaluate the amount of product made or reagent required of each unknown species based on the known quantities. This is determined by comparing the number of moles of product formed for each mole of the reactant used. Do this for each of the known reactants.
4. Compare the amount of product made by each reagent.
5. The limiting reagent is the one that produces the least amount and is the one that any subsequent calculations should be based on.
Example

\[ 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) \]

Calculate:

a) the stoichiometric ratio of moles \( \text{H}_2 \) to moles \( \text{O}_2 \)

b) the actual moles \( \text{H}_2 \) to moles \( \text{O}_2 \) when 1.50 mol \( \text{H}_2 \) is mixed with 1.00 mol \( \text{O}_2 \)

c) the limiting reactant (\( \text{H}_2 \) or \( \text{O}_2 \)) for the mixture in (b)

d) the theoretical yield, in moles, of \( \text{H}_2\text{O} \) for the mixture in (b)
a) The stoichiometric ratio is given by using the coefficients of the balanced equation. The coefficients are the numbers listed before each formula.

\[ 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\ell) \]

This equation is already balanced,

2 mol H₂ react with 1 mol O₂

b) The actual ratio refers to the number of moles actually provided for the reaction.

This may or may not be the same as the stoichiometric ratio. In this case, it is different:

\[ 1.50 \text{ mol H}_2 / 1.00 \text{ mol O}_2 = 1.50 \text{ mol H}_2 / \text{ mol O}_2 \]
• The actual ratio of reactants is smaller than the required or stoichiometric ratio, which means there is insufficient H₂ to react with all of the O₂ that has been provided.

• The 'insufficient' component (H₂) is the limiting reactant. Another way to put it is to say that O₂ is in excess.

• When the reaction has proceeded to completion, all of the H₂ will have been consumed, leaving some O₂ and the product, H₂O.
• Theoretical yield is based on the calculation using the amount of limiting reactant, 1.50 mol H₂. Given that 2 mol H₂ forms 2 mol H₂O, we get:

• Theoretical yield H₂O = 1.50 mol H₂ x 2 mol H₂O
  / 2 mol H₂
• theoretical yield H₂O = 1.50 mol H₂O

• Note, that the only requirement for performing this calculation is knowing the amount of the limiting reactant and the ratio of the amount of limiting reactant to the amount of product.
Why have limiting reactants?

If you produce no more product, then it just does not make economic sense to use an excess of one reagent.

- Not all reactions go 100% to completion, in fact the majority of really interesting ones do not.
- However one trick employed to make them go to completion is to start with an excess of one of the reactants.
- This essentially makes the other the limiting reagents. For economical reasons it makes sense to choose the less expensive reagent as one to use in excess.
Background Information for Lab

\[ 2Na_3PO_4 \cdot 12H_2O(aq) + 3BaCl_2 \cdot 2H_2O(aq) \rightarrow Ba_3(PO_4)_2(s) + 6NaCl(aq) + 30H_2O(l) \]

Barium Phosphate is the insoluble product
Sodium Chloride remains in solution

The ionic equation can be written:
\[ 3Na^+ + 2PO_4^{3-} + 3Ba^{2+} + 2Cl^- \rightarrow Ba_3(PO_4)_2(s) + 6Na^+ + Cl^- + 30H_2O \]

The ‘spectator’ ions can be cancelled out, leaving the net ionic eqn.
\[ 2PO_4^{3-}(aq) + 3Ba^{2+}(aq) \rightarrow Ba_3(PO_4)_2(s) \]
Using the balanced equation:

- Molar mass of $\text{Na}_3\text{PO}_4\cdot12\text{H}_2\text{O} = 380.12$
- The water is included in the formula mass
- To calculate the % of each ion present we can use the molar mass
- % of $\text{H}_2\text{O}$ present in formula –
  - $\text{H}_2\text{O}$ Molar mass = 18.01
  - 12 are present in the formula = $12 \times 18.01 = 216.12$
  - % of $\text{H}_2\text{O}$ present = $216.12 / 380.12 \times 100 = 56.86\%$
2PO$_4^{3-}$ (aq) + 3Ba$^{2+}$ (aq) $\rightarrow$ Ba$_3$(PO$_4$)$_2$ (s)

- Ratio of reactants is 2:3 (1 : 1.5)
- In this experiment, known masses of sodium phosphate and barium chloride will be reacted.
- For example:
  - 1g of sodium phosphate
  - Calculate the no. of moles
  - # of moles = mass / Molar mass
    - $= 1 / 380.12 = 0.00263$
  - From the balanced equation, we know we need 0.00263 x 1.5 moles = 0.00395
  - Using the no. of moles equation and the molar mass of BaCl2, it can be calculated how much is required:
    - 0.0395 = mass / 244.27
    - 0.0395 x 244.27 = 0.96g
• You will be provided with a sample of unknown composition of Na$_3$PO$_4$•12H$_2$O/BaCl$_2$•2H$_2$O
• This will be added to water
• A precipitate of barium phosphate will form
• This will be collected by filtration, dried and weighed
• The supernatant (the liquid left after the solid is removed) will be analyzed to see what ions are left in solution
Analyzing the supernatant

• Analyzing the supernatant aims to determine which is the limiting reactant.
• Possible ions in solution are $\text{Ba}^{2+}$ or $\text{PO}_4^{3-}$
• Excess $\text{Ba}^{2+}$ is tested by the addition of a phosphate ion, if a precipitate forms, excess $\text{Ba}^{2+}$ ions are present, no precipitate means no $\text{Ba}^{2+}$, therefore $\text{Ba}^{2+}$ is the Limiting Reactant
• Likewise, $\text{PO}_4^{3-}$ excess is tested by addition of $\text{Ba}^{2+}$ ions, if a precipitate forms, excess $\text{PO}_4^{3-}$ ions are present
Using the data to calculate composition of salt

- Use what you know:
  - Weight of initial sample (e.g., 0.942g)
  - Formula of precipitate: \( \text{Ba}_3(\text{PO}_4)_2 \)
  - Molar mass of \( \text{Ba}_3(\text{PO}_4)_2 \) = 601.93
  - Amount of \( \text{Ba}_3(\text{PO}_4)_2 \) formed, this is the solid collected by filtration (e.g. 0.118g)
  - What was left in solution (excess Barium or phosphate ions), therefore know the limiting reactant.
Using the mass collected of $\text{Ba}_3(\text{PO}_4)_2$, the number of moles can be calculated:

\[
\text{# of moles of } \text{Ba}_3(\text{PO}_4)_2 = \frac{0.188}{601.093} \\
\text{# of moles of } \text{Ba}_3(\text{PO}_4)_2 = 0.00031 \ (3.12 \times 10^{-4})
\]

Going back to the balanced ionic equation:

\[
2\text{PO}_4^{3-} (\text{aq}) + 3\text{Ba}^{2+} (\text{aq}) \rightarrow \text{Ba}_3(\text{PO}_4)_2
\]

it can be seen that every 1 mole of product (precipitate) is formed from 3 moles of $\text{Ba}^{2+}$ and 2 moles of $\text{PO}_4^{3-}$. 
• Therefore, if we have $3.12 \times 10^{-4}$ moles of $\text{Ba}_3(\text{PO}_4)_2$ and Ba is the limiting reactant.

• No of moles of $\text{Ba}^{2+}$ in the sample $= 3.12 \times 10^{-4} \times 3 = 9.36 \times 10^{-4}$

• Using the molar mass of $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$, and the equation $n = \frac{m}{M}$, the mass of barium chloride can be calculated.

• $9.36 \times 10^{-4} = \frac{\text{mass}}{244.27}$

• Mass $= 9.36 \times 10^{-4} \times 244.27 = 0.23\text{g}$
• Mass of sodium phosphate can be determined from the initial mass weighed.
• 0.942g was weighed of the mixture
• Mass of Barium Chloride = 0.229g
• Mass of $\text{Na}_3\text{PO}_4\cdot12\text{H}_2\text{O}$ = 0.942 – 0.229
• Mass of $\text{Na}_3\text{PO}_4\cdot12\text{H}_2\text{O}$ = 0.713g
• % of $\text{Na}_3\text{PO}_4\cdot12\text{H}_2\text{O}$ in sample = $\frac{0.713}{0.942} \times 100$
• % of $\text{Na}_3\text{PO}_4\cdot12\text{H}_2\text{O}$ in sample = 75.7%