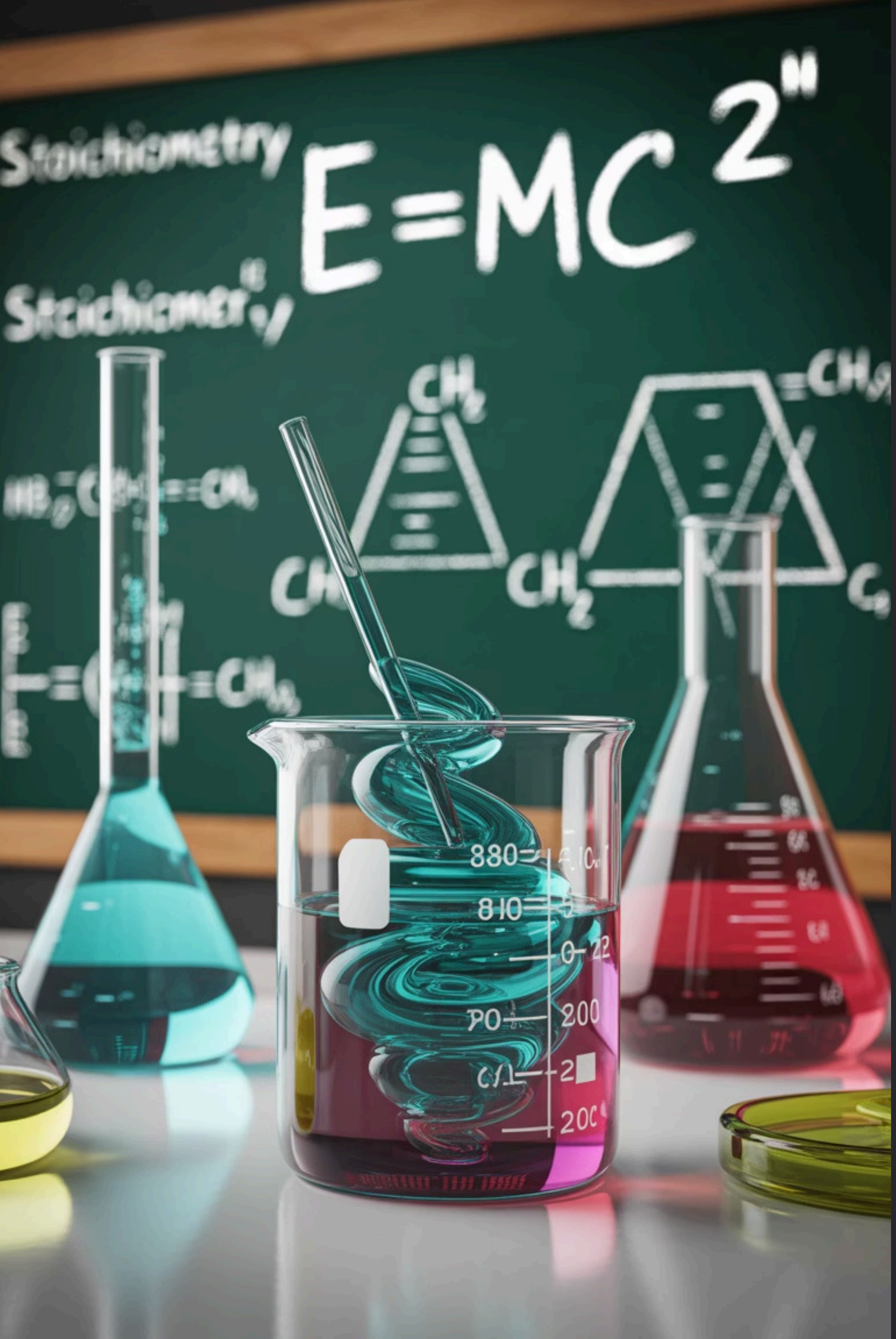

Chemistry Fundamentals

Lecture 18: Basic Stoichiometry

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Introduction to Stoichiometry - Recipe Chemistry

Definition: Quantitative relationship between reactants and products in chemical reactions

Etymology: From Greek "stoicheion" (element) + "metron" (measure)

Key Concept: Balanced equations provide molar ratios

Real-World Importance:

- Drug manufacturing dosages
- Industrial chemical production
- Environmental impact calculations
- Economic considerations in manufacturing

Cooking Analogy: Like following a recipe - need right proportions

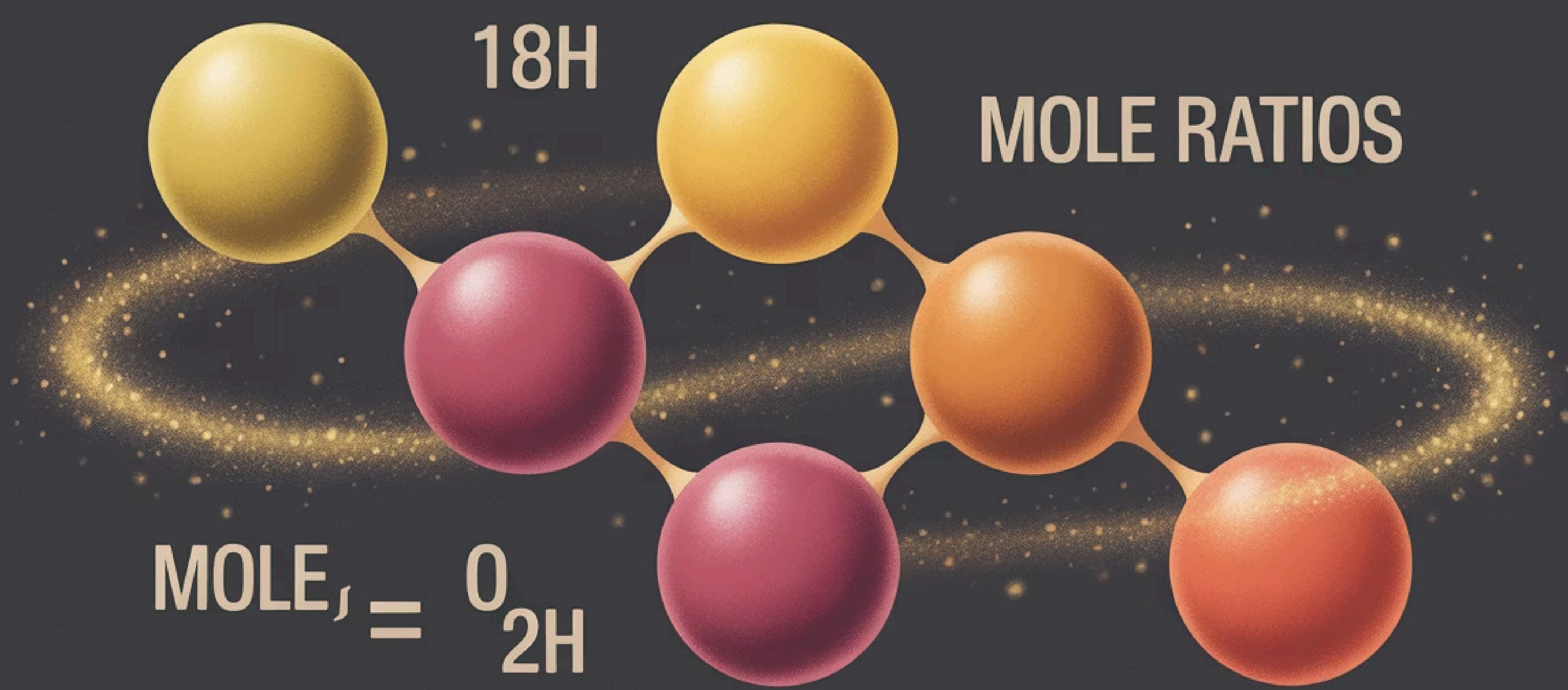
Recipe: 2 slices bread + 1 slice cheese → 1 sandwich

Chemistry: $2H_2 + O_2 \rightarrow 2H_2O$

Mole-to-Mole Calculations - The Foundation

Basic Relationship: Coefficients in balanced equations = molar ratios

Example Equation: $N_2 + 3H_2 \rightarrow 2NH_3$



Molar Ratios

- 1 mol N_2 : 3 mol H_2 : 2 mol NH_3
- 1 mol N_2 produces 2 mol NH_3
- 3 mol H_2 produces 2 mol NH_3

Conversion Factor Method

- Use coefficients as conversion factors
- Example: mol NH_3 = mol N_2 × (2 mol NH_3/1 mol N_2)

Worked Problem: How many moles of NH_3 from 4.5 mol N_2?

4.5 mol N_2 × (2 mol NH_3/1 mol N_2) = 9.0 mol NH_3

Reverse Calculation: How many moles N_2 needed for 7.2 mol NH_3?

7.2 mol NH_3 × (1 mol N_2/2 mol NH_3) = 3.6 mol N_2

Mass-to-Mass Calculations - Practical Applications

Step 1

Mass of given substance → moles of given substance

Step 2

Moles of given substance → moles of desired substance

Step 3

Moles of desired substance → mass of desired substance

Example Reaction: $2Al + 3CuSO_4 \rightarrow Al_2(SO_4)_3 + 3Cu$

Problem: How many grams of Cu from 15.0 g Al?

Step-by-Step Solution:

Step 1: 15.0 g Al × (1 mol Al/26.98 g Al) = 0.556 mol Al

Step 2: 0.556 mol Al × (3 mol Cu/2 mol Al) = 0.834 mol Cu

Step 3: 0.834 mol Cu × (63.55 g Cu/1 mol Cu) = 53.0 g Cu

One-Line Setup:

15.0 g Al × (1 mol Al/26.98 g Al) × (3 mol Cu/2 mol Al) × (63.55 g Cu/1 mol Cu) = 53.0 g Cu

Limiting Reagent Concept - The Bottleneck

Definition: Reactant that is completely consumed first, limiting product formation

Sandwich Analogy

- 10 slices bread, 3 slices cheese
- Can make only 3 sandwiches
- Cheese is limiting reagent
- Bread is excess reagent (4 slices left over)

Chemical Example: $2H_2 + O_2 \rightarrow 2H_2O$

- Given: 5 mol H_2 and 2 mol O_2
- Ratio needed: 2 mol H_2 : 1 mol O_2
- Available: 5 mol H_2 : 2 mol O_2 = 2.5:1 ratio
- O_2 is limiting (need 2:1 ratio, have 2.5:1)

Identification Method:

1. Calculate moles of each reactant
2. Determine which runs out first based on stoichiometry
3. Use limiting reagent for product calculations

Economic Importance: Minimize waste, maximize profit in industrial processes

Limiting Reagent Calculations - Step-by-Step

Problem Setup: $2Al + 3Br_2 \rightarrow 2AlBr_3$

Given: 25.0 g Al and 100.0 g Br_2

1

Convert to moles

Al: 25.0 g ÷ 26.98 g/mol = 0.927 mol Al

Br_2: 100.0 g ÷ 159.8 g/mol = 0.626 mol Br_2

2

Calculate required ratios

Need 2 mol Al : 3 mol Br_2

For 0.927 mol Al: need 0.927 × (3/2) = 1.39 mol Br_2

Have only 0.626 mol Br_2

Br_2 is limiting reagent

3

Calculate products using limiting reagent

$AlBr_3$ produced: 0.626 mol Br_2 × (2 mol $AlBr_3$/3 mol Br_2) = 0.417 mol $AlBr_3$

Mass $AlBr_3$: 0.417 mol × 266.7 g/mol = 111 g $AlBr_3$

4

Calculate excess reagent remaining

Al used: 0.626 mol Br_2 × (2 mol Al/3 mol Br_2) = 0.417 mol Al

Al remaining: 0.927 - 0.417 = 0.510 mol Al = 13.8 g Al

Theoretical and Percent Yield

Key Concepts:

- **Theoretical Yield:** Maximum amount of product possible based on limiting reagent
- **Actual Yield:** Amount of product actually obtained in experiment
- **Percent Yield:** (Actual yield/Theoretical yield) × 100%

Why Yields Are Less Than 100%:

- Incomplete reactions
- Side reactions
- Product lost during purification
- Measurement errors
- Reversible reactions

Example Calculation:

- Theoretical yield: 111 g $AlBr_3$
- Actual yield: 95.2 g $AlBr_3$
- Percent yield: (95.2 g/111 g) × 100% = 85.8%

Interpreting Percent Yield:

- 90%: Excellent yield
- 70-90%: Good yield
- 50-70%: Fair yield
- <50%: Poor yield (investigate problems)

Industrial Considerations: Higher yields = greater profitability

Gas Stoichiometry - Working with Gas Volumes

Key Relationships at STP

- 1 mole of any gas = 22.4 L
- Gas volumes are directly proportional to moles

Modified Stoichiometry Steps

1. Convert gas volume to moles (÷ 22.4 L/mol)
2. Use molar ratios from balanced equation
3. Convert back to volume if needed (× 22.4 L/mol)

Example Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Problem: What volume of O_2 (at STP) reacts with 15.0 L H_2?

Step-by-Step Solution:

1. 15.0 L H_2 ÷ 22.4 L/mol = 0.670 mol H_2
2. 0.670 mol H_2 × (1 mol O_2/2 mol H_2) = 0.335 mol O_2
3. 0.335 mol O_2 × 22.4 L/mol = 7.50 L O_2

Direct Volume Ratio:

At same T and P, volume ratios = molar ratios

15.0 L H_2 × (1 L O_2/2 L H_2) = 7.50 L O_2

Real-World Application: Industrial gas reactions, fuel combustion calculations

Complex Stoichiometry Problems - Putting It All Together

1

Multi-Step Problem Strategy

Write and balance the equation

2

Identify given information and what to find

3

Determine limiting reagent if multiple reactants given

4

Use appropriate stoichiometric relationships

5

Check units and significant figures

Comprehensive Example: Combustion of propane

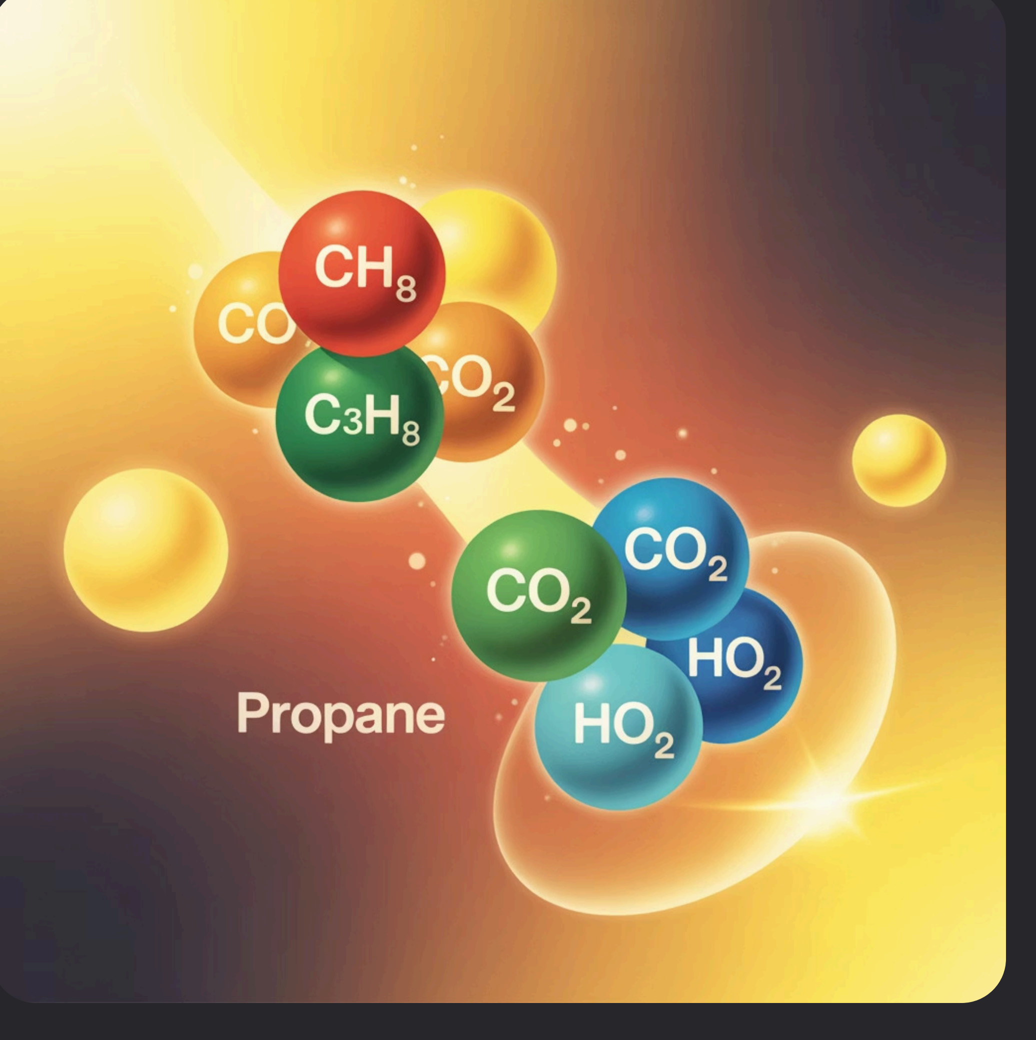
Equation: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Given: 50.0 g C_3H_8 burns in 120.0 g O_2

Find: Mass of CO_2 produced and percent yield if 125 g CO_2 obtained

Solution:

1. Convert to moles:
   - C_3H_8: 50.0 g ÷ 44.10 g/mol = 1.134 mol
   - O_2: 120.0 g ÷ 32.00 g/mol = 3.75 mol
2. Find limiting reagent:
   - Need 1.134 mol C_3H_8 × (5 mol O_2/1 mol C_3H_8) = 5.67 mol O_2
   - Have only 3.75 mol O_2 → O_2 is limiting



1. Calculate theoretical yield:
   - CO_2: 3.75 mol O_2 × (3 mol CO_2/5 mol O_2) = 2.25 mol CO_2
   - Mass: 2.25 mol × 44.01 g/mol = 99.0 g CO_2
2. Calculate percent yield:
   - Percent yield: (125 g/99.0 g) × 100% = 126%
   - **Error Check:** >100% suggests experimental error

I hope that you all enjoyed the course

Looking forward to seeing you soon!

Mohamed Kamal