CHEM 191

Module 1

Chemical Reactions in Aqueous Solution

Lecture 1

Stoichiometry

Brown et al Chapter 3, 4.5

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Module 1 Lecture 1

Learning objectives

- Understand the concept of the mole
- Write BALANCED chemical equations
- ★ Successfully carry out calculations using $n = \frac{m}{M}$ and $c = \frac{n}{V}$
- Understand the concept of a Limiting Reactant

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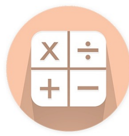
Stoichiometry "Chemical Arithmetic"



- Stoichiometry is concerned with the relative **amounts** of reactants and products in a chemical reaction. The word is derived from the Greek for 'element' and 'to measure'

- It allows us to weigh bulk quantities of reactants and products in chemical reactions, rather than having to weigh individual atoms and molecules.

Laboratory-size sample

Single molecule

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Chemical equations

- A chemical equation tells us about the ratio in which the reactants in a chemical reaction react to give products.

- It is concerned with **numbers**

- For example, the equation

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

  tells us that 1 molecule of nitrogen will react with 3 molecules of hydrogen to give 2 molecules of ammonia.

- Chemical equations **MUST** be balanced.

- But we want to deal with chemical reactions on a large scale, not atoms and molecules.

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The mole

- The mole (abbreviation mol) is the SI unit of the amount of substance.
- Defined as “the amount of substance that contains the same number of specified entities as there are atoms in exactly 12 g of the carbon isotope ^{12}C”
- There are 6.022×10^{23} atoms in exactly 12 g of the carbon isotope ^{12}C.
  Therefore, 1 mole of anything contains 6.022×10^{23} entities.

Lorenzo Romano Amedo Carlo Avogadro
Count of Quaregna and Cerreto

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The mole

The ***International Avogadro Project*** with the aid of a single crystal of highly enriched ^{28}Si, has measured the Avogadro constant more accurately than ever before.

Avogadro’s constant = $6.02214078(18) \times 10^{23}$ mol^{-1}

The redefinition of the kilogram (May 2019) allows this constant to be defined exactly.

Lorenzo Romano Amedo Carlo Avogadro
Count of Quaregna and Cerreto

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The mole

- Mole is the chemists "dozen"

- One dozen eggs and one dozen people are 12 things which have different weights
- As chemists, we are interested in the mass of 1 mole of a particular element or compound.

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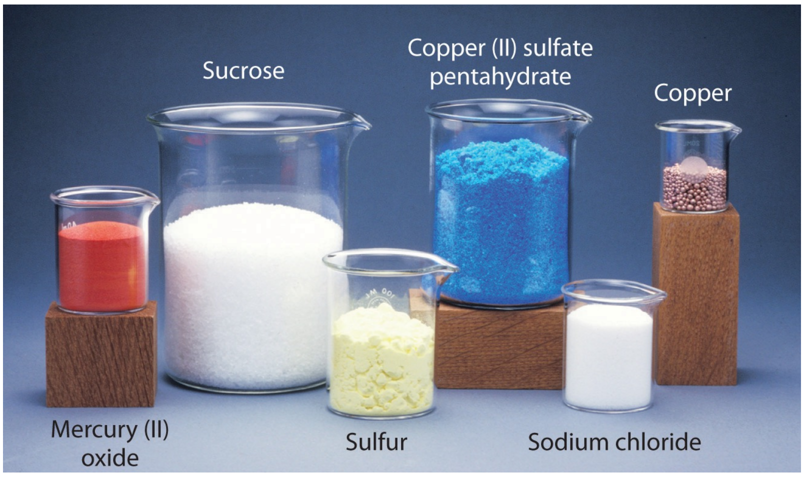

All 1 mole of the substance, but different masses

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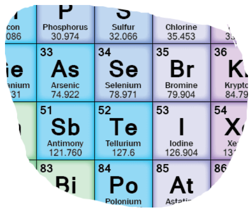
Molar mass



- Molar mass (M) is the mass of 1 mole of a specified entity.

- It is defined in terms of mass (m) and amount of substance (n) as

$$M = \frac{m}{n}$$

Eminem

$$\boxed{n = \frac{m}{M}}$$

- M has units of g mol^{-1} (read grams per mole). Use the units to remember the correct form of the equation – it must be grams divided by moles to give the correct units.

- Molar mass values are obtained from tables.

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Example

- Diamond consists of pure carbon. The molar mass of carbon is 12.01 g mol^{-1}. What amount of C does the largest known cut diamond (109.13 g) contain?

- Use the equation

$$n = \frac{m}{M}$$

Golden Jubilee Diamond

$$n = \frac{m}{M} = \frac{109.13\ \text{g}}{12.01\ \text{g mol}^{-1}} = 9.087\ \text{mol}$$

- Note that the units will always work out if you have rearranged the equation correctly

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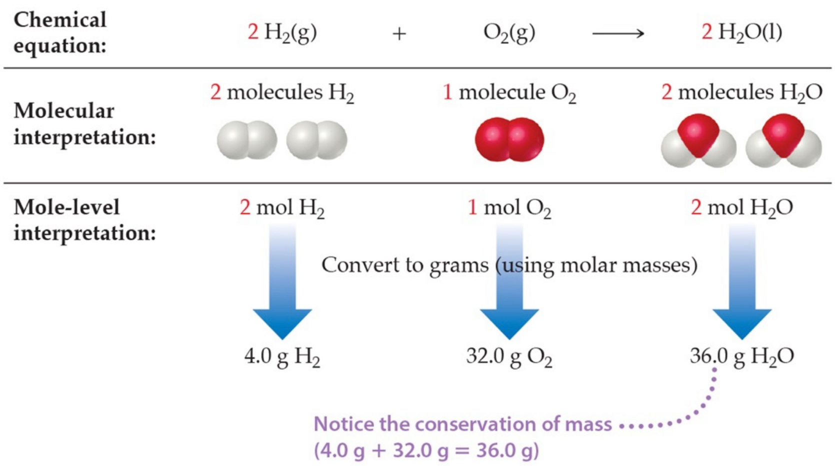
Mole relationships

Balanced chemical equations give mole relationships between all reactants and products.



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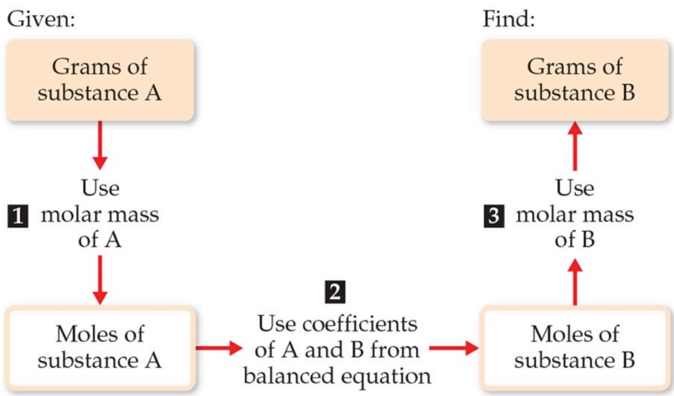
For the reaction

A → B



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Example

Metallic iron reacts with oxygen gas to give iron oxide according to the following equation:

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

If 2.0 g of iron reacts with excess oxygen, what mass of iron oxide is formed?

1. First we work out how many moles of iron 2.0 g corresponds to.

$$n(\text{Fe}) = \frac{m}{M} = \frac{2.0\ \text{g}}{55.85\ \text{g mol}^{-1}} = \mathbf{0.0358\ mol}$$

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$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

2. The balanced chemical equation tells us that 4 moles of Fe react to give 2 moles of Fe_2O_3 (ie half as much)

So 0.0358 mol of Fe should give $\dfrac{\mathbf{0.0358\ mol}}{2}$

= **0.0179 mol** of Fe_2O_3

3. Finally, we can work out the mass that **0.0179 mol** of Fe_2O_3 has:

$M(\text{Fe}_2\text{O}_3) = (2 \times 55.85\ \text{g mol}^{-1}) + (3 \times 16.00\ \text{g mol}^{-1})$
$= \mathbf{159.7\ g\ mol^{-1}}$

$m = nM = \mathbf{0.0179\ mol} \times \mathbf{159.7\ g\ mol^{-1}}$
$= \mathbf{2.859\ g}$

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Limiting reagents

- Sometimes, the reactants are not present in exact stoichiometric amounts.
- In these cases, one reactant will be a **limiting reagent**. For example

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

- 5.0 g of $H_2(g)$ was reacted with 21.0 g of $O_2(g)$
- What mass of which reactant remains after the reaction is complete?

Brown (15th) pages 162-165

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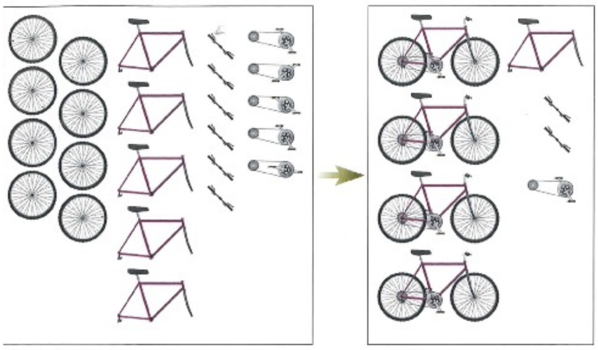
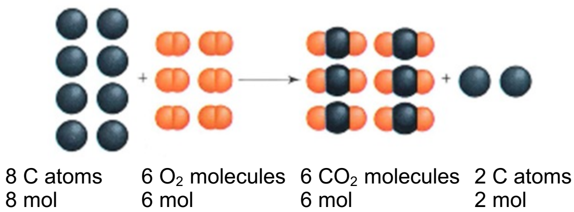
Limiting reagents



How many bicycles can be made from these parts?

The wheels are the **limiting reagent**

$$C + O_2 \rightarrow CO_2$$



Brown (15th) pages 162-165

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Limiting reagents

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

- Need to calculate amounts of both reactants.

  $n(H_2)$ = 5.0 g/2.0 g mol^{-1} = 2.5 mol

  $n(O_2)$ = 21.0 g/32 g mol^{-1} = 0.66 mol

- From stoichiometry work out which gives the smallest amount of product

  2.5 mol H_2 gives 2.5 mol H_2O

  0.66 mol O_2 gives 0.66 × 2 = **1.32 mol H_2O**

- So when 1.32 mol H_2O has been produced **all** of the O_2 has reacted and the reaction stops. H_2 is the reactant in excess

Brown (15th) pages 162-165

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Limiting reagents

- So when 1.32 mol H_2O has been produced all of the O_2 has reacted and the reaction stops.

- When 1.32 mol H_2O has been produced 1.32 mol H_2 must have reacted.

- Therefore H_2 remaining 2.5 – 1.32 = 1.18 mol

  $m = M \times n$ = 1.18 mol × 2.0 g mol^{-1}
  = 2.4 g H_2 remaining or in excess

Brown (15th) pages 162-165

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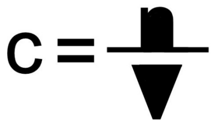
Solutions

- Define the composition of a solution in terms of its concentration – the amount of solute per volume of solvent

$$\boxed{c = \frac{n}{V}}$$



Cowboy equation

- E.g. 10.0 g glucose (M = 180.156 g mol^{-1}) dissolved in water to give final volume of 0.500 L.

$$n = \frac{m}{M} = \frac{10.0\text{ g}}{180.156\text{ g mol}^{-1}} = 5.55 \times 10^{-2}\text{mol}$$

$$c = \frac{n}{V} = \frac{5.55 \times 10^{-2}\text{mol}}{0.500\text{ L}} = 1.11 \times 10^{-1}\text{mol L}^{-1}$$

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NOTE

There are different ways to express concentration

Traditionally we use **mol L^{-1}**,

but the textbook uses either
mol dm^{-3} (moles per cubic decimeter) or **M** (molarity)

These are all the same.

But we will use mol L^{-1} in the lectures and in the labs

Also, the textbook sometimes gives volumes in cm^3
instead of mL – again these are the same.

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Conclusions

- You only have to know ***two*** equations to be able to do stoichiometry.

$$n = \frac{m}{M} \quad \text{and} \quad c = \frac{n}{V}$$

- You need to be able to balance chemical equations to do stoichiometry.
- Practice, practice, practice.....

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✱ Homework ✱

Brown (15^{th})

Problems 3.45, 3.56, 3.94, 3.102, 4.27, 4.80

Answers on Blackboard

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