Trinity College Dublin
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Preliminary Chemistry Course

Stoichiometry

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What is stoichiometry?

The meaning of the word:

The word stoichiometry comes from two Greek words: στοιχηον(meaning “element”) and μετρον(meaning “measure”)

Stoichiometry deals with calculations concerning the masses (& sometimes volumes) of reactants and products involved in chemical reactions. It is sometimes known as chemical arithmetic.

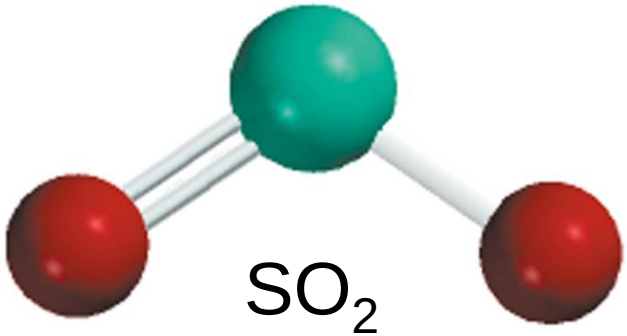
In the sense of Element measuring/counting

Moles, Molar Mass, Amount and Mass of substance

Molar mass is the mass of 1 mole of atoms, molecules or whatever in grams

Molar Mass is also referred to as Molecular Weight or Formula Weight

Molecular mass (or molecular weight) is the sum of the atomic masses in a molecule.

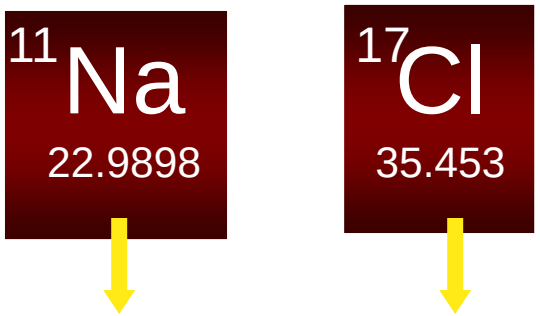


SO_2

1S	32.07
2O	+ 2 x 16.00
SO_2	64.07

1 mole SO_2 = 64.07 g SO_2

Molecular Weights of Compounds



Formula Mass is useful for e.g. Ionic compounds and metals that do not form discrete molecules.

E.g. Formula mass of Na = molar mass of Na = 22.9898 g

Formula mass of NaCl = Na (1 x 22.9898) + Cl (1 x 35.4527) = 58.44

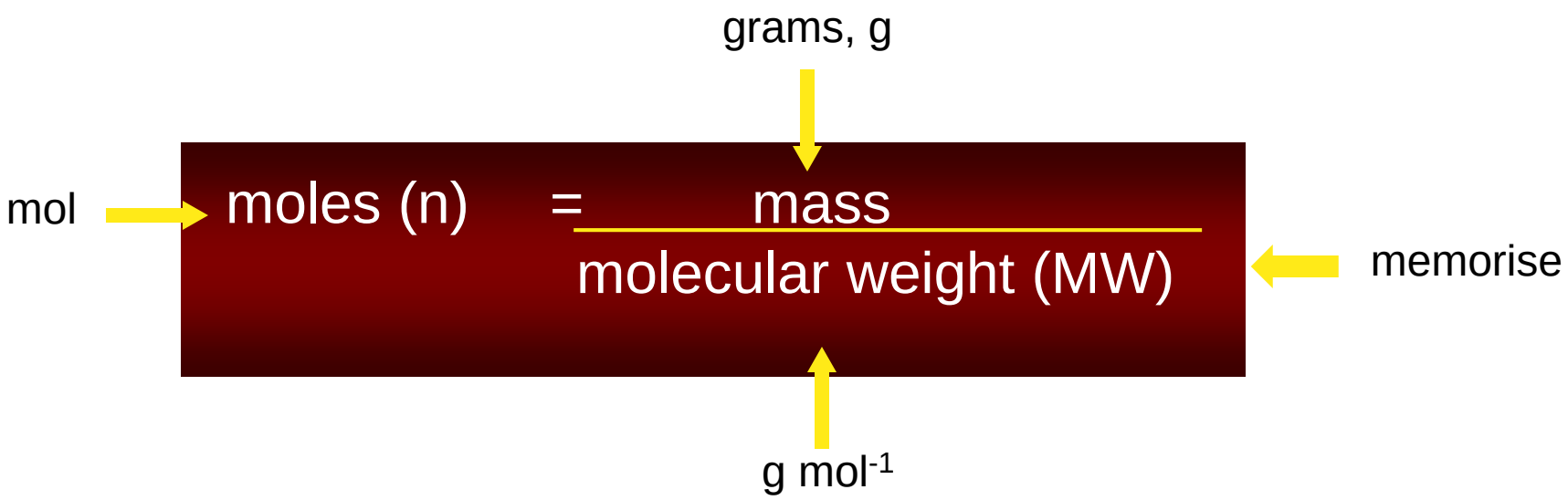
Q1

What is the molecular weight (MW) of…?

water (H_2O) = 18 g/mol

carbon dioxide (CO_2) = 44 g/mol

Relating moles and mass



Q 2

How many moles are there in…?

12.011 g of charcoal (carbon) = 1 mol

20 g of ethanol (CH_3CH_2OH) = 0.43 mol

Relating moles and mass

$$\text{moles} = \frac{\text{mass}}{\text{M.W.}}$$

rearrange →

$$\text{mass} = \text{moles} \times \text{M.W.}$$

Q 3

How many grams is…?

Two moles of carbon dioxide, CO_2 = 88 g

Three quarters of a mole of water, H_2O = 13.5 g

Calculating Mass Percentage and Masses of Elements in a Sample of a Compound - I

Problem: Sucrose ($C_{12}H_{22}O_{11}$) is common table sugar.

Q 4: What is the mass percent of each element in sucrose?

First, find the mass present of each element, and the molar mass**:**

mass of C = 12 x 12.01 g C/mol =	144.12 g C
mass of H = 22 x 1.008 g H/mol =	22.176 g H
mass of O = 11 x 16.00 g O/mol =	176.00 g O
Molar Mass of Sucrose	342.296 g
	= 342.3 g

Calculating Mass Percents and Masses of Elements in a Sample of Compound - II

Finding the mass % of C in Sucrose C **:**

Mass % of C = **(**144.12/342.3) x 100%

= 42.105% C

Mass % of H = (22.176/342.3) x 100%

= 6.479% H

Mass % of O = (176.0/342.3) x 100%

= 51.417% O

Remember always check your answer adds up to 100%

Calculating amounts from equations

A process in which one or more substances is changed into one or more new substances is a ***chemical reaction***

A ***chemical equation*** uses chemical symbols to show what happens during a chemical reaction

$$2\ Mg + O_2 \longrightarrow 2\ MgO$$

reactants ⟶ products

$2Mg + O_2 = 2MgO$

- What does this MEAN?
  - 2 mol Mg react with 1 mol O_2 to give 2 mol MgO
  - 48.6 g Mg will react with 32 g O_2 to give 80.6 g MgO
  - With other amounts, reaction will be in this ratio by mole or by mass .....

$2Mg + O_2 = 2MgO$

And therefore:

a) 48.6 g Mg will react with 33 g O_2 to give 80.6 g MgO and leave 1g O_2 unreacted.

b) 25g Mg will react with 16 g O_2 to give 40.3 g MgO and leave 0.7 g Mg unreacted

Limiting reagent

This leads us to the useful concept of the limiting reagent.

This is the reagent which is present in the lowest relative molar amount compared to the equation (stoichiometric amount) – e..g. The Mg in (a) and the O_2 in (b) on the last slide

And therefore limits the amount of product available from the reaction

Theoretical Yield is the amount of product that would result if all the limiting reagent reacted.

Actual Yield is the amount of product actually obtained from a reaction.

$$\textbf{\% Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$

Balancing Chemical Equations

1. Write the **correct** formula(s) for the reactants on the left side and the **correct** formula(s) for the product(s) on the right side of the equation.

Ethane reacts with oxygen to form carbon dioxide and water

$$C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$$

2. Change the numbers in front of the formulas (***stoichiometric coefficients***) to make the number of atoms of each element the same on both sides of the equation. Do not change the subscripts.

e.g. 2 C_2H_6 and NOT C_4H_{12}

Balancing Chemical Equations

3. Start by balancing those elements that appear in only one reactant and one product.

$C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$ start with C or H but not O

2 carbon on left

1 carbon on right

multiply CO_2 by 2

$C_2H_6 + O_2 \longrightarrow 2CO_2 + H_2O$

6 hydrogen on left

2 hydrogen on right

multiply H_2O by 3

$C_2H_6 + O_2 \longrightarrow 2CO_2 + 3H_2O$

Balancing Chemical Equations

4. Balance those elements that appear in two or more reactants or products.

$C_2H_6 + O_2 \longrightarrow 2CO_2 + 3H_2O$ multiply O_2 by $\frac{7}{2}$

2 oxygen on left | 4 oxygen (2x2) + 3 oxygen (3x1) = 7 oxygen on right

$C_2H_6 + \frac{7}{2}O_2 \longrightarrow 2CO_2 + 3H_2O$

remove fraction
multiply both sides by 2

$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$

Balancing Chemical Equations

5. Check to make sure that you have the same number of each type of atom on both sides of the equation.

$$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$$

14 O (2 x 7)

14 O (4 x 2 + 6)

Reactants	Products
4 C	4 C
12 H	12 H
14 O	14 O

Exercise

$2\,Zn + O_2 \longrightarrow 2\,ZnO$

$2\,KClO_3 \longrightarrow 2\,KCl + 3\,O_2$

$2\,B + 3\,F_2 \longrightarrow 2\,BF_3$

$2\,CaCO_3 + 5\,C \longrightarrow 2\,CaC_2 + 3\,CO_2$

Atomic weight determination

- 1.35 g Ca reacts with Oxygen to give 1.88 g CaO.

Q 5: What is the atomic weight of Ca?

- 1 mole CaO contains 1 mole Ca atoms and 1 mole O atoms
- 1.35 g Ca reacts with 0.53 g O
  (1.35x16/0.53)g Ca reacts with 1 mole O (atoms!)
  so 1 mole of Ca atoms = 1.35x16/0.53 = 41 g
- **Atomic weight of Ca is 41**

Reaction Yield

Q 6: How much CO_2 will be produced from complete combustion of 1 dm^3 of Octane(C_8H_{18})? (Density of Octane : 570 g dm^{-3})

Equation is :

$$C_8H_{18} + 25/2\ O_2 = 8\ CO_2 + 9\ H_2O$$

i.e. 1 mole C_8H_{18} (molar mass 114) yields 8 moles CO_2 (44)

1 dm^3 C_8H_{18} = 570 g = 570/114 = 5 moles

and 5 mole C_8H_{18} yields (5 *x* 8) = 40 moles CO_2 =(40 *x* 44/1000) kg CO_2

= 896 dm^3 at S.T.P.

≈ 1000 dm^3 (1 m^3) at room temperature and pressure

- Depending on road conditions, this is the CO_2 produced by a car travelling approximately 10 miles
- I have "fiddled" the density of octane - see if you can repeat the calculation using the true value for the density.

Reagent Composition

and – eventually – reagent formula

Complete combustion of 1g of a compound of C, H, O produces 2.000 g of CO_2 and 1.010 g of H_2O.

Q 7: What is the composition (%age by mass) of the compound?

(i) 1 mole of CO_2 contains 1 mole of C atoms

so 44 g of CO_2 contains 12 g of C atoms

and 2.000 g of CO_2 contains (12x2.000/44) g of C atoms = **0.5455 g C**

(ii) 1 mole of H_2O contains 2 mole of H atoms

so 18 g of H_2O contains 2 g of H atoms

and 1.010 g of H_2O contains (1.010x2/18) g of H atoms = **0.0909 g H**

(iii) O = remainder = (1 - 0.5455 - 0.0909) = **0.3636 g O**

Therefore 1 g contains 0.5455 g C; 0.0909 g H; 0.3636 g O

and

composition is **54.55% C** **9.09% H** **36.36% O**

Q 8 : What is the Empirical formula of this compound?

- **EMPIRICAL FORMULA : the SIMPLEST formula for a compound compatible with the composition.** A true molecular formula requires an estimate of molar mass.
- Remember the compound had composition (%) by mass =
  C : 54.55 H : 9.09 O : 36.36
  (i) Get molar amounts (composition by relative numbers of aroms) by dividing by atomic weight :
  C = 54.55/12 = 4.55; H = 9.09/1 = 9.09; O = 36.36/16 = 2.27

  (ii) Now get relative molar ratio by dividing across by smallest :
  C = 4.55/2.27 = 2.00; H = 9.09/2.27 = 4.00; O = 1.00

  (iii) In this case round to integers and get answer : **C_2H_4O**
  (It **may** be necessary to multiply results in (iii) by small integer - e.g. 2 or 3 - to get answers close to integers)

Molecular formula

- The compound has a molar mass (molecular weight) “close to 100”.
- Q 9: What is the molecular formula?
- The molecular formula must be an integer multiple of the empirical formula, (“formula mass” = 44) and so the molar mass must be the same multiple of 44.
- Possibilities are :

  C_2H_4O which implies a molar mass of 44

  $\Rightarrow$ **$C_4H_8O_2$ which implies a molar mass of 88** $\Leftarrow$

  $C_6H_{12}O_3$ which implies a molar mass of 132

  $C_8H_{16}O_4$ which implies a molar mass of 176

- **Molecular formula is $C_4H_8O_2$**
- N.B.
  - note that molar mass need only be approximate!
  - take nearest multiple of empirical formula