Revision of calculations
Stoichiometric calculations
Osmotic pressure and osmolarity

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Concentration of a solution

- mass concentration: grams of substance per litre of solution
- molar concentration: moles of substance per litre of solution
- in %:
  - **% (w/v):** weight per volume, grams of substance per 100 ml of solution
  - **% (v/v)** volume per volume, ml of substance per 100 ml of solution

Molar Volume

one mole of any gaseous substance occupies the same volume at the same temperature and pressure

..22.414 litres at 101.325 kPa, 0 °C (273.15 K)

(Avogadro's Law)

$P \cdot V = n \cdot R \cdot T$

P: pressure in kPa

V: volume in dm^3 (l)

n: number of moles

R: universal gas constant (8.31441 $N.m.mol^{-1}.K^{-1}$)

T: temperature in K

Example: what is volume of one mole of gas at 101.325 kPa and 25 °C ?

$$P.V = n.R.T$$

$$V = \frac{n.R.T}{P} = \frac{1 \times 8.31441 \times (273.15+25)}{101.325} =$$

$$= 24.465\ dm^3$$

Conversions between mass and molarity: Summary

- **Always distinguish between amount of substance in moles (grams) and concentration of substance in mol/l (g/l)**
- **For conversion from mass to molarity divide the mass (g or g/l) with molar mass (relative AW/MW/FW)**
- **For conversion from molarity to mass multiply the molarity (mol or mol/l) with molar mass (relative AW/MW/FW)**

Conversion from mass to molar

Example: Calculate molar concentration of Na_2HPO_4 solution c = 21 g /l.
(AW of Na: 23, P: 31, O: 16, H: 1)

FW of Na_2HPO_4 : 46+1+31+4x16 = 142

Molar concentration = Mass conc. (g/l) / FW

= 21 / 142 = 0.15 mol/l

Conversion from molar to mass

Example: Calculate how many g of $KClO_4$ is needed for preparation of 250 ml of 0.1 M solution.
(AW of K: 39, Cl: 35.4, O: 16)

FW of $KClO_4$: 39 + 35.4 + 4x16 = 138.4

Mass conc. = molar conc. x FW

we need 138.4 x 0.1 x 0.25 = 3.46 g $KClO_4$

Conversion from % to molarity

Example: The physiological saline is NaCl 0.9 % (w/v) What is molar concentration of NaCl in this solution? (AW of Na: 23, Cl: 35.5)

FW of NaCl : 23+35.45 = 58.5

0.9 % (w/v) is 0.9 g/100 ml = Mass conc. 9 g/l

Molar concentration = Mass conc. (g/l) / FW

= 9/58.5 = 0.154 mol/l

Calculations with molar volume

Example: What is weight (in grams) of 1 liter of oxygen at atmospheric pressure and ambient temperature ?

(AW of O: 16)

Molar volume at 101.325 kPa and 25 °C: 24.5 l/mol

1 liter of oxygen is 1/24.5 = 0.040816 mol

Conversion to mass: 0.040816 x 32 = **1.306 g**

Diluting solutions

Example: You need to prepare 1 liter of 0.1 M HCl. How many ml of concentrated HCl (12 M) do you need to take ?

$$c_1 \cdot v_1 = c_2 \cdot v_2$$

$$12 \times v_1 = 0.1 \times 1000$$

$$v_1 = 100/12 = \underline{\mathbf{8.33\ ml}}$$

What is molarity of pure water?

Molar concentration: moles of substance per liter of solution

1 liter of water weighs 997 g at 25 °C

FW of H_2O: 2+16=18

997 g H_2O is 997/18 = 55.4 moles

Molarity of pure water is **<u>55.4 mol/l</u>**

Stoichiometric calculations

Titration calculations

Example: An unknown sample of sulfuric acid H_2SO_4 was titrated with the known KOH solution. It was found that 12 mL of the KOH c=0.1 mol/L was needed for just complete neutralisation of 10 mL H_2SO_4 unknown sample.

What is concentration of sulfuric acid in the sample?

Equation: $H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2\ H_2O$

Calculation: H_2SO_4 KOH

$$c_1 \cdot v_1 = c_2 \cdot v_2$$

$$c_1 = c_2 \cdot v_2 / v_1$$

$$c_1 = 0.1 \cdot 12 / 10 = 0.12$$

Including stoichiometry : $c(H_2SO_4) = 0.12/2 =$ **0.06 mol/L**

Stoichiometric calculations

Example: In the reaction between barium nitrate and sodium sulfate, how many grams of barium sulfate can be prepared from 10 ml of 10 % (w/v) barium nitrate? Take into account that about 5% of the product is lost.
(AW of barium: 137.3, sulfur: 32.1, nitrogen: 14.0, oxygen: 16.0)

equation: $Ba(NO_3)_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaNO_3$

FW $Ba(NO_3)_2$: 261.3 FW $BaSO_4$: 233.4

10 ml of 10% (w/v) $Ba(NO_3)_2$: 1 g ... 1/261.3 = 0.003827 moles

amount of $BaSO_4$ formed: 0.003827 moles ....

... 0.003827 x 233.4 = 0.8932 g (theoretical yield, 100%)

Actual yield: 0.8932 x 0.95 = **0.849 g**

Stoichiometric calculations

Example II: Propane gas burns on air to water and carbon dioxide:

$CH_3CH_2CH_3(g) + O_2(g) \rightarrow H_2O(g) + CO_2(g)$

Balance the equation and then calculate how many grams of water and carbon dioxide will result from burning of 10 liters of propane gas (molar volume at 25 °C and atmospheric pressure: 24.465 l/mol)

Balanced equation:

$CH_3CH_2CH_3(g) + 5O_2(g) \rightarrow 4H_2O(g) + 3CO_2(g)$

10 l ? (MW: 18) ? (MW: 44)

10 l of propane: 0.4087 moles

... → 1.635 mol H_2O = **29.4 g**

... → 1.226 mol CO_2 = **53.9 g**

Stoichiometric calculations

Example III: Solid lithium hydroxide is used in space shuttles to remove exhaled carbon dioxide from the living environment:

$$2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(g) + H_2O(l)$$

Imagine that you are planning a space mission of two astronauts for 72 hours. One astronaut will produce 250 ml of CO_2 per minute at rest. How many kg of solid lithium hydroxide are needed for the mission? (AW Li: 6.941, molar volume 24.465 L/mol)

CO_2 production: $0.25\ L \times 60 \times 72 \times 2 = 2160\ L$ (88.3 mol)

2×88.3 mol LiOH needed: 176.6 mol

FW LiOH: 6.941 + 17 = 23.941

176.6 mol LiOH is 4228 g = ~ **4.23 kg**

Osmolarity
Osmotic pressure

Osmolarity

Sum of all osmotically active particles (OAP) in a solution

One of the colligative properties: only number of particles counts, not their kind !

Units: moles of osmotically active particles (osm) per liter

Example:

NaCl 0.15 mol/l, in solutions exists as ions Na^+, Cl^- … 2 OAP

….. Osmolarity **0.3 mol OAP/l (0.3 osm/l)**

Osmotic pressure

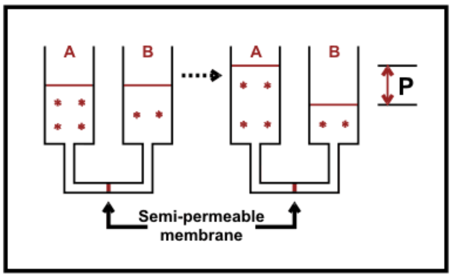


Figure from: http://www.bbc.co.uk/dna/h2g2/A686766

$$\Pi = n \cdot C \cdot R \cdot T$$

Osmolarity

Π: osmotic pressure in kPa

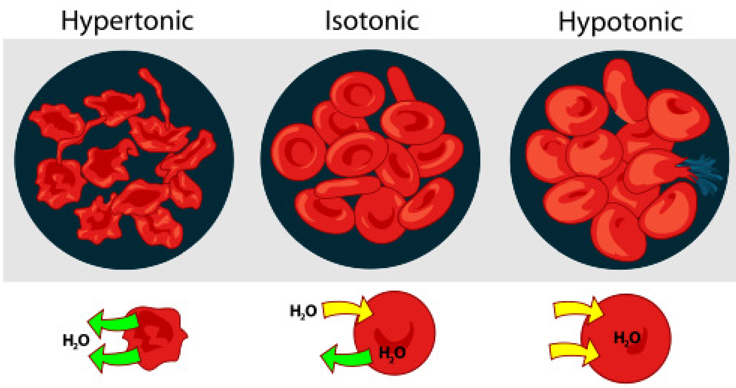
n: number of OAP per mole

C: molar concentration in mol/l

R: universal gas constant ($8.31441\ N.m.mol^{-1}.K^{-1}$)

T: temperature in K

Osmolarity is important in medicine



- Isotonic: osmolarity = 0.3 osm/l (NaCl 0.15 mol/l)
- Hypotonic: osmolarity < 0.3 osm/l
- Hypertonic: osmolarity > 0.3 osm/l

Figure from: Wikipedia

Calculations of osmolarity/osmotic pressure

Example I: Calculate <u>osmolarity</u> of Na_2HPO_4 solution of c = 21 g /l.
(AW of Na: 23, P: 31, O: 16, H: 1)

FW of Na_2HPO_4 : 46+1+31+4x16 = 142

Molar concentration = Mass conc. (g/l) / FW

= 21 / 142 = <u>0.15 mol/l</u>

3 OAP: 2x Na^+, 1x HPO_4^{2-}

Osmolarity: 0.15 x 3 = <u>0.45 mol OAP/l</u>

Calculations of osmolarity/osmotic pressure

Example II: Calculate osmotic pressure of Na_2HPO_4 solution of c = 21 g /l at 37 °C.
(AW of Na: 23, P: 31, O: 16, H: 1; R = 8.31441 $N.m.mol^{-1}.K^{-1}$)

FW of Na_2HPO_4 : 46+1+31+4x16 = 142

Molar concentration = Mass conc. (g/l) / FW

= 21 / 142 = 0.15 mol/l

3 OAP: 2x Na^+, 1x HPO_4^{2-}

Osmolarity: 0.15 x 3 = 0.45 mol OAP/l

Osmotic pressure: $\Pi = n . C . R . T$

$\Pi = 3 \times 0.15 \times 8.31441 \times (273.15 + 37) =$ 1160 kPa

(hypertonic)

Calculations of osmolarity/osmotic pressure

Example III: 0.2 M KCl solution is combined with an equal volume of 0.5 M glucose solution.
What is the resulting osmolarity?

After mixing:

KCl:

c= 0.1 mol/l, 2 OAP: contribution to osmolarity 0.2 mol/l

Glucose:

c=0.25 mol/l, 1 OAP: contribution to osmolarity 0.25 mol/l

Total osmolarity: 0.2 + 0.25 = 0.45 mol OAP/l