4 Moles, Molarity and Solutions

It is very often necessary in a Chemistry or Biology experiment to make up a solution of a certain concentration.

There are different ways to describe the concentration of a solution.

One very common way is by expressing the MOLARITY of the solution.

To understand MOLARITY, we must define the "mole".

Making up Solutions

The MOLE: SI unit for ‘amount of substance’

The mole is the counting unit that represents a certain number of elementary units of a substance.

We use the mole to relate the number of elementary units of the substance to the actual mass of a sample of the substance.

Elementary Unit: atom or molecule

The Mole

A mole is the amount of substance that contains the same number of elementary units as there are in exactly 12 g of carbon-12 (C^{12})

This number of elementary units is called

Avogadro's Number, N_A ($N_A = 6.022 \times 10^{23}$)

- 1 mole contains 6.022×10^{23} elementary units.
- Elementary units can be : atoms, molecules, ions. e.g.
  - 1 mole of ^{12}C atoms contains 6.022×10^{23} carbon *atoms*
  - 1 mole of oxygen gas contains 6.022×10^{23} oxygen *molecules*

Relationship between mass and moles:

- *The atomic mass of an element expressed in amu is numerically the same as the mass of one mole of atoms of the element expressed in grams*
- one atom of helium has a mass of 4 amu
- one mole of helium atoms has a mass of 4 g (i.e. the molar mass of He is 4 g)

The mass of one mole (in g) is called the molar mass

Moles, Mass and number of atoms

One mole of atoms = 6.022×10^{23} atoms

atomic mass (written in g) = the mass of one mole

- Therefore 19 g fluorine = 1 mole

  (19 g fluorine contains 6.022×10^{23} atoms)

- 31 g phosphorous = 1 mole

  (31 g phosphorous contains 6.022×10^{23} atoms)

Moles of Compound (Molecules – not atoms)

- One mole of a compound = molecular mass written in grammes
- the molecular mass of a compound is the sum of the atomic masses of its elements
  - molecular mass H_2O = 2(atomic mass H) + atomic mass O
  - =2 (1.008 amu) + 16 amu = 18.02 amu
  - one mole of water = 18.02 g
  - (This contains 6.022×10^{23} molecules of water)

Converting mass to number of moles

We can calculate the number of moles in a given mass of a compound.

Simple formula:

$$\text{Number of moles} = \frac{\text{Actual Mass (of compound)}}{\text{Molar Mass}}$$

$$n = m / M$$

Example: How many moles in 65 g of NaCl?

The molar mass of NaCl is: 23 + 35.5 = 58.5 g

Using Formula: n = mass / molar mass

= 65/ 58.5 = 1.1 moles

Converting mass to number of moles

How many moles in 2 g of potassium?

1 mol K = 39.098 g

How many times is 39.098 g in 2 *g?*

Answer: 2 / 39.098 = 0.051

Using the formula:

$n = m / M = 2 / 39.098$

$= 0.051$ *moles*

Converting between moles and mass

- *How many moles of carbon atoms are contained in a 1.0 carat (0.20g) diamond?*

Molar mass of carbon = 12.011 g

Number of moles in 0.20 g = 0.20 / 12.011 = 0.17 moles

- *A litre of dry air contains about 9.2×10^{-4} mol of atoms of the element argon. What is the mass of argon in a Litre of air*

Mass of 1 mole of argon = 39.948 g

Mass of 9.2×10^{-4} moles = $9.2 \times 10^{-4} \times 39.948$ = 0.037g

Moles of Atoms in Molecules

- **The chemical formula for a molecule of a particular substance allows us to see the number of atoms of each element present in the molecule.**
- **One mole of molecules contains the same number of moles of atoms as there are atoms in the formula:**
- e.g. ethanol C_2H_5OH

1 mole of ethanol contains 2 moles of carbon;

1 mole of ethanol contains 6 moles of hydrogen

1 mole of ethanol contains 1 mole of oxygen

Mass and Moles of compounds

- *A packet of an artificial sweetener contains 40 mg of saccharin $C_7H_5NO_3S$. How many moles of saccharin are contained in the 40 mg of saccharin? How many molecules of saccharin? How many atoms of carbon ?*

Mass of 1 mole of $C_7H_5NO_3S$ = 183.187 g/mol

Number of moles in 40 mg (0.04 g)

N = mass / molar mass = 0.04 / 183.187

= 2.2×10^{-4} mol saccharin

Number of molecules = $2.2 \times 10^{-4} \times 6.022 \times 10^{23}$

= 1.3×10^{20} molecules

Number of C atoms = $1.3 \times 10^{20} \times 7$ atoms

Questions

1. What is the molecular mass of sodium cyanide (NaCN)?
2. How many moles of Na are there in 20 g of Na?
3. What is the mass in grams of 2.5 moles of NaI?
4. How many molecules are there in 4 moles of H_2 ?
5. How many moles of oxygen atoms are there in 3 moles of potassium permanganate ($KMnO_4$) ?
6. If you have 100 g of hydrated copper sulphate ($CuSO_4 . 6H_2O$), how many moles do you have?

Solutions

- A solution is a homogeneous mixture of a solute, the substance that dissolves, and a solvent, the substance in which the solute dissolves.
- Solute or solvent can be a solid, liquid or gas
- addition of a little solute gives a dilute solution
- the addition of more solute gives a concentrated solution
- the amount of solute dissolved in a solvent is called the concentration of the solution

Concentration of Solutions

- Concentration measures amount of one substance (solute) contained within unit measure of another (solution).
- Most common unit is molarity (M)
  - **Molarity: the number of moles of solute contained in exactly 1 litre of solution.**

- **Formula: Molarity = number of moles/ volume in litres**
  - **M = n/V**

- Concentration is the amount of solute per litre; it does NOT depend on the total amount of solution

Calculations with Molarity ….

Example 1: A volume of 5 litres of dilute NaCl solution contains 2 moles of NaCl. What is the molarity of the solution?

- **Formula: Molarity = number of moles/ volume in litres**
  - **M = n/V**
    - **= 2/5**
    - **= 0.4 M**
- Answer: The solution is 0.4 Molar
- We write this : 0.4 M

Calculations with Molarity ….

Example 2

How many moles of NaCl are contained in 0.250 L of a 5.3 M solution?

Two ways to approach the problem:

(1) The Logical Way:

Molarity = Number of moles in one litre of solution

5.3 M: Means that there are 5.3 moles in 1 Litre

Therefore there must be

5.3 moles x 0.250 moles in 0.250 Litres

=1.325 moles

Calculations with Molarity ….

Or (still using the logical way, but working in mls):

Molarity = Number of moles in 1000 ml of solution

5.3 M: Means that there are 5.3 moles in 1000 ml

Therefore there must be

$\frac{5.3}{1000}$ moles in 1 ml

And therefore $\frac{5.3x250}{1000}$ moles in 250 ml

That is 1.325 moles

Calculations with Molarity ….

(2) The Formula Way:

Example 2 (again): How many moles of NaCl are contained in 250 mL of a 5.3 M solution?

Formula: $M = n / V$

$M = 5.3$

$V = 0.250$

$n = ?$

$n = M \times V = 5.3 \times 0.250$

$= 1.325$ moles (1.325 mol)

Note: The abbreviation for moles is "mol".

Making up Solutions

Imagine we want to dissolve a substance in de-ionized water so as to make a solution:

We must know three things:

- what is the substance and what is it molar mass;
- what is the Molarity of the solution that is required;
- what is the volume of solution that is required.

With this information we FIRST DO A CALCULATION;

then we will be ready to make up the solution.

Calculations with Molarity ….Method

1. *Work out the molar mass:*
   this is mass required to make 1 Litre (1000 mL) of 1 M solution

2. *Calculate the number of moles that will be needed for the Molarity of solution required:*
   n = M X V (Molarity X Volume in litres)

3. *Convert the number of moles to the actual mass:*
   (n x Molar Mass)

How many grams of NaCl are needed to make 300 ml of 2M NaCl?

Using definition of molarity:

1 Mole of NaCl = 58.43 g

1M: 58.43 g in 1 Litre

2M: (58.43 X 2)g in 1 Litre

= (58.43 x 2) X 0.300 g in 300 mL

=35.06 g

Using moles formula:

1 Mole of NaCl = 58.43 g

Number of moles required

= M X V

= 2 X 0.300

= 0.6 moles

0.6 moles = 58.43 x 0.6

= 35.06 g

Calculations with Molarity ….

How many grams of NaCl are needed to make 400 ml of 0.25 M solution?

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1 Mole of NaCl = 58.43 g

Number of moles = 0.25 X 0.400 = 0.01 moles

Convert to gram: 0.01 X 58.43

= 5.843 g

Quick Pointers for making solution from a Dry (solid) solute

- *Add solid to volumetric flask*
- *Add a little water and shake or wait for solid to dissolve.*
- *Add almost all the rest of the water – almost up to the mark.*
- *Use pipette to add water to get exactly to the mark (Q.S.)*

Making up a Solution from a solid solute

Previous example: making up 400 mL of 0.25 M NaCl

From calculation we see that we need 5.843 g of NaCl

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1) *Get ready: 400 mL volumetric flask, pipette, analytical balance and weighing boat, beaker (500mL), stock NaCl*
2) *Weigh out exactly 5.843 g of NaCl and transfer to the volumetric flask.*
3) *Add de-ionised water to volumetric flask, about 50 mLs; shake to dissolve the NaCl. Allow time for temperature equilibrium to be achieved.*
4) *Add de-ionised water up to volume of approx. 80% of total (or to within 5 or 10 mL of total)*
5) *Q.S. with de-ionised water, to exact mark, using pipette.*

Q.S.

.Q.S. stands for "Quantity Sufficient".

It means "add enough solvent to get to the right volume"

You can only Q.S. a solution in a <u>calibrated</u> vessel e.g. in a volumetric flask.

Making Solutions from Hydrated Compounds

A hydrated compound has water molecules attached.

This water contributes to the solvent.

So you must take it into account.

The easiest way to do this is to make sure to not put any more than 80% of the required final volume into the volumetric flask before checking .*Remember to work out the FULL molecular mass (including the attached water)*

Examples of Hydrated Compounds

- Copper chloride dihydrate: CuCl. $2H_2O$
- Cobalt chloride hexahydrate:
- Copper sulfate pentahydrate:
- Washing soda: sodium carbonate decahydrate:
- Epsom slats: magnesium sulfate dihydrate:

Molarity of anion and cation

- **One mole of molecules contains the same number of moles of atoms as there are atoms in the formula:**
- e.g **NaCl**

  1 mole of sodium chloride contains 1 mole of Na^+ (sodium cation) and 1 mole of Cl^- (chloride anion).

So when we make a 1M solution of NaCl the solution is 1M in the sodium cation AND 1M in the chloride anion.

- e.g **$CaCl_2$**

1 mole of calcium chloride contains 1 mole of Ca^+ (calcium cation) and 2 moles of Cl^- (chloride anion).

So when we make a 1M solution of $CaCl_2$ the solution is 1M in the calcium cation AND 2M in the chloride anion.

N.B. if we wanted the solution to be 1M in the chloride anion, we would have to make a solution of 0.5M $CaCl_2$