# 1.2 The mole concept

## Understandings:

- The mole is a fixed number of particles and refers to the amount, ***n***, of substance.

***Guidance***

*The value of the Avogadro's constant (L or $N_A$) is given in the data booklet in section 2 and will be given for Paper 1 questions.*

- Masses of atoms are compared on a scale relative to $^{12}C$ and are expressed as relative atomic mass ($A_r$) and relative formula/molecular mass ($M_r$).
- Molar mass ($M$) has the units g $mol^{-1}$.

***Guidance***

*The generally used unit of molar mass (g $mol^{-1}$) is a derived SI unit.*

- The empirical and molecular formula of a compound give the simplest ratio and the actual number of atoms present in a molecule respectively.

## Applications and skills:

- Calculation of the molar masses of atoms, ions, molecules, formula units.
- Solution of problems involving the relationship between the number of particles, the amount of substance in moles, and the mass in grams.
- Interconversion of the percentage composition by mass and the empirical formula.
- Determination of the molecular formula of a compound from its empirical formula and molar mass.
- Obtaining and using experimental data for deriving empirical formulas from reactions involving mass changes.

## What is the relative atomic mass ($A_r$) and relative molecular mass ($M_r$)?

When talking about atomic and molecular masses we use the term molar mass . This is a mass (of an atom or molecule) given in the units g/mol . This allows us to calculate the number of grams if we know the number of moles.

E.g. What is the mass of exactly 1 mole of O atoms (M = 16.00 g/mol)?

1 mol x 16.00 g/mol = 16.00 g

When comparing the masses of atoms we tend to use relative atomic or relative molecular masses . These are actually ratios between themolar mass of something and $^1/_{12}$ of the molar mass of an atom of $^{12}C$. As the molar mass of a carbon-12 atom is 12 g/mol - $^1/_{12}$ x 12 g/mol = 1 g/mol

So if I compare an oxygen atom (M = 16.00 g/mol) with 1 g/mol my ratio is:

16.00 g/mol : 1 g/mol

16.00 : 1

Ratio = 16

(The units can be cancelled out so relative masses do not have any units.)

If this is confusing, consider what the ratio is between 4 red apples and 2 green apples. Hoopefully you would state the ratio as 2:1 or simply 2 without any units.

What is the molecular mass of:

1. $Mg(NO_3)_2$
2. $Zn(OH)_2$
3. $MgSO_4 \cdot 7H_2O$
4. $[Al(H_2O)_6]^{3+}$

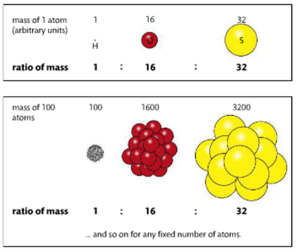
(Use your periodic table!)

# 1.2 - The mole concept

As the masses of individual atoms are so small we prefer to deal with quantities of atoms in SI units of moles .

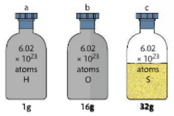
This allows use to deal with more sensible masses instead of values like 3.27 x $10^{-25}$ kg.

If we compare the masses of a hydrogen, oxygen and sulphur atom:




$6.02 \times 10^{23}$

Now if we could take $6 \times 10^{23}$ atoms of hydrogen, it happens that this would have a mass of 1 g. It follows from the ratios above, that *the same number of atoms* of oxygen would have a mass of 16 g while *the same number of atoms* of sulfur has a mass of 32 g. So we now have a quantity of atoms that we can measure in grams.




The final number allows us to convert the mass of a single atom to a mass in grams. This number is called the Avagadro number (after Amadeo Avagadro). This number is the basis for our unit of quantity.

1 mole of a substance = 6.02 x $10^{23}$ particles of that substance

$N_A$

So a mole is just a quantity of something (just like a dozen eggs is 12 eggs).

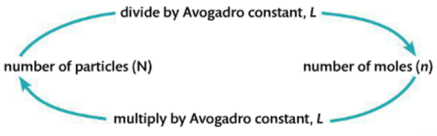
http://www.kokogiak.com/megapenny/

**Worked example**

A tablespoon holds 0.500 moles of water. How many molecules of water are present?

**Worked example**

A solution of water and ammonia contains $2.10 \times 10^{23}$ molecules of $H_2O$ and $8.00 \times 10^{21}$ molecules of $NH_3$. How many moles of hydrogen atoms are present?




**Exercises**

**13** Calculate how many hydrogen atoms are present in :
- **(a)** 0.020 moles of $C_2H_5OH$
- **(b)** 2.50 moles of $H_2O$
- **(c)** 0.10 moles of $Ca(HCO_3)_2$

**14** Propane has the formula $C_3H_8$. If a sample of propane contains 0.20 moles of C, how many moles of H are present?

**15** Calculate the amount of sulfuric acid, $H_2SO_4$, which contains $6.02 \times 10^{23}$ atoms of oxygen.

As 1 mole of any substance will give the same number of grams as its molar mass:

Number of moles x Molar mass (g/mol) = Mass (g)

$n = \frac{m}{\text{molar mass}}$

What is the mass of the following?

(a) 6.50 moles of NaCl

(b) 0.10 moles of $OH^-$ ions

Hint: give your answers to the same number of significant figures as given in the question.

What is the amount in moles of the following?

(a) 32.50 g $(NH_4)_2SO_4$

(b) 273.45 g $N_2O_5$

## What is an empirical formula?

An empirical formula show the simplest whole-number ratio of atoms (of each element) in a compound.

Remember, themolecular formula shows the actual number of each atom.

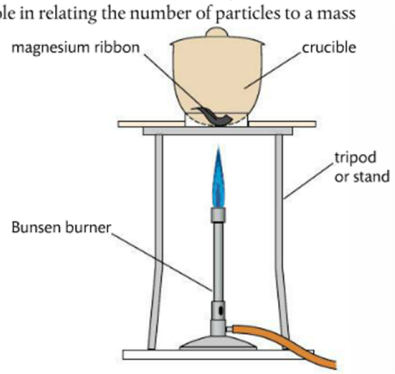
| Molecular formula | Empirical formula |
|---|---|
| $C_2H_6$ | |
| $H_2O_2$ | |
| $H_2O$ | |
| $C_4H_8O_2$ | |
| $C_6H_{12}O_6$ | |

### The empirical formula of a compound gives the simplest ratio of its atoms

Magnesium burns brightly in air to form a white solid product, and we might ask how many atoms of magnesium combine with how many atoms of oxygen in this reaction? Thanks to the mole, and its central role in relating the number of particles to a mass that can be measured, we can find the answer to this quite easily.

All we have to do is:

- burn a known mass of Mg, and from this calculate the moles of Mg;
- calculate the mass of oxygen that reacted from the increase in mass, and from this calculate the moles of O;
- express the ratio of moles Mg : moles O in its simplest form;
- the ratio of moles is the ratio of atoms, so we can deduce the simplest formula of magnesium oxide.




Example data: Mass of magnesium used: 0.043 g

Mass of oxygen in compound: 0.029 g

A of Mg = 24.31

A of O = 16.00

**Worked example**

A sample of urea contains 1.120 g N, 0.161 g H, 0.480 g C, and 0.640 g O. What is the empirical formula of urea?

Pull

**Solution**

- Convert the mass of each element to moles by dividing by its molar mass, *M*.
- Divide by the smallest number to give the ratio.
- Approximate to the nearest whole number.

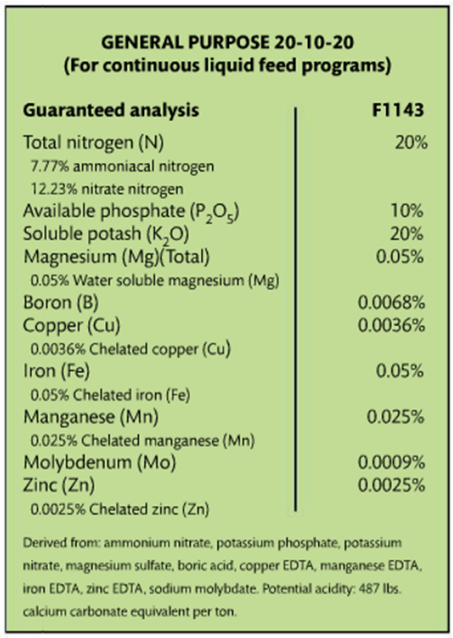
| | Nitrogen, N | Hydrogen, H | Carbon, C | Oxygen, O |
|---|---|---|---|---|
| mass / g | 1.120 | 0.161 | 0.480 | 0.640 |
| $M$ / g mol$^{-1}$ | 14.01 | 1.01 | 12.01 | 16.00 |
| number of moles / mol | 0.0799 | 0.159 | 0.0400 | 0.0400 |
| divide by smallest | 2.00 | 3.98 | 1.00 | 1.00 |
| nearest whole number ratio | 2 | 4 | 1 | 1 |

Smog is common in cities throughout the world. One component of smog is PAN (peroxyacylnitrate) which consists of 20.2 % C, 11.4 % N, 65.9 % O and 2.50 % H by mass.
Determine the empirical formula of PAN, showing your working.

12.01 14.01 16.00 1.01 g/mol

(HINT: Imagine you have 100g of the compound)

I used a mass spectrometer to calculate the relative molecular mass of PAN as 242.
What is the molecular formula?



**GENERAL PURPOSE 20-10-20**
**(For continuous liquid feed programs)**

| Guaranteed analysis | F1143 |
|---|---|
| Total nitrogen (N) | 20% |
| 7.77% ammoniacal nitrogen | |
| 12.23% nitrate nitrogen | |
| Available phosphate ($P_2O_5$) | 10% |
| Soluble potash ($K_2O$) | 20% |
| Magnesium (Mg)(Total) | 0.05% |
| 0.05% Water soluble magnesium (Mg) | |
| Boron (B) | 0.0068% |
| Copper (Cu) | 0.0036% |
| 0.0036% Chelated copper (Cu) | |
| Iron (Fe) | 0.05% |
| 0.05% Chelated iron (Fe) | |
| Manganese (Mn) | 0.025% |
| 0.025% Chelated manganese (Mn) | |
| Molybdenum (Mo) | 0.0009% |
| Zinc (Zn) | 0.0025% |
| 0.0025% Chelated zinc (Zn) | |

Derived from: ammonium nitrate, potassium phosphate, potassium nitrate, magnesium sulfate, boric acid, copper EDTA, manganese EDTA, iron EDTA, zinc EDTA, sodium molybdate. Potential acidity: 487 lbs. calcium carbonate equivalent per ton.

<-- An example of percentage by mass information can be seen on fertilizer bags.

Percentage by mass just shows composition of a substance in terms of mass.

Question:

A company claims that its plant fertiliser, sodium tetraborate pentahydrate ($Na_2B_4O_7 \cdot 5H_2O$), contains 15.2% by mass of boron. What is the percentage error in this claim?

The mineral celestine consists mostly of a compound of strontium, sulfur, and oxygen. It is found by combustion analysis to have the composition 47.70% by mass Sr, 17.46% S, and the remainder is O. What is its empirical formula?