Chapter 3 - Moles, Atoms, Mass Percents and Stoichiometry

Section 1 – Moles and Atoms

Dr. Sapna Gupta

Introduction

Mass of an element/compound is necessary to carry out reactions. When we carry out reactions, certain mass of starting materials are used to form the products. In order to predict how much product we will form; we need to know how many atoms are reacting. This also makes sure that the law of conservation of matter is obeyed.

We know that all atoms on the periodic have different weights since they have different number of protons. But in reactions we cannot count atoms, so we have to weigh out chemicals. We need to have a conversion factor to know many atoms are in a certain mass of element or compound.

In this section we will learn how to convert mass of element or compound into number of atoms and a new unit, mole, which unifies everything in chemistry.

Molecular and Formula Mass of Compounds

- The periodic table has the atomic mass of all atoms. We can calculate mass of a compound by adding the atomic mass of all the elements in that compound using the periodic table (PT). But what are the units? Is this in grams? We will learn that as we progress.
- The terms are molecular mass for covalent compounds and formula mass for ionic compounds. However, for the purpose of our learning, I will refer to all masses as molecular mass or molecular weight (mol. wt. or MW).
- Good nomenclature skills will help you in knowing the formula of a compound and thus adding the element weights in the right amount. Not knowing the formula of the compound can lead to wrong mol wt. and thus derail all your calculations.
- One more point: How many significant places to keep in final answer? On the periodic table the mass may be given from 4 to 8 numbers. I recommend keeping your answer to maximum 3 decimal places. For my class you can use 2 decimal places also.

Calculating Formula Mass

Formula mass of any compound is the mass of element multiplied by the number of atoms in the formula and then adding them all.

$BaCl_2$ has 1 Barium ion and 2 Chloride ions.

1 Ba = 1x 137.33 = 137.33

2 Cl = 2 x 35.45 = 70.9

208.23

Units – at this time the units we will use are "amu" – **a**tomic **m**ass **u**nits.

The mass of $BaCl_2$ is 208.23 amu.

When there are brackets e.g. in $Ba_3(PO_4)_2$, then multiply each of the atoms in the brackets with the subscript. Or write the PO_4 twice and then add up the atoms.

3 Ba + $2PO_4$ = 3 Ba + 2 P + 8 O

NOTE: Ions do not make any difference in the mass of the atom because mass number is protons + neutrons.

Solved Problems: Calculating molecular weights

Calculate the formula weight of the following compounds from their formulas. Report your answers to four significant figures.

Magnesium hydroxide, $Mg(OH)_2$

1 Mg	1(24.31) =	24.31 amu
2 O	2(16.00) =	32.00 amu
2 H	2(1.008) =	2.016 amu
Total		58.326 amu; correct SF = 58.33 amu

Nitrous acid, HNO_2

1 H	1(1.008) =	1.008 amu
1 N	1(14.01) =	14.01 amu
2 O	2(16.00) =	32.00 amu
Total		47.018 amu; correct SF = 47.02 amu

Dimethylamine, $(CH_3)_2NH$

2 C	1(12.01) =	12.01 amu
1 N	1(14.01) =	14.01 amu
7 H	5(1.008) =	5.040 amu
Total		31.060 amu; correct SF = 31.06 amu

Atomic Weight and Number of Atoms

As we learned in Dalton's atomic theory that in a chemical reaction atoms will rearrange to form new compounds as product. There is no loss or gain of atoms. This is the Law of Conservation of Matter. Thus, we have to account for ALL atoms. To find out how many atoms will be undergoing rearrangement to form new compounds, we need to be able to count them. Which is impossible as atoms are so tiny! Their radius in measured in 10^{-10} m.

How do we manage this? In order to understand the size of the atoms let's do a small conceptual problem.

You have 1.00 gram of gold and 1.00 gram of helium. Which one has more atoms?

Helium weighs 4.0 amu and gold is 196.97 amu. It means you will need to many more atoms of helium to have the same weight as 1 g of gold because gold is very heavy.

Moles and Atoms

In a chemical reaction we are not counting atoms in a certain weight of the compound reacting. So we need to have a unit that will let us know how many atoms of each chemical is reacting. For this we use “moles”. (The abbreviated form of mole is mol.) How much is a mol?

- Amedeo Avogadro, an Italian chemist, in 1820s, was the first one to calculate a number of atoms using mass of protons and carbon -12 isotope.
- He proposed a new unit to account for number of atoms – mole. He said one mole of substance will have 6.022×10^{23} number of atoms which is equal to the mass of that atom.

1 mole atoms = 6.022×10^{23} atoms = atomic weight of the atom in grams.

For Helium: 1 mol He = 6.022×10^{23} atoms of He = 4.00 g

This translates to the fact that all weights of elements on the periodic table are now in grams in one mol of that element. Helium is 4.00 g in one mol or 4.00 g/mol. Gold is 196.96 g/mol.

Mole Concept (mol) contd…

1 mole is like a count of anything e.g., a dozen to convey the number 12, decade for 10 years etc.

- 1 mole has the count of 6.022×10^{23} :
  - 1 mole of people are 6.022×10^{23} of people
  - 1 mole of pencils are 6.022×10^{23} number of pencils
  - 1 mole of stars are 6.022×10^{23} number of stars
- So again:

1 mol C = 12.01 g of C = 6.022×10^{23} atoms of C

1 mol Fe = 55.847 g Fe = 6.022×10^{23} atoms of Fe

Now we will not be using amu. From now we will use g/mol as the units for all the atomic mass.

Solved Problem: Calculating atoms from grams

Helium and gold are two elements on the periodic table. Helium weighs 4 amu (atomic mass unit) and silver is 108 amu. If we had 1 gram each of helium and silver, which would have a greater number of atoms? 1.00 g of He or 1.00 g of Au?

$$1.00\ \cancel{g}\ He \times \frac{1\ \cancel{mol}}{4.00\ \cancel{g}} \times \frac{6.022 \times 10^{23}\ atoms}{1\ \cancel{mol}} = \boxed{1.5055 \times 10^{23}\ atoms\ He}$$

$$1.00\ \cancel{g}\ Au \times \frac{1\ \cancel{mol}}{196.97\ \cancel{g}} \times \frac{6.022 \times 10^{23}\ atoms}{1\ \cancel{mol}} = 3.057 \times 10^{21}\ atoms\ Au$$

Answer: He – it will take many more atoms of helium to weigh 1 g because the mass is less than Au.

Atomic Mass, Periodic Table and Reactions

The periodic table can now be viewed in a different light. The atomic number is the same, however the mass number now has the units g/mol of that element instead of what we were using - amu (atomic mass unit) as our unit of weight.

Oxygen is 15.99 g/mol – there are 15.99 g of O in every mol of O (which has 6.022×10^{23} number of atoms).

- Mole is an easy way to work with atoms without working in exponents.
- Practically we cannot measure moles or count atoms, so we work with weight. We figure out how many mols we need in a reaction and convert to grams and then weigh it using a balance.
- The number of atoms are still important because reactions occur at atomic level and according to the conservation of mass no atoms are destroyed – only rearranged. We take care of that when we write equations.

Molecular/Formula Mass

- Atomic mass is obtained from the periodic table. These mass numbers have been determined by using analytical instruments which takes into account all the isotopes.
- Molar mass or molecular weight or formula mass is the addition of the mass of ALL the atoms in the formula.
- **Example**: As before calculate the mass of magnesium hydroxide. Use the same numbers and method, but instead of using amu – use g/mol.
- Again – I recommend, unless specified, calculate molecular weight in up to 2 decimal places for most calculations.

Magnesium hydroxide, $Mg(OH)_2$

1 Mg	1(24.31) =	24.31 g/mol
2 O	2(16.00) =	32.00 g/mol
2 H	2(1.008) =	2.016 g/mol
Total		58.326 g/mol; correct SF = 58.33 g/mol

Solved Problem: Mole to gram

How many grams are in a 0.255 mol of nitrous acid, HNO_2?

You should be able to covert mols into atoms and into grams and all possible conversions. Follow the dimensional analysis learned in chapter 1 to do these calculations.

First, find the molar mass of HNO_2:

1 H	1(1.008) = 1.008	
1 N	1(14.01) = 14.01	
2 O	2(16.00) = 48.00	
Total		47.018 g/mol

$$0.255\ \cancel{\text{mol}} \times \frac{47.02\ \text{g}}{1\ \cancel{\text{mol}}} = 11.9901\ \text{g} = \boxed{12.0\ \text{g}}$$

Note: here is the calculation of 0.255 x 47.018 = 11.9859 g. This is just to show you that using the mol wt in three decimal places vs two decimal places will not not make a difference in the final answer.

***Note**: Final answer should be the same significant figures as the data, which here is 0.255 mols, 3 sig figs.*

Solved Problem: Gram to mole

Washing soda, sodium carbonate, Na_2CO_3 is used as a washing aid at home. How many mols are in 10.5 g of washing soda?

First, find the molar mass of Na_2CO_3:

2 Na	2(22.98) =	45.96
1 C	1(12.01) =	12.01
3 O	3(16.00) =	48.00
		105.97

Next, find the number of moles in 23.6 g:

$$10.5\ \text{g} \times \frac{1\ \text{mol}}{105.97\ \text{g}} = 0.0990846\ g\ and\ \boxed{9.91\ x\ 10^{-2} g\ in\ correct\ sig\ figs.}$$

Solved Problem: Gram to atoms

The daily requirement of calcium in the human diet is 1300. mg. How many atoms of atoms does this represent?

Atomic weight of calcium = 40.08 g/mol

Strategy will be to convert mass -> mol -> atoms.

Note: *convert mg to g since atomic weight from PT is always in grams.*

New strategy:

mg - > g -> mol -> atoms.

$$1300\ \text{mg} \times \frac{1\ \text{g}}{1000\ \text{mg}} \times \frac{1\ \text{mol}}{40.08\ \text{g}} \times \frac{6.022 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = 1.95324 \times 10^{22}\ \text{atoms}$$

1.953×10^{22} atoms
(4 significant figures)

Solved Problem: Mass to atoms of one element in a compound

The average daily requirement of the essential amino acid leucine, $C_6H_{14}O_2N$, is 2.202 g for an adult. How many atoms of carbon are in this daily requirement of leucine in moles?

First, find the molar mass of leucine:

6 C	6(12.01) =	72.06
2 O	2(16.00) =	32.00
1 N	1(14.01) =	14.01
14 H	14(1.008) =	14.112

2 decimal places

132.182 = 132.18 g/mol

Strategy: g -> mol -> mol ratio to C - > atoms of C

$$2.202 \text{ g leucine} \times \frac{1 \text{ mol leucine}}{132.18 \text{ g}} \times \frac{6 \text{ mol C}}{1 \text{ mol leucine}} \times \frac{6.022 \text{ x } 10^{23} \text{ atoms}}{1 \text{ mol}}$$

$$= 6.019 \times 10^{22} \text{ atoms of C}$$

Solved Problem: Moles and atoms

In 85.00 g of sodium chlorate, $NaClO_3$. determine

a) the number of moles of $NaClO_3$ and

b) the number of oxygen atoms in $NaClO_3$?

a) Moles

$$85.00 \text{ g NaClO}_3 \times \frac{1 \text{ mol NaClO}_3}{106 \text{ g NaClO}_3} = 0.7986 \text{ mol NaClO}_3$$

b) Atoms O

$$0.7986 \text{ mol NaClO}_3 \times \frac{3 \text{ mol O}}{1 \text{ mol NaClO}_3} \times \frac{6.02 \times 10^{23} \text{ atoms}}{1\text{mol O}} = 1.442 \times 10^{24} \text{atoms O}$$

Key Words and Concepts

- Formula mass
- Mole concept
- Avogadro's number