Introductory Chemistry, 2nd Edition
Nivaldo Tro

Chapter 6 Chemical Composition

Roy Kennedy
Massachusetts Bay Community College
Wellesley Hills, MA

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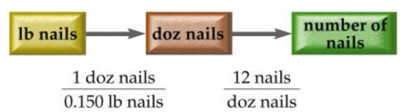
6.1 How Much Sodium?

6.2 Counting Nails by the Pound

A hardware store customer buys 2.60 pounds of nails. How many nails did the customer buy?

A dozen of the nails has a mass of 0.150 pounds.

Counting Nails by the Pound



$$2.60\,\text{lbs.}\times\frac{1\,\text{doz. nails}}{0.150\,\text{lbs.}}\times\frac{12\,\text{nails}}{1\,\text{doz.}}=208\,\text{nails}$$

- The customer bought 2.60 lbs of nails and received 208 nails. He counted the nails by weighing them!

6.3 & 6.4 Counting Atoms and Molecules by the Gram

By analogy we can calculate how many atoms or molecules there are in a given mass of an element or compound.

Atoms or Molecules and Moles

- If we can find the mass of a particular number of atoms or molecules, we can use this information to convert the mass of a element or compound sample to the number of atoms or molecules in the sample.

Counting Atoms or Molecules by Moles

The number of atoms or molecules we will use is 6.022×10^{23} and we call this a **mole**

- ✓1 mole = 6.022×10^{23} particles
- ✓Like 1 dozen = 12 particles

- The number of particles in 1 mole is called **Avogadro's Number = 6.0221421×10^{23}**

We can make two conversion factors:

A) $\dfrac{1 \text{ mole}}{6.022 \times 10^{23} \text{ atoms}}$

B) $\dfrac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mole}}$

A) For converting atoms → mole
B) For converting mole → atoms

Practice 1

Conversion sequence: moles → atoms, molecules

1. How many atoms are in 6.28 moles of aluminum?
2. How many atoms are in 90.43 moles of copper?
3. How many atoms in 7.64 moles of barium?
4. How many molecules in 3.72 moles of sulfur dioxide?
5. 76.4 moles of oxygen difluoride contain how many molecules?

Practice 2

Conversion sequence: atoms, molecules → moles

1. How many moles of water are represented by 8.33×10^{18} molecules of water?
2. How many moles of magnesium is 3.01×10^{22} atoms of magnesium?
3. How many moles are 1.20×10^{25} atoms of phosphorous?

Moles and Mass

The mass of one mole of atoms or molecules is called the **molar mass**

Moles and Mass (cont.)

The molar mass of an element, in grams, is numerically equal to the element's atomic mass.

1 mole $^{12}_{6}C$

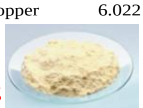
is 6.022×10^{23} atoms

and has a mass of exactly 12 grams

Mole and Mass Relationships

Substance	*Pieces in 1 mole*	*Weight of 1 mole*
hydrogen	6.022×10^{23} atoms	1.008 g
carbon	6.022×10^{23} atoms	12.01 g
oxygen	6.022×10^{23} atoms	16.00 g
sulfur	6.022×10^{23} atoms	32.06 g
calcium	6.022×10^{23} atoms	40.08 g
chlorine	6.022×10^{23} atoms	35.45 g
copper	6.022×10^{23} atoms	63.55 g

1 mole Sulfur 32.06 g



1 mole Carbon 12.01 g

Moles and Mass (cont.)

The molar mass of a compound, in grams, is numerically equal to the sum of the atomic masses of the elements in the compounds formula.

The molar mass of water is calculated from the atomic weights of hydrogen and oxygen.

Formula = H_2O

Formula Mass = 2(1.01 amu H) + 16.00 amu O = 18.02 amu

Molar Mass = 18.02 g

Practice 3

Calculate formula mass and Molar Mass

FORMULA	FORMULA MASS (amu)	MOLAR MASS (g)
Br_2		
sodium sulfide		
potassium hydroxide		
fluorine		
Ni		
$BaCl_2$		
$Fe(SO_4)_2$		

Converting Between Grams and Moles

Practice 4

Conversion sequence: moles → grams

How many grams for each of the following:

1. 7.24 moles of silver phosphate
2. 2.88 moles of diphosphorous pentoxide
3. 0.0009273 moles of zinc bicarbonate
4. 154.8 moles of silicon tetraiodide
5. 88.624 moles of silver

Practice 5

Conversion sequence: grams → moles

How many moles for each of the following?

1. 28 grams of CO_2
2. 452 g of argon
3. 9.273 kg of zinc bicarbonate
4. 25.0 g of iron
5. 88.624 mg of silver

Converting Between Grams and Number of Atoms or Molecules

Practice 6

Conversion sequence: grams → moles → atoms

How many atoms or molecules for each of the following?

1. 28 grams of CO_2
2. 452 g of argon
3. 9.273 kg of zinc bicarbonate
4. 25.0 g of iron
5. 88.624 mg of silver

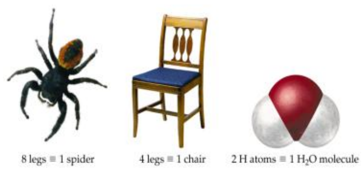
Practice 7

Conversion sequence: atoms → moles → grams

How many grams in each of the following?

1. 3.01×10^{23} atoms of sodium (Na)
2. 4.5×10^{25} atoms of argon
3. 9.27×10^{30} molecules of zinc bicarbonate
4. 2.50×10^{19} atoms of iron
5. 8.86×10^{15} molecules of dinitrogen tetroxide

6.5 Chemical Formulas as Conversion Factors



- 1 spider ≡ 8 legs
- 1 chair ≡ 4 legs
- 1 H_2O molecule ≡ 2 H atoms ≡ 1 O atom

Mole Relationships in Chemical Formulas

Moles of Compound	Moles of Constituents
1 mol NaCl	1 mole Na, 1 mole Cl
1 mol H_2O	2 mol H, 1 mole O
1 mol $CaCO_3$	1 mol Ca, 1 mol C, 3 mol O
1 mol $C_6H_{12}O_6$	6 mol C, 12 mol H, 6 mol O

Aka…Mole Ratios…
always whole number ratios

Writing Mole Ratios

Moles of Compound	Moles of Constituents
1 mol NaCl	1 mole Na, 1 mole Cl
1 mol H_2O	2 mol H, 1 mole O
1 mol $CaCO_3$	1 mol Ca, 1 mol C, 3 mol O
1 mol $C_6H_{12}O_6$	6 mol C, 12 mol H, 6 mol O

Practice 8

1. How many moles Cl in 4.7 mol $CaCl_2$?
2. How many mol of H in 54.1 mol C10H22?
3. How many oxygen atoms in 2.00 mol O_2?
4. How many grams of Cl in 55 g of CF_3Cl?
5. How many grams of Fe in 1.0 x 10^3 kg of Fe_2O_3?

6.6 Percent Composition

- Percentage of each element in a compound by mass

Determined from

1. The formula of the compound
2. The experimental mass analysis of the compound

$$\text{Percentage} = \frac{\text{part}}{\text{whole}} \times 100\%$$

1. Percent Composition from the Formula C_2H_5OH

2. Percent Composition from experiment
A 30.0 g sample of carvone contains 24.0 g of C, 3.2 g O and the rest H?

What is it’s percent composition

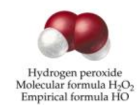
Mass Percent as a Conversion Factor

6.8 & 6.9 Empirical and Molecular Formulas

- The simplest, whole-number ratio of atoms in a molecule is called the **Empirical Formula**
- The Molecular Formula is a multiple of the Empirical Formula

Empirical Formulas

Hydrogen Peroxide
Molecular Formula = H_2O_2
Empirical Formula = HO



Benzene
Molecular Formula = C_6H_6
Empirical Formula = CH

Glucose
Molecular Formula = $C_6H_{12}O_6$
Empirical Formula = CH_2O

Finding an Empirical Formula

1) convert the percentages to grams (skip if already grams)
2) convert grams to moles (use molar mass of each element)
3) write a pseudoformula using moles as subscripts
4) divide all by smallest number of moles
5) multiply all mole ratios by whole number (2, 3, 4, 5, etc.) to make all mole ratios whole numbers. (skip if all mole ratios already whole numbers)

Finding an Empirical Formula from Experimental Data

Example:

- A laboratory analysis of aspirin determined the following mass percent composition. Find the empirical formula.

C = 60.00%

H = 4.48%

O = 35.53%

All these molecules have the same Empirical Formula. How are the molecules different?

Name	Molecular Formula	Empirical Formula
glyceraldehyde	$C_3H_6O_3$	CH_2O
erythrose	$C_4H_8O_4$	CH_2O
arabinose	$C_5H_{10}O_5$	CH_2O
glucose	$C_6H_{12}O_6$	CH_2O

All these molecules have the same Empirical Formula. How are the molecules different?

Name	Molecular Formula	Molar Mass, g	Empirical Formula	EF Molar Mass, g
glyceraldehyde	$C_3H_6O_3$	90	CH_2O	30
erythrose	$C_4H_8O_3$	120	CH_2O	30
arabinose	$C_5H_{10}O_5$	150	CH_2O	30
glucose	$C_6H_{12}O_6$	180	CH_2O	30

Molecular Formulas

- The molecular formula is a multiple of the empirical formula
- To determine the molecular formula you need to know the empirical formula and the molar mass of the compound

$$\frac{\text{Molar Mass}_{\text{real formula}}}{\text{Molar Mass}_{\text{empirical formula}}} = \text{factor used to multiply subscripts}$$

All these molecules have the same Empirical Formula. How are the molecules different?

Name	Molecular Formula	Molar Mass, g	Empirical Formula	EF Molar Mass, g	FACTOR
glyceraldehyde	$C_3H_6O_3$	90	CH_2O	30	3
erythrose	$C_4H_8O_3$	120	CH_2O	30	4
arabinose	$C_5H_{10}O_5$	150	CH_2O	30	5
glucose	$C_6H_{12}O_6$	180	CH_2O	30	6

Determine the Molecular Formula of Cadinene if it has a molar mass of 204 g and an empirical formula of C_5H_8

1. Determine the empirical formula
   - May need to calculate it as previous

   C_5H_8
2. Determine the molar mass of the empirical formula

   5 C = 60.05 g, 8 H = 8.064 g

   C_5H_8 = 68.11 g

3. Divide the given molar mass of the compound by the molar mass of the empirical formula
   - ✓ Round to the nearest whole number

$$\frac{204\ \text{g}}{68.11\ \text{g}} = 3$$

4. Multiply the empirical formula by the factor above to give the molecular formula

$(C_5H_8)_3 = C_{15}H_{24}$