Counting Atoms Using the Mole

Syllabus Learning Outcomes : 5, 6, 7

Counting Atoms

Chemistry is a quantitative science —we need a "counting unit."

MOLE

1 mole is the amount of substance that contains as many particles (atoms, molecules) as there are in 12.0 g of ^{12}C.

518 g of Pb =2.50 mol

Particles in a Mole

Avogadro's Number

6.02×10^{23}

There is Avogadro's number of particles in a mole of any substance.

Molar Mass

1 mol of ^{12}C
= 12.00 g of C
= 6.02×10^{23} atoms of C

12.00 g of ^{12}C is its MOLAR MASS

Taking into account all of the isotopes of C, the molar mass of C is 12.011 g/mol

Atomic Weight & Molar Mass

- Atomic Weight (u) - mass of one atom of an element relative to one atom of another element (^{12}C) in atomic mass units.
- Molar Mass (g/mol) – mass in grams of 1 mole of atoms. Given on periodic table

One-mole Amounts

Can be found for each element on the periodic table (bottom center of each box).

They represent the number of grams of element in 1 mole of element.

What amount of Mg is represented by 0.200 g? How many atoms?

Mg has a molar mass of 24.305 g/mol.

$$0.200\ g\ Mg \times \frac{1\ mol\ Mg}{24.305\ g\ Mg} = 8.23\times10^{-3}\ mol\ Mg$$

How many atoms are in this piece of Mg?

$$8.23\times10^{-3}\ mol\ Mg \times \frac{6.02\times10^{23}\ atoms\ Mg}{1\ mol\ Mg} =$$

$$= 4.95 \times 10^{21}\ atoms\ Mg$$

Summary

- Convert back and forth between number of atoms and moles of an element (Avogadro's Number)
- Convert from moles of an element to grams using the molar mass (g/mol) from the Periodic Table.
- Calculate the mass (g) of one average atom.

Laws of Chemical Combination

- **Law of Conservation of Mass**
  - The total mass remains constant during a chemical reaction.
- **Law of Definite Proportions**
  - All samples of a compound have the same composition, or ...
  - All samples have the same proportions, by mass, of the elements present.
- **Law of Multiple Proportions**
  - When two or more different compounds of the same two elements are compared, the masses of one element that combine with a fixed mass of the second element are in the ratio of small whole numbers.

Molecular Masses and Formula Masses

- **Molecular mass**: sum of the masses of the atoms represented in a molecular formula.
- Simply put: the mass of a molecule.
- Molecular mass is specifically for molecules.
- Ionic compounds don't exist as molecules; for them we use …
- **Formula mass**: sum of the masses of the atoms or ions present in a formula unit.

Molecular weight and molar mass

Molecular weight = sum of the atomic weights of all atoms in the molecule.

Molar mass = mass in grams of 1 mole of molecules, atoms, or particles

Calculate the molar mass of ethanol, C_2H_6O.

1 mol contains

2 mol *C* (12.011 g *C*/1 mol) = 24.022 g *C*

6 mol H (1.008 g H/1 mol) = 6.048 g H

1 mol *O* (15.999 g *O*/1 mol) = 15.999 g *O*

TOTAL = molar mass = 46.069 g/mol

Calculate molar mass to as many digits as you need

Molecular and Empirical Formulas

- A **molecule** is a group of two or more atoms held together by covalent bonds.
- A **molecular formula** gives the number of each kind of atom in a molecule.
- An **empirical formula** gives the (whole number) ratio of atoms of elements in a compound.

Compound	Molecular formula	Empirical formula
Hydrogen peroxide	H_2O_2	HO
Octane	C_8H_{18}	????

Calculate molar masses at home:

$C_9H_8O_4$ = 180.2g/mol

$CuCl_2 \cdot 2H_2O$ = 170.5g/mol

Fe_2O_3 = 159.7g/mol

H_2O = 18.02g/mol

Check that you get these answers

How many moles of alcohol are in a shot containing 13.7 g of C_2H_6O?

(a) Molar mass of C_2H_6O = 46.069 g/mol

(b) Calc. moles of alcohol

$$13.7\text{g } C_2H_6O \times \frac{1 \text{ mol } C_2H_6O}{46.069\text{g } C_2H_6O} = 0.297\text{mol } C_2H_6O$$

How many molecules of alcohol are in a shot containing 13.7 g of C_2H_6O?

We know there are 0.297 mol of C_2H_6O.

$$0.297 \text{ mol } C_2H_6O \times \frac{6.02 \times 10^{23} \text{ molecules } C_2H_6O}{1 \text{ mol } C_2H_6O} =$$

$$= 1.79 \times 10^{23} \text{ molecules } C_2H_6O$$

How many moles of H are in a shot containing 13.7 g of C_2H_6O?

There is 0.279mol C_2H_6O, and each mol contains 6 mol of H. The mol of H is:

$$0.279 \text{ mol } C_2H_6O \times \frac{6 \text{ mol H}}{1 \text{ mol } C_2H_6O} =$$

$$= 1.67 \text{mol H}$$

Summary

- Calculate molar mass of a molecule using the periodic table.
- Convert between mass in grams for a molecule and number of molecules in moles using the molar mass of a molecule.
- Convert between moles and number of molecules using Avogadro's Number.
- Calculate the number of any particular atoms in a molecule using the chemical formula
- Understand molecular and empirical formulas

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Ionic Compounds

- Ionic compounds are composed of ions, where ions have charges
- Generally involve a metal and a nonmetal
- Ions are arranged in a network called a crystal lattice.
- Tend to have high melting points
- Tend to be hard solids
- Can be cleaved along a sharp boundary by causing breakage along the crystal lattice

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IONS AND IONIC COMPOUNDS

- IONS are atoms or groups of atoms with a positive or negative charge.
- Taking away an electron from an atom gives a CATION with a positive charge
- Adding an electron to an atom gives an ANION with a negative charge.

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Forming Cations & Anions

metals

A CATION forms when an atom loses one or more electrons.

$Mg \rightarrow Mg^{2+} + 2\ e^-$

nonmetals

An ANION forms when an atom gains one or more electrons

$F + e^- \rightarrow F^-$

Predicting ion charges

In general

- metals (Mg) lose electrons → cations
- nonmetals (F) gain electrons → anions
- (Noble gases are not reactive)

See top of each column of periodic table for common ion charges

By losing or gaining e-, atom has same number of e-'s as nearest Group 8A atom.

Naming metal ions

$M \rightarrow n\ e^- + M^{n+}$

where n = periodic group

Na^+ sodium ion

Mg^{2+} magnesium ion

Al^{3+} aluminum ion

Transition metals → M^{2+} or M^{3+} are common

Fe^{2+} is iron(II) ion

Fe^{3+} is iron(III) ion

Naming Nonmetal Ions

NONMETAL + n e- → X^{n-}

where n = 8 - Group no.

carbon becomes carbide (C^{4-})

nitrogen becomes nitride (N^{3-})

oxygen becomes oxide (O^{2-})

fluorine becomes fluoride (F^{-})

Name derived by adding -ide to stem

Polyatomic Ions

- Sulfate
- Sulfite
- Nitrate
- Nitrite
- Phosphate
- Hydrogen phosphate
- Dihydrogen phosphate
- Hydroxide
- Cyanide
- Acetate
- Ammonium
- Hypochlorite
- Chlorite
- Chlorate
- Perchlorate

Use exam handout for your homework

Note: many O containing anions have names ending in –ate (or -ite).

Writing Formulas of Compounds

- The total positive and negative charge must sum to zero (or the charge on an ion).
- To write a proper formula, use the least common factor or the crossover rule.
- The factors needed to balance the charge appear as subscripts in the formula.
- Use parentheses to group numbers of more than one polyatomic ion

Writing Formulas and Naming Ionic Compounds

- Names of ionic compounds are built from the names of the positive and negative ions in the compound.
- The charge of elements that can have more than one charge is indicated with a Roman numeral in parentheses.
- Be able to go back and forth between writing and naming compounds

$CaBr_2$	calcium bromide
$NaHSO_4$	sodium hydrogen sulfate
$(NH_4)_2CO_3$	ammonium carbonate
$Mg(OH)_2$	magnesium hydroxide
$TiCl_2$	titanium(II) chloride
Co_2O_3	cobalt(III) oxide

- When writing a formula, the total charge must add to the charge on the substance, which is often zero

Molecular Compounds

- Molecular compounds are composed of molecules (not ions) because electrons are shared
- Can be gases to liquids to solids at room temperature
- Larger and more complex molecules tend to be solids
- Molecules are the smallest unit of a compound that retains the characteristics of the compound.

Elements that exist as diatomic molecules

hydrogen ($H \rightarrow H_2$)
oxygen ($O \rightarrow O_2$)
nitrogen ($N \rightarrow N_2$)
chlorine ($Cl \rightarrow Cl_2$)
bromine ($Br \rightarrow Br_2$)
iodine ($I \rightarrow I_2$)
fluorine ($F \rightarrow F_2$)

MOLECULAR FORMULAS

- Molecular formula for glycine is

  $C_2H_5NO_2$

- In one molecule there are
  - 2 C atoms
  - 5 H atoms
  - 1 N atom
  - 2 O atoms

Writing formulas

- Can also write glycine formula as

  $–H_2NCH_2COOH$

  to show atom ordering
- or in the form of a **structural formula**

Naming Molecular Compounds

- Binary compounds of hydrogen with oxygen, sulfur and the halogens:

HF hydrogen fluoride
HCl hydrogen chloride
HBr hydrogen bromide
HI hydrogen iodide
H_2S hydrogen sulfide

Naming Molecular Compounds

- For binary compounds for Groups 4A to 7A, write formulas with elements in order of increasing group number

NF_3 nitrogen trifluoride
NO nitrogen monoxide
NO_2 nitrogen dioxide
N_2O dintrogen monoxide
N_2O_4 dinitrogen tetraoxide
PCl_3 phosphorous trichloride
SF_6 sulfur hexafluoride
S_2F_{10} disulfur decafluoride

Naming Molecular Compounds

- Many binary compounds of nonmetals were discovered years ago and have common names

H_2O	water
NH_3	ammonia
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
N_2H_4	hydrazine
PH_3	phosphine
NO	nitric oxide
N_2O	nitrous oxide