

Counting Atoms Using the Mole

Syllabus Learning Outcomes : 5, 6, 7

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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.

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

Mg has a molar mass of 24.305 g/mol.

$$\begin{array}{r} 1 \text{ mol Mg} \\ 0.200 \text{ g Mg} \text{ -----} = 8.23 \times 10^{-3} \text{ mol Mg} \\ 24.305 \text{ g Mg} \end{array}$$

How many atoms are in this piece of Mg?

$$\begin{array}{r} 6.02 \times 10^{23} \text{ atoms Mg} \\ 8.23 \times 10^{-3} \text{ mol Mg} \text{ -----} = \\ 1 \text{ mol Mg} \end{array}$$

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

8 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.

9 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:

$$\text{C}_9\text{H}_8\text{O}_4 = 180.2\text{g/mol}$$

$$\text{CuCl}_2 \cdot 2\text{H}_2\text{O} = 170.5\text{g/mol}$$

$$\text{Fe}_2\text{O}_3 = 159.7\text{g/mol}$$

$$\text{H}_2\text{O} = 18.02\text{g/mol}$$

Check that you get these answers

How many moles of alcohol are in a shot containing 13.7 g of $\text{C}_2\text{H}_6\text{O}$?

(a) Molar mass of $\text{C}_2\text{H}_6\text{O} = 46.069\text{ g/mol}$

(b) Calc. moles of alcohol

$$\frac{13.7\text{g } \text{C}_2\text{H}_6\text{O}}{46.069\text{g } \text{C}_2\text{H}_6\text{O}} = 0.297\text{mol } \text{C}_2\text{H}_6\text{O}$$

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 0.279 mol 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

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

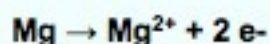
IONS AND IONIC COMPOUNDS

- **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**.

Forming Cations & Anions

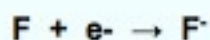
metals

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



nonmetals

An **ANION** forms when an atom **gains** one or more electrons



Predicting ion charges

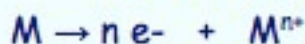
In general

- 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



where n = periodic group

Na⁺ sodium ion

Mg²⁺ magnesium ion

Al³⁺ aluminum ion

Transition metals → M²⁺ or M³⁺ are common

Fe²⁺ is iron(II) ion

Fe³⁺ is iron(III) ion

Naming Nonmetal Ions



where $n = 8 - \text{Group no.}$

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 | • Hydroxide |
| • Sulfite | • Cyanide |
| • Nitrate | • Acetate |
| • Nitrite | • Ammonium |
| • Phosphate | • Hypochlorite |
| • Hydrogen phosphate | • Chlorite |
| • Dihydrogen phosphate | • 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

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- 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
$(\text{NH}_4)_2\text{CO}_3$	ammonium carbonate
$\text{Mg}(\text{OH})_2$	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

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- 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.

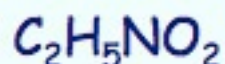
Elements that exist as diatomic molecules

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hydrogen ($\text{H} \rightarrow \text{H}_2$)
oxygen ($\text{O} \rightarrow \text{O}_2$)
nitrogen ($\text{N} \rightarrow \text{N}_2$)
chlorine ($\text{Cl} \rightarrow \text{Cl}_2$)
bromine ($\text{Br} \rightarrow \text{Br}_2$)
iodine ($\text{I} \rightarrow \text{I}_2$)
fluorine ($\text{F} \rightarrow \text{F}_2$)

MOLECULAR FORMULAS

- Molecular formula for glycine is



- In one molecule there are

-2 C atoms

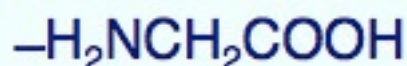
-5 H atoms

-1 N atom

-2 O atoms

Writing formulas

- Can also write glycine formula as



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

H₂S hydrogen sulfide

Naming Molecular Compounds

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- 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 dinitrogen monoxide

N_2O_4 dinitrogen tetraoxide

PCl_3 phosphorous trichloride

SF_6 sulfur hexafluoride

S_2F_{10} disulfur decafluoride

Naming Molecular Compounds

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- 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