

How much does a single atom weigh?

Different elements weigh different amounts – related to what makes them unique.

What units do we use to define the weight of an atom?

amu – units of atomic weight. (atomic mass unit)

1 amu – 1/12 the mass of 1 “carbon-12” atom.

But in the lab, scientists use grams – it’s more practical.

When scientists do experiments with substances (elements, molecules, ionic compounds), they usually

- Use the *chemical formula* to plan (ratio of atoms, NaCl)
- Measure the amount needed in *grams*

How can we relate *grams* to the *chemical formula*?

1.0 g C – 5.0×10^{22} C atoms

1.0 g Ba – 4.4×10^{21} Ba atoms

Inconvenient to work with such large numbers all the time. Chemists use another unit which works like a ‘dozen’:

Mole – 6.022×10^{23} particles
(atoms, molecules or formula units)

Avogadro’s number

Why do we use such a weird number?

Because it gives us an ‘easy’ relationship between amus and grams.

one mole of atoms of an element has a mass in grams numerically equal to the atomic weight of the element

1 H atom	1 amu
1 mol H	1 g
1 C atom	12 amu
1 mol C	12 g

The *ratio of atoms* in the simplest formula for a compound is the same as the *ratio of moles of atoms* of the elements in a sample of the compound

1 H ₂ O molecule
2 H atoms
1 O atom
1 mol H ₂ O
2 mol H
1 mol O

How much does H₂O weigh?

Formula weights – the sum of the atomic weights of the elements in the formula, each taken the number of times the element occurs.

water	H ₂ O	$2(1.01) + 1(16.00) = 18.02$ amu
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Chlorine	Cl ₂	$2(35.45) = 70.90$ amu
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Calcium nitrate	Ca(NO ₃) ₂	nitrate - $14.00 + 3(16.00) = 62.00$ amu $1(40.08) + 2(62.00) = 164.08$ amu
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formula weight – all compounds, molecules and elements

atomic weight – atoms

molecular weight – molecules

How many atoms are there in one mole of propane (C₃H₈)?

1 molecule of propane = 3 carbon atoms + 8 hydrogen atoms = 11 atoms

$$\begin{aligned} 1 \text{ mole propane} & \times \frac{6.022 \times 10^{23} \text{ molecules propane}}{1 \text{ mole propane}} \times \frac{11 \text{ atoms}}{1 \text{ molecule propane}} \\ & = 6.624 \times 10^{24} \text{ atoms} \end{aligned}$$

Molar mass – the mass of one mole of a substance. (g/mol)

Numerically equivalent to formula weight
(amu/formula unit)

Calculate the number of C₃H₈ molecules in 74.6 g propane.

$$\begin{array}{rclclcl} \text{Molar mass of C}_3\text{H}_8 & = & \text{C} & 3 (12.01 \text{ g/mol}) & = & 36.03 \text{ (g/mol)} \\ & & \text{H} & 8 (1.008 \text{ g/mol}) & = & \underline{8.064} \text{ (g/mol)} \\ & & & & & 44.09 \text{ (g/mol)} \end{array}$$

$$\begin{aligned} 74.6 \text{ g propane} & \times \frac{1 \text{ mole propane}}{44.09 \text{ g propane}} \times \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mole propane}} \\ & = 1.02 \times 10^{24} \text{ molecules propane} \end{aligned}$$

Percent composition – the % of each element in the compound (by mass)

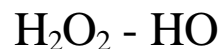
ex. calculate the percent composition of C and H in C₃H₈.

$$\begin{array}{rclclcl} \text{Molar mass of C}_3\text{H}_8 & = & \text{C} & 3 (12.01 \text{ g/mol}) & = & 36.03 \text{ (g/mol)} \\ & & \text{H} & 8 (1.008 \text{ g/mol}) & = & \underline{8.064} \text{ (g/mol)} \\ & & & & & 44.09 \text{ (g/mol)} \end{array}$$

$$\% \text{ carbon:} \quad = \quad \frac{36.03 \text{ (g/mol)}}{44.09 \text{ (g/mol)}} \times 100 = 81.71\%$$

$$\% \text{ hydrogen} \quad = \quad \frac{8.064 \text{ (g/mol)}}{44.09 \text{ (g/mol)}} \times 100 = 18.29\%$$

empirical formula – the smallest, whole number ratio of elements present



Molecular formula – actual number of atoms present in a molecule

If we have the % composition of a substance, we can determine the *empirical* formula

Ex. 24.74% K	24.74 g K
34.76% Mn	34.76 g Mn
<u>40.50% O</u>	<u>40.50 g O</u>
100.00%	100 g substance

$$24.74 \text{ g K} \quad \times \quad \frac{1 \text{ mol K}}{39.10 \text{ g}} \quad = \quad 0.6327 \text{ mol K}$$

$$34.76 \text{ g Mn} \quad \times \quad \frac{1 \text{ mol Mn}}{54.94 \text{ g}} \quad = \quad 0.6327 \text{ mol Mn}$$

$$40.50 \text{ g O} \quad \times \quad \frac{1 \text{ mol O}}{16.00 \text{ g}} \quad = \quad 2.531 \text{ mol O}$$

divide through by smallest # moles to get the ratio:

$$0.6327 \text{ mol K}/0.6327 \quad = \quad 1$$

$$0.6327 \text{ mol Mn}/0.6327 \quad = \quad 1$$

$$2.532 \text{ mol O}/0.6327 \quad = \quad 4$$

empirical formula is KMnO_4

but we still don't know the *molecular* formula unless we also have the *molar mass* of the substance

ex. in previous example, if molar mass = 158 g/mol
empirical formula = molecular formula

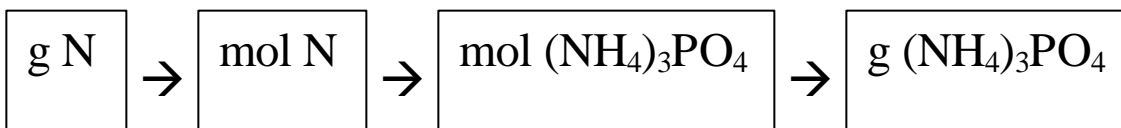
if a compound has the empirical formula HO
and its molar mass = 34.0 g/mol

$$\text{HO} \quad = \quad 1.0 + 16.0 = 17.0 \text{ g/mol}$$

$$34/17 \quad = \quad 2$$

$$2(\text{HO}) \quad = \quad \text{H}_2\text{O}_2 \quad \text{molecular formula}$$

ex. what mass of ammonium phosphate, $(\text{NH}_4)_3\text{PO}_4$, would contain 15.0 grams of nitrogen (N)?



$$15.0 \text{ g N} \times \frac{1 \text{ mol N}}{14.0 \text{ g N}} = 1.07 \text{ mol N}$$

1 mole of $(\text{NH}_4)_3\text{PO}_4$ contains 3 moles of N

$$1.07 \text{ moles N} \times \frac{1 \text{ mole } (\text{NH}_4)_3\text{PO}_4}{3 \text{ moles N}} = 0.357 \text{ mol } (\text{NH}_4)_3\text{PO}_4$$

molar mass of $(\text{NH}_4)_3\text{PO}_4$ is

3(14.00) g N
12(1.01) g H
1(30.97) g P
<u>4(16.00) g O</u>
149.09 g/mol

$$0.357 \text{ mol } (\text{NH}_4)_3\text{PO}_4 \times \frac{149.09 \text{ g}}{1 \text{ mol } (\text{NH}_4)_3\text{PO}_4} = 53.2 \text{ g } (\text{NH}_4)_3\text{PO}_4$$

ex. what mass of propane, C_3H_8 , would contain the same mass of carbon as is contained in 1.35 grams of barium carbonate, BaCO_3 ?



molar mass $\text{BaCO}_3 = 137.33 + 12.01 + 3(16.00) = 197.34 \text{ g/mol}$
 1 mol BaCO_3 has 1 mol C per formula unit

$$1.35 \text{ g BaCO}_3 \times \frac{1 \text{ mol BaCO}_3}{197.34 \text{ g}} \times \frac{1 \text{ mol C}}{1 \text{ mol BaCO}_3} = 6.84 \times 10^{-3} \text{ mol C}$$

1 mol C_3H_8 has 3 mol C per formula unit
 molar mass $\text{C}_3\text{H}_8 = 44.09 \text{ g/mol}$ (see previous example)

$$6.84 \times 10^{-3} \text{ mol C} \times \frac{1 \text{ mol C}_3\text{H}_8}{3 \text{ mol C}} \times \frac{44.09 \text{ g}}{1 \text{ mol C}_3\text{H}_8} = 0.100 \text{ g C}_3\text{H}_8$$