*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 – $5.0 \times 10^{22}$ C atoms
1.0 g Ba – $4.4 \times 10^{21}$ Ba atoms

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

<u>*Mole*</u> – $6.022 \times 10^{23}$ 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 $H_2O$ molecule
    2 H atoms
    1 O atom
1 mol $H_2O$
    2 mol H
    1 mol O

How much does $H_2O$ 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 | $H_2O$ | 2 (1.01) + 1(16.00) = 18.02 amu |
| Chlorine | $Cl_2$ | 2(35.45) = 70.90 amu |
| Calcium nitrate | $Ca(NO_3)_2$ | nitrate - 14.00 + 3(16.00) = 62.00 amu<br>1(40.08) + 2(62.00) = 164.08 amu |

*formula weight* –all compounds, molecules and elements
*atomic weight* – atoms
*molecular weight* – molecules

## How many atoms are there in one mole of propane ($C_3H_8$)?

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

$$1 \text{ mole propane} \times \frac{6.022 \times 10^{23} \text{ molecules propane}}{1 \text{ mole propane}} \times \frac{11 \text{ atoms}}{1 \text{ molecule propane}}$$

$$= 6.624 \times 10^{24} \text{ atoms}$$

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

Numerically equivalent to formula weight
(amu/formula unit)

## Calculate the number of $C_3H_8$ molecules in 74.6 g propane.

| | | | | | |
|---|---|---|---|---|---|
| Molar mass of $C_3H_8$ | = | C | 3 (12.01 g/mol) | = | 36.03 (g/mol) |
| | | H | 8 (1.008 g/mol) | = | <u>8.064</u> (g/mol) |
| | | | | | 44.09 (g/mol) |

$$74.6 \text{ g propane} \times \frac{1 \text{ mole propane}}{44.09 \text{ g propane}} \times \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mole propane}}$$

$$= 1.02 \times 10^{24} \text{ molecules propane}$$

*Percent composition* – the % of each element in the compound (by <u>mass</u>)

ex. calculate the percent composition of C and H in $C_3H_8$.

| | | | | | |
|---|---|---|---|---|---|
| Molar mass of $C_3H_8$ | = | C | 3 (12.01 g/mol) | = | 36.03 (g/mol) |
| | | H | 8 (1.008 g/mol) | = | <u>8.064</u> (g/mol) |
| | | | | | 44.09 (g/mol) |

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

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

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

NaCl $H_2O$ $H_2O_2$ - HO

*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 |
| | 40.50% O | 40.50 g O |
| | 100.00% | 100 g substance |

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

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

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

divide through by smallest # moles to get the ratio:

0.6327 mol K/0.6327 = 1
0.6327 mol Mn/0.6327 = 1
2.532 mol O/0.6327 = 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

HO = 1.0 + 16.0 = 17.0 g/mol

34/17 = 2

2(HO) = $H_2O_2$ molecular formula

## ex. what mass of ammonium phosphate, $(NH_4)_3PO_4$, would contain 15.0 grams of nitrogen (N)?

| g N | → | mol N | → | mol $(NH_4)_3PO_4$ | → | g $(NH_4)_3PO_4$ |
|---|---|---|---|---|---|---|

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

1 mole of $(NH_4)_3PO_4$ contains 3 moles of N

$$1.07 \text{ moles N} \times \frac{1 \text{ mole } (NH_4)_3PO_4}{3 \text{ moles N}} = 0.357 \text{ mol } (NH_4)_3PO_4$$

molar mass of $(NH_4)_3PO_4$ is

| | |
|---|---|
| 3(14.00) g | N |
| 12(1.01) g | H |
| 1(30.97) g | P |
| 4(16.00) g | O |
| 149.09 g/mol | |

$$0.357 \text{ mol } (NH_4)_3PO_4 \times \frac{149.09 \text{ g}}{1 \text{ mol } (NH_4)_3PO_4} = 53.2 \text{ g } (NH_4)_3PO_4$$

## 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, $BaCO_3$?

g $BaCO_3$ → mol $BaCO_3$ → mol C → mol $C_3H_8$ → g $C_3H_8$

molar mass $BaCO_3$ = 137.33 + 12.01 + 3(16.00) = 197.34 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 $C_3H_8$ = 44.09 g/mol (see previous example)

$$6.84 \times 10^{-3} \text{ mol C} \times \frac{1 \text{ mol } C_3H_8}{3 \text{ mol C}} \times \frac{44.09 \text{g}}{1 \text{ mol } C_3H_8} = 0.100 \text{ g } C_3H_8$$