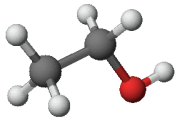
Law of Definite Proportions

1

A pure compound always consists of the same elements combined in the same proportions by mass.

Therefore, we can express molecular composition as percent by mass

Ethanol, C_2H_6O
52.13% C
13.15% H
34.72% O



Syllabus Learning Outcomes : 7

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Empirical and Molecular Formulas

2

- 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}	????

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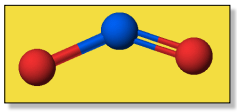
Percent Composition

3

Consider some of the family of nitrogen-oxygen compounds:

NO_2, nitrogen dioxide and closely related, NO, nitrogen monoxide (or nitric oxide)



Structure of NO_2

Chemistry of NO, nitrogen monoxide

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Calculate Mass Percent Composition

4

Consider NO_2, Molar mass = ?

What is the mass percent of N and of O?

$$Mass\,\%\,N = \frac{14.0\text{ g N}}{46.0\text{ g }NO_2} \cdot 100\% = 30.4\,\%$$

$$Mass\,\%\,O = \frac{2(16.0\text{ g O})}{46.0\text{ g }NO_2} \cdot 100\% = 69.6\,\%$$

What are the mass percentages of N and O in NO?

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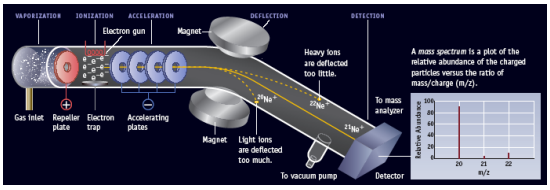
How to Determine a Formula?

5



Mass spectrometer

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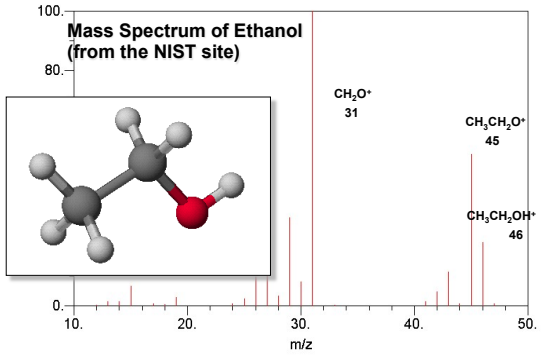

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Determining Formulas

In **chemical analysis** we determine the % by mass of each element in a given amount of pure compound and derive the **EMPIRICAL** or **SIMPLEST** formula.

PROBLEM: *A compound of B and H is 81.10% B. What is its empirical formula?*

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A compound of B and H is 81.10% B. What is its empirical formula?

- Because it contains only B and H, it must contain 18.90% H.
- In 100.0 g of the compound there are 81.10 g of B and 18.90 g of H.
- Calculate the number of moles of each constituent.

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A compound of B and H is 81.10% B. What is its empirical formula?

Calculate the number of moles of each element in 100.0 g of sample.

$$81.10 \text{ g B} \cdot \frac{1 \text{ mol}}{10.81 \text{ g}} = 7.502 \text{ mol B}$$

$$18.90 \text{ g H} \cdot \frac{1 \text{ mol}}{1.008 \text{ g}} = 18.75 \text{ mol H}$$

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A compound of B and H is 81.10% B. What is its empirical formula?

Now, recognize that **atoms combine in the ratio of small whole numbers.**

1 atom B + 3 atoms H --> 1 molecule BH_3

or

1 mol B atoms + 3 mol H atoms ---> 1 mol BH_3 molecules

Find the ratio of moles of elements in the compound.

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A compound of B and H is 81.10% B. What is its empirical formula?

Take the ratio of moles of B and H. **Always divide by the smaller number.**

$$\frac{18.75 \text{ mol H}}{7.502 \text{ mol B}} = \frac{2.499 \text{ mol H}}{1.000 \text{ mol B}} = \frac{2.5 \text{ mol H}}{1.0 \text{ mol B}}$$

But we need a whole number ratio.

2.5 mol H/1.0 mol B = 5 mol H to 2 mol B

EMPIRICAL FORMULA = B_2H_5

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Determining Formulas - Recap

- **PROBLEM:** *A compound of B and H is 81.10% B. What is its empirical formula?*
- **Stepwise solution**

	%	g	mol	mol ratio	E.F.
B	81.10%	81.10g	7.502mol	1	2 B_2H_5
H	18.90%	18.90g	18.75mol	2.5	5

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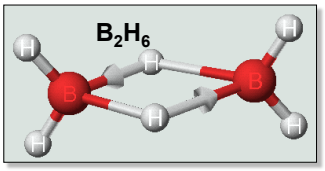
A compound of B and H is 81.10% B. Its empirical formula is B_2H_5. What is its molecular formula?

Is the molecular formula B_2H_5, B_4H_{10}, B_6H_{15}, B_8H_{20}, etc.?

B = 10.811
H = 1.0079



B_2H_6 is one example of this class of compounds.

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A compound of B and H is 81.10% B. Its empirical formula is B_2H_5. What is its molecular formula?

We need to do an EXPERIMENT to find the MOLAR MASS.

Here experiment gives 53.3 g/mol

Compare with the mass of B_2H_5

= 26.66 g/unit

B = 10.811
H = 1.0079

Find the ratio of these masses.

$$\frac{53.3 \text{ g/mol}}{26.66 \text{ g/unit of } B_2H_5} = \frac{2 \text{ units of } B_2H_5}{1 \text{ mol}}$$

Molecular formula = B_4H_{10}

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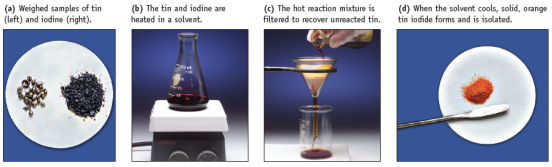
DETERMINE THE FORMULA OF A COMPOUND OF Sn AND I



$Sn(s) + \text{some } I_2(s) \longrightarrow SnI_x$

Have g of Sn used, (excess) g of I_2 used, and g of SnI_x formed

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Data to Determine the formula of a Sn—I Compound

- Reaction of Sn and I_2 is done using excess Sn.
- Mass of Sn in the beginning = 1.056 g
- Mass of iodine (I_2) used = 1.947 g
- Mass of Sn remaining = 0.601 g

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Determining Formulas

- Similar stepwise solution

g → mol → mol ratio → E.F.

Sn

I_2 ←

- Watch how much Sn used, how much I

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Tin and Iodine Compound

Find the mass of Sn that combined with 1.947 g I_2.

Mass of Sn initially = 1.056 g

Mass of Sn recovered = 0.601 g

Mass of Sn used = 0.455 g ←

Find moles of Sn used:

$$0.455 \text{ g Sn} \cdot \frac{1 \text{ mol}}{118.7 \text{ g}} = 3.83 \times 10^{-3} \text{ mol Sn}$$

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Tin and Iodine Compound

Now find the number of moles of I_2 that combined with 3.83×10^{-3} mol Sn. Mass of I_2 used was 1.947 g.

$$1.947 \text{ g } I_2 \cdot \frac{1 \text{ mol}}{253.81 \text{ g}} = 7.671 \times 10^{-3} \text{ mol } I_2$$

How many mol of iodine atoms?

$$7.671 \times 10^{-3} \text{ mol } I_2 \left(\frac{2 \text{ mol I atoms}}{1 \text{ mol } I_2}\right)$$

$$= 1.534 \times 10^{-2} \text{ mol I atoms}$$

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Tin and Iodine Compound

Now find the ratio of number of moles of moles of I and Sn that combined.

$$\frac{1.534 \times 10^{-2} \text{ mol I}}{3.83 \times 10^{-3} \text{ mol Sn}} = \frac{4.01 \text{ mol I}}{1.00 \text{ mol Sn}}$$

Empirical formula is SnI_4

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Determining Formulas of Hydrated Compounds

- Similar solution approach to other problems
- In the lab, heat hydrated copper sulfate and collect these data:

$1.023\text{g } CuSO_4 \cdot x\ H_2O \rightarrow 0.654 \text{ g } CuSO_4 + ?\text{g } H_2O$

- What is x for the number of moles of water?

Need mass of water first, g

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Determine Mass of Water

Mass of hydrated compound	1.023 g
Mass of anhydrous compound	– 0.654 g
Mass of water	0.369 g

Solution is just like for determining emiprical formulas (g to mol to mol ratio to simplest whole number ratio to formula)

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Calculate Moles

- $0.369 \text{ g } H_2O \cdot \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.0205 \text{ mol } H_2O$
- $0.654\text{g } CuSO_4 \cdot \frac{1 \text{ mol } CuSO_4}{159.6 \text{ g } CuSO_4} = 0.00410 \text{ mol } CuSO_4$

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Determine Mole Ratios and Empirical Formula

- Find simplest whole number mole ratio

$$\frac{0.0205 \text{ mol } H_2O}{0.00410 \text{ } CuSO_4} = \frac{5 \text{ mol } H_2O}{1 \text{ mol } CuSO_4}$$

- Write the empirical formula

$CuSO_4 \cdot 5H_2O$ copper sulfate pentahydrate

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Summary

- Determine the mass percent or percent composition of each element of a molecule using the molecular formula
- Determine an empirical formula using percent composition (% → g → mol → mol ratios).
- Determine a molecular formula using molar mass or molecular weight.

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