Which Formula Is More Informative?

Why are we doing this?

Scientists use chemical formulas as a shorthand method of communicating with each other about the composition and structure of compounds. There are several types of formulas that are used to convey different types of information. This activity will compare two types of useful formulas.

Your Learning Outcomes

You will be able to:

1. Determine the percent composition of a compound from its chemical formula.
2. Determine the empirical formula for a compound from its molecular formula.
3. Describe the relationship between the percent composition of a compound and its empirical formula.
4. Determine the molecular formula for a compound from its empirical formula and molecular mass.

The Plan

1. Assign roles*.
    a. ***Manager*** – This person will keep the team on task and provide direction to the group. This person is responsible for uploading the group's work to Gradescope. Make sure you make a note of everyone in the group. You must add everyone's name when submitting your answers to Gradescope.
    b. ***Spokesperson*** – This person will represent the group be responsible for speaking for the group to the rest of the class.
    c. ***Recorder*** – This person will be responsible for recording the team's answers to the Critical Thinking Questions in an organized and coherent manner.
    d. ***Analyst*** – This person will be responsible for critical analysis of the team's work (i.e., the Devil's Advocate). This person should make sure everyone understands what is happening before the group moves forward.
2. Complete the Critical Thinking Questions as a group.
3. Submit your team's work via Gradescope. Groups may choose to work in a Word document or write out their answers on a separate sheet of paper. All work must be upload to Gradescope as a PDF file.

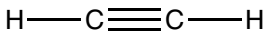
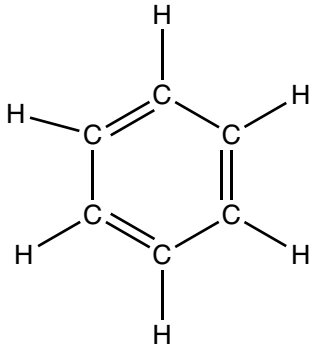
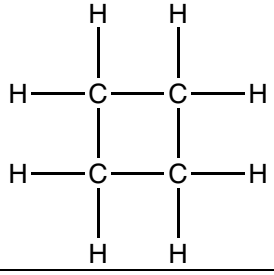
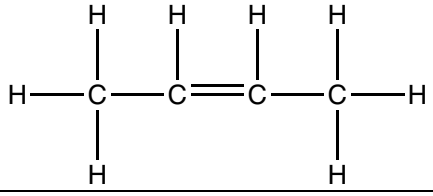
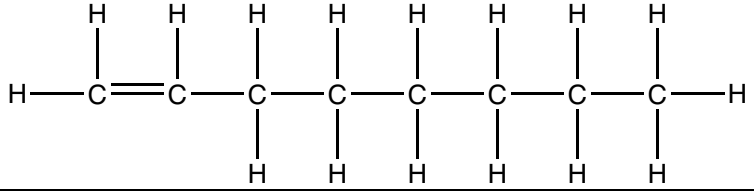
**Students may choose to complete this activity independently if they are unable to attend discussion due to illness or injury; in which case, the student must perform all roles and complete all aspect of the activity. To receive full credit, documentation as to the need for the absence from discussion must be included with the submission and your TA must be notified of the absence.*

Model 1: Percent Composition

The **percent composition** (by mass) of an element in a molecule is the mass of the element in the molecule divided by the mass of the entire molecule times 100. Or because the number of atoms (or molecules) is proportional to the number of moles of atoms (or molecules),

$$\text{percent composition of element i} = \frac{\text{mass of i in one mole of the compound}}{\text{mass of one mole of the compound}} \bullet 100\%$$

Table 1. Percent composition (by mass) of some common organic molecules.

Compound Name	Structural Formula	Molecular Formula	Percent Composition (by mass)	
			% C	% H
Ethyne		C_2H_2	92.26	7.74
Benzene		C_6H_6	92.26	7.74
Cyclobutane		C_4H_8	85.63	14.37
2-butene		C_4H_8	85.63	14.37
1-octene		C_8H_{16}	85.63	14.37

Critical Thinking Questions

1. Verify that the percent composition given in the table for ethyne in Table 1 is correct.
   2(12.011g/mol) + 2(1.008g/mol) = 26.038 g/mol
   2(12.011g/mol)/26.038=0.9226+100=92.26%C. 2(1.008g/mol)/26.038=0.0774*100=7.74% H

2. Fill in the missing molecular formulas and percent compositions in Table 1.
   See Table 1

3. Given the original data in Table 1, describe how to determine the percent composition by mass of H for 2-butene without using the equation given in Model 1.
   C_4H_8
   4(12.011) + 8(1.008g/mol) = 56.108 g/mol
   8(1.008g/mol) /56.108 g/mol = 0.1437*100 = 14.37% H
   Also, 100-85.63 = 14.37

4. Based on the data in Table 1, is it possible to determine the molecular formula solely from the percent compositions information? Explain your reasoning.
   No. Ethyne and benzene have identical percent compositions but different molecular formulas.

5. What feature related to the composition do all compounds with the same percent composition have?
   They all have the same molecular ratios. For example, the H to C molar ratio is 1:1 in C_2H_2 and C_6H_6.

Information

The **empirical formula** of a compound describes the relative number of each type of atom in the compound. It is given in terms of the smallest-possible-whole-number ratios (as subscripts). For example, the empirical formula of ethane, C_2H_6 is CH_3. The C:H ratio of 2:6 can be reduced by a factor of two to 1:3. (note that the subscript "1" is omitted from the chemical formula).

Critical Thinking Questions

6. What feature related to the composition of a compound can be determined solely by the percent composition?
   The empirical formula.

7. Determine the empirical formula for each of the molecules in Table 1.
   ethyne and benzene: CH
   cyclobutane, 2-butene, and 1-octene: CH_2

8. Compare the empirical formulas your determined in Question 7 to the percent composition for those molecules in Table 1. Describe the relationship between the percent composition and the empirical formula.
   Compounds with the same empirical formula will have the same percent composition.

9. As a chemist, if you were given the choice of knowing the molecular formula or empirical formula for a substance, which formula would give you more information so that you could uniquely identify the substance? Explain your choice using examples from Model 1.
The empirical formula tells you the ratio of elements within a compound, but it does not describe the number of each element within a unique compound For example, both ethyne and benzene have a one to one ratio of carbon:hydrogen; however, one molecule of benzene contains three times as many atoms as ethyne. A molecular formula, on the other hand, tells you about the specific composition of the compound. Therefore, the molecular formula gives you more information because it describes both the ratio of elements and the unique composition of a compound.

Model 2: Determining Molecular Formulas Without a Molecular Structure

Compound Name	**Molecular Formula's Mass (amu) (*MF mass*)**	**Empirical Formula**	**A Empirical Formula's Mass (amu) (*EF mass*)**	**B Ratio of $\frac{MF\ mass}{EF\ mass}$**	**C Molecular Formula**
Methane	16.0	CH_4	16.0	16.0/16.0 = 1	CH_4
Ethyne	26.0	CH	13.0	26.0/13.0 = 2	C_2H_2
Benzene	78.0	CH	13.0	78.0/13.0 = 6	C_6H_6
Ethene	28.0	CH_2	14.0	28.0/14.0 = 2	C_2H_4
Propene	42.0	CH_2	14.0	42.0/14.0 = 3	C_3H_6
Cyclohexane	84.0	CH_2	14.0	84.0/14.0 = 6	C_6H_{12}
Ethane	30.0	CH_3	15.0	30.0/15.0 = 2	C_2H_6

Critical Thinking Questions

10. Determine the empirical formula mass for each substance in Model 2 and enter it into Column A. Be sure that your entire group agrees on these values.

    a. Do the substances with the same empirical formula have the same empirical formula mass?
    Yes

    b. Do these substances have the same molecular mass?
    No

11. Determine the (MF mass)/(EF mass) ratio for each substance and enter it into Column B of the table in Model 2. Be sure that your entire group agrees on the values.
See the table in Model 2.

12. Look at the information in Column C that is given for ethyne and ethene and write a complete sentence to describe the relationship between the ratio in Column B and the molecular formula for each of the compounds.
    The ratio in Column B describe how many times larger the molecular formula is as compared to the empirical formula.

13. Using your answer to Question 12 as a guide, complete Column C for all of the substances in Model 2. Again, be sure that all members of the group agree on the information that is in the table.
    See the table in Model 2.

14. If compounds have the same empirical formula, what must be true about the molecular formulas of these compounds?
    The molecular formulas must have the same ratio of elements (i.e., the same percent composition).

15. One of the compounds in Model 2 has the same empirical formula and molecular formula. Name the compound and indicate what information this conveys about the compound.
    Methane has the same empirical formula and molecular formula. This indicates that one molecule of this compound contains the simplest, whole number ratio of elements. The empirical formula's mass is the same and the molecular formula's mass; therefore, the ratio is 1 and the formulas are the same.