Empirical Formula and Molecular Formula
Which formula is more informative?

Why?

Scientists use chemical formulas as a shorthand method of communicating with each other about the make-up 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.

Model 1: Comparison of Percent Composition and Empirical Formula

Substance	Compound Name	Molecular Formula	Empirical formula	Percent Composition: Carbon	Percent Composition: Hydrogen
1	ethane	C_2H_6	CH_3		
2	propene	C_3H_6	CH_2		
3	ethyne (acetylene)	C_2H_2	CH		
4	benzene	C_6H_6	CH		

1. Divide up the work within your team and calculate the percent composition for substances in the table in Model 1. Put the values into the table. Show your calculation(s) below.

2. Identify the substances in Model 1 that have the same empirical formula.

3. Identify the substances in Model 1 that have the same percent composition.

4. Using the examples in Model 1, suggest an explanation as to why substances with different molecular formulas (but the same empirical formula) can have the same percent composition.

5. For each substance in Model 1 you will notice that the molecular formula and empirical formula are not the same. What mathematical operation would enable you to determine the empirical formula of a compound if you are given the compound's molecular formula?

6. Using the operation that you suggested in question 5, determine the empirical formula for the compounds with the following molecular formulas:

    a. C_4H_8

    b. C_6H_{12}

7. Which substance(s) in Model 1 have the same empirical formula(s) as the substances in Question 6?

8. Predict the percent composition(s) for C_4H_8 and C_6H_{12}. Check with your teacher to see if you have the correct 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.

STOP

Model 2: Determining Molecular Formulas

Substance Name	Molecular Mass (g) (*MF mass*)	Empirical formula	A Empirical formula mass (g) (*EF mass*)	B Ratio of $\frac{(MF\ mass)}{(EF\ mass)}$	C Representing # of *EF* units in each MF	D Molecular Formula
Methane	16.0	CH_4				
Ethyne	26.0	CH	13.0	26.0/13.0 = 2 units	$(CH)_2$	C_2H_2
Benzene	78.0	CH				
Ethene	28.0	CH_2	14.0	28.0/14.0 = 2 units	$(CH_2)_2$	C_2H_4
Propene	42.0	CH_2				
Cyclohexane	84.0	CH_2				
Ethane	30.0	CH_3				

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?

      b. Do these substances have the same molecular mass?

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.

12. Look at the information in Column C and Column D 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.

13. Using your answer to Question 12 as a guide, complete Columns C and D 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.

14. If compounds have the same empirical formula, what must be true about the molecular formulas of these compounds?

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.

16. Determine the molecular formula for the following compounds:

      a. Empirical formula is NaO, mass is 78 g/mole. _____

      b. Empirical formula is CH_2Cl, mass is 99.0 g/mole. _____

      c. Empirical formula is C_3H_4, mass is 121 g/mole. _____

STOP

Extension Questions:

17. An oxide of nitrogen is found to contain 69.6% oxygen and has a molar mass of 92.0 g/mole.
    a. What is the % nitrogen in this compound?

    b. Find the empirical formula and molecular formula for this compound.

18. Calculate the molecular formula for caffeine, a compound with a molar mass of 195 g and the following percent composition: 49.5% C, 5.15% H, 28.9% N, 16.5% O.

HSPI Activity Teacher Resources
Empirical Formula and Molecular Formula
Which formula is more informative?

Learning Objectives
1. Distinguish between Empirical Formula and Molecular Formula
2. Determine a Molecular Formula given molecular mass and empirical formula for a compound
3. Students will be able to convert between empirical and molecular formulas thereby observing the usefulness of the different types of formulas

Prerequisites:
Students should:
1. know how to determine the mass of a compound or formula using the atomic masses from the periodic table
2. be able to calculate percent composition given a chemical formula
3. be able to determine empirical formulas using percent composition data

Assessment Questions:
1. Which formula is an empirical formula?
   a) N_2F_2, b) N_2F_4, *c) HNF_2*, d) H_2N_2
2. What could be the molecular formula for a compound whose empirical formula is CF?
   a) C_2F_2, b) CF_4, c) C_3F_8, d) C_2F_4
3. What is the molecular formula for Vitamin C, which has an empirical formula of $C_3H_4O_3$ and a gmm of 176.0 g/mole?

Teacher Tips:
- Be sure to do the previous activity on Percent Composition and Empirical Formulas

Optional Support Materials:
- Simulations at the Greenbowe animations site includes tutorials:
Determination of the formula of a hydrate i.e. empirical formula:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/stoichiometry/empirical.html

Target Responses:

Model 1: Comparison of Percent Composition and Empirical Formulas

Sample formulas	Molecular formulas	Compound Name	Empirical formulas	% Composition Carbon	% Composition Hydrogen
1	C_2H_6	*ethane*	CH_3	*80.0 % C*	*20.0 % H*
2	C_3H_6	*propene*	CH_2	*85.7 % C*	*14.3 % H*
3	C_2H_2	ethyne (acetylene)	CH	*92.3 % C*	*7.7 % H*
4	C_6H_6	benzene	CH	*92.3 % C*	*7.7 % H*

1. Divide up the work within your team and calculate the percent composition for substances in the table in Model 1. Put the values into the table. Show your calculation(s) below.

Molecular formula mass for ethane =30.0 g *24.0 g C / 30.0 g C_2H_6 = 80.0 % C* *6.0 g H / 30.0 g C_2H_6 = 20.0 % H*	*Molecular formula mass for propene =42.0 g* *36.0 g C / 42.0 g C_3H_6 = 85.7 % C* *6.0 g H / 42.0 g C_3H_6 = 14.3 % H*
Molecular formula mass for ethyne is 26.0 g *24.0 g C/26.0 g C_2H_2 = 92.3% C* *2.0 g H/26.0 g C_2H_2 = 7.7% H*	*Molecular formula mass for benzene =78.0 g* *72.0 g C / 78.0 g C_6H_6 = 92.3 % C* *6.0 g H / 78.0 g C_6H_6 = 7.7 % H*

2. Identify the substances in Model 1 that have the same empirical formula. *Ethyne and Benzene*

3. Identify the substances in Model 1 that have the same percent composition. *Ethyne and Benzene*

4. Using the examples in Model 1, suggest an explanation as to why substances with different molecular formulas (but the same empirical formula) can have the same percent composition.
The percent composition is a ratio between the mass contributions from each the elements in a compound and the mass of the entire compound. If the ratios between the elements are the same for the empirical and molecular formulas, then the percent compositions would be the same.

5. For each substance in Model 1 you will notice that the molecular formula and empirical formula are not the same. What mathematical operation would enable you to determine the empirical formula of a compound if you are given the compound's molecular formula?
Find the simplest whole number ratio between the elements in the molecular formula of a compound, and that will give the empirical formula of the compound.

6. Using the operation that you suggested in question 5, determine the empirical formula for the compounds with the following molecular formulas:
   a. C_4H_8 CH_2

   b. C_6H_{12} CH_2

7. Which substance(s) in Model 1 have the same empirical formula(s) as the substances in Question 6?
Propene

8. Predict the percent composition(s) for C_4H_8 and C_6H_{12}. Check with your teacher to see if you have the correct percent composition.
85.7 % C, 14.3 % H; this answer should correspond to the data entered in Model 1 for propene.

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.
Molecular formula would give more information. Two (or more) substances could have the same empirical formula, such as ethyne and benzene, but they are different substances with different molecular formulas and different chemical and physical properties.

Model 2: Determining Molecular Formulas

Substance Name	Molecular Mass (g) (*MF mass*)	Empirical formula	A Empirical formula mass (g) (*EF mass*)	B Ratio of (*MF mass*) (*EF mass*)	C Representing # of *EF* units in each MF	D Molecular Formula
Methane	16.0	CH_4	*16.0*	*16.0/16.0 = 1unit*	*CH_4*	*CH_4*
Ethyne	26.0	CH	13.0	26.0/13.0 = 2 units	$(CH)_2$	C_2H_2
Benzene	78.0	CH	*13.0*	*78.0/13.0 = 6units*	*$(CH)_6$*	*C_6H_6*
Ethene	28.0	CH_2	14.0	28.0/14.0 = 2 units	$(CH_2)_2$	C_2H_4
Propene	42.0	CH_2	*14.0*	*42.0/14.0 = 3 units*	*$(CH_2)_3$*	*C_3H_6*
Cyclohexane	84.0	CH_2	*14.0*	*84.0/14.0 = 6 units*	*$(CH_2)_6$*	*C_6H_{12}*
Ethane	30.0	CH_3	*15.0*	*30.0/15.0 = 2 units*	*$(CH_3)_2$*	*C_2H_6*

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 II. Be sure that your entire group agrees on the values. *See Table in Model 2*

12. Look at the information in Column C and Column D 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 gives a multiplier that can be used to convert the empirical formula into the molecular formula. When the atoms represented in an empirical formula are multiplied by the number of units generated by the ratio of (molecular formula mass/empirical formula mass), the*

molecular formula can be determined.

13. Using your answer to Question 13 as a guide, complete Columns C and D 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 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 of the compounds have the same ratio for the atoms that make up the molecule.

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.
Since the empirical and molecular formulas are the same for methane (CH_4), this indicates that the molecular formula represents the simplest whole number ratio between the elements found in the compound.

16. Determine the molecular formula for the following compounds:
   a. Empirical formula is NaO, mass is 78 g/mole.

   78.0g/ 39.0 g per unit = 2 units; Mol. Formula is Na_2O_2 (sodium peroxide)

   b. Empirical formula is CH_2Cl, mass is 99.0 g/mole. _____

   99.0g/49.5g per unit = 2 units; Mol. Formula is $C_2H_4Cl_2$ (dichloroethane)

   c. Empirical formula is C_3H_4, mass is 120 g/mole. _____

   120 g/40g per unit = 3units; Molecular formula is C_9H_{12} (mesitylene)

Extension Questions:
17. An oxide of nitrogen is found to contain 69.6% oxygen and has a molar mass of 92.0 g/mole.
   a. What is the % nitrogen in this compound? *(100% − 69.6% = 30.4%)*
   b. Find the empirical formula and molecular formula for this compound.
      Calculate the Empirical formula:
      69.6% C → 69.6% O/ 16.0 g O/mole = 4.35 mole O
      30.4 % N → 30.4 g N/ 14.00 g N/mole = 2.17 Moles N
      Divide all by the least number of moles i.e. (4.35 mole O/= 2.17 Moles N) = 2
      Empirical formula is NO_2; Empirical formula mass is 46.0 g/unit
      (92.0 g/46.0g per unit) = 2 Units; Molecule is $(NO_2)_2$; N_2O_4

18. Calculate the molecular formula for caffeine, a compound with a molar mass of 194 g and the following percent composition: 49.5% C, 5.15% H, 28.9% N, 16.5% O.
      Calculate the Empirical formula:
      49.5% C → 49.5 g C/ 12.0 g C/mole = 4.125 mole C
      5.15% H → 5.15g H/ 1.00 g H/mole = 5.15 Moles H

28.9% N ➔ 28.9 g N/ 14.0 g N/mole = 2.06 moles N

16.5% O➔ 16.5% O/ 16.0 g/mole = 1.03 mole O

Divide all by the least number of moles, i.e. 1.03 mole Oxygen, and the ratio of the elements and the empirical formula is $C_4H_5N_2O$.

Calculate the empirical formula mass = (4*12.00 g C) + (5*1.00 g H)+(2*14.0g N) +(1*16.0g O) = 97.0g

Divide the Empirical formula mass into the molecular formula mass to get the number of Empirical units in the molecule, i.e., (194. g/mole)/ 97.0 g per unit = 2 units; multiply the empirical formula by 2 to get the molecular formula $C_8H_{10}N_4O_2$