Chapter 10: Chemical Quantities

10.1 The Mole: A Measurement of Matter

Measuring Matter

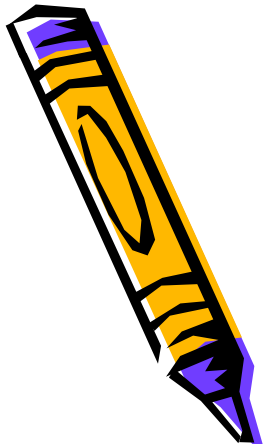
- You often measure the amount of something by one of three different methods—by count, by mass, and by volume.

Sample Problem 10.1

Finding Mass from a Count

What is the mass of 90 average-sized apples if 1 dozen of the apples has a mass of 2.0 kg?

for Sample Problem 10.1



1. If 0.20 bushel is 1 dozen apples and a dozen apples has a mass of 2.0 kg, what is the mass of 0.50 bushel of apples?

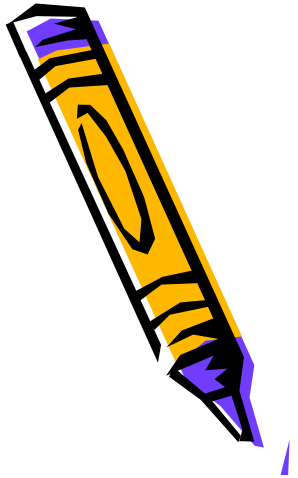
What is a Mole?

- **A mole of any substance contains Avogadro's number of representative particles, or 6.02×10^{23} representative particles.**
  - The term **representative particle** refers to the species present in a substance: usually atoms, molecules, or formula units.

- Converting Number of Particles to Moles
  - One **mole** (mol) of a substance is 6.02×10^{23} representative particles of that substance and is the SI unit for measuring the amount of a substance.
  - The number of representative particles in a mole, 6.02×10^{23}, is called **Avogadro's number**.

$$\text{moles} = \text{representative particles} \times \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ representative particles}}$$

Sample Problem 10.2



Converting Number of Atoms to Moles

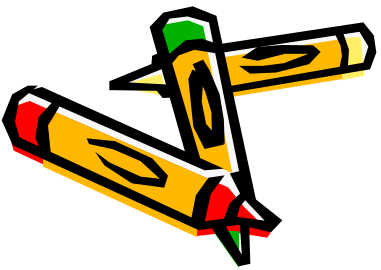
Magnesium is a light metal used in the manufacture of aircraft, automobile wheels, tools, and garden furniture. How many moles of magnesium is 1.25×10^{23} atoms of magnesium?

for Sample Problem 10.2

4. How many moles is 2.17×10^{23} representative particles of bromine?

Practice

- 1) How many moles are in 5.75×10^{24} molecules CO_2?
- 2) How many moles are in 3.75×10^{24} atoms of Al?
- 3) How many moles are in 3.58×10^{23} formula units ZnO_2?



What is a Mole?

–Converting Moles to Number of Particles

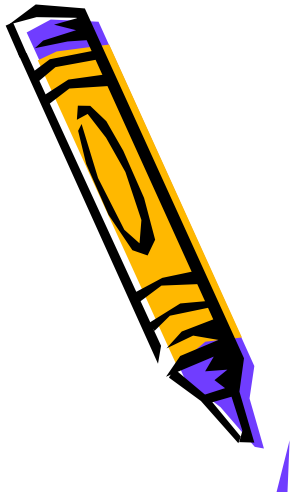
$$\text{representative particles} = \text{moles} \times \frac{6.02 \times 10^{23}\ \text{representative particles}}{1\ \text{mole}}$$

Sample Problem 10.3

Converting Moles to Number of Atoms

Propane is a gas used for cooking and heating. How many atoms are in 2.12 mol of propane (C_3H_8)?

for Sample Problem 10.3



5. How many atoms are in 1.14 mol SO_3?

Practice

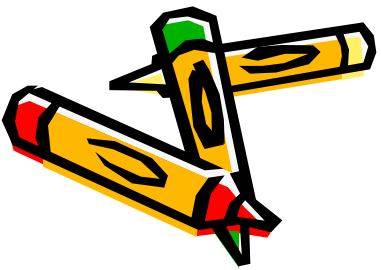
- 1) How many atoms are in 2.50 mol Zn?
- 2) How many formula units are in 3.25 mol $AgNO_3$?
- 3) How many molecules are in 11.25 mol H_2O?

The Mass of a Mole of an Element

- **The atomic mass of an element expressed in grams is the mass of a mole of the element.**
  - The mass of a mole of an element is its **molar mass**.

B. Molar Mass Examples

- carbon
- aluminum
- zinc

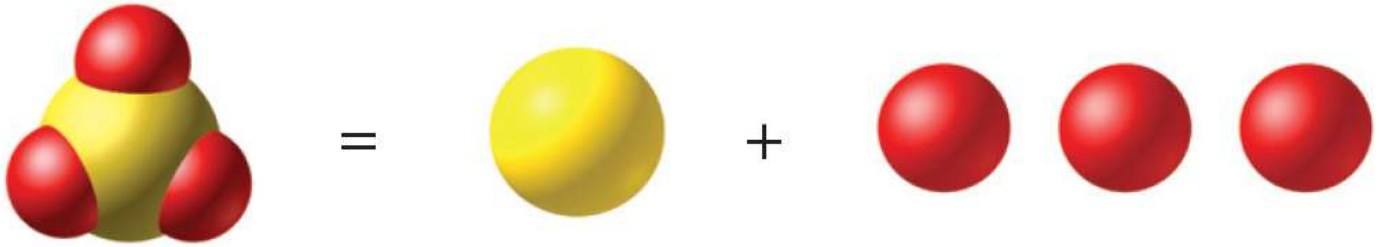


The Mass of a Mole of a Compound

- To calculate the molar mass of a compound, find the number of grams of each element in one mole of the compound. Then add the masses of the elements in the compound.

The Mass of a Mole of a Compound

- Substitute the unit grams for atomic mass units. Thus 1 mol of SO_3 has a mass of 80.1 g.



SO_3 = 1 S atom + 3 O atoms

1 S atom + 3 O atoms

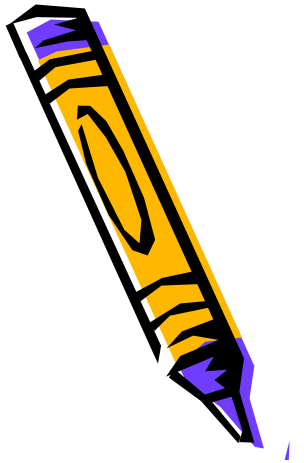
32.1 amu + 16.0 amu + 16.0 amu + 16.0 amu = 80.1 amu

Sample Problem 10.4

Finding the Molar Mass of a Compound

The decomposition of hydrogen peroxide (H_2O_2) provides sufficient energy to launch a rocket. What is the molar mass of hydrogen peroxide?

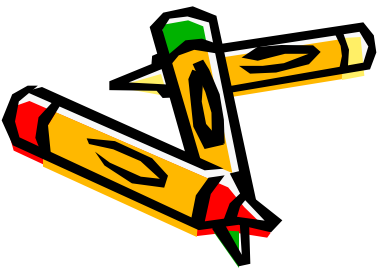
for Sample Problem 10.4



7. Find the molar mass of PCl_3.

Calculate the molar mass of:

- 1) C_2H_3Cl
- 2) NH_3
- 3) $Ca(OH)_2$
- 3) $Ca_3(PO_4)_2$



Bell Work

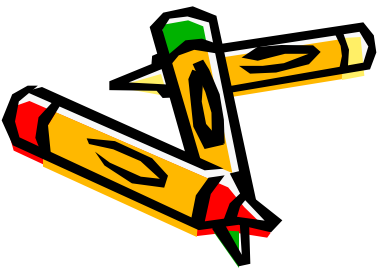
- How many molecules are in 11.25 mol H_2O?
- How many moles are in 5.38×10^{24} formula units of NaCl?
- How many atoms are in 0.707 mole of silicon?
- How many moles are in 3.45×10^{23} molecules of CO_2?

10.1 Section Quiz.

- 1. Three common ways of measuring the amount of something are by count, by mass, and
  - a) by temperature.
  - b) by volume.
  - c) by area.
  - d) by density.

10.1 Section Quiz.

- 2. A mole of hydrogen gas, $H_2(g)$, contains 6.02×10^{23}
  - a) molecules.
  - b) atoms.
  - c) amu.
  - d) grams.



10.1 Section Quiz.

- 3. The atomic mass of fluorine is 19.0 amu, so the molar mass is
  - a) 19.0 amu.
  - b) 19.0 g.
  - c) 6.02×10^{23} amu.
  - d) 6.02×10^{23} g.

10.1 Section Quiz.

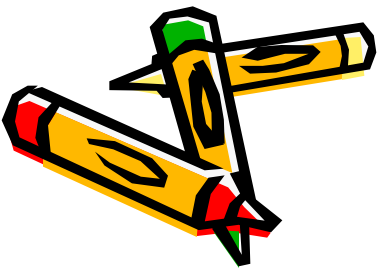
– 4. Calculate the molar mass of ammonium nitrate.

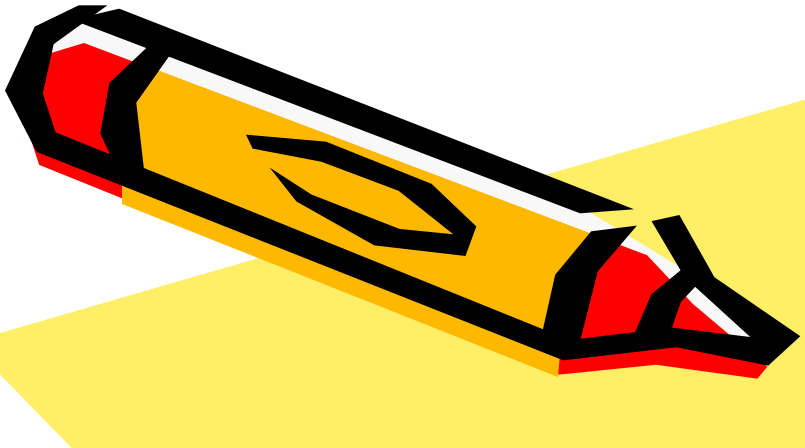
a) 45.02 g

b) 80.05 g

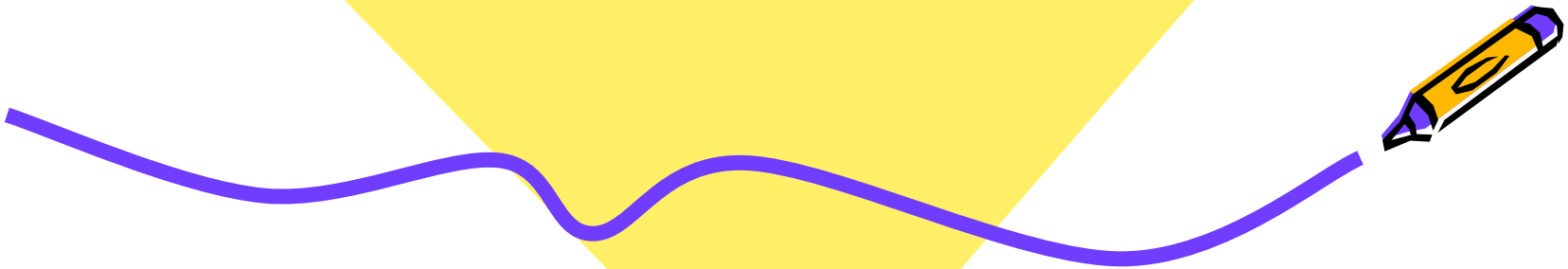
c) 60.06 g

d) 48.05 g





10.2 Mole-Mass and Mole-Volume Relationships



The Mole-Mass Relationship

- **Use the molar mass of an element or compound to convert between the mass of a substance and the moles of a substance.**

$$\text{mass (grams)} = \text{number of moles} \times \frac{\text{mass (grams)}}{1 \text{ mole}}$$

$$\text{moles} = \text{mass (grams)} \times \frac{1 \text{ mole}}{\text{mass (grams)}}$$

Sample Problem 10.5

Converting Moles to Mass

The aluminum satellite dishes in Figure 10.8 are resistant to corrosion because the aluminum reacts with oxygen in the air to form a coating of aluminum oxide (Al_2O_3). This tough, resistant coating prevents any further corrosion. What is the mass of 9.45 mol of aluminum oxide?

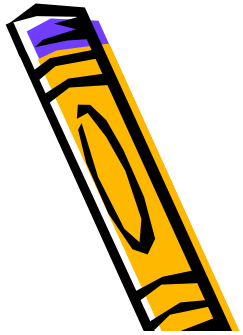
for Sample Problem 10.5

16. Find the mass, in grams, of 4.52×10^{-3} mol $C_{20}H_{42}$.

Practice

- What is the mass of:
  - A) 2.86 mol $CaCO_3$
  - B) 1.48 mol potassium oxide
  - C) 4.85 mol $HC_2H_3O_2$

Sample Problem 10.6



Converting Mass to Moles

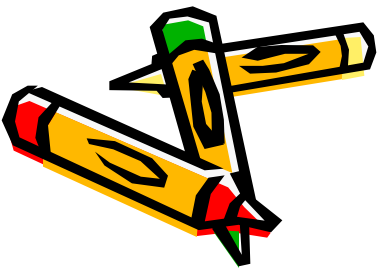
When iron is exposed to air, it corrodes to form red-brown rust. Rust is iron(III) oxide (Fe_2O_3). How many moles of iron(III) oxide are contained in 92.2 g of pure Fe_2O_3?

for Sample Problem 10.6

18. Find the number of moles in 3.70×10^{-1} g of boron.

Practice

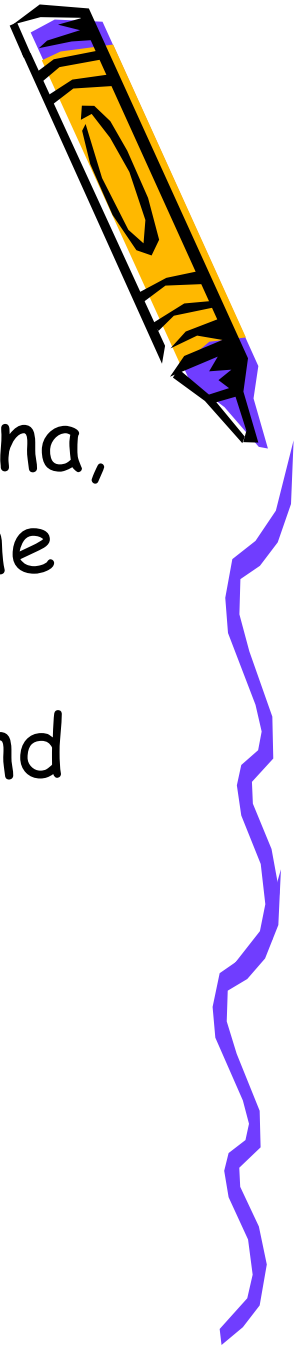
- How many moles are in:
  - A) 1.56 g $C_{10}H_6O_3$
  - B) 7.55 g H_2CO
  - C) 22.6 g $AgNO_3$
  - D) 6.50 g tetraphosphorus decoxide



Practice: Mass to Particles

- 1) How many water molecules are in 10.0g?
- 2) How many molecules are in 135 g Teflon (C_2F_4)?
- 3) How many molecules are in a 5 lb bag of sugar ($C_{12}H_{22}O_{11}$)?

Mole Relationships from a chemical formula



- Aluminum oxide, often called alumina, is the principle raw material for the production of aluminum. Alumina occurs in the minerals corundum and bauxite. Determine the moles of aluminum ions (Al^{3+}) in 1.25 mol of Al_2O_3.

Practice

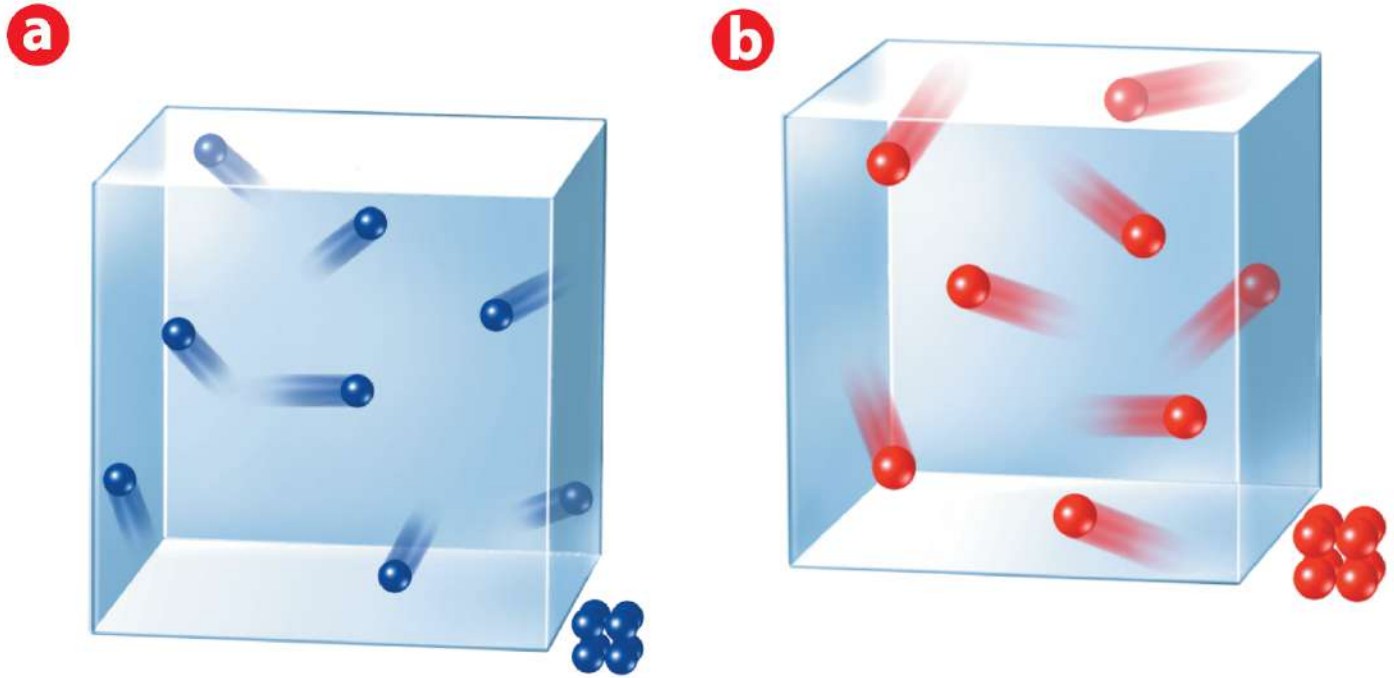
- How many moles of oxygen atoms are present in 5.00 mol of diphosphorus pentoxide?
- Ethanol (C_2H_5OH) is often blended with gasoline. A sample of ethanol has a mass of 45.6 g. How many hydrogen atoms are present?
- A sample of aluminum chloride has a mass of 35.6 g. How many chloride ions (Cl^-) are present?

Practice

- The pain reliever Ibuprofen has the chemical formula $C_{13}H_{18}O_2$. If the tables in a bottle contain 33 g of ibuprofen, what mass of carbon is present?

The Mole–Volume Relationship

- Avogadro's hypothesis states that equal volumes of gases at the same temperature and pressure contain equal numbers of particles.



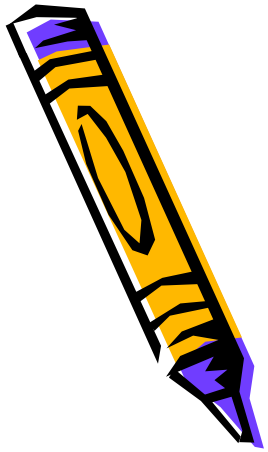
The Mole-Volume Relationship

- The volume of a gas varies with temperature and pressure. Because of these variations, the volume of a gas is usually measured at a standard temperature and pressure.
- **Standard temperature and pressure (STP)** means a temperature of 0°C and a pressure of 101.3 kPa, or 1 atmosphere (atm).

The Mole–Volume Relationship

- **At STP, 1 mol or, 6.02 × 10^{23} representative particles, of any gas occupies a volume of 22.4 L.**
  - The quantity 22.4 L is called the **molar volume** of a gas.

The Mole-Volume Relationship



- Calculating Volume at STP

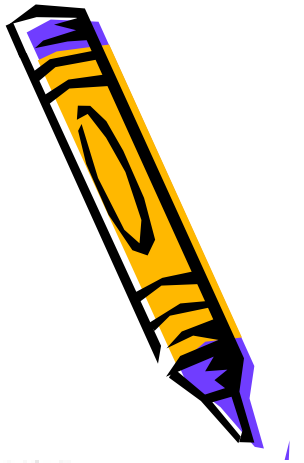
$$\text{volume of gas} = \text{moles of gas} \times \frac{22.4\ \text{L}}{1\ \text{mol}}$$

Sample Problem 10.7

Calculating the Volume of a Gas at STP

Sulfur dioxide (SO_2) is a gas produced by burning coal. It is an air pollutant and one of the causes of acid rain. Determine the volume, in liters, of 0.60 mol SO_2 gas at STP.

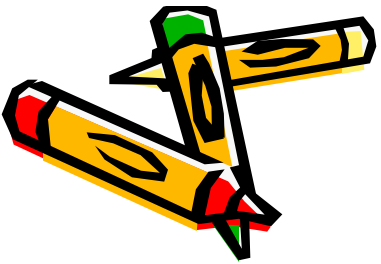
for Sample Problem 10.7



20. What is the volume of these gases at STP?

a. 3.20×10^{-3} mol CO_2

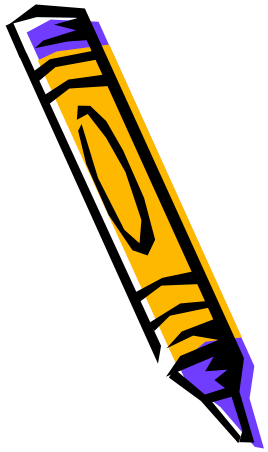
b. 3.70 mol N_2



More Moles

- 1)How many Liters are in 0.25 mol oxygen gas?
- 2) How many grams are in 3.25 Liters of carbon dioxide gas?
- 3) How many liters are in 8.76 grams of SO_3?

The Mole-Volume Relationship



- Calculating Molar Mass from Density

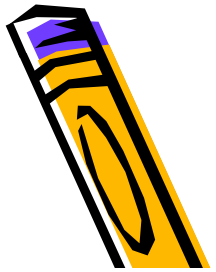
$$\frac{\text{grams}}{\text{mole}} = \frac{\text{grams}}{\text{L}} \times \frac{22.4\ \text{L}}{1\ \text{mole}}$$

Sample Problem 10.8

Calculating the Molar Mass of a Gas at STP

The density of a gaseous compound containing carbon and oxygen is found to be 1.964 g/L at STP. What is the molar mass of the compound?

for Sample Problem 10.8



22. A gaseous compound composed of sulfur and oxygen, which is linked to the formation of acid rain, has a density of 3.58 g/L at STP. What is the molar mass of this gas?

10.2 Section Quiz.

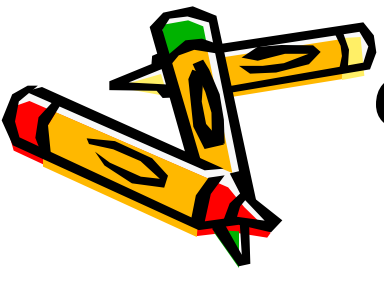
–1. Calculate the mass in grams of a sample containing 1.85×10^{34} molecules of water.

a) 3.07×10^{10} g

b) 5.53×10^{11} g

c) 188 g

d) 8.46×10^{3} g



10.2 Section Quiz.

- 2. Calculate the number of moles in a spoonful of table sugar ($C_{12}H_{22}O_{11}$) having a mass of 10.5 g.
- a) 32.6 mol

  b) 3.59×10^{3} mol

  c) 3.07×10^{-2} mol

  d) 1.85×10^{22} mol

10.2 Section Quiz.

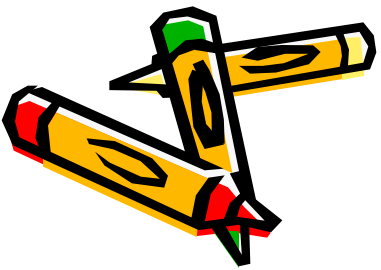
– 3. What is the volume of 0.35 mol of oxygen gas at STP?

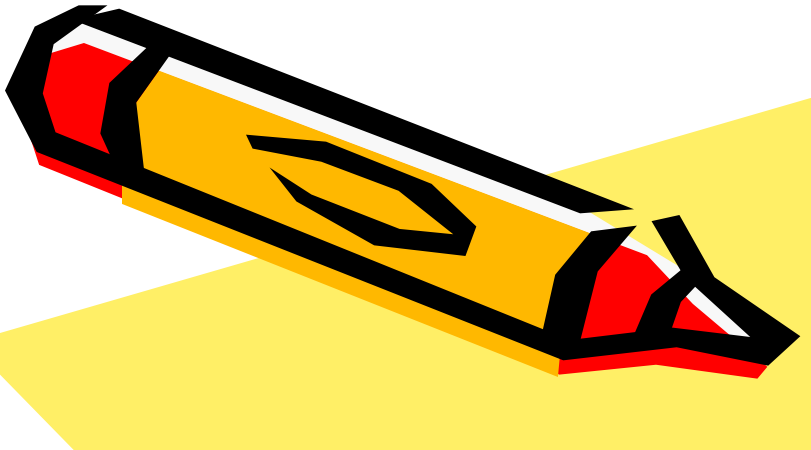
a) 32 L

b) 64 L

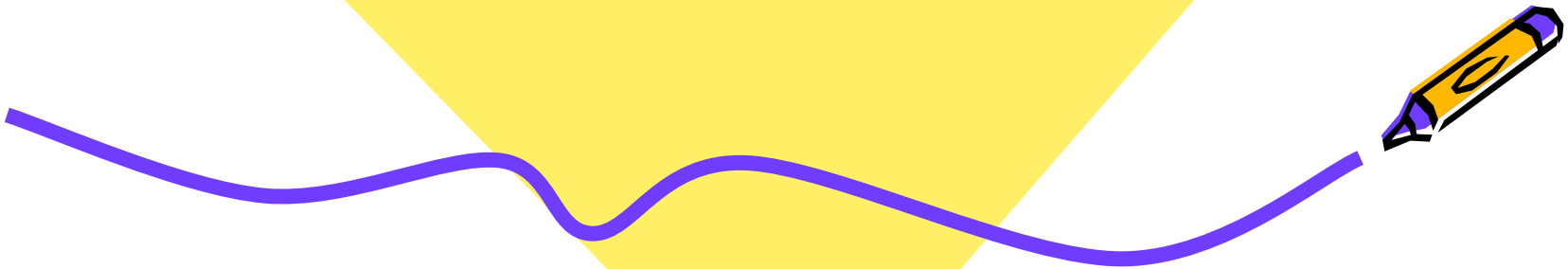
c) 7.8 L

d) 16 L



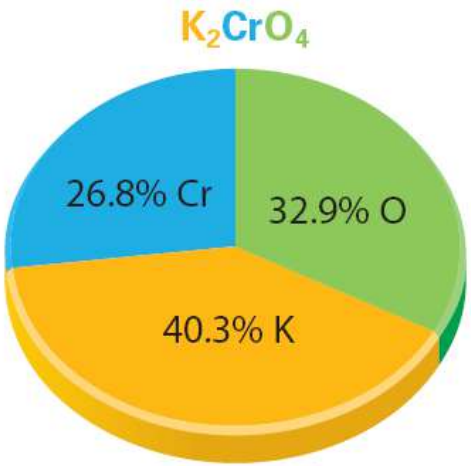


10.3 Percent Composition and Chemical Formulas

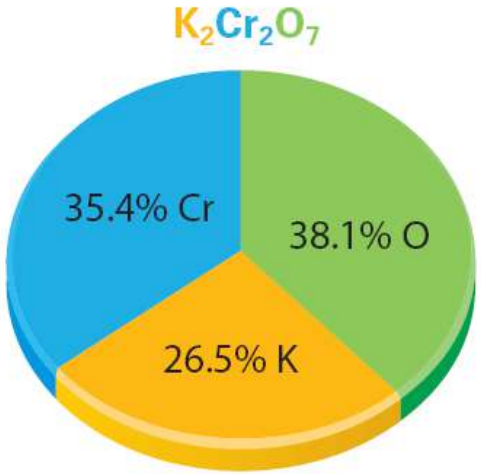


The Percent Composition of a Compound

- The percent by mass of an element in a compound is the number of grams of the element divided by the mass in grams of the compound, multiplied by 100%.



Potassium chromate, K_2CrO_4



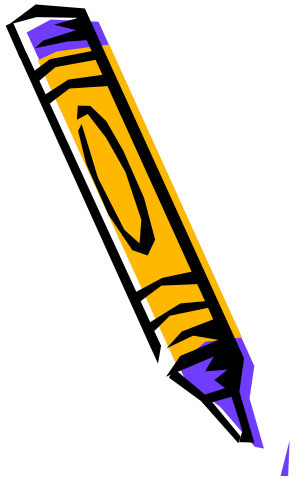
Potassium dichromate, $K_2Cr_2O_7$

The Percent Composition of a Compound

- Percent Composition from Mass Data
  - The relative amounts of the elements in a compound are expressed as the **percent composition** or the percent by mass of each element in the compound.

$$\%\ \text{mass of element} = \frac{\text{mass of element}}{\text{mass of compound}} \times 100\%$$

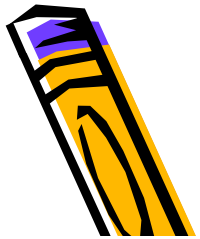
Sample Problem 10.9



Calculating Percent Composition from Mass Data

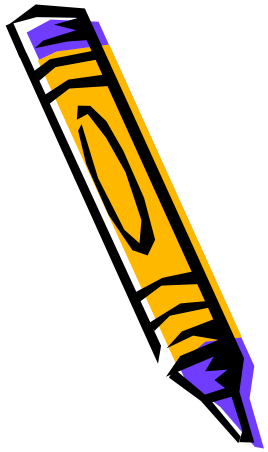
When a 13.60-g sample of a compound containing only magnesium and oxygen is decomposed, 5.40 g of oxygen is obtained. What is the percent composition of this compound?

for Sample Problem 10.9



33. When a 14.2-g sample of mercury(II) oxide is decomposed into its elements by heating, 13.2 g Hg is obtained. What is the percent composition of the compound?

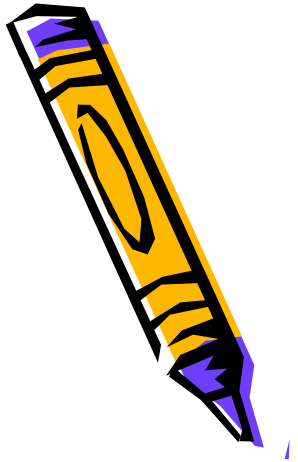
The Percent Composition of a Compound



–Percent Composition from the Chemical Formula

$$\%\ \text{mass} = \frac{\text{mass of element in 1 mol compound}}{\text{molar mass of compound}} \times 100\%$$

Sample Problem 10.10



Calculating Percent Composition from a Formula

Propane (C_3H_8), the fuel commonly used in gas grills, is one of the compounds obtained from petroleum. Calculate the percent composition of propane.

for Sample Problem 10.10

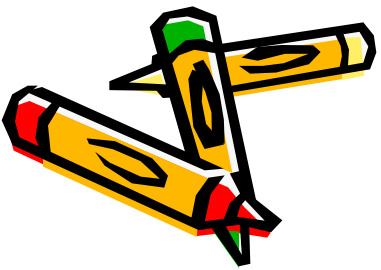
35. Calculate the percent nitrogen in these common fertilizers.

a. NH_3

b. NH_4NO_3

Practice

- Calculate percent composition of:
  - A) C_2H_5OH (ethanol)
  - B) sulfuric acid (H_2SO_4)
  - C) C_3H_7OH (isopropyl alcohol)
  - D) $C_{14}H_{20}N_2SO_4$ (penicillin)



Empirical Formulas

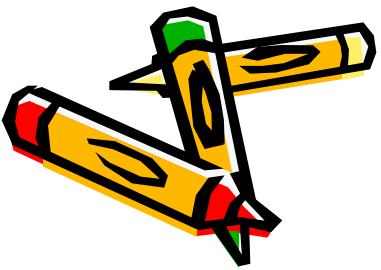
- The **empirical formula** gives the lowest whole-number ratio of the atoms of the elements in a compound.

Empirical Formulas

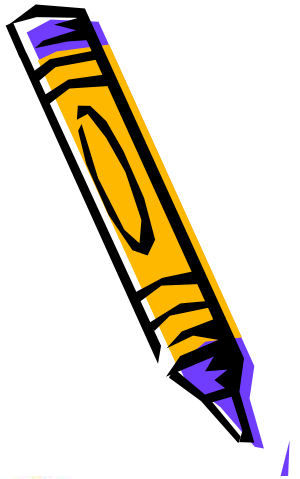
- Ethyne (C_2H_2) is a gas used in welder's torches. Styrene (C_8H_8) is used in making polystyrene.
- These two compounds of carbon have the same empirical formula (CH) but different molecular formulas.

Write empirical formulas for:

- 1) $C_5H_{10}O_5$
- 2) $C_6H_{12}O_2$
- 3) $C_{12}H_{17}ON$
- 4) C_6H_6

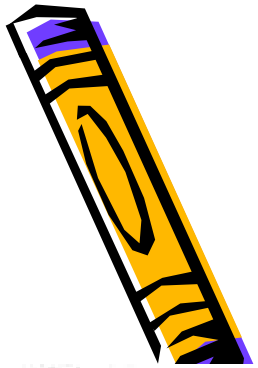


Sample Problem 10.11



Determining the Empirical Formula of a Compound

A compound is analyzed and found to contain 25.9% nitrogen and 74.1% oxygen. What is the empirical formula of the compound?



for Sample Problem 10.11

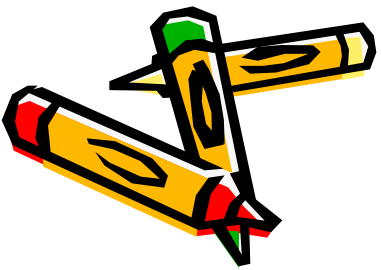
37. 1,6-diaminohexane is used to make nylon. What is the empirical formula of this compound if it is 62.1% C, 13.8% H, and 24.1% N?

Practice

- A sample contains 3.161 g of phosphorus, 0.3086 g of hydrogen and 6.531 g of oxygen. Determine the empirical formula.

Practice

- A sample of Nylon is 63.68% carbon, 12.38% nitrogen, 9.80% hydrogen, and 14.14% oxygen. Determine the empirical formula.



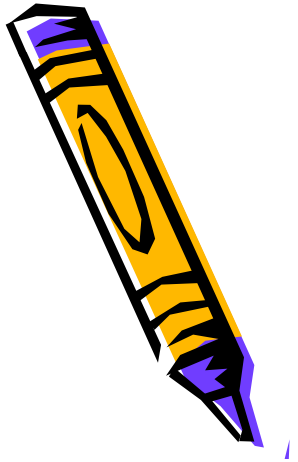
Practice

- Find the empirical formula of a compound found to contain 26.56% potassium, 35.41% chromium, and the remainder oxygen.
- A compound containing sodium, chlorine and oxygen is 25.42% sodium by mass. A 3.25 sample gives 4.33 x 10^{22} atoms of oxygen. What is the empirical formula?

Molecular Formulas

- The molecular formula of a compound is either the same as its experimentally determined empirical formula, or it is a simple whole-number multiple of its empirical formula.

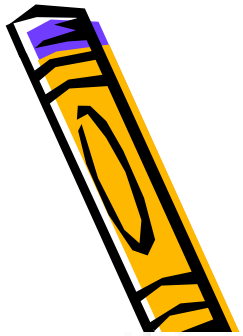
Sample Problem 10.12



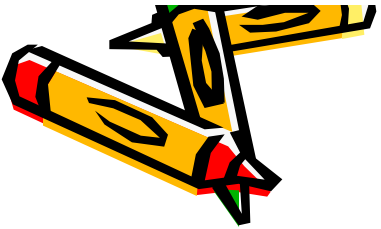
Finding the Molecular Formula of a Compound

Calculate the molecular formula of a compound whose molar mass is 60.0 g/mol and empirical formula is CH_4N.

for Sample Problem 10.12

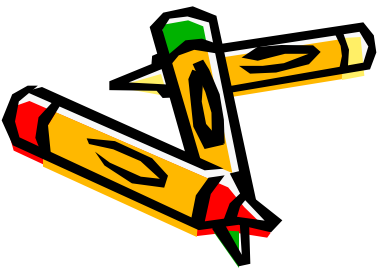


38. Find the molecular formula of ethylene glycol, which is used as antifreeze. The molar mass is 62 g/mol and the empirical formula is CH_3O.



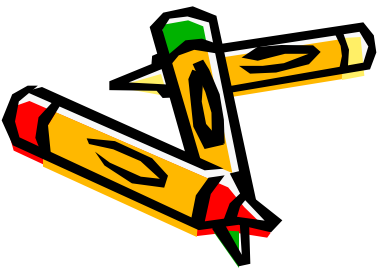
Example

- A white powder is analyzed and has an empirical formula of P_2O_5. It has a molar mass of 283.88 g/mol. What is the molecular formula?



Practice

- Caffeine is 49.47% carbon, 5.191% hydrogen, 28.6% nitrogen, and 16.48% oxygen and has a molar mass of 194 g/mol. What is the molecular formula?



Practice

- A gasoline additive to prevent knocking is 71.65% Cl, 24.27% C, and 4.07% H. The molar mass is 98.96 g. Determine the empirical and molecular formulas.

10.3 Section Quiz.

– 1. Calculate the percent by mass of carbon in cadaverine, $C_5H_{14}N_2$, a compound present in rotting meat.

a) 67.4% C

b) 58.8% C

c) 51.7% C

d) 68.2% C

10.3 Section Quiz.

–2. Which of the following is NOT an empirical formula?

a) NO_2

b) H_2N

c) CH

d) C_3H_6

10.3 Section Quiz.

- 3. Determine the molecular formula of a compound that contains 40.0 percent C, 6.71 percent H, and 53.29 percent O and has a molar mass of 60.05 g.

  a) $C_2H_4O_2$

  b) CH_2O

  c) C_2H_3O

  d) C_2H_4O