Stoichiometry

Mass ⇌ Mole Conversions

mass ⇌ mole

↑ physical amount

↑ count of atoms

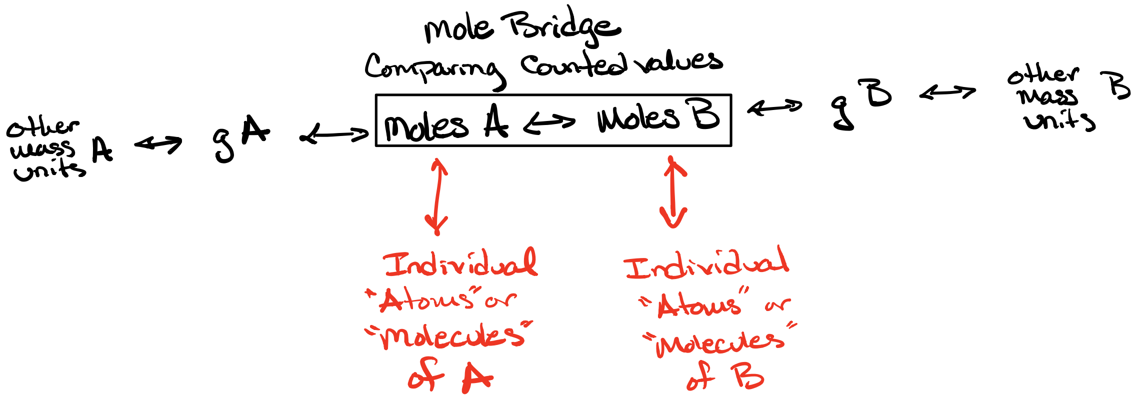
General Road Map for Stoichiometry

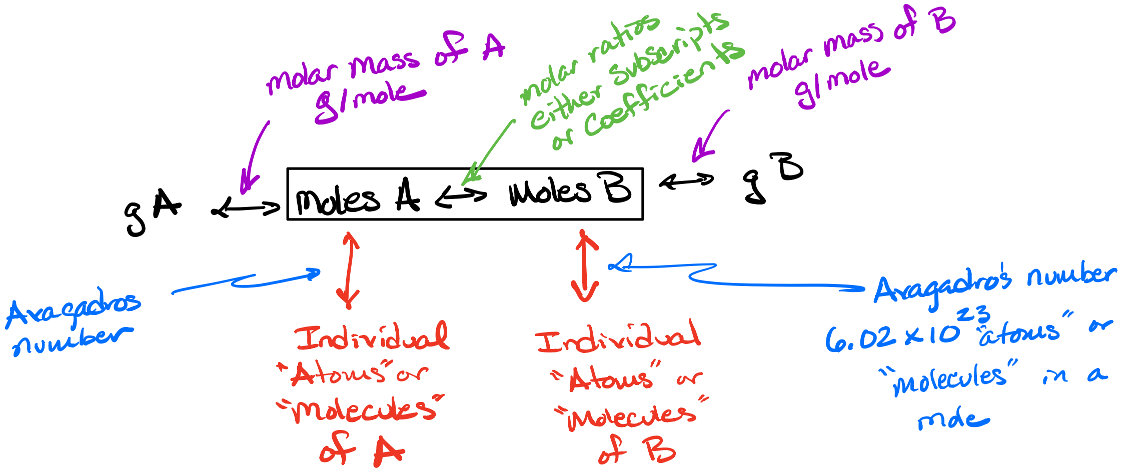
A = Substance A

B = Substance B

mole = 6.02×10^{23} anything 3 SF

6.022×10^{23} 4 SF

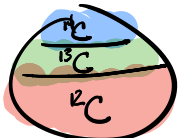




Molar Mass

6
C
12.011

12.011 amu for an average C atom
(weighted average of all carbon isotopes)



Ave C atom = 12.011 amu

* 12.011 g for one mole of C atoms

12.011 g/mole C

Calculate the molar mass of Water H_2O

Count

$$2 \text{ atoms of H} \times \frac{\overset{4}{1.008} \text{ amu}}{1 \text{ atom H}} = 2.01|6 \text{ amu}$$

Count

$$1 \text{ atom of O} \times \frac{\overset{4}{16.00} \text{ amu}}{1 \text{ atom O}} = + 16.00| \text{ amu}$$

$$18.01|6 \text{ amu}$$

= 18.02 amu for 1 H_2O molecule

1 mole Packages

$= 6.02 \times 10^{23}$ packages

$\boxed{H_2O}$

How many H's $6.02 \times 10^{23} \times 2$

2 mole H

How many O's $6.02 \times 10^{23} \times 1$

1 mole O

Count

$$2 \text{ mole H} \times \frac{\overset{4}{1.008} \text{ g H}}{1 \text{ mole H}} = 2.01\underline{6} \text{ g}$$

Count

$$1 \text{ mole O} \times \frac{\overset{4}{16.00} \text{ g O}}{1 \text{ mole O}} = +\, 16.\underline{00} \text{ g}$$

$$18.016$$

$\boxed{18.02 \text{ g/mole } H_2O}$

$18.02 \text{ g} = 1 \text{ mole } H_2O = 6.02 \times 10^{23}$ molecules H_2O

Molar Mass of Glucose $C_6H_{12}O_6$

Exact

$$\overset{\text{Exact}}{6}\text{ mole C} \times \frac{\overset{4}{12.01}\text{ g}}{1\text{ mole C}} = 72.0\underline{6}$$

$$12\text{ mole H} \times \frac{\overset{4}{1.008}\text{ g}}{1\text{ mole H}} = 12.0\underline{9}6$$

$$6\text{ mole O} \times \frac{\overset{4}{16.00}\text{ g}}{1\text{ mole O}} = +\ 96.\underline{00}$$

$$180.0\underline{5}\,|\,3$$

$$\boxed{180.05\text{ g/mole } C_6H_{12}O_6}$$

Activity 13 - Measuring Mass: A Means of Counting[1]

Goals

- ☐ Properly use a top loading balance to determine the mass of a sample.
- ☐ Use molar masses to connect the measured mass of a sample to the number of particles in that sample.
- ☐ Use safe lab techniques to characterize matter.
- ☐ Apply principles to samples of both pure substances and mixtures.
- ☐ Apply dimensional analysis techniques to count small particles such as atoms and molecules.

Pre-Lab Lecture Questions. *Answer these questions on a separate sheet using complete sentences.*

1. What is the difference between weight and mass? How do you "properly" use a balance in the laboratory?
2. What determines the number of significant figures/digits in a measurement?
3. What determines the number of significant figures/digits in a calculation?
4. What is molar mass?
5. What is Avogadro's number?
6. Write as many different conversion factors as you can using the chemical formula of water, the molar mass of water, the definition of a mole, and Avogadro's number.
7. Read through the experimental procedure and classify substances as either pure or a mixture.

Concepts to Review

Classification of Matter: What is a pure substance (element, atom, molecule, compound?) and what is a mixture?
Significant Figures/Digits
Chemical Formulas
Unit Conversion Methods (Dimensional Analysis describing Atoms, Molecules and Ions)

Introduction

Our world contains groupings of objects everywhere: a dozen eggs, a pair of socks, a gross of pencils. These collections are convenient "packets" of individual pieces. The individual "pieces" of pure substances can be described by chemical formulas, e.g., H_2O is the chemical formula for water. This formula indicates that each molecule of water consists of two atoms of hydrogen combined with one atom of oxygen. The mass of this molecule is the sum of the masses of the atoms combined to form this compound. We cannot directly measure the mass of one molecule of water but we can recognize its relative mass and use a convenient "packet" of molecules to describe real world quantities. The **mole** is the chemist's standard collection of particles and is defined **as the amount of substance in a sample that contains as many units as there are atoms in exactly 12 grams of carbon-12**. That number of carbon-12 atoms is **6.022×10^{23}** and is known as **Avogadro's number**.

1 mole carbon atoms = 12.0 g C = 6.022×10^{23} atoms C

1 mole H_2O = 2(1.008 g H) + 1(16.00 g O) = 18.02 g H_2O = 6.022×10^{23} molecules of water

Using these relationships, any mass of water can be converted into a number of molecules:

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[1] Adapted from: Waterman, E. L. *Chemistry: Small-Scale Chemistry Laboratory Manual;* Addison-Wesley/Prentice-Hall, Inc.: Upper Saddle River, New Jersey, 2002; pp 59-62.

$$100.00\text{ g H}_2\text{O}\left(\frac{1\text{ mol H}_2\text{O}}{18.02\text{ g H}_2\text{O}}\right)\left(\frac{6.022\times10^{23}}{1\text{ mol}}\right)=3.34\times10^{24}\text{ molecules H}_2\text{O}$$

In this lab you will measure amounts of substances. You will then calculate the number of particles contained in the sample, numbers that cannot be counted—only calculated.

Safety

Act in accordance with the laboratory safety rules of Cabrillo College. Wear safety glasses at all times. Avoid contact with all chemical reagents and dispose of reactions using an appropriate waste container.

Materials:

Reagent Central solutions include:

Sucrose ($C_{12}H_{22}O_{11}$), sodium chloride (NaCl), chalk (calcium carbonate)

🗐**Check out** a sample containing:

Glass slides (assumed to be pure silicon dioxide), polystyrene peanuts, sulfur, fluorite, hematite, (or other minerals as provided by stockroom)

Equipment:	Balance	Plastic spoons

Experimental Procedure

1. Using a weighing paper or boat and balance, "weigh" one level teaspoon of sodium chloride and record its mass in your laboratory notebook and/or Table 1. This mass is the mass of your "sample." Using the same balance, measure the mass of one teaspoon of water and one of sucrose.
2. "Weigh" a glass slide, and record its mass in your laboratory notebook and/or Table 2. Repeat for the piece of chalk and a polystyrene peanut.
3. "Weigh" a piece of sulfur, and record its mass in your laboratory notebook and/or Table 3. Repeat for a piece of fluorite and a piece of hematite.
4. A nickel coin is a mixture of metals called an alloy. It consists of 75% copper and 25% nickel. Design and carry out an experiment to find out how many nickel atoms there are in one 5-cent piece. Record your experiment procedure in your laboratory notebook and/or in Table 4. Show all your calculations and give your final answer with the correct number of significant figures and in scientific notation.

Chemical Calculations

For each of the masses recorded:

1. Use the formula (see below) to determine the molar mass in units of g/mol.
2. Use the molar mass to determine the number of moles.
3. Use the number of moles of the substance and molar ratios to calculate the moles of each element.
4. Use the moles of each element in each sample along with Avogadro's number to calculate the number of atoms of each element.
5. Use the above calculations as a model to help you determine the number of nickel atoms in one 5-cent piece.

Activity 13 - Measuring Mass: A Means of Counting

Name______________________________

Section____________ **Date**_______

*Given Data to Complete the Lab

Experimental Data and Calculations

1. Complete the following tables: Table 1. Counting Particles in Common Substances

Formula	Name ✓	Sample Mass (g)	Molar Mass (g/mol) ✓	Moles in sample ✓	Moles each element in sample ✓	Atoms each element in sample ✓
NaCl 2 atoms		5.25g	1 answer	1 answer	2 answers	2 answers
H_2O 2atoms	Water	6.72g	1 answer	1 answer	2 answers H, O	2 answers
$C_{12}H_{22}O_{11}$ 3 atoms	Sucrose	5.95 g	1 answer	1 answer	3answers C, H, O	3 answer

Table 2. Counting Particles in Common Items.

Formula	Name	Sample Mass (g)	Molar Mass (g/mol)	Moles in sample	Moles each element in sample	Atoms each element in sample
SiO_2 (molecule)	Glass slides	9.72g				
$CaCO_3$ (formula unit)	Chalk	4.02g				
$C_{8000}H_{8000}$(molecule)	Polystyrene	0.00255 g				

Table 3. Counting Particles in Minerals.

Formula	**Name**	**Sample Mass (g)**	**Molar Mass (g/mol)**	**Moles in sample**	**Moles each element in sample**	**Atoms each element in sample**
S_8 (molecule)		8.25g				
CaF_2 (formula unit)	Fluorite	9.87g				
Fe_2O_3 (________)	Hematite	8.84g				

Table 4. Counting the Atoms of Nickel in a Nickel

Describe your experimental procedure:

Mass of nickel coin = 5.02g

Show all the steps of your calculations and your final answer including the correct number and units:

Demonstration of Calculations

From work sheet we are given 5.25g Sample NaCl

⇒ Give name $\underset{1}{Na}\underset{1}{Cl}$ = Sodium Chloride

⇒ Molar Mass in g/mol

$$\overset{\text{Exact}}{1} \text{ mole Na} \times \frac{22.9\overset{4}{9}\text{ g}}{1 \text{ mole Na}} = 22.9\underline{9}\text{ g}$$

$$1 \text{ mole Cl} \times \frac{35.4\overset{4}{5}\text{ g}}{1 \text{ mole Cl}} = \begin{array}{r} 35.4\underline{5}\text{ g} \\ \hline 58.4\underline{4}\text{ g} \end{array}$$

$$\boxed{= 58.44 \text{ g/mole NaCl}}$$

⇒ Calc Moles in Sample (5.25g NaCl)

Road Map

$$\begin{tikzcd} \boxed{gA \arrow[r] & \text{mole A}} \arrow[d] \arrow[r] & \text{mole B} \arrow[r] \arrow[d] & g\,B \\ & \text{atoms or molecules A} & \text{atoms or molecules B} & \end{tikzcd}$$

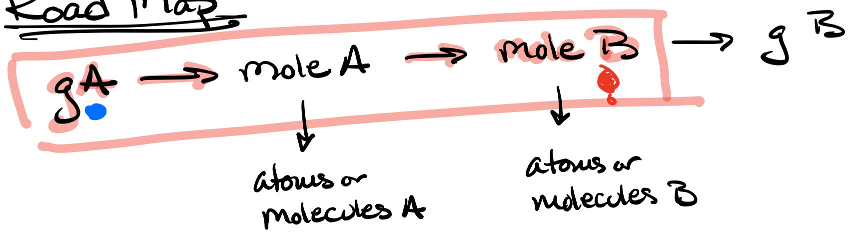
$$g\,\text{NaCl} \xrightarrow{58.44\text{ g/mole}} \text{mole NaCl}$$

$$\overset{3}{5.25}\text{ g }\cancel{\text{NaCl}} \times \frac{1 \text{ mole NaCl}}{\underset{4}{58.44}\text{ g }\cancel{\text{NaCl}}} = 0.0898357289528 \text{ moles}$$

$$= \boxed{0.0898 \text{ moles NaCl}}$$

⇒ moles Each element in 5.25g NaCl

Road Map



mole Bridge Conversion factors

$$1\text{ mole }\mathrm{Na}_{1}\mathrm{Cl}_{1} = 1\text{ mole Na}$$

$$1\text{ mole }\mathrm{Na}_{1}\mathrm{Cl}_{1} = 1\text{ mole Cl}$$

Subscripts ~~can~~ are used as molar ratios to relate the whole to the part

2 Calculations

g NaCl → mole NaCl → mole Na

$$\overset{3}{5.25\text{g NaCl}} \times \frac{1\text{ mole NaCl}}{\underset{4}{58.44\text{g}}\text{ NaCl}} \times \overset{\text{Exact}}{\frac{1\text{ mole Na}}{1\text{ mole }\mathrm{Na}_{1}\mathrm{Cl}_{1}}} = 0.0898|35728\text{ mole Na}$$

$$\boxed{= 0.0898\text{ mole Na}}$$

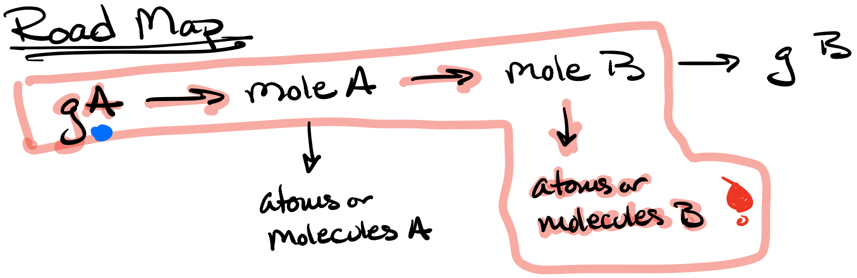
g NaCl → mole NaCl → mole Cl

$$\overset{3}{5.25\text{g NaCl}} \times \frac{1\text{ mole NaCl}}{\underset{4}{58.44\text{g}}\text{ NaCl}} \times \overset{\text{Exact}}{\frac{1\text{ mole Cl}}{1\text{ mole }\mathrm{NaCl}_{1}}} = 0.0898|35728\text{ mole Cl}$$

$$= \boxed{0.0898\text{ mole Cl}}$$

⇒ atoms of each element in sample

Road Map



g NaCl → mole NaCl → mole Na → atoms Na

$$\overset{3}{5.25}\text{ g NaCl} \times \frac{1\text{ mole NaCl}}{\underset{4}{58.44}\text{ g NaCl}} \times \frac{1\text{ mole Na}}{1\text{ mole NaCl}} \times \frac{\overset{3}{6.02}\times 10^{23}\text{ atoms Na}}{1\text{ mole Na}} =$$

$$\underset{\substack{\text{EE}\\(\times 10^{\wedge})}}{5.25 \times 6.02\text{ E }23} \div 58.44 = 5.40811088296\,\underline{\text{E}}\,22$$

$$= 5.40811088296 \times 10^{22}$$

$$= \boxed{5.41 \times 10^{22}\text{ atoms Na}}$$

g NaCl → mole NaCl → mole Cl → atoms Cl

$$\overset{3}{5.25}\text{ g NaCl} \times \frac{1\text{ mole NaCl}}{\underset{4}{58.44}\text{ g NaCl}} \times \frac{\overset{\text{Exact}}{1\text{ mole Cl}}}{1\text{ mole NaCl}} \times \frac{\overset{3}{6.02}\times 10^{23}\text{ atoms Cl}}{1\text{ mole Cl}} =$$

$$5.408111 \times \underline{10}^{22}$$

$$= \boxed{5.41 \times 10^{22}\text{ atoms Cl}}$$

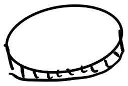
Sucrose example

$C_{12}H_{22}O_{11}$

molar Equalities

$$\frac{12 \text{ mole C}}{1 \text{ mole } C_{12}H_{22}O_{11}} \qquad \frac{22 \text{ mole H}}{1 \text{ mole } C_{12}H_{22}O_{11}} \qquad \frac{11 \text{ mole O}}{1 \text{ mole } C_{12}H_{22}O_{11}}$$

Nickel Coin Experiment



Coin
5.02g

= 25% Ni
75% Cu

How many Ni atoms in the coin?

$$\frac{25\text{g Ni}}{100\text{g Coin}}$$

$\cancel{\text{Coin}}$
5.02g

% by mass

$$\times \frac{25\text{g Ni}}{100\text{g } \cancel{\text{Coin}}} \leftrightarrow \text{g Ni} \xrightarrow{\text{molar mass Ni}} \text{mole Ni} \xrightarrow{\text{avagadro's number } 6.02\times10^{23} \text{ atoms} = 1 \text{ mole}} \text{atoms Ni}$$

Activity 14 – Mole Worksheet

Name____________________________

Section____________ **Date**_______

Questions and Problems

Solve the following problems. Your final answer should include the correct number of significant figures and the units. Use scientific notation if the answer is greater than 1000 or less than 1. **Note: Make sure you have the correct chemical formula before doing any calculations**. You will need a periodic table for this exercise; **make sure to show all your work.**

1. A sample of mercury (II) bromide weighs 7.56 g.
    a. What is the molar mass of mercury (II) bromide?
    b. How many moles are in this sample?

2. What is the mass of 0.81 mol of Ammonium carbonate?

3. A sample of Chlorine gas contains 8.25 moles. (Remember that the formula for chlorine gas is Cl_2.)
    a. How many ***molecules*** of chlorine are in the sample?
    b. How many chlorine ***atoms*** are in the sample? (Remember that each chlorine molecule, Cl_2, consists of 2 chlorine atoms.)

4. Calculate the percent by mass of barium in barium sulfate.

5. What is the mass of 4.2×10^{23} molecules of carbon dioxide?

6. Use the equation below to solve the following problems:

$$2\ KMnO_4 \quad + \quad 16\ HCl \quad \longrightarrow \quad 5\ Cl_2 \quad + \quad 2\ KCl \quad + \quad 2\ MnCl_2 \quad + \quad 8\ H_2O$$

a. How many moles of HCl are required to react completely with 1.00 mole of $KMnO_4$?

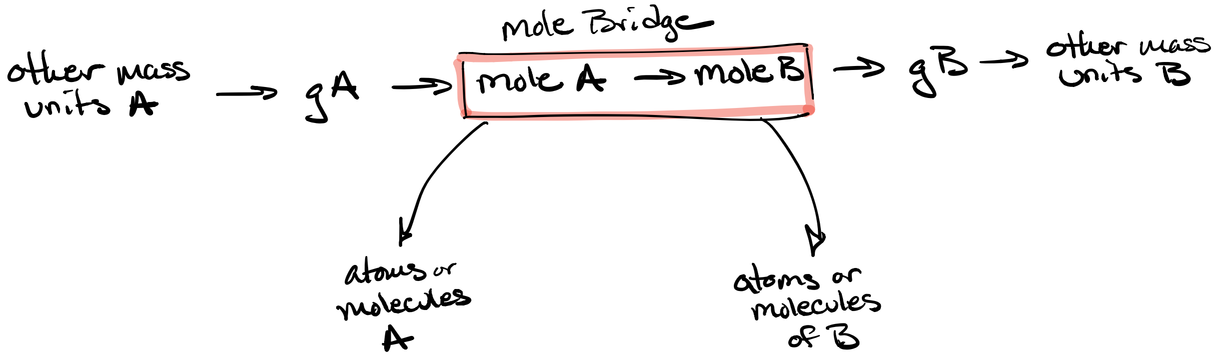
b. How many moles of chlorine will be produced by 25.0 moles of $KMnO_4$ assuming that an excess of HCl is present?

c. How many moles of water will be produced if 40. g of HCl are completely reacted with excess potassium permanganate?

d. What is the maximum mass of manganese(II) chloride that will be produced if 40. g of HCl are completely reacted with excess Potassium permanganate?

7. A water solution of sulfuric acid (H_2SO_4) has a density of 1.67 g/mL and is 75 percent H_2SO_4 by mass. How many moles of $H_2SO_4$are contained in 500. mL of this solution?

8. Cobalt chloride ($CoCl_2$) exists as a hydrate (has non-covalently bound waters of hydration) with a molecular mass of 237.93. Prolonged heating can drive off the waters of hydration. A 54.8 g sample of the hydrate was heated for 15 minutes, cooled and reweighed. The residual mass was found to be 33.2 g. Calculate the number of water molecules associated with each $CoCl_2$ in the hydrate



Mole Bridge Ratios Can be Subscripts within a formula

Ex

$HgBr_2$

$$\frac{1 \text{ mole Hg}}{1 \text{ mole } HgBr_2} \quad \text{or} \quad \frac{2 \text{ mole Br}}{1 \text{ mole } HgBr_2}$$

molar ratios

Mole Bridge Ratios Can be Coefficients in a balanced chemical Equation.

molar ratios

$$2KMnO_4 + 16HCl \longrightarrow 5Cl_2 + 2KCl + 2MnCl_2 + 8H_2O$$

$$\frac{16 \text{ mole HCl}}{2 \text{ mole } KMnO_4} \qquad \frac{8 \text{ mole } H_2O}{16 \text{ mole HCl}}$$

$$5 \text{ mole } Cl_2 = 2 \text{ mole KCl}$$

↙ ↘

$$\frac{5 \text{ mole } Cl_2}{2 \text{ mole KCl}} \quad \text{or} \quad \frac{2 \text{ mole KCl}}{5 \text{ mole } Cl_2}$$