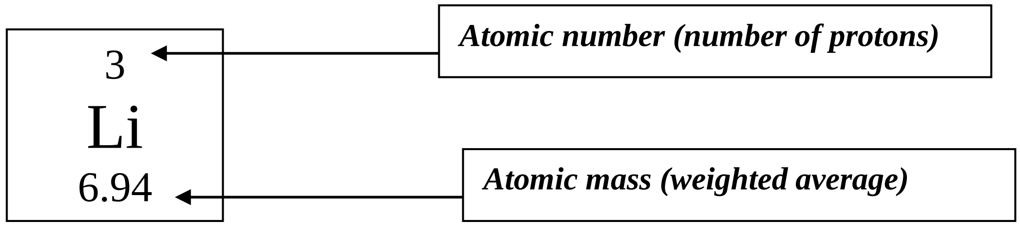
The Material World: Stoichiometry

9. <u>Stoichiometry</u>
A. Calculating Atomic Masses



a. The periodic table lists atomic masses for each element.
b. The atomic mass is *not* a whole number because it is the weighted average of the masses of the different isotopes of that element.
c. Atomic masses do not always increase directly with relation to atomic number. See the exceptions for Co and Ni; Cu and Te; and Te, I and Xe.

<u>Example 1</u> An element has two isotopes: one of mass 63 u; the other with a mass of 65 u. If the relative abundance of the isotopes is 69.1 and 30.9 %, respectively, find the atomic mass of the element.

<u>Example 2</u> If the relative abundance of a neon isotope was 5.7%, and the rest was only Ne-20, what was the mass number of the minor isotope?

Exercises

1. Mark is looking for the **atomic mass** and the **name** of an element. The data he has collected so far is recorded in the following table :

Mass number of each of the natural isotopes of this element	Relative abundance in nature (%) of each of these isotopes
20	90.92
21	0.26
22	8.82

Given this information, calculate the atomic mass and name the element Mark is looking for.

2. Copper, Cu, whose atomic number is 29, has two stable isotopes. The first isotope has 34 neutrons and the second has 36 neutrons.

If the first isotope accounted for 20% of all copper atoms, what would be the atomic mass of copper?

3. Given that the progression of the values of atomic masses in the periodic table is not perfectly constant, which of the following statements are true?

1- The number of protons varies irregularly from one element to another.
2- The number of neutrons varies irregularly from one element to another.
3- The number of protons and neutrons varies irregularly from one element to another.
4- The atomic number varies irregularly from one element to another.
5- The number of electrons varies irregularly from one element to another.

4. Calculate, to the nearest hundredth, the atomic mass of the element magnesium, given that it is comprised of three different isotopes:

79.00% of magnesium-24, (that' s not a negative sign!)
10.00% of magnesium-25,
and the rest is magnesium-26.

5. Two isotopes of Cl exist in nature. Find the missing one from the table.

ISOTOPE	**MASS NUMBER**	**Relative abundance (%)**
^{35}Cl	35	77.35
???	???	

6. Given the following atomic masses, predict what the most common isotope actually is.

H	1.00797 u
O	15.9994 u
C	12.001 u

7. Assume that ^{12}C accounts for 99% of carbon. If the rest consists of ^{13}C and ^{14}C, then ^{14}C makes up what percent of carbon?

   (**Hint**: there seems to be information missing, but if so, you are forgetting to look something up in the periodic table.)

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B- The Mole: introduction

Suppose you needed to buy sand to prepare some concrete. Would you ask for it in grains? Is there a more convenient unit ?

Given: 1 bag of sand = 20 kg

Convert the following using the factor label method:

a. 4.5 bags of sand = _?_ kg

b. 30 kg = _?_ bags of sand

When it comes to chemistry it is also not practical (or reliable) to count grains. It would be even less practical to count molecules. So we use the idea of a bag or a mole which is about 6.02×10^{23} particles (atoms or molecules) of the substance were talking about. Right now that number is not too important. What we need to focus on is that different atoms come with a different number of protons and neutrons. As a result a bag or mole of carbon will have a greater mass than a mole of lithium. We can look up the mass of individual elements in the periodic table.

Examples

Find the molar mass of the following
(This is like getting the mass of a bag or of a mole of the following)

a. H

c. NO_2

b. Fe

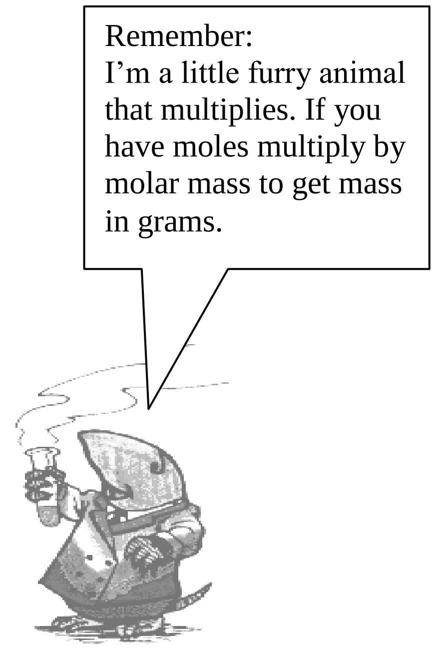
d. $Ca_3(PO_4)_2$

Think of the sand bag analogy and find the mass of...

a. 3.0 moles of C

b. 0.25 moles of Fe

c. 7.1 moles of $Ca_3(PO_4)_2$



Now for the reverse operation, find the number of moles represented by...

d. 6.0 grams of C

e. 138 g of NO_2

f. 1.0 g of $Ca_3(PO_4)_2$

The Mole: Glossary of Terms to Remember

- **Mass**: depends on the amount of matter in a substance. Unlike weight it does not depend on gravity. In chemistry we most commonly measure mass in grams.
- **Mole**: a package of 6.02×10^{23} items, usually molecules. Technically, it is the number of atoms found in 12.000 grams of ^{12}C. (One way of getting the number is from a mass spectrometer. With a CH_4 sample, the instrument will give, through a graph, a relative measurement of how much heavier a $12C^+$ fragment is compared to H^+. Since the mass of a proton(H^+) is known, this will yield the mass of ^{12}C. dividing 12.000g by the mass of 1 atom will give us the number of atoms in that mole or 6.02×10^{23}.)
- **Molar Mas**s: the mass of 1 mole of a substance. Molar mass is expressed in *g/mole*. It is the sum of the atomic masses (listed in the periodic table) of the elements in a substance's formula. For example the molar mass of Ne = 20 g/mole. H_2O = [**2** *1.0 + 1(16)] = 18 g/mole.
- **Avogadro's Number**: a name for 6.02×10^{23}, the number of particles in a mole

g. How many molecules are in a drop of water = 0.1 ml = 0.1 g because of liquid water's density of 1.0 g/ml?

First convert to moles:

Then convert to molecules:

h. What is the mass of a single molecule of H_2?

Exercises

1. Find the molar mass for each of the following:

a. Be
b. Al_2O_3
c. H_2
d. C_6H_6
e. CH_3CO_2H
f. $Cu(NO_3)_2$
g. $XePtF_6$

2. Convert the following:

a. 10 grams of Be = __?__ moles

b. 36 g of C = __?__ moles

c. 0.105 moles of NaOH = __?__ grams

d. One gram of water = __?__ moles

e. 0.56 g of $Cu(NO_3)_2$ =__?_ moles

f. 0.750 kg of N_2 = __?__ moles (Remember: 1 kg = 1000 g)

3. What is the mass, in grams, of 120 moles of CH_4?

4. a. How many atoms of H are there in one molecule of H_2O?
   b. How many moles of H atoms are there in one mole of water molecules?
   c. How many moles of O atoms are there in one mole of water molecules?

5. Keeping in mind the number of atoms present in a mole (see notes on previous page), how many atoms are found in 0.00010 moles of a monoatomic substance?

6. The atomic masses scale is based on carbon 12 (the isotope of a carbon atom with 6 neutrons). Such an isotope is assigned an atomic mass of exactly 12 units. Yet the periodic table lists carbons mass as 12.011. Why?

7. How many molecules are contained in a drop of water whose mass is 0.2 g?

8. Find the molar mass for each of the following:

a. He
b. Fe_2O_3
c. O_3 (ozone)
d. C_5H_5OH
e. $(NH_4)_2S$
f. $Ca(NO_3)_2$
g. Na_2SO_4

9. Convert the following:

a. 30 grams of C = __?__ moles

b. 56 g of N= __?__ moles

c. 0.356 moles of $NaNO_3$ = __?__ grams

d. One gram of H_2O_2 = __?__ moles

e. 100 g of $Ca(NO_3)_2$ =__?__ moles

f. 0.750 g of O_2 = __?__ moles

g. One mole of copper= ___?___grams.

h. 2.0 moles of sodium phosphate = ___?___ grams

i. 2.58 g of potassium chloride = ___?___ moles

10. What is the mass, in grams, of 12.0 moles of C_3H_8?

11. What is the mass of a single atom of He?

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C- Stoichiometry: Using mole ratios based on balanced equations

Example 1 The enzyme catalase breaks down hydrogen peroxide according to :

$$2\ H_2O_{2(l)} \rightarrow 2\ H_2O_{(l)} + O_{2(g)}$$

a. In an experiment a student adds 0.20 moles of hydrogen peroxide to a test tube containing chopped liver. How many grams of oxygen will be produced?

b. If a student had reacted only 3.4 grams of peroxide, how many moles of oxygen would have escaped into the atmosphere?

Example 2 If a patients blood is too acidic, doctors often use sodium hydrogen carbonate to raise the pH to a normal level.

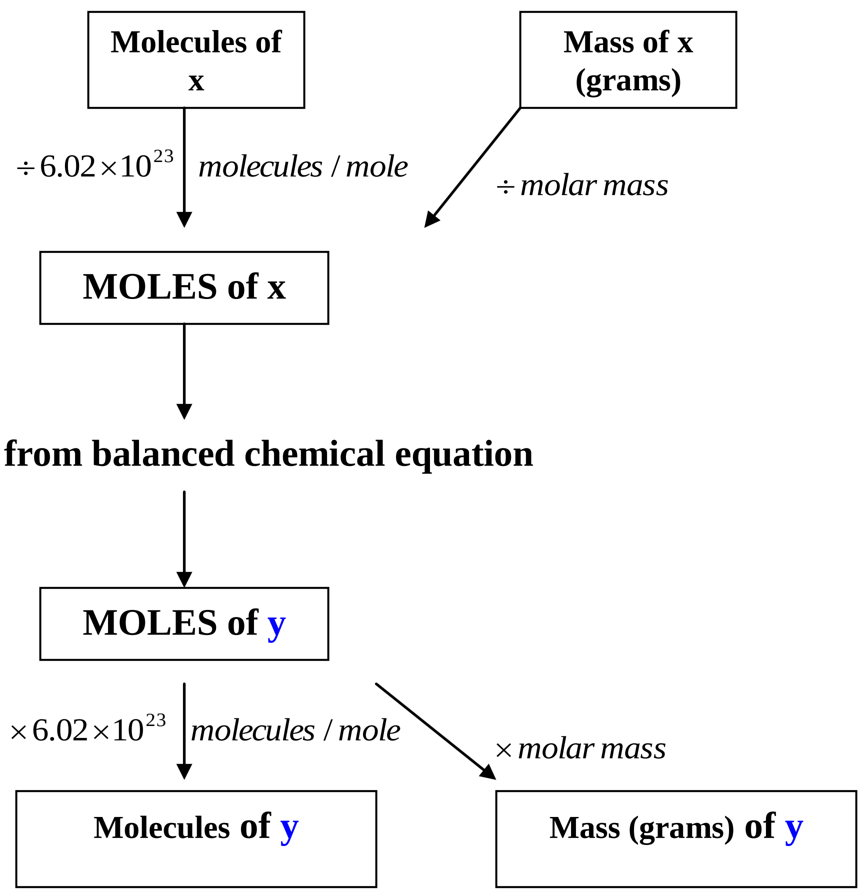
Given: $NaHCO_3 + H^{+1} \rightarrow CO_2 + H_2O + Na^{+1}$

How many grams of sodium hydrogen carbonate should be administered to eliminate 0.50 grams of excess acid (H^{+1}) ?

Example 3 $AlCl_3$ + 4 NaOH → $NaAlO_2$ + 3 NaCl + 2 H_2O

For every 1.0 gram of NaCl that is produced in the above reaction, what mass of water, is also created?

Summary of Conversions:



Extra

How long is a line of 1 mole of sand grains, each 1 mm in length? (to make sense of your answer keep in mind that the closest star is about 2×10^{13} km away from us; the center of the Milky Way galaxy is about 2×10^{17} km away)

Suppose you took a *mole of water molecules* and divided them into droplets as wide as the sand grains. Using the volume of a sphere = $(4/3)(3.14)r^3$, the volume of a spherical droplet, 1 mm in diameter, is 5.23×10^{-4} cm^3, and each gram of water = 1 cm^3. If you lined them up, what would *their* length be?

What is to be learnt from all these calculations?

Molecules are extremely small compared to sand grains. An equal number is considered in both examples, and yet the length between the two is dramatically different.

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Exercises Part 1

1. For the reaction: $2K + 0.5\ O_2 \rightarrow K_2O$

a. How many moles of O_2 are needed to react with 0.56 moles of K?

b. How many moles of O_2 are needed to make 7.6 g of K_2O?

c. How many grams of K_2O will be produced from 0.50 g of K?

2. For the reaction: $Na_2O + H_2O \rightarrow 2\ NaOH$

a. What mass of NaOH could be made from 12.4 g of Na_2O?

b. How many moles of Na_2O are needed to make 1000 g of NaOH?

c. **BONUS**: What would happen if 18 g of water were mixed with 18 g of sodium oxide?

3. <u>First balance,</u> and answer the questions that follow:

$C + H_2 \rightarrow CH_4$

a. How many moles of CH_4 can be made from 7.0 g of H_2?

b. What weight of H_2 is needed to react with 5.0 g of C?

c. **BONUS**: What would happen if 20 g of hydrogen were mixed with 20 g of carbon?

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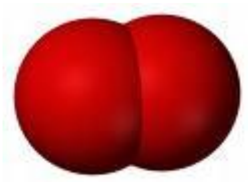
Stoichiometry Exercises Part 2

1. How many molecules are found in 2 moles of helium?
2. How many molecules are in a 250 gram glass of water?
3. What is the mass of 1 molecule of O_2?



4. **Given:** $2\ H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{(g)}$

a) How many molecules of oxygen reacted if we produced 30 moles of water?
b) If 40.0 g of hydrogen react, how many molecules of water will be produced?

5. Find the approximate number of molecules in a banana, given that a 100 g banana contains 75 g of H_2O, 23 g of $C_{12}H_{22}O_{11}$ (sugar) and 1 g of a specific protein with a molar mass of 13 600 g/mole.

Stoichiometry Exercises Part 3

1. Given: $4\ NH_{3(g)} + 5\ O_{2(g)} \rightarrow 4\ NO_{(g)} + 6\ H_2O_{(g)}$

   a. How many moles of oxygen are needed to completely burn 3.0 moles of ammonia(NH_3)?
   b. How many grams of NO will form for every 3 moles of oxygen that react?
   c. How many moles of water will accompany the formation of 2.8 g of NO?
   d. What mass of oxygen reacted if 90 g of water were formed?

2. Given: $H_2 + Cu_2O \rightarrow 2\ Cu + H_2O$

   a. How many moles of solid copper should be produced if 4 moles of solid Cu_2O react?
   b. A similar reaction occurs between hydrogen and Cu_2S. Write a balanced equation to represent such a reaction. Then calculate the mass of copper that will be produced for every gram of hydrogen gas that reacts.

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3. Given: C_6H_{14} + $9.5\ O_2 \rightarrow$ $6\ CO_2$ + $7\ H_2O$ + 3500 kJ

   a. How much heat in kJ will be released if only 0.34 moles of C_6H_{14} react?(treat kJ like moles)

   b. How many moles of CO_2 will escape if 4.5 moles of oxygen react?

   c. This reaction is called an exothermic one? Why? What's the opposite of an exothermic reaction.

   d. It's also called an oxidation reaction. Why?

4. As pointed out in a *Scientific American* article, a match is fascinating because it is a miniature pyrotechnic device. All the effects of fireworks are present on a small scale: heat, smoke, sound, gas and light. Here is the main reaction that occurs:

   $16\ KClO_3 + 3\ P_4S_3 \rightarrow 6\ P_2O_5 + 16\ KCl + 9\ SO_2$

   a. How many grams of sulfur dioxide escape each time 0.0010 moles of $KClO_3$ react?

   b. If 4.40 g of P_4S_3 react, how many moles of SO_2 form?

   c. How many grams of potassium chloride will form if 12.2 g of $KClO_3$ react?

5. The explosion of gunpowder can be represented by the following:

   $4\ KNO_3 + 7\ C + S \rightarrow K_2CO_3 + K_2S + 3\ CO + 3\ CO_2 + 2\ N_2$

   a. How many grams of carbon will completely react with 2.00 moles of KNO_3?

   b. If 1010 g of KNO_3 explode, what *total* mass of carbon dioxide and carbon monoxide will be created?
   c. How many moles of sulfur must react to produce 4.4 g of carbon dioxide?

6. Vodka is 40% alcohol by volume. Ethyl alcohol (C_2H_6O)'s density is 0.7893 g/ml. What is the minimum mass of HCl needed to destroy the alcohol in 2.0 L of vodka?

   $3\ C_2H_6O + 4\ H_2CrO_4 + 12\ HCl \rightarrow C_2H_4O_2 + 4\ CrCl_3 + 13\ H_2O$