Chemistry 120 Fall 2016

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Office Hours: M,W,F 9:30-11:30 am T,R 8:00-10:00 am or by appointment;

Test Dates:

September 23, **2016 (Test 1): Chapter 1,2 &3**

October 13, **2016 (Test 2): Chapter 4 & 5**

October 31, **2016 (Test 3): Chapter 6, 7 & 8**

November 15, **2016 (Test 4): Chapter 9, 10 & 11**

November 17, **2016 (Make-up test) comprehensive: Chapters 1-11**

Chapter 6. Chemical Calculations:

Chapter 6

Chemical calculations, formula masses, moles, and chemical equations

Formula masses

- The sum of the atomic masses of all of the atoms represented in the chemical formula of a substance is the formula mass.

- Example: for H_2O

$$2\_atoms\_hydrogen\left(\frac{1.01\_amu}{1\_atom\_hydrogen}\right) = 2.02\_amu$$

$$1\_atom\_oxygen\left(\frac{16.00\_amu}{1\_atom\_oxygen}\right) = 16.00\_amu$$

Formula mass = 18.02 amu

Formula masses

- The elemental masses that are used to determine the formula mass are found in the periodic table.
- Another example: glucose, $C_6H_{12}O_6$

$$6\_atoms\_carbon\left(\frac{12.01\_amu}{1\_atom\_carbon}\right) = 72.06\_amu$$

$$12\_atoms\_hydrogen\left(\frac{1.01\_amu}{1\_atom\_hydrogen}\right) = 12.12\_amu$$

$$6\_atoms\_oxygen\left(\frac{16.00\_amu}{1\_atom\_oxygen}\right) = 96.00\_amu$$

Formula mass = 180.18 amu

The mole: a counting unit for chemists

- The quantity of material in a sample can be counted in units of mass or units of amount.
- Example:
  - 15 pounds of nails ← Counting by mass
  - 70 dozen nails ← Counting by amount

The mole: a counting unit for chemists

- Masses need to be specified with their associated units. Otherwise, the quantity is meaningless.
- Example: Mr. Powers, you've got eight to get out of the building before it explodes…

Would be nice to know if this is eight seconds or minutes.

The mole: a counting unit for chemists

- Since atoms are so small, we routinely deal with enormous numbers of them in our everyday experiences.
  - A spoon of sugar for your coffee has around 3 x 10^{21} sugar molecules in it.
  - A cup of water is about 8 x 10^{24} water molecules.
- It is convenient to count things by amounts in chemistry, and the quantity used is the mole.

The mole: a counting unit for chemists

Avogadro's number

- One mole is 6.02 x 10^{23} objects. This quantity should be treated in the same way that other amount figures are used (e.g. a dozen objects is twelve objects).
- A dozen eggs would be 12 eggs. Half a dozen eggs would be 6 eggs.
- A mole of eggs would be 6.02 x 10^{23} eggs. Half a mole of eggs would be 3.01 x 10^{23} eggs.
- Conversion factors that will often be used are

$$\frac{1\_mole}{6.02x10^{23}\_objects} \qquad \frac{6.02x10^{23}\_objects}{1\_mole}$$

The mole: a counting unit for chemists

- Using dimensional analysis, it is easy to determine the number of molecules, atoms, etc. that are present in some sample.
- Example: how many molecules of water are in 0.25 moles of water? How many hydrogen atoms are in 0.25 moles of water?

$$0.25\_moles\_H_2O\left(\frac{6.02x10^{23}\_H_2O\_molecules}{1\_mole\_H_2O}\right) = 1.5x10^{23}\_H_2O\_molecules$$

$$1.5x10^{23}\_H_2O\_molecules\left(\frac{2\_H\_atoms}{1\_H_2O\_molecule}\right) = 3.0x10^{23}\_H\_atoms$$

This conversion factor is based on the fact that there are two H atoms in each H_2O molecule

Mass of a mole

- The mass of a mole of some chemical substance is the numerically the same as the substance's formula mass. Instead of units of *amu*, the mole has mass units of grams.
  - The mass of a molecule of H_2O is 18.02 amu
  - The mass of a mole of H_2O is 18.02 g

This quantity is called the "molar mass' of water

Mass of a mole

- A molar mass itself is a conversion factor:

1 mole H_2O = 18.02 g H_2O

$$\frac{1\_mole\_H_2O}{18.02\_g\_H_2O} \qquad \frac{18.02\_g\_H_2O}{1\_mole\_H_2O}$$

- Converting between grams and moles is straightforward using dimensional analysis.
- How much does 4.0 moles of water weigh?

$$(4.0\_moles\_H_2O)\left(\frac{18.02\_g\_H_2O}{1\_mole\_H_2O}\right) = 72g$$

Desired unit

Given unit

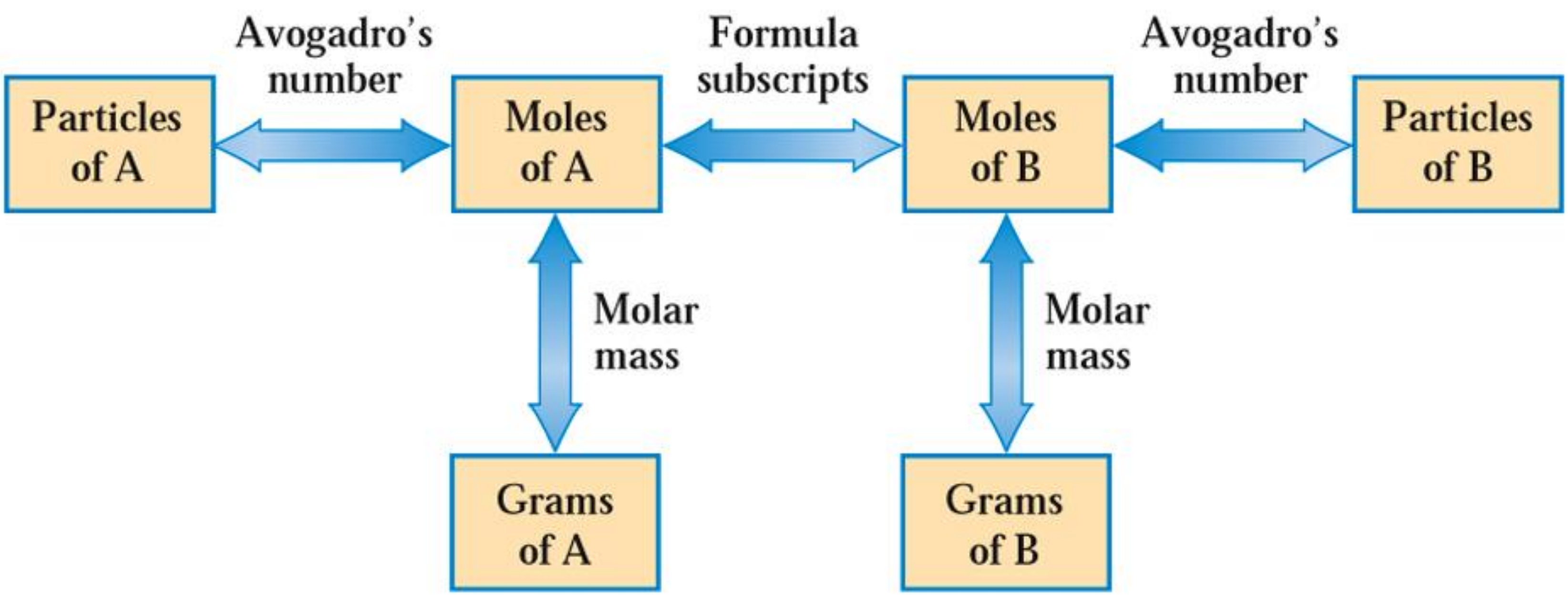
Given unit

Mass of a mole

- Avogadro's number (6.02×10^{23}) is the number of atoms of ^{12}C in an isotopically pure sample of ^{12}C that weighs exactly 12g.

The mole and chemical calculations

As we saw a few slides ago, it is possible to use a chemical formula to create a conversion factor that allows us to determine the number of atoms of some element is a sample. We also know that 1 mole means Avogadro's number of objects (molecules, atoms, etc.)



e.g. 1) How many $C_6H_{12}O_6$ molecules are in 1.0 g of $C_6H_{12}O_6$?

2) How many H atoms are in 1.0 g of $C_6H_{12}O_6$?

The mole and chemical calculations

- 1)Work out the molar mass for $C_6H_{12}O_6$ first:

$$6xC = 6\left(12.01\frac{g}{mol\_C}\right)$$

$$12xH = 12\left(1.01\frac{g}{mol\_H}\right)$$

$$6xO = 6\left(16.00\frac{g}{mol\_O}\right)$$

$$= 180.18\frac{g}{mol\_C_6H_{12}O_6}$$

Then use known conversion factors to change g $C_6H_{12}O_6$ to molecules of $C_6H_{12}O_6$

$$1.0\_g\_C_6H_{12}O_6\left(\frac{1\_mole\_C_6H_{12}O_6}{180.18\_g\_C_6H_{12}O_6}\right)\left(\frac{6.02x10^{23}\_C_6H_{12}O_6\_molecules}{1\_mole\_C_6H_{12}O_6}\right)$$

Avogadro's number:
1 mole = 6.02×10^{23} objects

= $3.3x10^{21}$ $C_6H_{12}O_6$ molecules

The mole and chemical calculations

- 2) From the formula ($C_6H_{12}O_6$) you can see that there are 12 H atoms in each $C_6H_{12}O_6$ molecule. Make another conversion factor to change molecules $C_6H_{12}O_6$ to atoms of H:

$$\left(\underline{3.3}4110...x10^{21} C_6H_{12}O_6\_molecules\right)\left(\frac{12\_H\_atoms}{1\_C_6H_{12}O_6\_molecule}\right)$$ = $4.0x10^{22}$ H atoms

The mole and chemical calculations

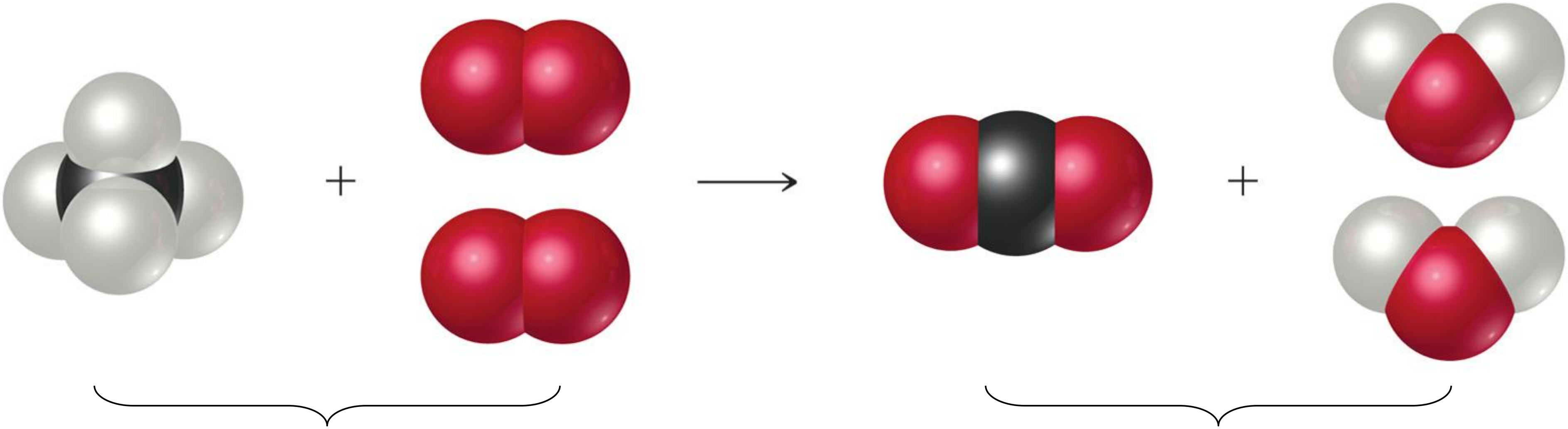
- This can be done all at once, too:

$$1.0\_g\_C_6H_{12}O_6\left(\frac{1\_mole\_C_6H_{12}O_6}{180.18\_g\_C_6H_{12}O_6}\right)\left(\frac{6.02x10^{23}\_C_6H_{12}O_6\_molecules}{1\_mole\_C_6H_{12}O_6}\right)\left(\frac{12\_H\_atoms}{1\_C_6H_{12}O_6\_molecule}\right)$$

= $4.0x10^{22}$ H atoms

Writing and balancing chemical equations

- A chemical equation is a statement that expresses what changes occur in a chemical reaction (i.e. what is reacting and what is created)

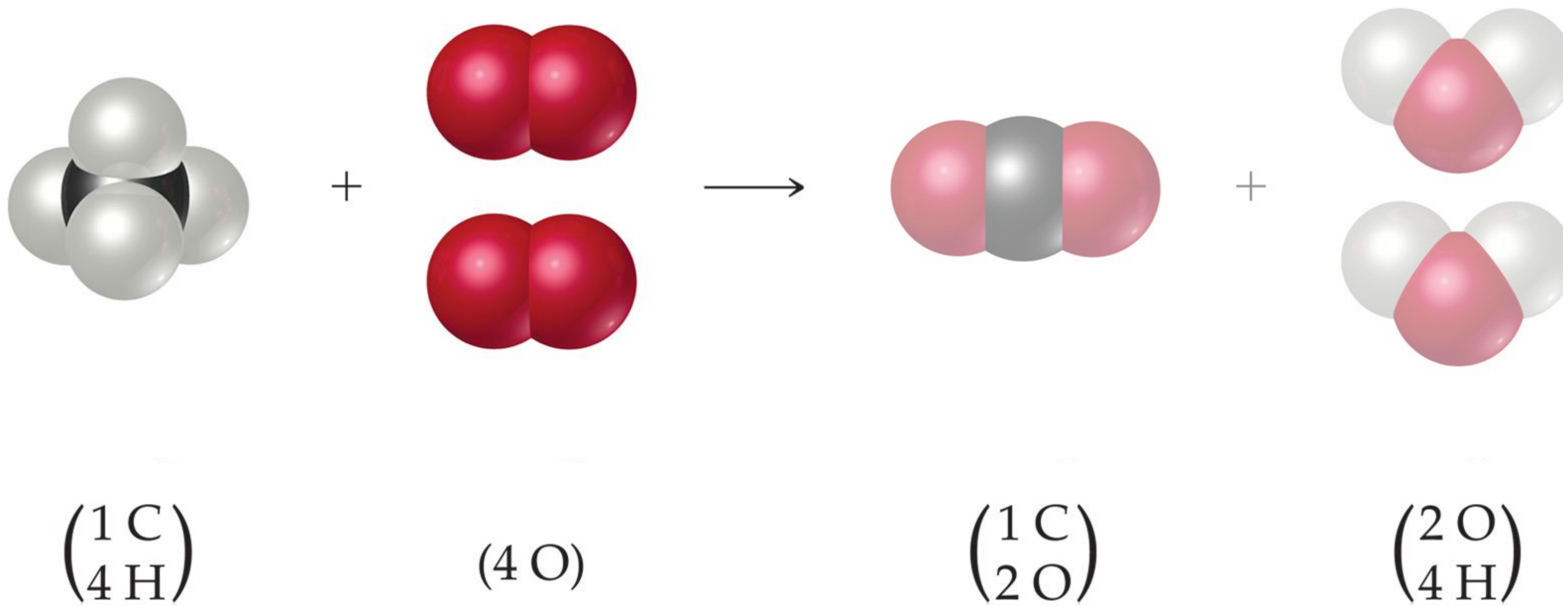


beginning of reaction

end of reaction

Writing and balancing chemical equations

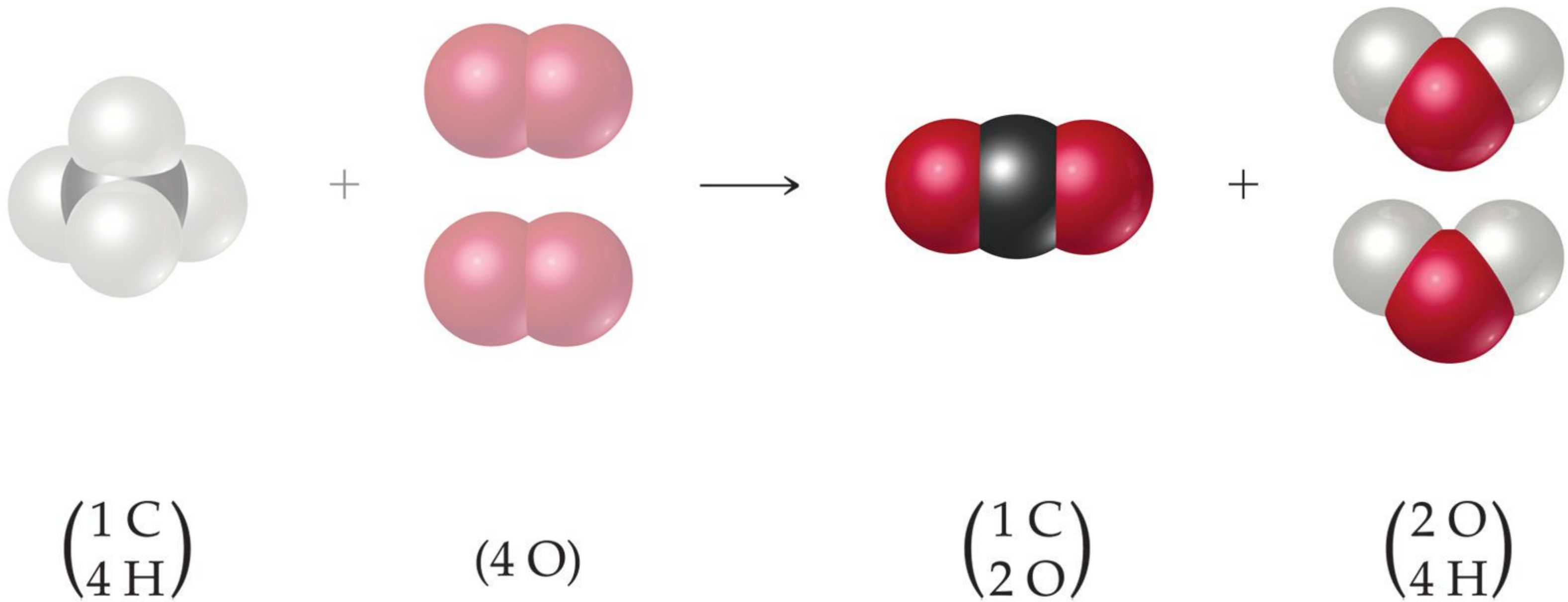
$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{(g)}$$



Reactants appear on the left side of the equation.

Writing and balancing chemical equations

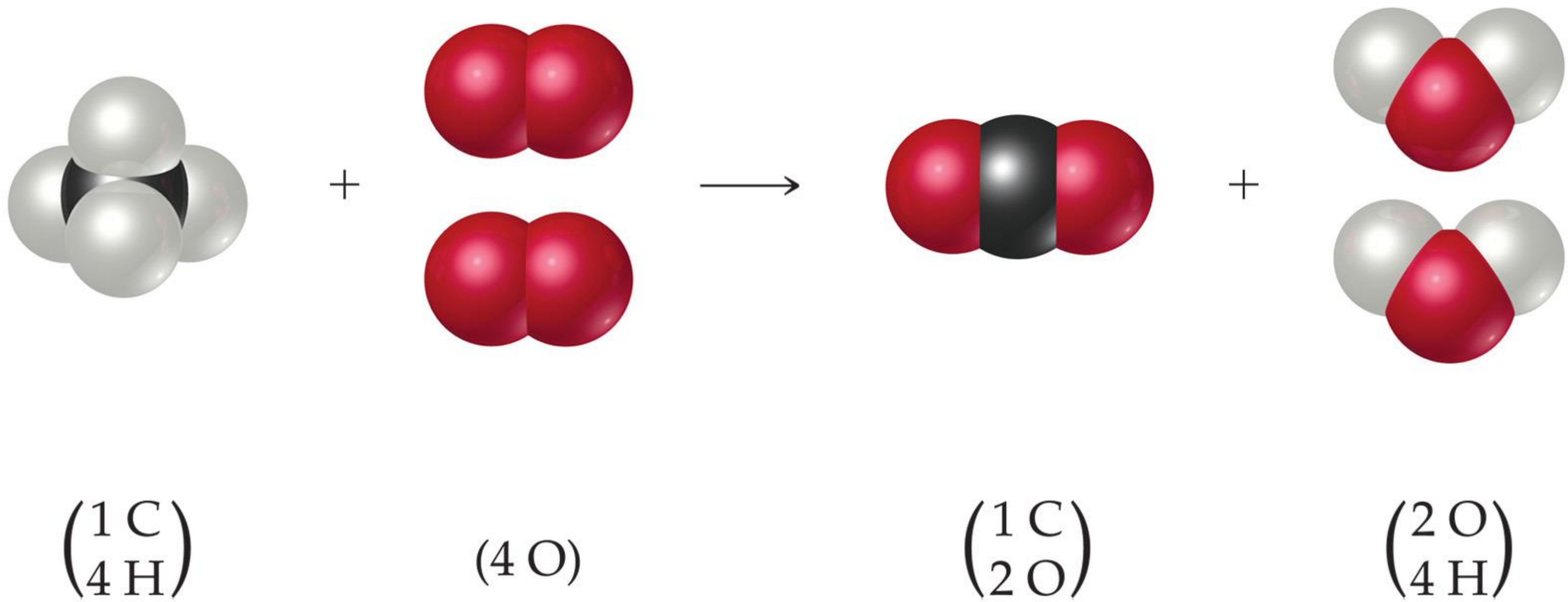
$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$



Products appear on the right side of the equation.

Writing and balancing chemical equations

$$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{\,(g)}$$

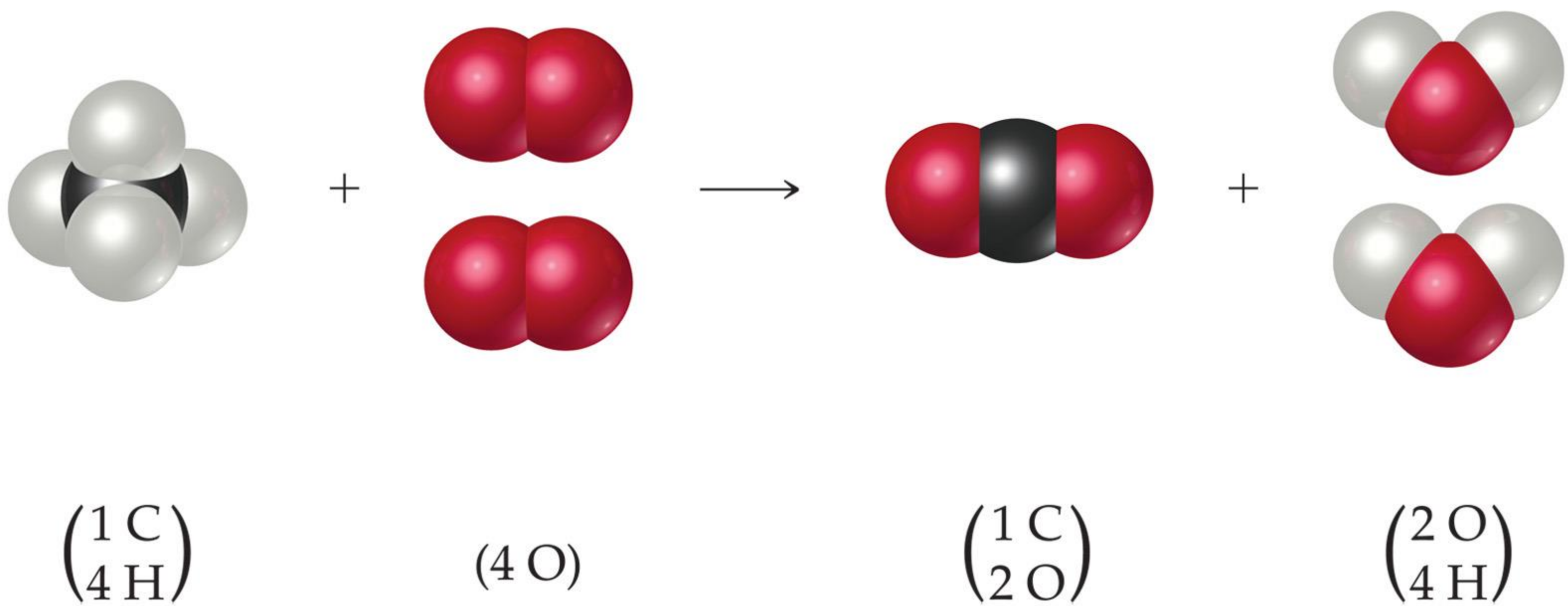


The states of the reactants and products are written in parentheses to the right of each compound.

(s) = solid
(l) = liquid
(g) = gas
(aq) = aqueous solution

Writing and balancing chemical equations

$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$

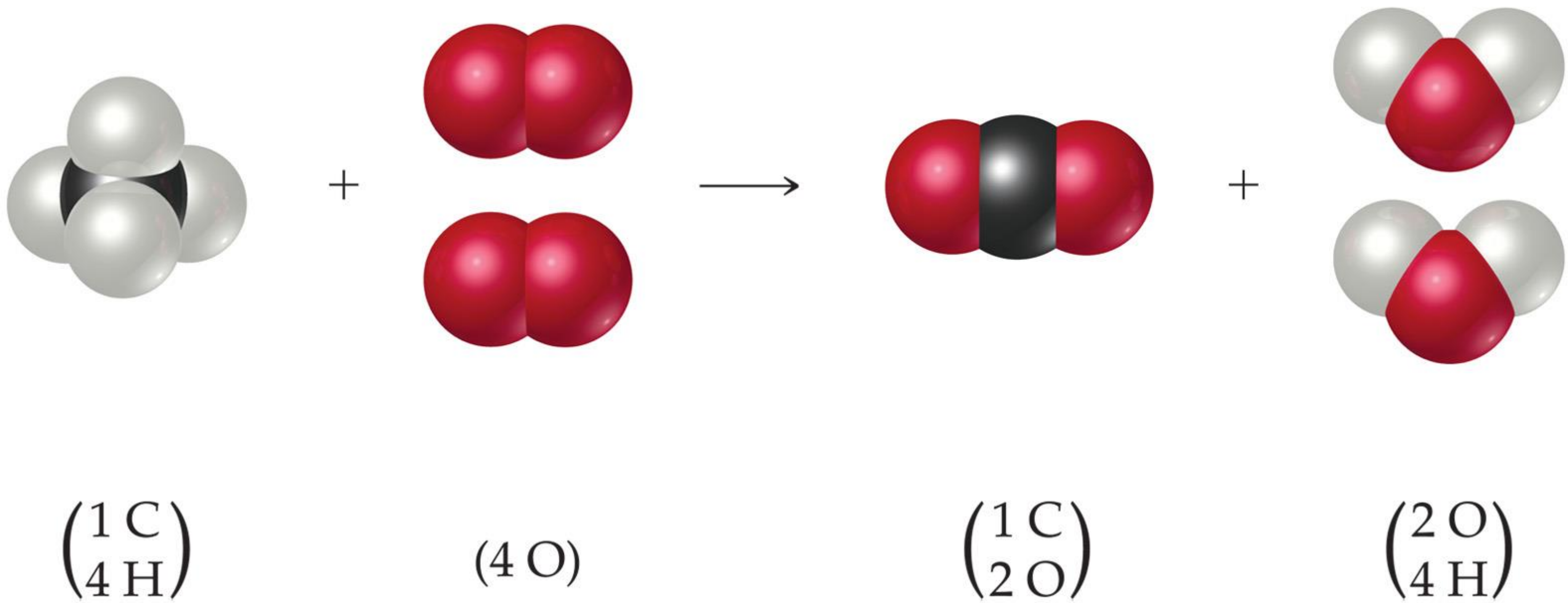


In this reaction, the reactants and products are said to be "balanced" – there are equal numbers of atoms of each element on the reactant and product sides of the equation.

A balanced equation contains the lowest possible whole number coefficients

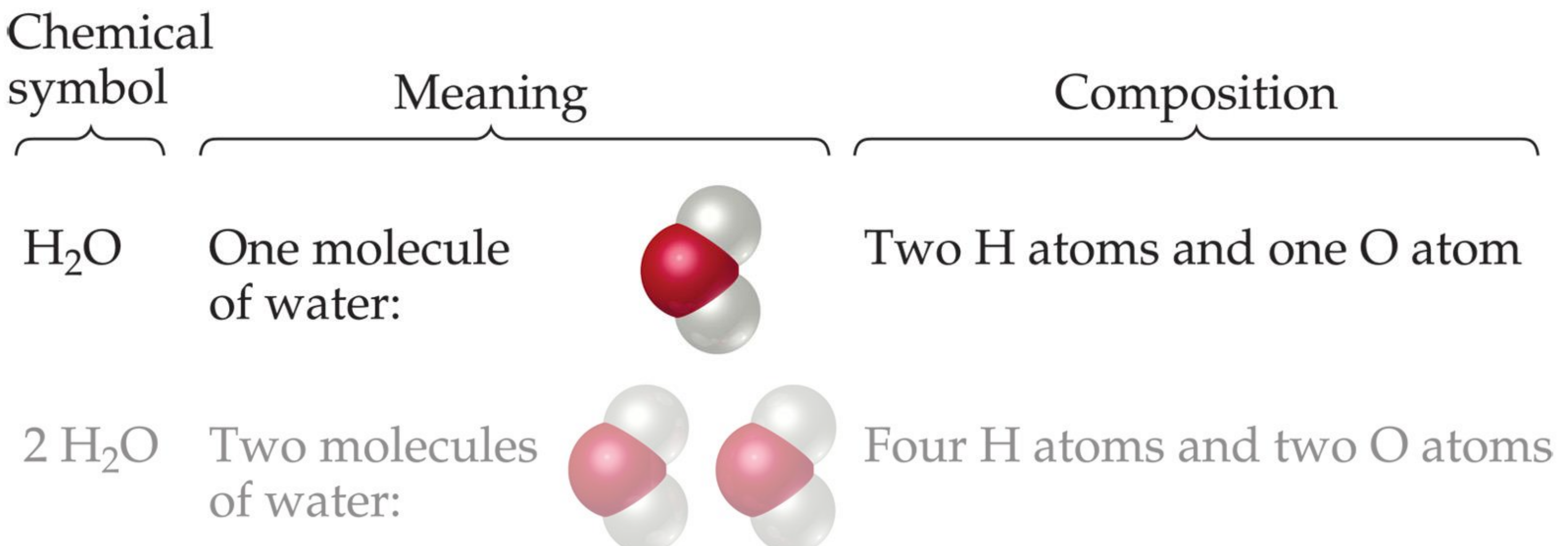
Writing and balancing chemical equations

$$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{\,(g)}$$



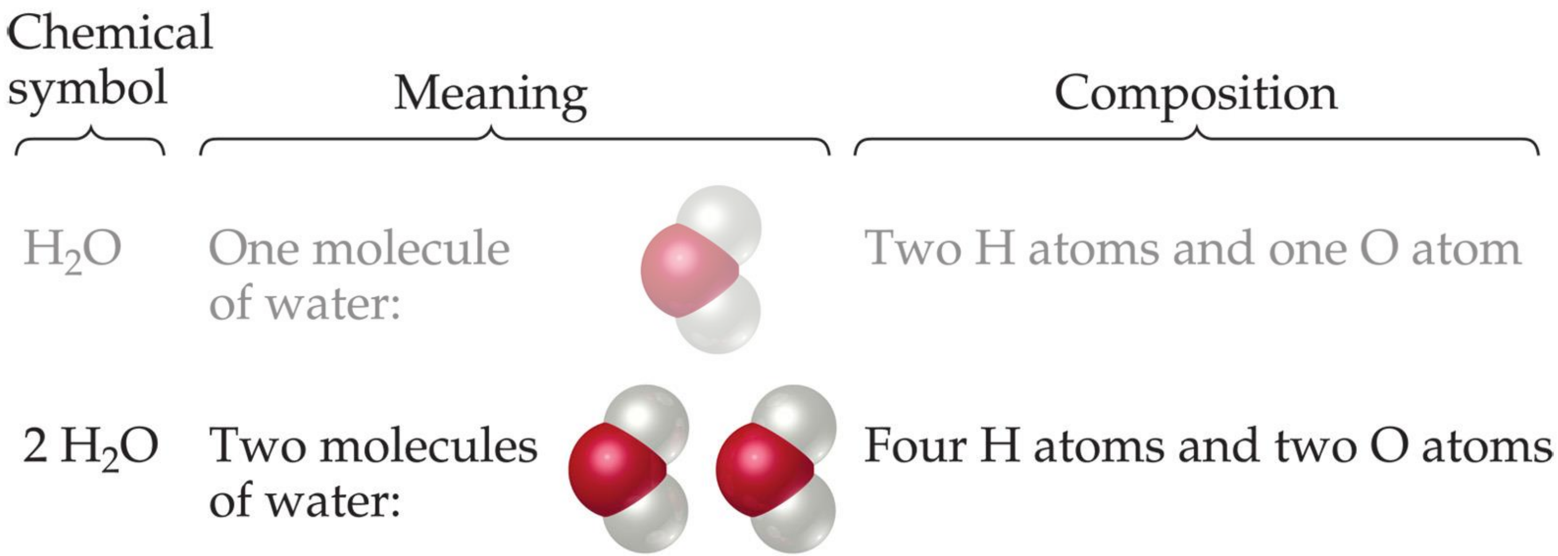
Coefficients are inserted to balance the equation.

Subscripts and Coefficients Give Different Information

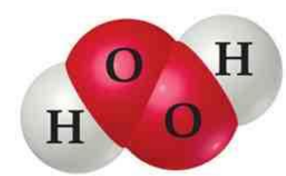


- Subscripts tell the number of atoms of each element in a molecule

Subscripts and Coefficients Give Different Information



- Subscripts tell the number of atoms of each element in a molecule
- Coefficients tell the number of molecules



Hydrogen peroxide, H_2O_2

Writing and balancing chemical equations

- One of the fundamental laws of nature is that matter and energy can’t be created or destroyed. In chemical equations, this is reflected in the need for equations to be balanced.
- There must be equal numbers of atoms of each element on both sides of the equation.

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$$

Writing and balancing chemical equations

- Balancing a chemical equation is probably best accomplished by starting with an element that occurs in only one formula on each side of the equation:

$$C_3H_6O + O_2 \rightarrow CO_2 + H_2O$$

Could start with carbon (C) or (H). I'll start with C.

There are 3 C atoms on the reactant side and only one on the product side. Write a coefficient of "3" in front of CO_2 to balance the carbon atoms in the equation

Writing and balancing chemical equations

- Balancing a chemical equation is probably best accomplished by starting with an element that occurs in only one formula on each side of the equation:

$$C_3H_6O + O_2 \rightarrow 3CO_2 + H_2O$$

Hydrogen occurs in only one formula on each side. Let's balance H next by putting a "3" in front of H_2O.

Writing and balancing chemical equations

- Balancing a chemical equation is probably best accomplished by starting with an element that occurs in only one formula on each side of the equation:

$$C_3H_6O + O_2 \rightarrow 3CO_2 + 3H_2O$$

Now, C and H are balanced in the above equation. Can see that there are unequal numbers of O atoms on each side (3 and 9). By putting a “4” in front of O_2, we balance the equation.

Writing and balancing chemical equations

- Balancing a chemical equation is probably best accomplished by starting with an element that occurs in only one formula on each side of the equation:

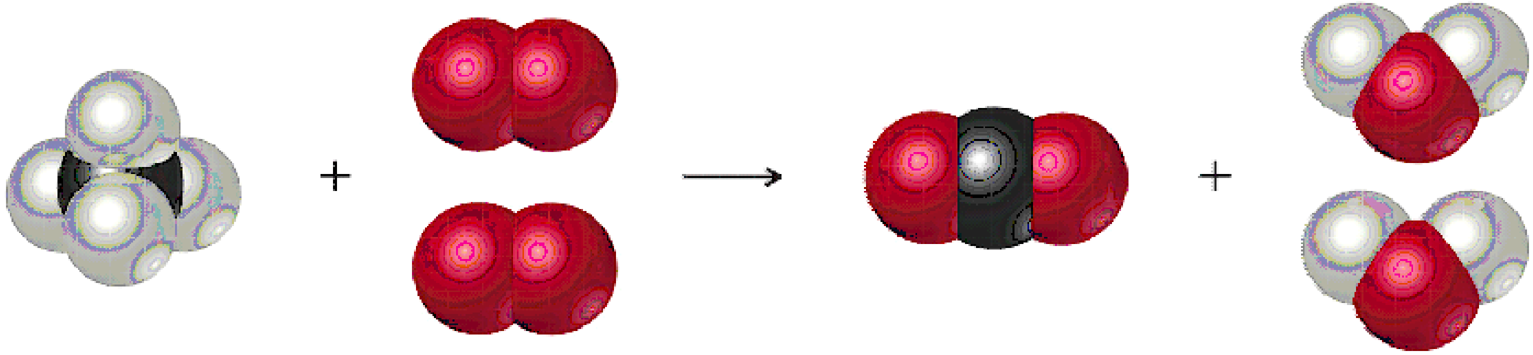
$$C_3H_6O + 4O_2 \rightarrow 3CO_2 + 3H_2O$$

Check:	reactants	products
C:	3	3
H:	6	6
O:	9	9

Chemical equations and the mole concept

- The coefficients in a balanced chemical equation tell us the molar ratios that exist between the substances consumed on the reactant side and the substances made (the product side)

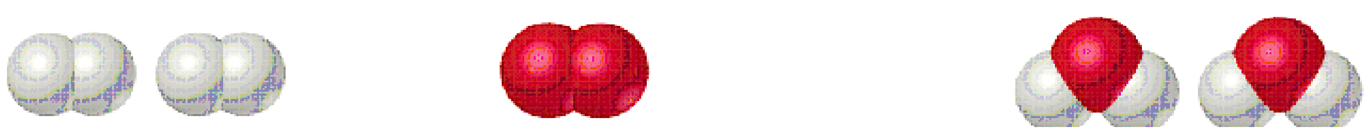
$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$



Chemical equations and the mole concept

- The following equation gives us these conversion factors:
  - Two H_2 molecules are needed in this reaction with O_2 to produce two H_2O molecules
  - Two moles of H_2 are needed in this reaction with O_2 to produce two moles of H_2O

Equation:	**2 $H_2(g)$**	**+**	**$O_2(g)$**	**⟶**	**2 $H_2O(l)$**
Molecules:	2 molecules H_2	+	1 molecule O_2	⟶	2 molecules H_2O



Amount (mol):	2 mol H_2	+	1 mol O_2	⟶	2 mol H_2O
Mass (g):	4.0 g H_2	+	32.0 g O_2	⟶	36.0 g H_2O

Chemical equations and the mole concept

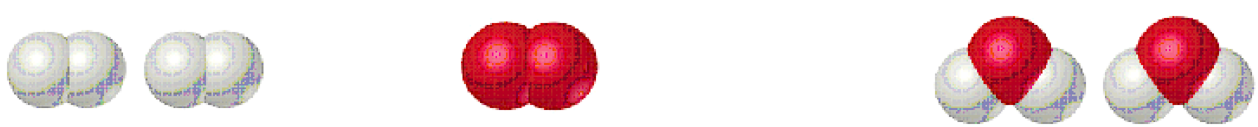
- The following equation gives us these conversion factors:

Between H_2 and H_2O: $$\frac{2mol\_H_2}{2mol\_H_2O} \qquad \frac{2mol\_H_2O}{2mol\_H_2}$$

Between H_2 and O_2: $$\frac{2mol\_H_2}{1mol\_O_2} \qquad \frac{1mol\_O_2}{2mol\_H_2}$$

Between O_2 and H_2O: $$\frac{2mol\_H_2O}{1mol\_O_2} \qquad \frac{1mol\_O_2}{2mol\_H_2O}$$

Equation:	$2\,H_2(g)$	+	$O_2(g)$	$\longrightarrow$	$2\,H_2O(l)$
Molecules:	2 molecules H_2	+	1 molecule O_2	$\longrightarrow$	2 molecules H_2O



Chemical calculations using chemical equations

- Using the molar relationship between a substance in a balanced chemical equation and some other reactant or product, you can determine the moles (or mass) of product that can be made starting with a certain mass (or number of moles) of reactant.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

How many grams of water will the body produce via this reaction if a person consumes a candy bar containing 14.2 g of glucose?

Consider the molar relationship between $C_6H_{12}O_6$ and H_2O. For every mole of $C_6H_{12}O_6$ consumed, 6 moles of H_2O will be produced.

$$\frac{1mol\_C_6H_{12}O_6}{6mol\_H_2O} \qquad \frac{6mol\_H_2O}{1mol\_C_6H_{12}O_6}$$

Chemical calculations using chemical equations

- We'll need to:
  - Convert 14.2g of $C_6H_{12}O_6$ using the molar mass for glucose (180.18 g = 1 mole)
  - Use the molar relationship that exists between $C_6H_{12}O_6$ and H_2O to convert moles of $C_6H_{12}O_6$ to moles of H_2O
  - Use the molar mass for H_2O (18.02 g = 1 mole)

Molar mass of $C_6H_{12}O_6$

Molar mass of H_2O

$$14.2g\_C_6H_{12}O_6\left(\frac{1mol\_C_6H_{12}O_6}{180.18g\_C_6H_{12}O_6}\right)\left(\frac{6mol\_H_2O}{1mol\_C_6H_{12}O_6}\right)\left(\frac{18.02g\_H_2O}{1mol\_H_2O}\right)=8.52g\_H_2O$$

Molar ratio between $C_6H_{12}O_6$ and H_2O

Chemical calculations using chemical equations

- There are a number of questions that may be asked in these types of problems:
  - How much of a product is made from a certain amount of a reactant?
  - How much of a second reactant is consumed when a given amount of the other reactant is involved?
  - How many molecules of a product are created, given a certain mass of reactant used?
  - How many grams of an element are present in a certain amount of product?

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

If 14.2g of $C_6H_{12}O_6$ are reacted, how many grams of O are present *in the water that is produced*?

$$14.2g\ C_6H_{12}O_6 \xrightarrow{\text{Molar mass } C_6H_{12}O_6} \text{mol } C_6H_{12}O_6 \xrightarrow{\frac{6mol\_H_2O}{1mol\_C_6H_{12}O_6}} \text{mol } H_2O \xrightarrow{\frac{1mol\_O}{1mol\_H_2O}} \text{mol O (in } H_2O) \xrightarrow{\text{Molar mass O}} \text{g O in } H_2O$$

Chemical calculations using chemical equations

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

If 14.2g of $C_6H_{12}O_6$ are reacted, how many grams of O are present *in the water that is produced*?

$$14.2g\ C_6H_{12}O_6 \xrightarrow{\text{Molar mass } C_6H_{12}O_6} \text{mol } C_6H_{12}O_6 \xrightarrow{\frac{6mol\_H_2O}{1mol\_C_6H_{12}O_6}} \text{mol } H_2O \xrightarrow{\frac{1mol\_O}{1mol\_H_2O}} \text{mol O (in } H_2O) \xrightarrow{\text{Molar mass O}} \text{g O in } H_2O$$

$$14.2g\_C_6H_{12}O_6\left(\frac{1mol\_C_6H_{12}O_6}{180.18g\_C_6H_{12}O_6}\right)\left(\frac{6mol\_H_2O}{1mol\_C_6H_{12}O_6}\right)\left(\frac{1mol\_O}{1mol\_H_2O}\right)\left(\frac{16.00g\_O}{1mol\_O}\right)$$

=7.57g of O