The Chemical Equation

State of Matter

$$C_2H_6O(l) + 3\ O_2(g) \ \text{---->}\ 2\ CO_2(g) + 3\ H_2O(g)$$

Reactants

Products

Coefficients (not written if it is a 1)

One molecule of liquid ethanol (C_2H_6O) reacts with three molecules of gaseous oxygen (O_2) to form two molecules of gaseous carbon dioxide (CO_2) and three molecules of gaseous water (H_2O).

A chemical equation is balanced with respect to the number and type of atoms on each side of the equation

Chemical Changes Described by Chemical Equations

Chemical equation: Reactant(s) $\longrightarrow$ Product(s)

Table 1.8 Characteristics of Chemical Equations

Always Conserved

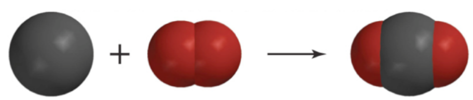
Identity of atoms in reactants = Identity of atoms in products
Number of atoms in reactants = Number of atoms in products
Mass of all reactants = Mass of all products

May Change

Number of molecules in reactants vs. Number of molecules in products
Physical states (*s*, *l*, or *g*) of reactants vs. physical states of products

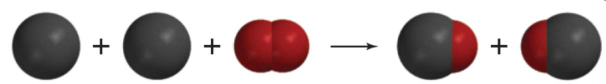
Carbon reacts with oxygen to form carbon dioxide (complete combustion):

$$C + O_2 \longrightarrow CO_2$$ *balanced equation*



subscripts: # of atoms in a molecule
in front = # of molecules in eqn.

When not enough O_2 is present, carbon monoxide is produced, and CO poisoning can occur:

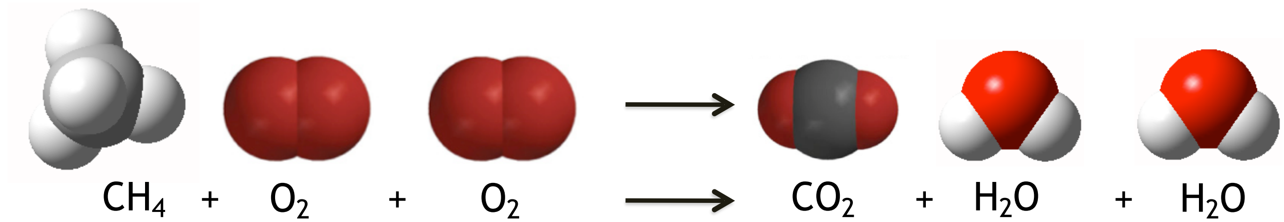


$$C + O_2 \longrightarrow CO \quad \Rightarrow \quad 2C + O_2 \longrightarrow 2CO$$

Burning to Balance Equations

Natural gas combustion: methane plus oxygen produces carbon dioxide plus water

$CH_4 + O_2 \rightarrow CO_2 + H_2O$ *not balanced: 4 H's on left and 2 H's on right, 2O's on left & 3 on right*

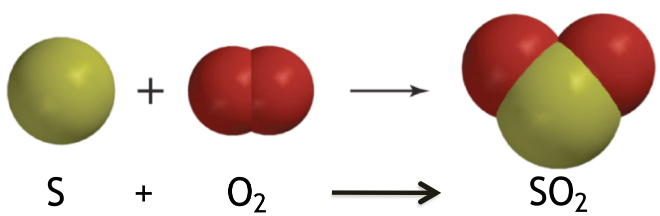


$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

in front indicates # molecules
Subscripts: # of atoms in a molecule

2x2=4

Small amount of sulfur present in coal
(it's removed during petroleum refining)

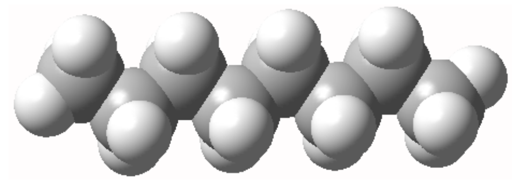


$S + O_2 \rightarrow SO_2$

13 3A	14 4A	15 5A	16 6A	17 7A	8A
					2 He 4.003
5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95

Tips for Balancing Chemical Equations

What about burning gasoline?



Octane, C_8H_{18}

Molecule + O_2 forms CO_2 + H_2O

$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$ $C_8H_{18} + O_2 \rightarrow 8CO_2 + H_2O$

$C_8H_{18} + O_2 \rightarrow 8CO_2 + 9H_2O$

8x2+9 O's on product side (25 O's), leads to 12 ½ O_2 can't have fractions

$2C_8H_{18} + 25\ O_2 \rightarrow 16CO_2 + 18H_2O$

- If an element is present in just one compound on each side, balance it *first*
- Balance anything that exists as a free element *last*
- Balance polyatomic ions as a unit
- Check when done – same number of atoms, and same total charge (if any) on both sides

Burning propane? $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

Patterns of Chemical Reactivity

Three of the most commonly encountered reaction types are *combination*, *decomposition*, and *combustion*.

Combination—two or more reactants combine to form a single product

$$NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$$

Decomposition—two or more products form from a single reactant

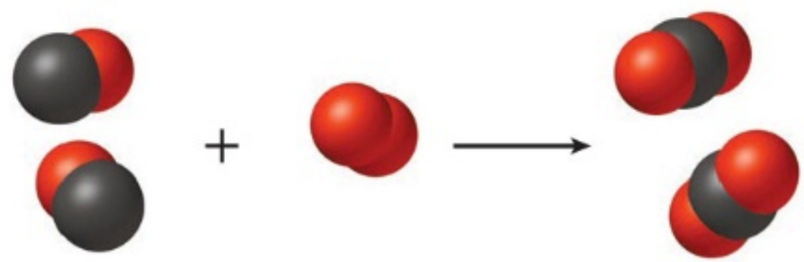
$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

Combustion—a substance burns in the presence of oxygen. Combustion of a compound that contains C and H (or C, H, and O) produces carbon dioxide gas and *liquid* water.

$$CH_2O(l) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$$

8.3 *Calculations with Balanced Chemical Equations*

Balanced chemical equations are used to predict how much product will form from a given amount of reactant.



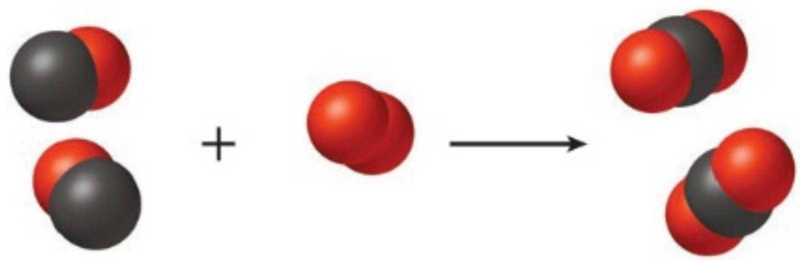
$$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$$

2 moles of CO combine with 1 mole of O_2 to produce 2 moles of CO_2.

2 moles of CO is stoichiometrically equivalent to 2 moles of CO_2.

Calculations with Balanced Chemical Equations (2)

Consider the complete reaction of 3.82 moles of CO to form CO_2. Calculate the number of moles of CO_2 produced.

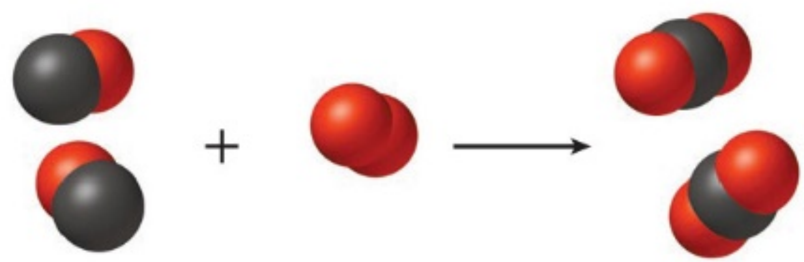


$$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$$

$$\text{moles } CO_2 \text{ produced} = 3.82 \cancel{\text{mol CO}} \times \frac{2 \text{ mol } CO_2}{2 \cancel{\text{mol CO}}} = 3.82 \text{ mol } CO_2$$

Calculations with Balanced Chemical Equations (3)

Consider the complete reaction of 3.82 moles of CO to form CO_2. Calculate the number of moles of O_2 needed.



$$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$$

$$\text{moles } O_2 \text{ needed} = 3.82\ \cancel{\text{mol CO}} \times \frac{1\ \text{mol } O_2}{2\ \cancel{\text{mol CO}}} = 1.91\ \text{mol } O_2$$

How much CO_2 do you emit when you drive to Denver?

$$60 \text{ miles} \times \frac{1 \text{ gal}}{20 \text{ miles}} \times \frac{6 \text{ lbs}}{1 \text{ gal}} \times \frac{1 \text{ kg}}{2.2 \text{ lbs}} \times \frac{1000 \text{ g}}{1 \text{ kg}}$$

= 8,200 g gasoline used, but we want to know how much CO_2 was produced while driving that distance…

Molar mass of gasoline? (assume C_8H_{18})

8x12.0 g = 96.0 g
18x1.0 g = 18.0 g
= 114.0 g/mol C_8H_{18}

Converting from C_8H_{18} to CO_2?

$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$

2 moles C_8H_{18} = 16 moles CO_2

Molar mass of CO_2?

1x12.0 g = 12.0 g
2x16.0 g = 32.0 g
= 44.0 g/mol CO_2

Building Solution here: 8,200 g gasoline $\times \frac{1 \text{ mol } C_8H_{18}}{114 \text{ g}} \times \frac{16 \text{ mol } CO_2}{2 \text{ mol } C_8H_{18}} \times \frac{44 \text{ g } CO_2}{1 \text{ mol } CO_2}$ = 25,000 g CO_2

Energy Flow

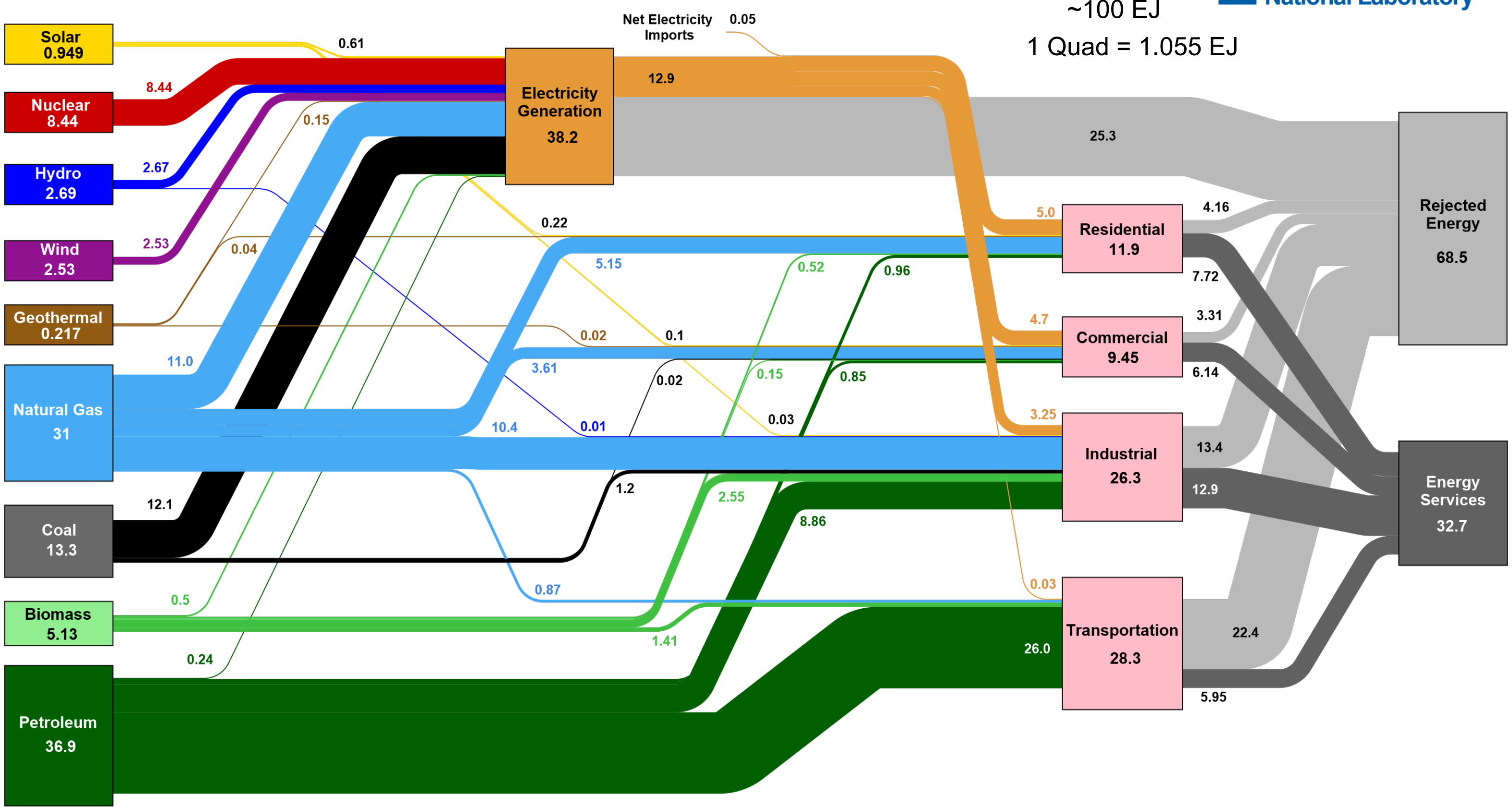
https://flowcharts.llnl.gov

Estimated U.S. Energy Consumption in 2018: 101.2 Quads

Lawrence Livermore National Laboratory

~100 EJ

1 Quad = 1.055 EJ



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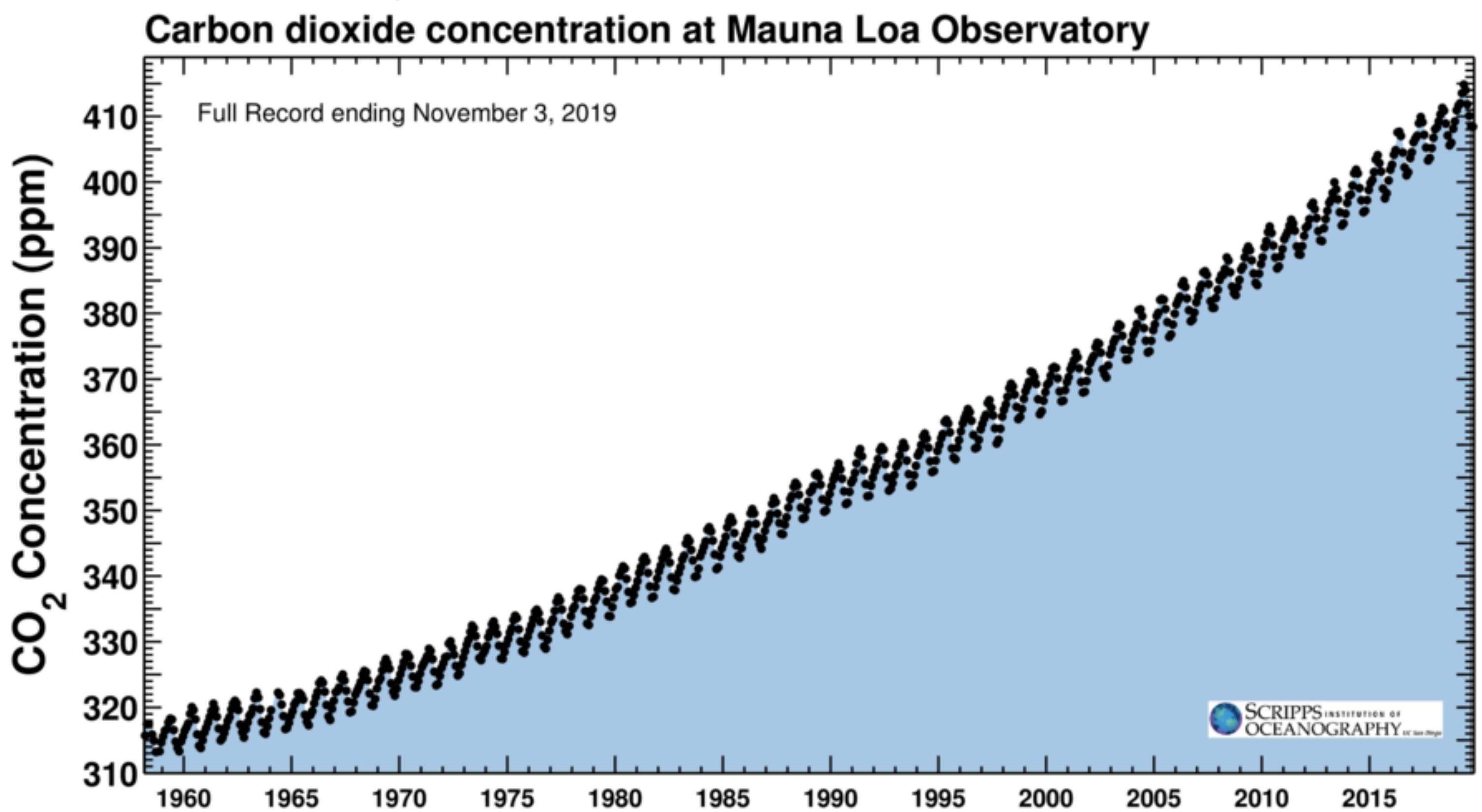
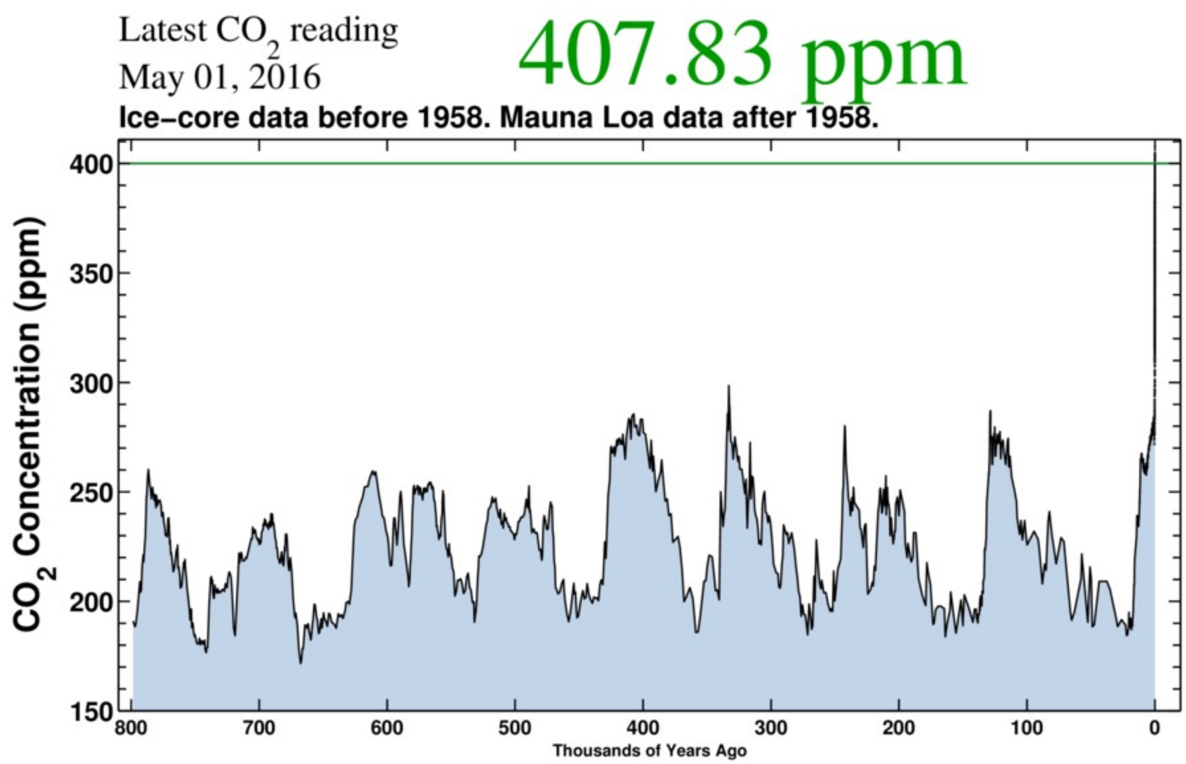
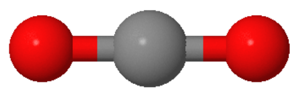


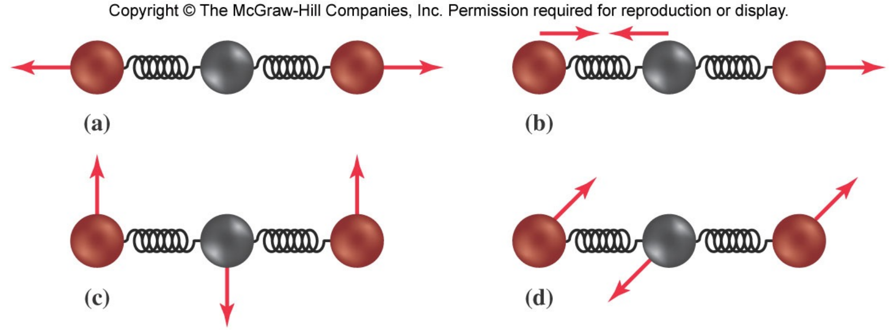
CO_2 Concentrations



Vibrational Modes for Carbon Dioxide and Infrared Spectrum



link to CO_2 vibrations!



a & b: stretching modes

c & d: bending modes

Which of these vibrational modes can be turned on by the absorption of IR photons?

(need change in center of mass of molecule)