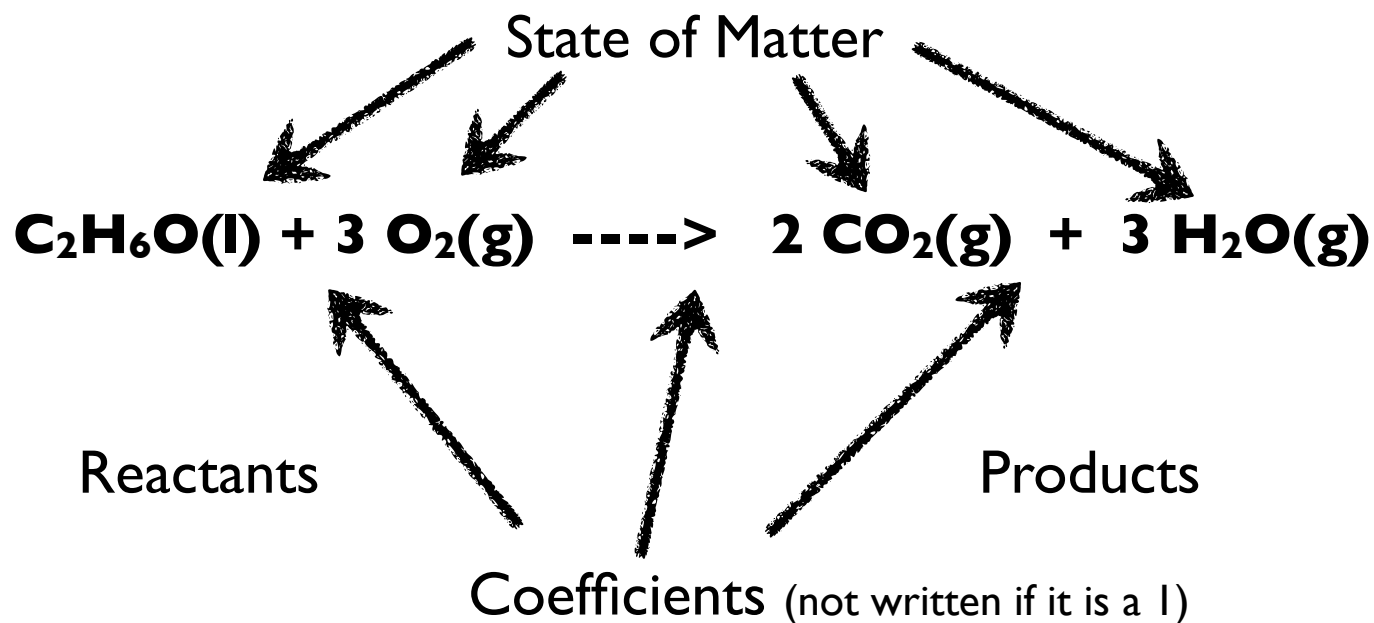


# The Chemical Equation



One molecule of liquid ethanol ( $\text{C}_2\text{H}_6\text{O}$ ) reacts with three molecules of gaseous oxygen ( $\text{O}_2$ ) to form two molecules of gaseous carbon dioxide ( $\text{CO}_2$ ) and three molecules of gaseous water ( $\text{H}_2\text{O}$ ).

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

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



© The McGraw-Hill Companies, Inc./Photo by Bob Coyle

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

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

**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

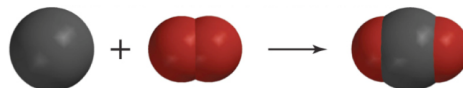
Mass of all reactants = Mass of all products

### *May Change*

Number of molecules in reactants vs. Number of molecules in products

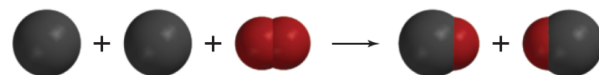
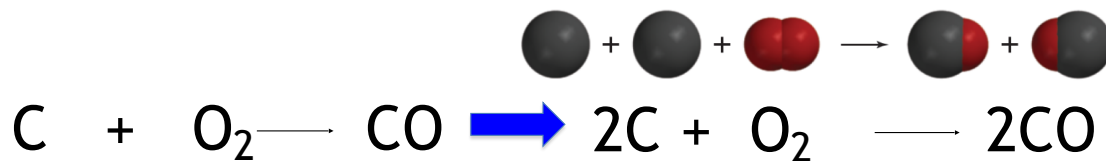
Physical states (*s*, *l*, or *g*) of reactants vs. physical states of products

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



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

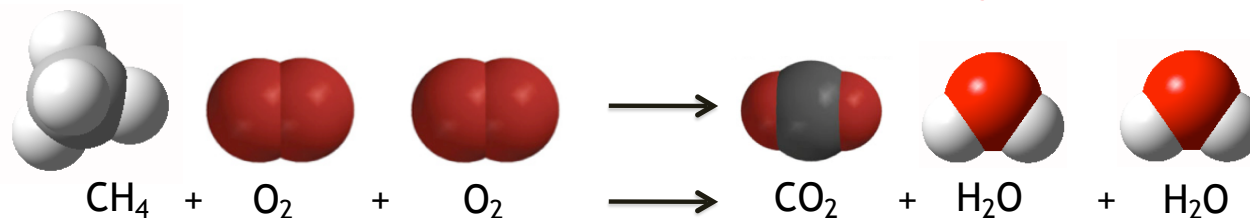
When not enough  $\text{O}_2$  is present, carbon monoxide is produced, and CO poisoning can occur:



## Burning to Balance Equations

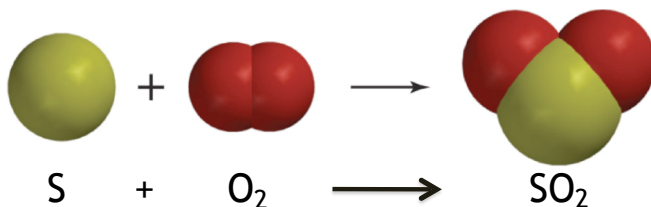
Natural gas combustion: methane plus oxygen produces carbon dioxide plus water

$\text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$  *not balanced: 4 H's on left and 2 H's on right, 2 O's on left & 3 on right*



# in front indicates # molecules       $2 \times 2 = 4$   
 Subscripts: # of atoms in a molecule

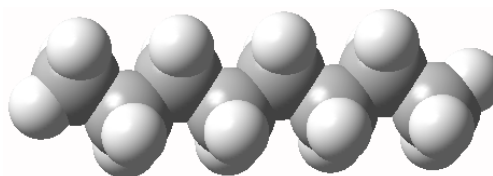
Small amount of sulfur present in coal  
 (it's removed during petroleum refining)



					2 He 4.003
13 3A	14 4A	15 5A	16 6A	17 7A	
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

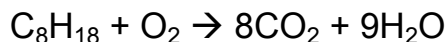
## Tips for Balancing Chemical Equations

What about burning gasoline?



Octane, C<sub>8</sub>H<sub>18</sub>

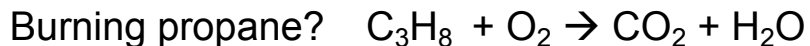
Molecule + O<sub>2</sub> forms CO<sub>2</sub> + H<sub>2</sub>O



8x2+9 O's on product side (25 O's), leads to 12 ½ O<sub>2</sub> can't have fractions



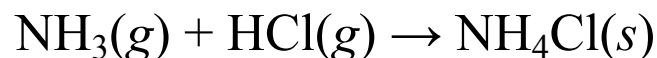
- If an element is present in just one compound on each side, balance it *first*
- Balance anything that exists as a free element *last*
- Balance polyatomic ions as a unit
- Check when done – same number of atoms, and same total charge (if any) on both sides



## ***Patterns of Chemical Reactivity***

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

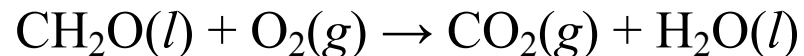
*Combination*—two or more reactants combine to form a single product



*Decomposition*—two or more products form from a single reactant



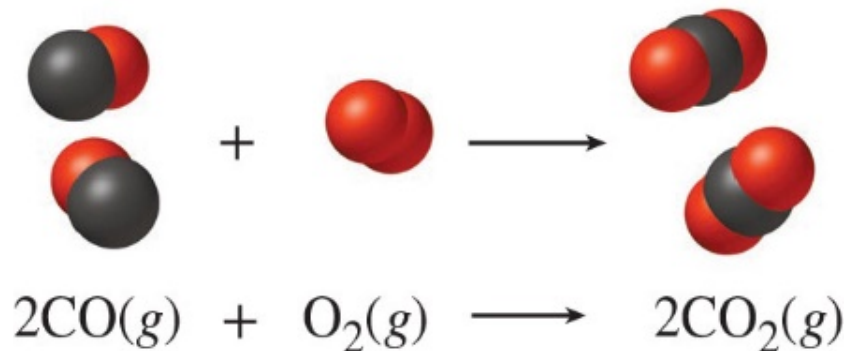
*Combustion*—a substance burns in the presence of oxygen. Combustion of a compound that contains C and H (or C, H, and O) produces carbon dioxide gas and *liquid* water.



### 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.

Copyright © McGraw-Hill Education. All rights reserved. No reproduction or distribution without the prior written consent of McGraw-Hill Education.



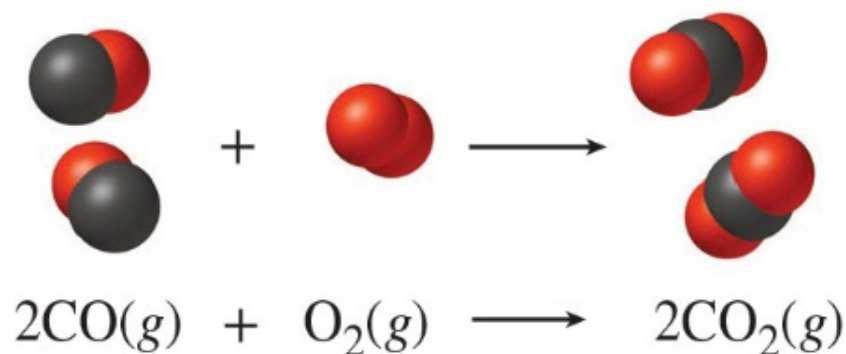
2 moles of CO combine with 1 mole of O<sub>2</sub> to produce 2 moles of CO<sub>2</sub>.

2 moles of CO is stoichiometrically equivalent to 2 moles of CO<sub>2</sub>.

## Calculations with Balanced Chemical Equations (2)

Consider the complete reaction of 3.82 moles of CO to form CO<sub>2</sub>. Calculate the number of moles of CO<sub>2</sub> produced.

Copyright © McGraw-Hill Education. All rights reserved. No reproduction or distribution without the prior written consent of McGraw-Hill Education.

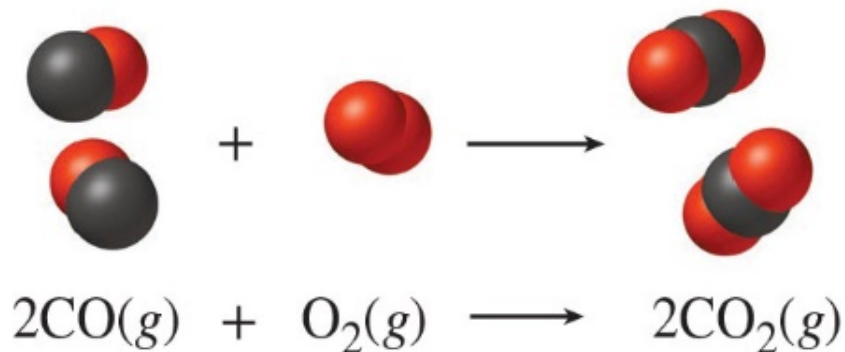


$$\text{moles CO}_2 \text{ produced} = 3.82 \cancel{\text{ mol CO}} \times \frac{2 \text{ mol CO}_2}{2 \cancel{\text{ mol CO}}} = 3.82 \text{ mol CO}_2$$

### ***Calculations with Balanced Chemical Equations (3)***

Consider the complete reaction of 3.82 moles of CO to form CO<sub>2</sub>. Calculate the number of moles of O<sub>2</sub> needed.

Copyright © McGraw-Hill Education. All rights reserved. No reproduction or distribution without the prior written consent of McGraw-Hill Education.



$$\text{moles O}_2 \text{ needed} = 3.82 \cancel{\text{ mol CO}} \times \frac{1 \text{ mol O}_2}{2 \cancel{\text{ mol CO}}} = 1.91 \text{ mol O}_2$$



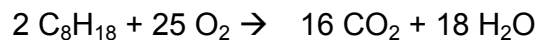
## How much CO<sub>2</sub> do you emit when you drive to Denver?

$$60 \text{ miles} \times \frac{1 \text{ gal}}{20 \text{ miles}} \times \frac{6 \text{ lbs}}{1 \text{ gal}} \times \frac{1 \text{ kg}}{2.2 \text{ lbs}} \times \frac{1000 \text{ g}}{1 \text{ kg}} = 8,200 \text{ g gasoline used, but we want to know how much CO}_2 \text{ was produced while driving that distance...}$$

Molar mass of gasoline? (assume C<sub>8</sub>H<sub>18</sub>)

$$\begin{aligned} 8 \times 12.0 \text{ g} &= 96.0 \text{ g} \\ 18 \times 1.0 \text{ g} &= 18.0 \text{ g} \\ &= 114.0 \text{ g/mol C}_8\text{H}_{18} \end{aligned}$$

Converting from C<sub>8</sub>H<sub>18</sub> to CO<sub>2</sub>?



$$2 \text{ moles C}_8\text{H}_{18} = 16 \text{ moles CO}_2$$

Molar mass of CO<sub>2</sub>?

$$\begin{aligned} 1 \times 12.0 \text{ g} &= 12.0 \text{ g} \\ 2 \times 16.0 \text{ g} &= 32.0 \text{ g} \\ &= 44.0 \text{ g/mol CO}_2 \end{aligned}$$

Building Solution here:  $8,200 \text{ g gasoline} \times \frac{1 \text{ mol C}_8\text{H}_{18}}{114 \text{ g}} \times \frac{16 \text{ mol CO}_2}{2 \text{ mol C}_8\text{H}_{18}} \times \frac{44 \text{ g CO}_2}{1 \text{ mol CO}_2} = 25,000 \text{ g CO}_2$

# Energy Flow

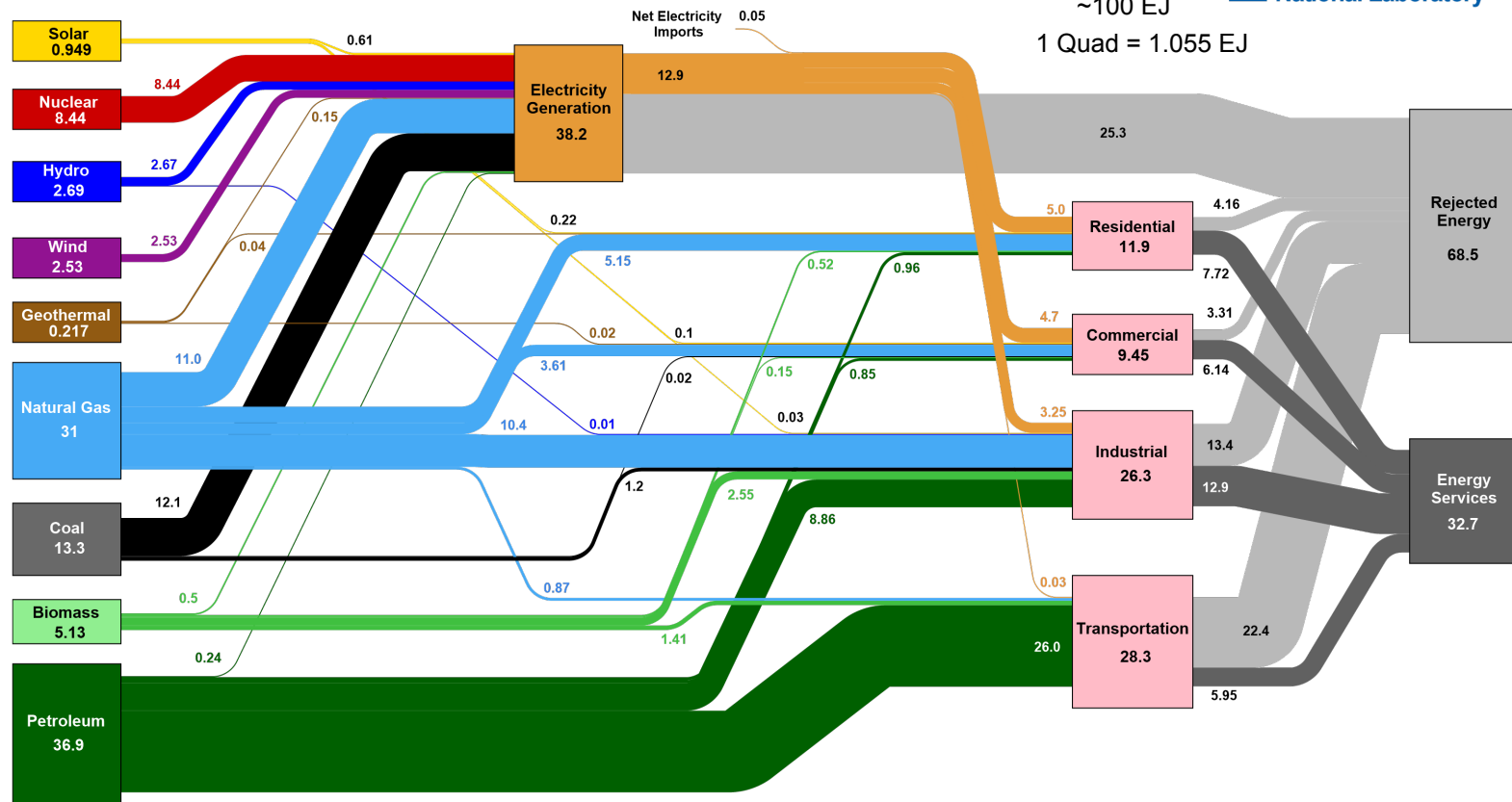
<https://flowcharts.llnl.gov>

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

Lawrence Livermore  
National Laboratory

~100 EJ

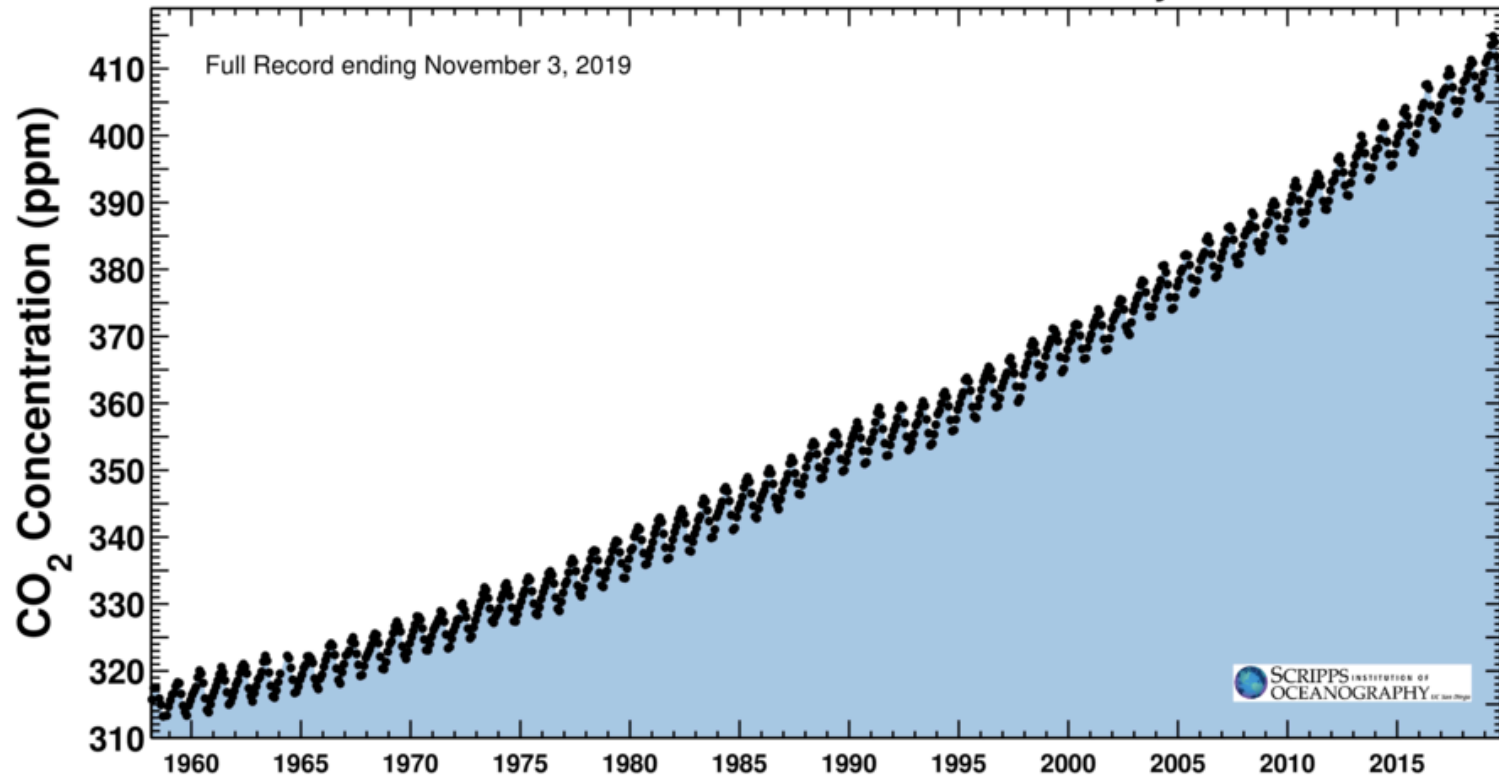
1 Quad = 1.055 EJ



Source: LLNL March, 2019. Data is based on DOE/EIA MER (2018). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

November 03, 2019

## Carbon dioxide concentration at Mauna Loa Observatory



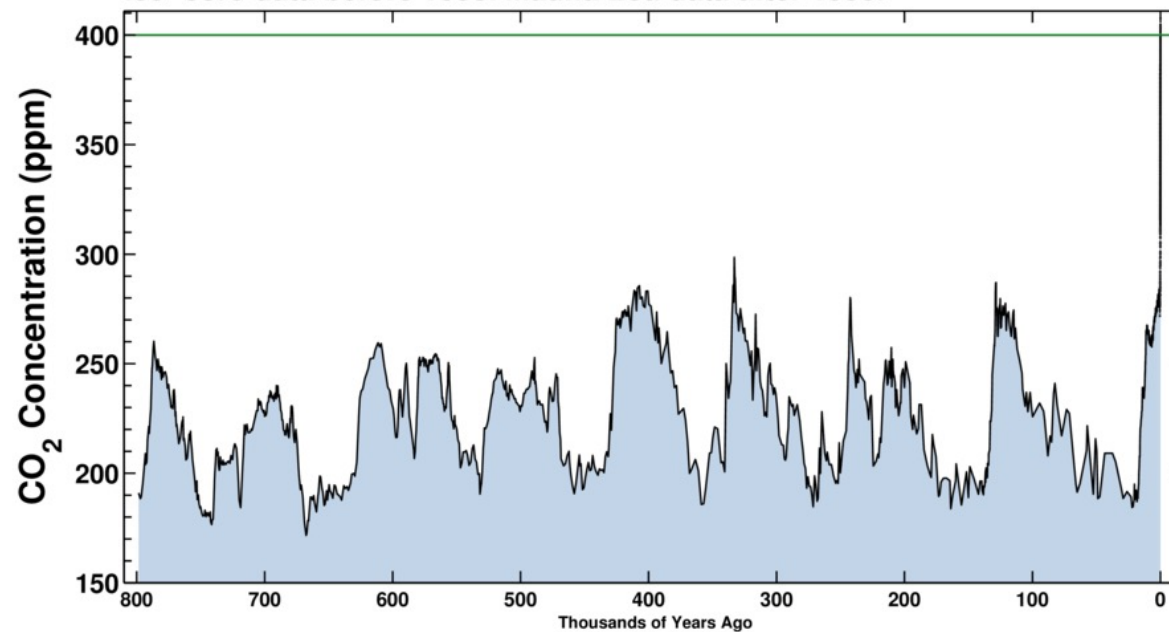
# CO<sub>2</sub> Concentrations

Latest CO<sub>2</sub> reading

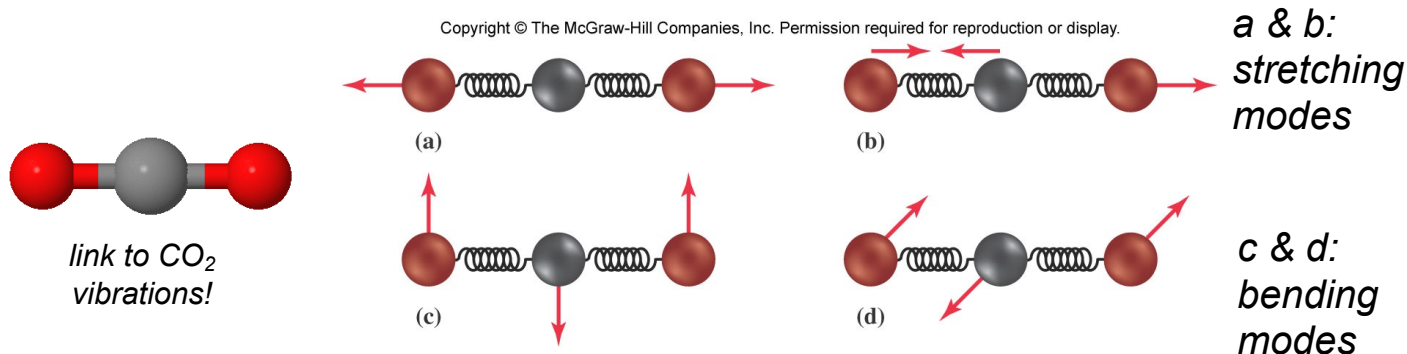
May 01, 2016

407.83 ppm

Ice-core data before 1958. Mauna Loa data after 1958.



## Vibrational Modes for Carbon Dioxide and Infrared Spectrum



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

*(need change in center of mass of molecule)*

