Energy of Chemical Transformations

Chemical Changes Described by Chemical Equations

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

Table 1.8 Characteristics of Chemical Equations

Always Conserved

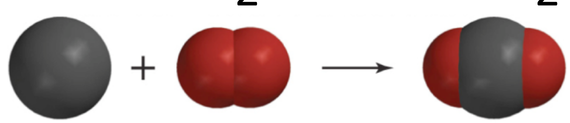
Identity of atoms in reactants = Identity of atoms in products
Number of atoms in reactants = Number of atoms in products
Mass of all reactants = Mass of all products

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):

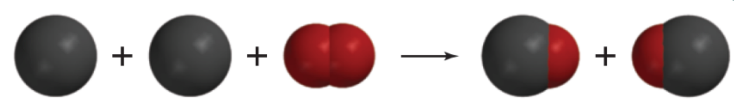
$$C + O_2 \longrightarrow CO_2$$



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:

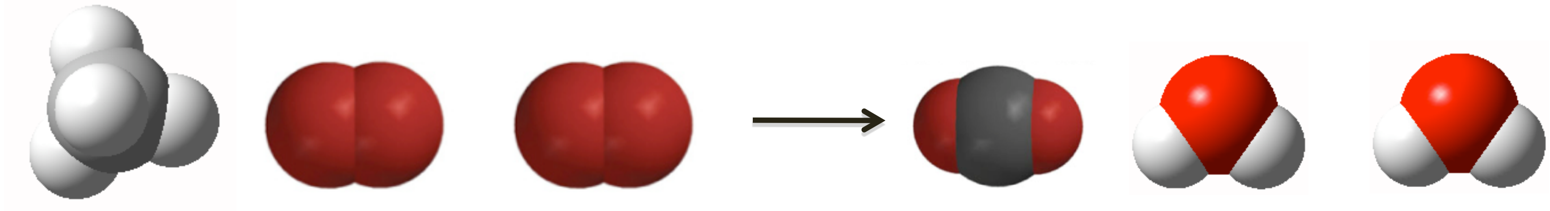


$$C + O_2 \longrightarrow CO \Rightarrow 2C + O_2 \longrightarrow 2CO$$

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*



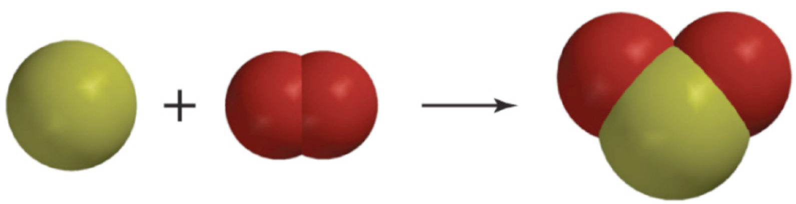
CH_4 + O_2 + O_2 ⟶ CO_2 + H_2O + H_2O

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

\# 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)



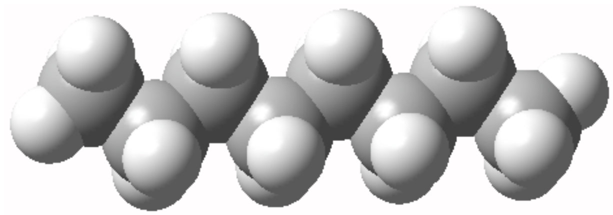
S + O_2 ⟶ SO_2

$S + O_2 \rightarrow SO_2$

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

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

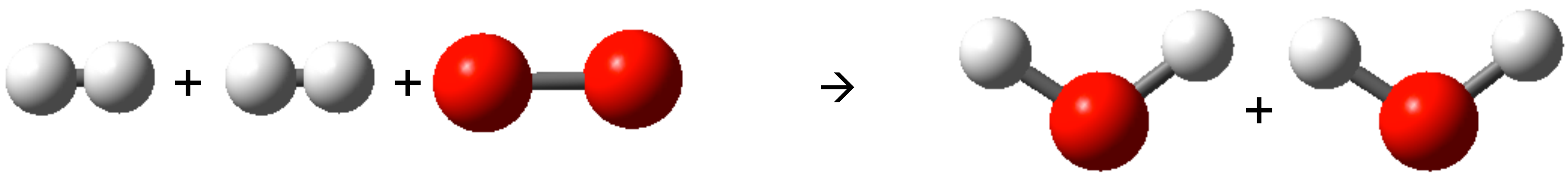
- If an element is present in just one compound on each side, balance it *first*
- Balance anything that exists as a free element *last*
- Balance polyatomic ions as a unit
- Check when done – same number of atoms, and same total charge (if any) on both sides

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

Chemical Energy and Thermochemical Cycles

Chemical energy is in bonds between atoms. Energy is either released (exothermic) or consumed (endothermic) depending upon the strengths of the bonds in reactants and products.

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$



Need to know the # and types of bonds in reactants and products

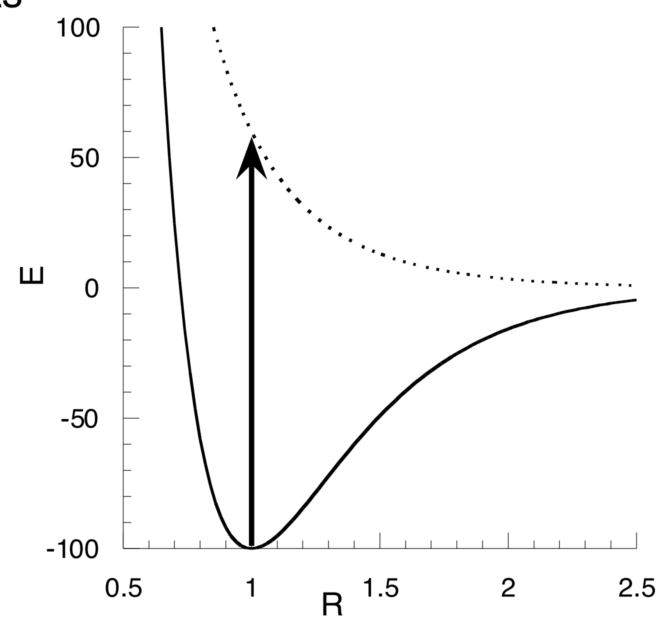
Table 4.2 Bond Energies (in kJ/mol)

	H	C	N	O	S	F	Cl	Br	I
Single Bonds									
H	436								
C	416	356							
N	391	285	160						
O	467	336	201	146					
S	347	272	—	—	226				
F	566	485	272	190	326	158			
Cl	431	327	193	205	255	255	242		
Br	366	285	—	234	213	—	217	193	
I	299	213	—	201	—	—	209	180	151

Multiple Bonds

C═C	598	C═N	616	C═O	803 in CO_2
C≡C	813	C≡N	866	C≡O	1073
N═N	418	O═O	498		
N≡N	946				

Source: Data from Darrell D. Ebbing, *General Chemistry*, Fourth Edition, 1993 Houghton Mifflin Co. Data originally from *Inorganic Chemistry: Principles of Structure and Reactivity*, Third Edition, by James E. Huheey, 1983, Addison Wesley Longman.



Structures of Molecules (Lewis Dot Structures)

Most atoms are reactive & react to form molecules with bonds between atoms—trying to achieve the same number of valence electrons as the noble gas of its period

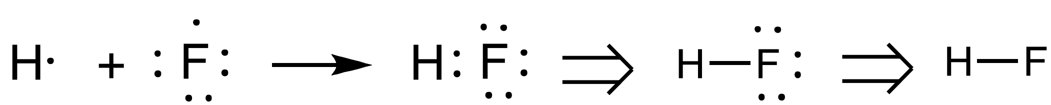
For our purposes, covalent bonds are pairs of shared electrons

Structures that show the outer electrons are called **Lewis (dot) structures**

Lewis structures of atoms help us build molecular structures

example 1: H• + •H → H:H → H-H

example 2: HF

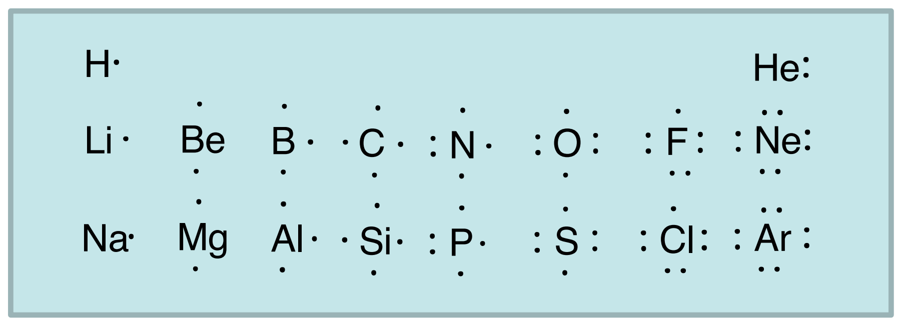


H looks like He and F looks like Ne   Line indicates a bond (pair of electrons)

Table 2.2 Total and Outer Electrons for Atoms of the First 18 Elements

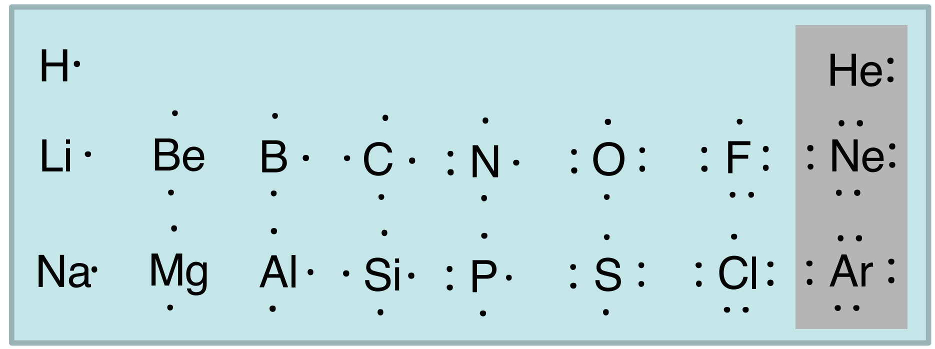
Group 1A	2A	3A	4A	5A	6A	7A	Noble Gases 8A
1 H 1							2 He 2
3 Li 1	4 Be 2	5 B 3	6 C 4	7 N 5	8 O 6	9 F 7	10 Ne 8
11 Na 1	12 Mg 2	13 Al 3	14 Si 4	15 P 5	16 S 6	17 Cl 7	18 Ar 8

- Number *above* the atomic symbol is the atomic number, the total number of protons. It also gives the total number of electrons in a neutral atom.
- Number *below* the atomic symbol is the number of **outer** electrons in a neutral atom.

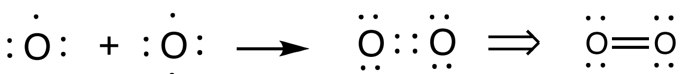


Di- and Triatomic Molecules

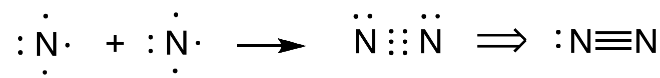
Atoms will share some or all of their valence electrons to achieve the same electronic configuration as the noble gas in its period. Covalent bonds are formed from pairs of shared electrons, and each atom gets to count the bonding electrons as its own…



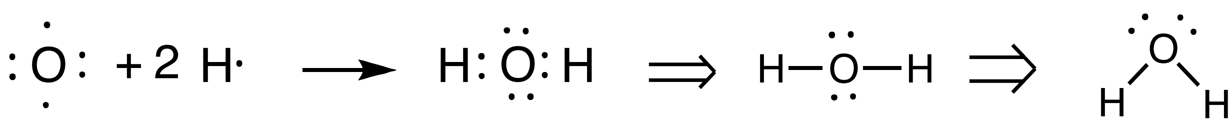
O_2



N_2



H_2O



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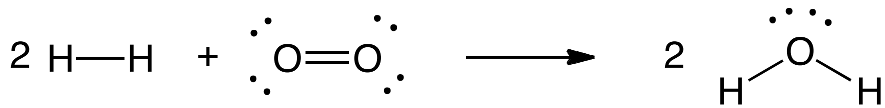
Chemical Energy and Thermochemical Cycles

Chemical energy is in bonds between atoms. Energy is either released (exothermic) or consumed (endothermic) depending upon the strengths of the bonds in reactants and products.

(a mole is a large number not unlike a dozen)

Consider:



A mole of O-H bonds is 467 kJ (we have 2)

A mole of H-H bonds is 436 kJ (we have 2)
A mole of O=O bonds is 498 kJ

Table 4.2 Bond Energies (in kJ/mol)

Single Bonds	H	C	N	O	S	F	Cl	Br	I
H	436								
C	416	356							
N	391	285	160						
O	467	336	201	146					
S	347	272	—	—	226				
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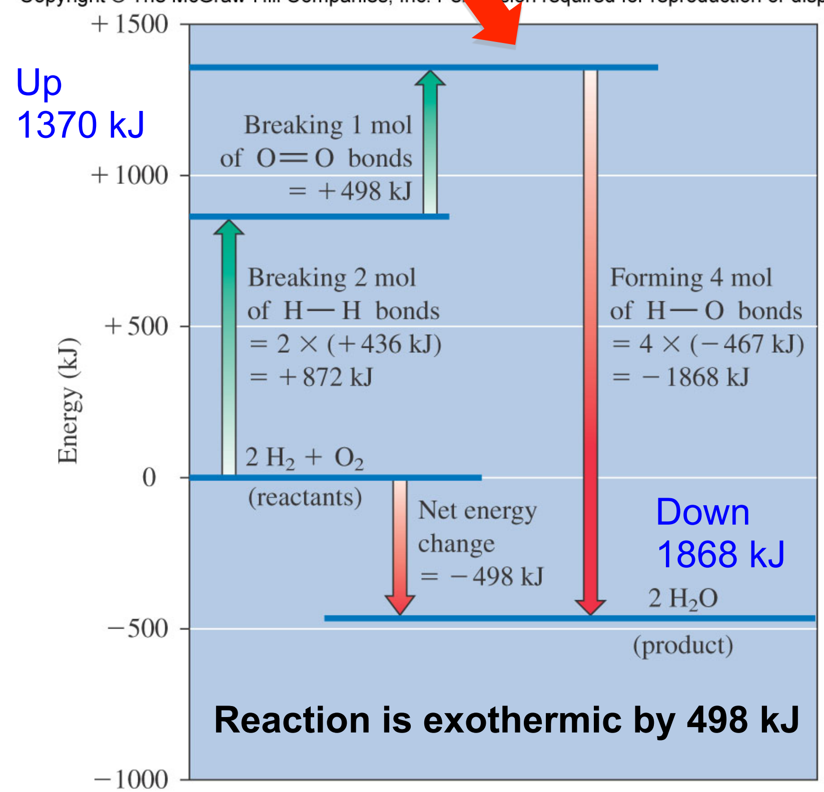
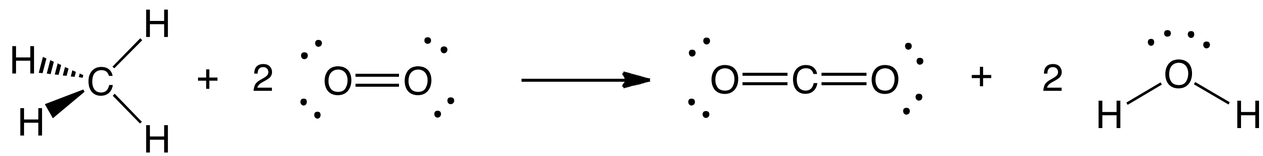


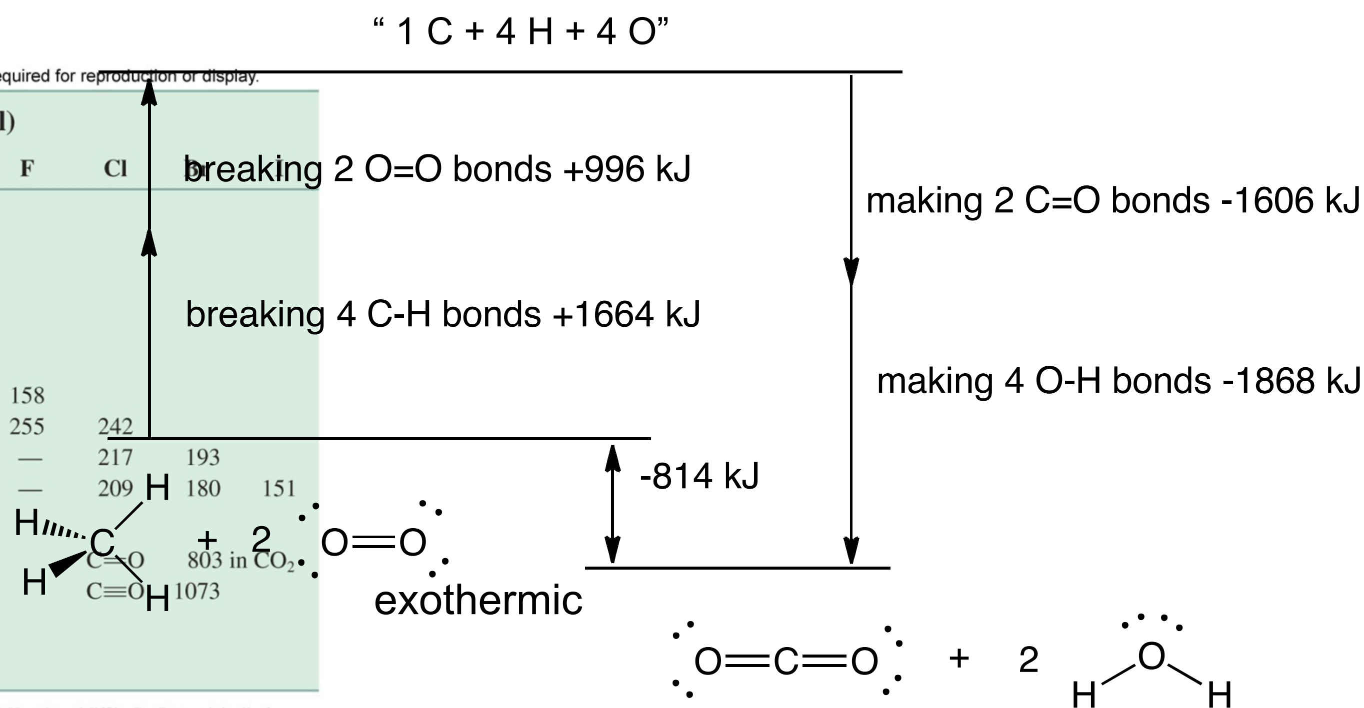
Thermochemical Cycle for Combustion of Methane

Why burning methane makes sense (from an energy standpoint) to generate power:



A mole of C-H bonds is 416 kJ (we have 4)
A mole of O=O bonds is 498 kJ (we have 2)

A mole of O-H bonds is 467 kJ (we have 4)
A mole of C=O bonds is 803 kJ (we have 2)



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Exothermic Reactions Require Bond Breaking to Cost Less Energy than Bond Making…

Hydrocarbons make good fuels because: O-H & C=O bonds are stronger than O=O, C-H, and C-C bonds

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