Name ________________________ Honors Chemistry ___/___/___

Covalent Bond Energies and Chemical Reactions

- Consider the stepwise decomposition of methane:
  - $CH_4(g) \rightarrow CH_3(g) + H(g)$ energy required: 435 kJ/mol
  - $CH_3(g) \rightarrow CH_2(g) + H(g)$ energy required: 453 kJ/mol
  - $CH_2(g) \rightarrow CH(g) + H(g)$ energy required: 425 kJ/mol
  - $CH(g) \rightarrow C(g) + H(g)$ energy required: 339 kJ/mol
  - Total = 1652 ÷ 4 = 413 kJ/mol
  - Note that the C—H bond is somewhat sensitive to its environment
- Consider the following molecules and the measured C—H bond energy (kJ/mol)

Molecule	Measure C-H bond energy (kJ/mol)
$HCBr_3$	380
$HCCl_3$	380
HCF_3	430
C_2H_6	410

- Again, C—H bond strength varies significantly with its environment, but the concept of an average bond energy is helpful to chemists.
- The average bond energies for various types of bonds are listed below.

TABLE 8.4 Average Bond Energies (kJ/mol)

Single Bonds						Multiple Bonds	
H—H	432	N—H	391	I—I	149	C=C	614
H—F	565	N—N	160	I—Cl	208	C≡C	839
H—Cl	427	N—F	272	I—Br	175	O=O	495
H—Br	363	N—Cl	200			C=O*	745
H—I	295	N—Br	243	S—H	347	C≡O	1072
		N—O	201	S—F	327	N=O	607
C—H	413	O—H	467	S—Cl	253	N=N	418
C—C	347	O—O	146	S—Br	218	N≡N	941
C—N	305	O—F	190	S—S	266	C≡N	891
C—O	358	O—Cl	203			C=N	615
C—F	485	O—I	234	Si—Si	340		
C—Cl	339			Si—H	393		
C—Br	276	F—F	154	Si—C	360		
C—I	240	F—Cl	253	Si—O	452		
C—S	259	F—Br	237				
		Cl—Cl	239				
		Cl—Br	218				
		Br—Br	193				

*C=O(CO_2) = 799

- In a single bond, one pair of electrons is shared, in a double bond, two pairs of electrons are shared and in a triple bond, three pairs of electrons are shared. Single bonds are the longest and weakest of the bonds. Triple bonds are the shortest and the strongest of the bonds.
- For bonds to be broken, energy must be added to a system – an endothermic process.
- Energy is released when a bond is formed.
- **$\Delta H° = \Sigma D$ (bonds broken) - ΣD (bonds formed),** Σ represents the sum of terms and D represents the bond energy per mole of bonds

- Example: Using the bond energies from above, calculate the ΔH for the reaction of methane with chlorine and fluorine to give Freon-12 (CF_2Cl_2)
    - $CH_4(g) + 2Cl_2(g) + 2F_2(g) \rightarrow CF_2Cl_2(g) + 2HF(g) + 2HCl(g)$
    - Bonds broken:
        - C—H: 4 x 413 = 1652 kJ
        - Cl—Cl : 2 x 239 = 478 kJ
        - F—F: 2 x 154 kJ = 308 kJ
        - Total = 2438 kJ
    - Bonds formed:
        - C—F: 2 x 485 = 970 kJ
        - C—Cl: 2 x 339 = 678 kJ
        - H—F: 2 x 565 = 1130 kJ
        - H—Cl: 2 x 427 = 854 kJ
        - Total energy released = 3632 kJ
    - ΔH° = ΣD (bonds broken) - ΣD (bonds formed)
    - ΔH° = 2438 kJ – 3632 kJ = -1194 kJ

Homework: Calculate the ΔH for each reaction below:

1. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
   941 + 3(432) → 6(391)
   2237 → 2346
   ΔH° = -109 kJ

2. $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O$
   4(413) + 2(495) → 2(799) + 4(467)
   1652 + 990 → 1598 + 4(467)
   2642 →3466
   ΔH° = -824 kJ

3. $CO(g) + 2\ H_2(g) \Longleftrightarrow CH_3OH(l)$
   1072 + 2(432) <===> 3(413) +(358) + (467)
   1936 <===> 2064
   ΔH° = -128 kJ

4. $C_2H_5Cl(g) + Cl_2(g) \Longleftrightarrow C_2H_4Cl_2\ (g) + HCl(g)$
   5(413) + (339) + (347) + (239) <===> 4(413) + 2(339) + (347) + (427)
   2990 <===> 3104
   ΔH° = -114 kJ

5. $Cl_2(g) + 3F_2(g) \rightarrow 2ClF_3(g)$
   (239) + 3(154) →6(253)
   701 →1518
   ΔH° = -817 kJ