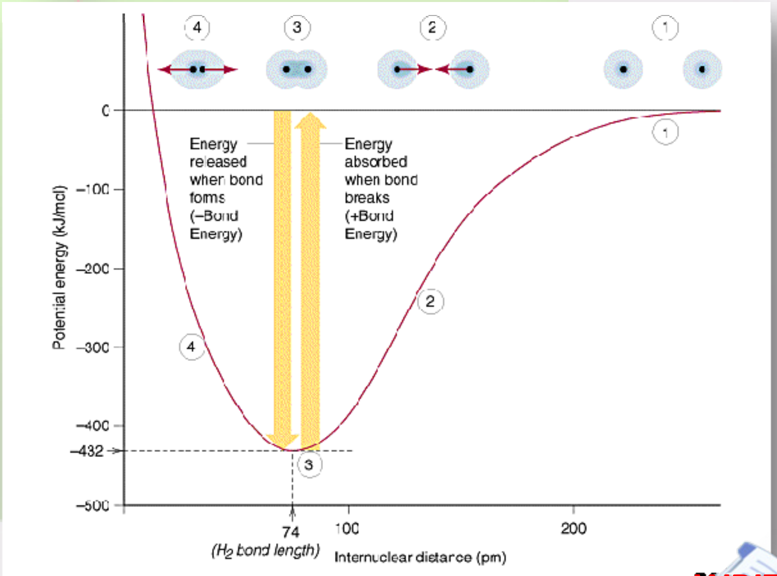
Bond Length

And Bond Dissociation Energy

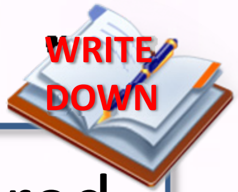
ENERGY PROFILE

- Bonds form because the system achieves the lowest possible energy.
- The energy profile is a function of distance.
  - As the atoms move closer the attractions between the electrons of one and the protons of another increases.
  - So does the mutual repulsion of their electrons and the mutual repulsion of their protons.



- The bond length is the distance at which the system has minimum energy.
(the best compromise between attraction and repulsion).

BOND ENERGY



- The bond energy is the average energy required to break all the similar bonds in a gas.
  - It takes 1650 kJ to break a mole of CH_4 into gaseous atoms (at 298 K and 100 kPa)
  - The average energy of the C–H bond is 413 kJ/mol.

$$\left(\frac{1650}{4} = 413\right)$$

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				

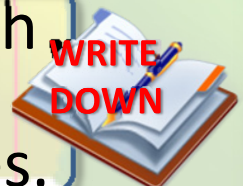
*C=O(CO_2) = 799

BOND ENERGY AND CHEMICAL REACTIONS

- Bonds are sensitive to their molecular environment.
- The energy associated with breaking a bond may differ under different circumstances.
- For example, methane has 4 of the same C–H bonds, each with different dissociation energies.
  - $CH_4(g) + 435\ kJ/mol \rightarrow CH_3(g) + H(g)$
  - $CH_3(g) + 377\ kJ/mol \rightarrow CH_2(g) + H(g)$
- That is why the concept of average bond energy is more useful.

Bond Energy, Bond Strength, and Bond Length

- As the number of bonds between atoms increases, so does the bond energy.
  - Bond strength increases with bond energy. So the strength of the bond increases as the number of bonds increases.
- As bond strength increases, bond length decreases.



Average Bond Energies (kJ/mol)

Single Bonds								Multiple Bonds	
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H—F	565	N—N	160	I—Cl	208			C≡C	839
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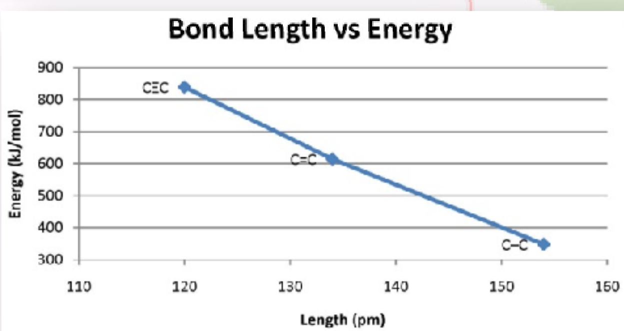
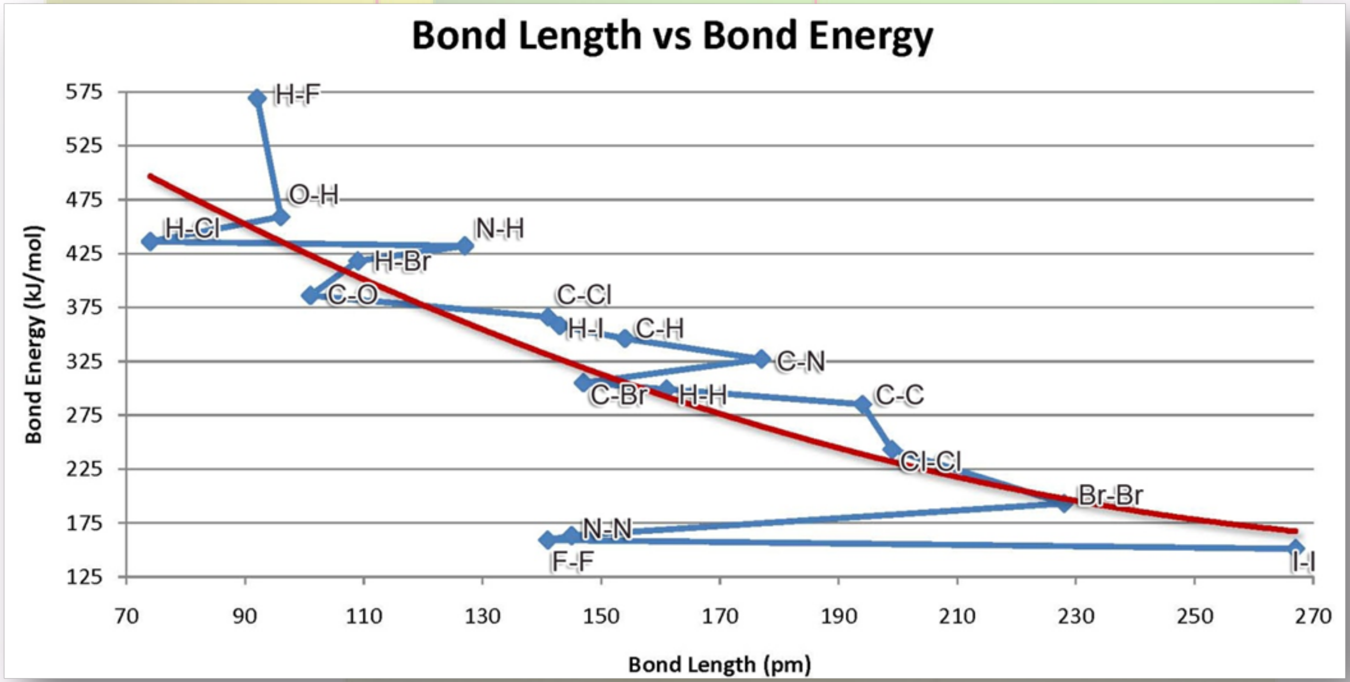


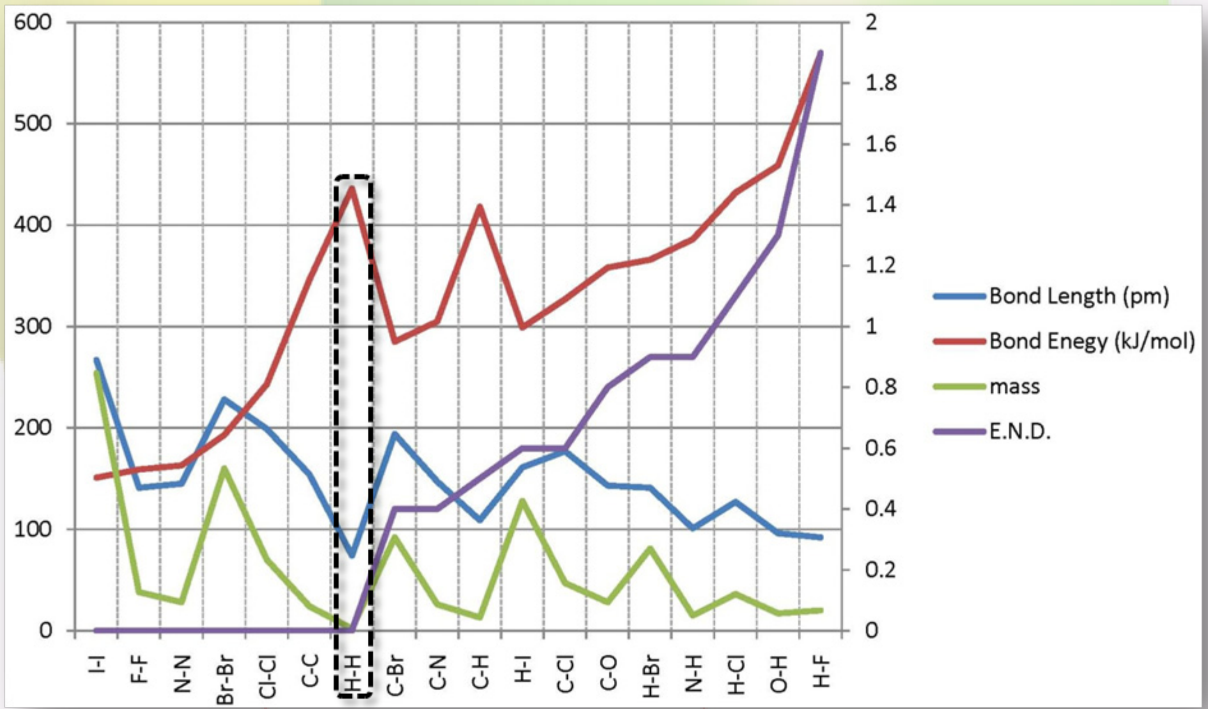
Bond Energy vs Bond Length

- In general, as bond energy increases, bond length decreases.
- There is no mathematical equation to describe this relationship.



Other Correlations

- Not surprisingly, as electronegativity difference increases, so does bond energy.



- Note, however, that, in general, the lower the mass of the nonpolar molecule is, the greater the bond strength is and the shorter the bond length is.

USING BOND ENERGIES

- If 413 kJ/mol are required to break a C–H bond then what happens when a C–H bond forms?

  413 kJ/mol are released

- Bond breaking requires energy (endothermic). Bond making releases energy (exothermic).
- If you know the amount of energy needed to break a bond, and the amount of energy released when a new bond forms, it is possible to approximate the energy change of a reaction.
  - The energy change of the reaction is the sum of the energies required for breaking the bonds minus the sum of the energies released making the bonds.

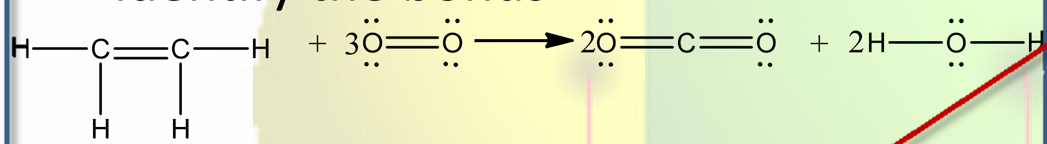
$$\Delta H = \Sigma\Delta H_{(\text{bond breaking})} - \Sigma\Delta H_{(\text{bond making})}$$

SAMPLE PROBLEM

What is the energy change associated with the reaction $C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$

WRITE DOWN

- **Step 1**: Draw Lewis structures to identify the bonds



- **Step 2**: Sum the energies of the bonds broken.

Bond	Bond Energy	Number	Total
C–H	413	4	1652
C=C	614	1	614
O=O	495	3	1485
		GRAND TOTAL	3751

Average Bond Energies (kJ/mol)

Single Bonds						Multiple Bonds	
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H—F	565	N—N	160	I—Cl	208	C≡C	[illegible]
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		Cl—Br	218				
		Br—Br	193				

*C=O(CO_2) = 799

- **Step 3**: Sum the energies of the bonds formed.

Bond	Bond Energy	Number	Total
C=O	799	4	3196
O–H	467	4	1868
		GRAND TOTAL	5064

- **Step 4**: Find the difference.

3751 kJ/mol – 5064 kJ/mol = −1313 kJ/mol