**Bond Length**

- Bond length depends on the size of bonded atoms.
- The values are in Angstrom units where 1 Å = 10^{-10} m.

- H—F: 1.040 Å
- H—Cl: 1.75 Å
- H—I: 1.95 Å

**Bond Strength**

- is measured by the energy required to break a bond. See Table 9.10 in the book for average strengths.
- increases as bond order increases.
- increases as bond length decreases.
- can be used to estimate the energetics of a reaction.

- 

**Bond Strength**

<table>
<thead>
<tr>
<th>BOND</th>
<th>STRENGTH (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H—H</td>
<td>436</td>
</tr>
<tr>
<td>C—C</td>
<td>346</td>
</tr>
<tr>
<td>C=C</td>
<td>602</td>
</tr>
<tr>
<td>C≡C</td>
<td>835</td>
</tr>
<tr>
<td>N≡N</td>
<td>945</td>
</tr>
</tbody>
</table>

- The GREATER the number of bonds (bond order) the HIGHER the bond strength and the SHORTER the bond.

See CD-ROM screen 9.19
Bond Strength

<table>
<thead>
<tr>
<th>Bond</th>
<th>Order</th>
<th>Length</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>HO—OH</td>
<td>1</td>
<td>147 pm</td>
<td>210 kJ/mol</td>
</tr>
<tr>
<td>O=O</td>
<td>2</td>
<td>121</td>
<td>498</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>128</td>
<td>~375</td>
</tr>
</tbody>
</table>

Using Bond Energies

Estimate the energy change in the reaction

\[ \text{H—H} + \text{Cl—Cl} \rightarrow 2 \text{H—Cl} \]

Net energy change = \( \Delta H_{\text{rxn}} \)

- energy required to break bonds (of reactants)
- energy evolved when (product) bonds are made

\[ \begin{align*}
\text{H—H} &= 436 \text{ kJ/mol} \\
\text{Cl—Cl} &= 243 \text{ kJ/mol} \\
\text{H—Cl} &= 431 \text{ kJ/mol}
\end{align*} \]

\( \Delta H^\circ = +679 \text{ kJ} \)

The sum of H-H + Cl-Cl bond energies = 436 kJ + 243 kJ = +679 kJ

The 2 moles of H-Cl bond energies = 862 kJ

Net = \( \Delta H \) = +679 kJ - 862 kJ = -183 kJ

Using Bond Energies

Estimate the energy change in the reaction

\[ \text{2 H—O—O—H} \rightarrow \text{O=O} + 2 \text{H—O—H} \]

Is the reaction exo- or endothermic?

Which is larger: the energy required to break bonds or the energy evolved on making bonds?
Using Bond Energies

2 H—O—O—H → O=O + 2 H—O—H

Energy required to break bonds:
- break 4 moles of O—H bonds = 4 × (463 kJ)
- break 2 moles O—O bonds = 2 × (146 kJ)
TOTAL ENERGY to break bonds = 2144 kJ

Energy evolved on making bonds:
- make 1 mol of O=O bonds = 498 kJ
- make 4 mol O—H bonds = 4 × (463 kJ)
TOTAL ENERGY evolved on making bonds = 2350 kJ

Net energy change = +2144 kJ - 2350 kJ = - 216 kJ
The reaction is exothermic!

More energy is evolved on making bonds than is expended in breaking bonds.

Formal Atom Charges

- Atoms in molecules often bear a partial charge (+ or -) because they have a weaker or stronger electron affinity than the partner atom.
- The predominant resonance structure of a molecule is the one with charges as close to 0 as possible.
- Formal charge = Group #
  - 1/2 (# of bond electrons)
  - (# of LP electrons)

Carbon Dioxide, CO₂

O atom charge is 0.

6 - (1/2)(4) - 4 = 0

C atom charge is 0.

4 - (1/2)(8) - 0 = 0
Carbon Dioxide, $\text{CO}_2$

O atom charge is $+1$.

\[ 6 - (1/2)(2) - 6 = -1 \]

\[ 6 - (1/2)(6) - 2 = +1 \]

C atom charge is $0$.

\[ 4 - (1/2)(8) - 0 = 0 \]

Which is the predominant resonance structure?

Predicted partial charges can be calculated by the CAChe molecular modeling system.

Carbon Dioxide, $\text{CO}_2$

The C-O bonds show partial charge separation.

Charge separation produces dipole moments. They are equal and opposite; they cancel.

Boron Trifluoride, $\text{BF}_3$

What if we form a B—F double bond to satisfy the B atom octet?

- To have $+1$ charge on F, with its very high affinity for electrons, is not good.
- Negative charges are best placed on atoms with high affinity for electrons.
Thiocyanate ion, SCN⁻

Which of three possible resonance structures is most important?

Calculated partial charges:

- S: -0.52
- C: -0.32
- N: -0.16