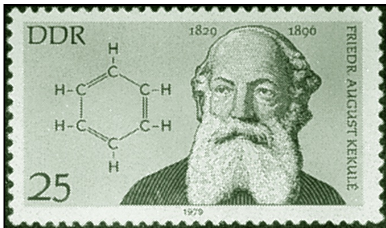
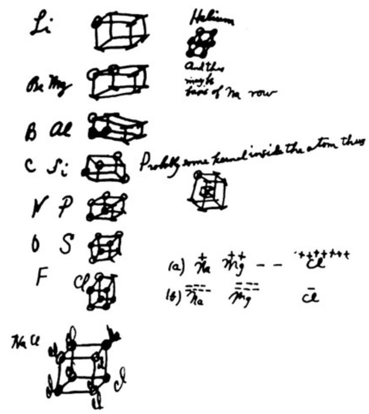


Chemical Bonding I: The Covalent Bond

Chapter 9



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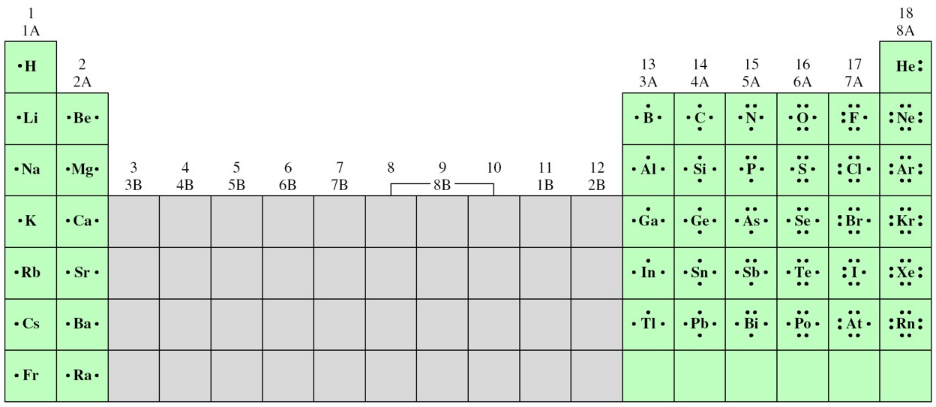
Valence electrons are the outer shell electrons of an atom. The valence electrons are the electrons that particpate in chemical bonding.

Group	e^- configuration	# of valence e^-
1A	ns^1	1
2A	ns^2	2
3A	ns^2np^1	3
4A	ns^2np^2	4
5A	ns^2np^3	5
6A	ns^2np^4	6
7A	ns^2np^5	7

2

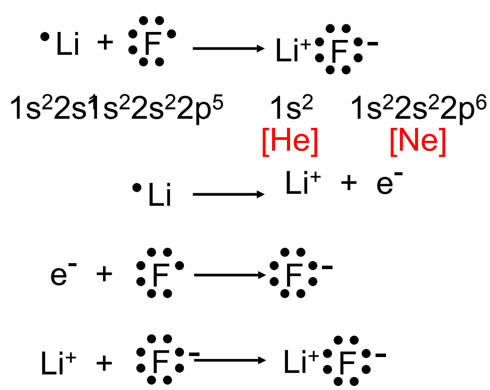
Lewis Dot Symbols for the Representative Elements & Noble Gases



3

The Ionic Bond

Ionic bond: *the electrostatic force that holds ions together in an ionic compound.*



4

Electrostatic (Lattice) Energy

Lattice energy (U) is the energy required to completely separate one mole of a solid ionic compound into gaseous ions.

$$E = k\frac{Q_+Q_-}{r}$$

E is the potential energy
Q_+ is the charge on the cation
Q_- is the charge on the anion
r is the distance between the ions

Lattice energy increases as ***Q increases*** and/or as ***r decreases***.

Compound	Lattice Energy (kJ/mol)	
MgF_2	2957	*Q:* +2,-1
MgO	3938	*Q:* +2,-2
LiF	1036	$r\,F^- < r\,Cl^-$
LiCl	853	

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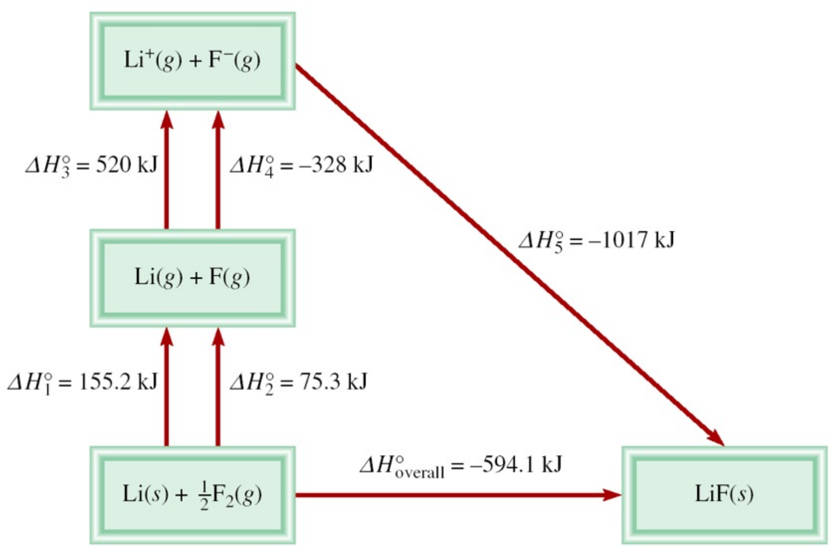
Born-Haber Cycle for Determining Lattice Energy



$$\Delta H^\circ_{overall} = \Delta H_1^\circ + \Delta H_2^\circ + \Delta H_3^\circ + \Delta H_4^\circ + \Delta H_5^\circ$$

6

Table 9.1

Lattice Energies and Melting Points of Some Ionic Compounds

	Lattice Energy (kJ/mol)	Melting Point (°C)
LiF	1017	845
LiCl	828	610
NaCl	788	801
NaBr	736	750
$MgCl_2$	2527	714
MgO	3890	2800
CaO	3414	2580

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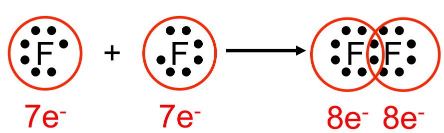
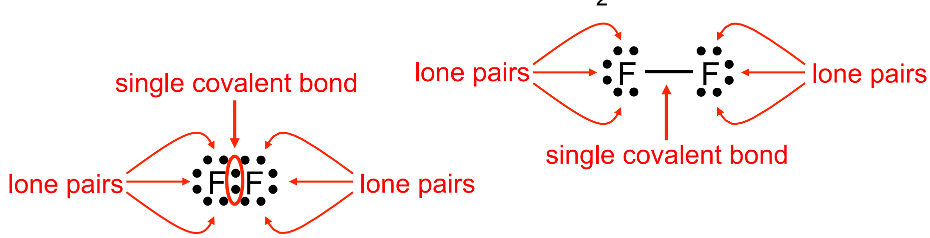
A ***covalent bond*** is a chemical bond in which two or more electrons are shared by two atoms.

Why should two atoms share electrons?



Lewis structure of F_2



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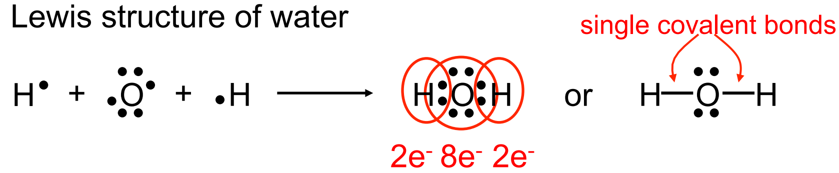
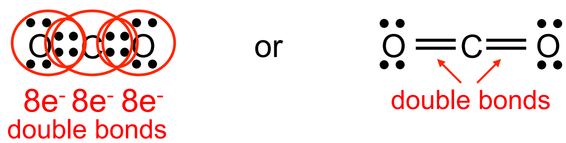
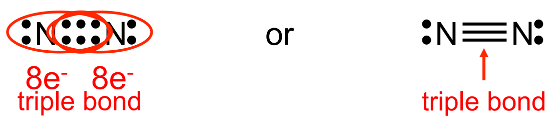
Lewis structure of water



Double bond – two atoms share two pairs of electrons



Triple bond – two atoms share three pairs of electrons



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Lengths of Covalent Bonds

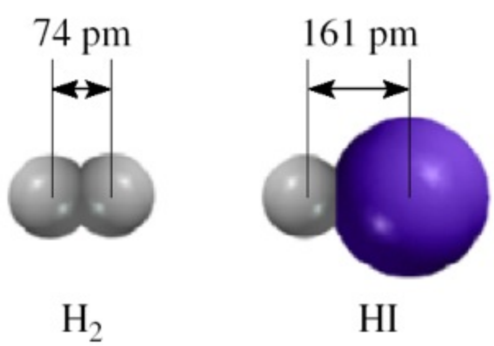


TABLE 9.2

Average Bond Lengths of Some Common Single, Double, and Triple Bonds

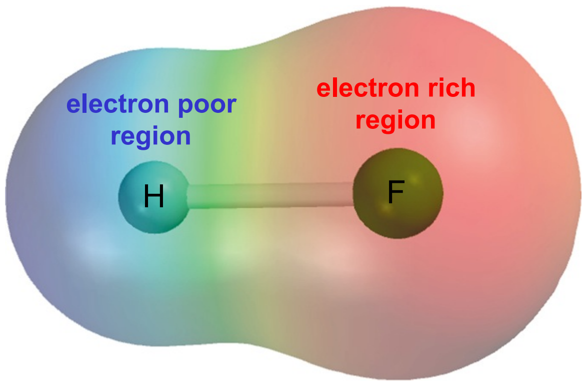
Bond Type	Bond Length (pm)
C—H	107
C—O	143
C═O	121
C—C	154
C═C	133
C≡C	120
C—N	143
C═N	138
C≡N	116
N—O	136
N═O	122
O—H	96

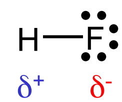
Bond Lengths

Triple bond < Double Bond < Single Bond

10

Polar covalent bond or ***polar bond*** is a covalent bond with greater electron density around one of the two atoms





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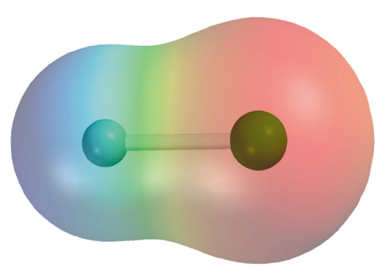
Electronegativity is the ability of an atom to attract toward itself the electrons in a chemical bond.

Electron Affinity - measurable, Cl is highest

$$X_{(g)} + e^{-} \longrightarrow X^{-}_{(g)}$$

Electronegativity - relative, F is highest



The Electronegativities of Common Elements

Increasing electronegativity →

Increasing electronegativity ↑

1A	2A	3B	4B	5B	6B	7B	8B			1B	2B	3A	4A	5A	6A	7A	8A
H 2.1																	
Li 1.0	**Be** 1.5											**B** 2.0	**C** 2.5	**N** 3.0	**O** 3.5	**F** 4.0	
Na 0.9	**Mg** 1.2											**Al** 1.5	**Si** 1.8	**P** 2.1	**S** 2.5	**Cl** 3.0	
K 0.8	**Ca** 1.0	**Sc** 1.3	**Ti** 1.5	**V** 1.6	**Cr** 1.6	**Mn** 1.5	**Fe** 1.8	**Co** 1.9	**Ni** 1.9	**Cu** 1.9	**Zn** 1.6	**Ga** 1.6	**Ge** 1.8	**As** 2.0	**Se** 2.4	**Br** 2.8	**Kr** 3.0
Rb 0.8	**Sr** 1.0	**Y** 1.2	**Zr** 1.4	**Nb** 1.6	**Mo** 1.8	**Tc** 1.9	**Ru** 2.2	**Rh** 2.2	**Pd** 2.2	**Ag** 1.9	**Cd** 1.7	**In** 1.7	**Sn** 1.8	**Sb** 1.9	**Te** 2.1	**I** 2.5	**Xe** 2.6
Cs 0.7	**Ba** 0.9	**La-Lu** 1.0-1.2	**Hf** 1.3	**Ta** 1.5	**W** 1.7	**Re** 1.9	**Os** 2.2	**Ir** 2.2	**Pt** 2.2	**Au** 2.4	**Hg** 1.9	**Tl** 1.8	**Pb** 1.9	**Bi** 1.9	**Po** 2.0	**At** 2.2	
Fr 0.7	**Ra** 0.9																

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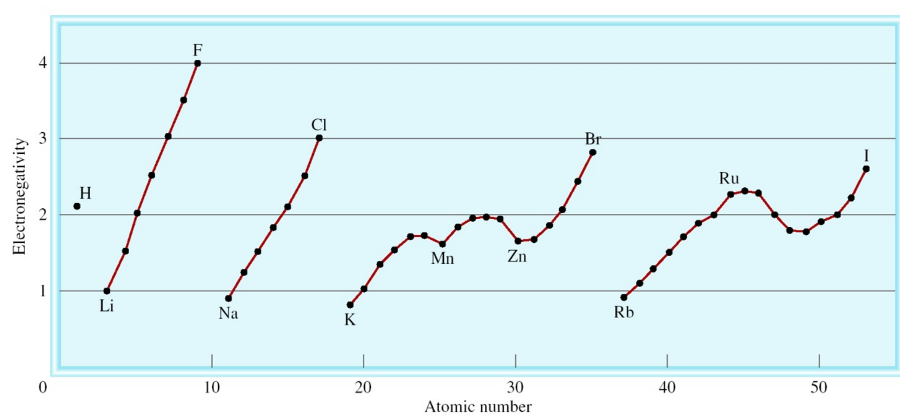
Variation of Electronegativity with Atomic Number



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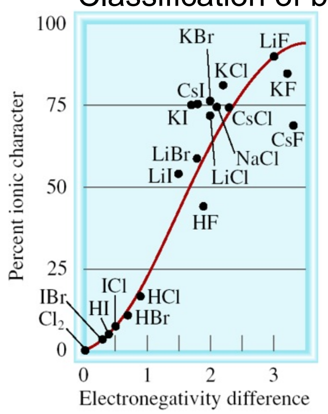
Classification of bonds by difference in electronegativity



Difference	Bond Type
0	Covalent
≥ 2	Ionic
0 < and <2	Polar Covalent

Increasing difference in electronegativity →

Covalent	→	Polar Covalent	→	Ionic
share e^-		partial transfer of e^-		transfer e^-

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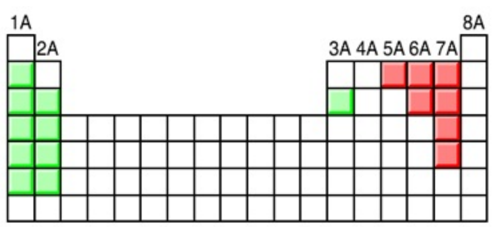
Classify the following bonds as ionic, polar covalent, or covalent: The bond in CsCl; the bond in H_2S; and the NN bond in H_2NNH_2.

Cs – 0.7	Cl – 3.0	3.0 – 0.7 = 2.3	Ionic
H – 2.1	S – 2.5	2.5 – 2.1 = 0.4	Polar Covalent
N – 3.0	N – 3.0	3.0 – 3.0 = 0	Covalent



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Writing Lewis Structures

1. Draw skeletal structure of compound showing what atoms are bonded to each other. Put least electronegative element in the center.
2. Count total number of valence e^-. Add 1 for each negative charge. Subtract 1 for each positive charge.
3. Complete an octet for all atoms ***except*** hydrogen
4. If structure contains too many electrons, form double and triple bonds on central atom as needed.

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Write the Lewis structure of nitrogen trifluoride (NF_3).

Step 1 – N is less electronegative than F, put N in center

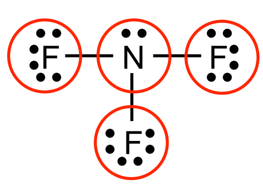
Step 2 – Count valence electrons N - 5 ($2s^2 2p^3$) and F - 7 ($2s^2 2p^5$)

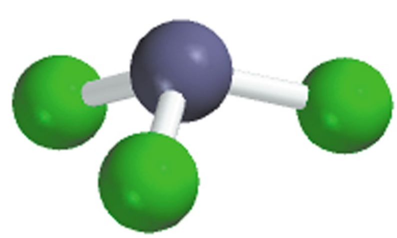
5 + (3 x 7) = 26 valence electrons

Step 3 – Draw single bonds between N and F atoms and complete octets on N and F atoms.

Step 4 - Check, are # of e^- in structure equal to number of valence e^- ?

3 single bonds (3x2) + 10 lone pairs (10x2) = 26 valence electrons





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Write the Lewis structure of the carbonate ion (CO_3^{2-}).

Step 1 – C is less electronegative than O, put C in center

Step 2 – Count valence electrons C - 4 ($2s^22p^2$) and O - 6 ($2s^22p^4$)
-2 charge – $2e^-$

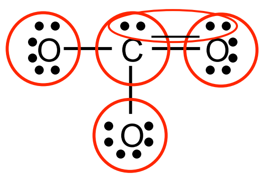
4 + (3 x 6) + 2 = 24 valence electrons

Step 3 – Draw single bonds between C and O atoms and complete octet on C and O atoms.

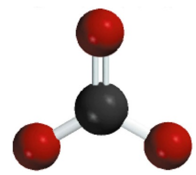
Step 4 - Check, are # of e^- in structure equal to number of valence e^- ?

3 single bonds (3x2) + 10 lone pairs (10x2) = 26 valence electrons

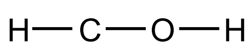
Step 5 - Too many electrons, form double bond and re-check # of e^-

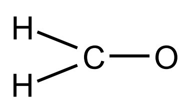


2 single bonds (2x2) = 4
1 double bond = 4
8 lone pairs (8x2) = 16
Total = 24



Two possible skeletal structures of formaldehyde (CH_2O)

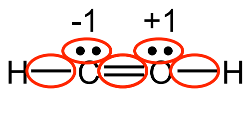




An atom's ***formal charge*** is the difference between the number of valence electrons in an isolated atom and the number of electrons assigned to that atom in a Lewis structure.

formal charge on an atom in a Lewis structure = total number of valence electrons in the free atom - total number of nonbonding electrons - $\frac{1}{2}$ (total number of bonding electrons)

The sum of the formal charges of the atoms in a molecule or ion must equal the charge on the molecule or ion.



C – 4 e^-
O – 6 e^-
2H – 2x1 e^-
12 e^-

2 single bonds (2x2) = 4
1 double bond = 4
2 lone pairs (2x2) = 4
Total = 12

formal charge on an atom in a Lewis structure = total number of valence electrons in the free atom - total number of nonbonding electrons - $\frac{1}{2}$ (total number of bonding electrons)

formal charge on C = 4 -2 -½ x 6 = -1

formal charge on O = 6 -2 -½ x 6 = +1

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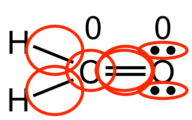


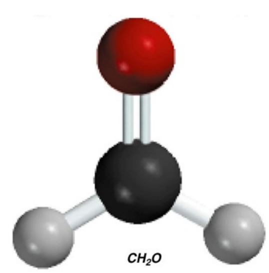
C – 4 e^-
O – 6 e^-
2H – 2x1 e^-
12 e^-

2 single bonds (2x2) = 4
1 double bond = 4
2 lone pairs (2x2) = 4
Total = 12

formal charge on an atom in a Lewis structure = total number of valence electrons in the free atom - total number of nonbonding electrons - $\frac{1}{2}$ (total number of bonding electrons)

formal charge on C = 4 -0 -½ x 8 = 0

formal charge on O = 6 -4 -½ x 4 = 0



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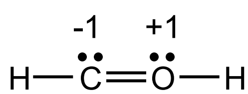
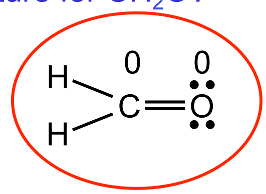
Formal Charge and Lewis Structures

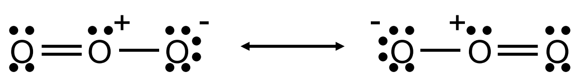
1. For neutral molecules, a Lewis structure in which there are no formal charges is preferable to one in which formal charges are present.
2. Lewis structures with large formal charges are less plausible than those with small formal charges.
3. Among Lewis structures having similar distributions of formal charges, the most plausible structure is the one in which negative formal charges are placed on the more electronegative atoms.

Which is the most likely Lewis structure for CH_2O?

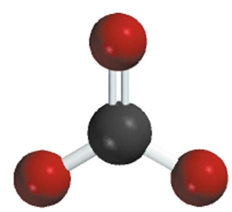


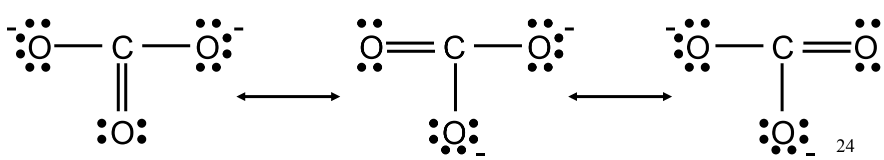


A ***resonance structure*** is one of two or more Lewis structures for a single molecule that cannot be represented accurately by only one Lewis structure.



What are the resonance structures of the carbonate (CO_3^{2-}) ion?





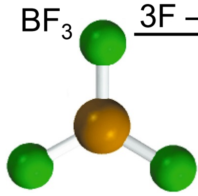
Exceptions to the Octet Rule

The Incomplete Octet

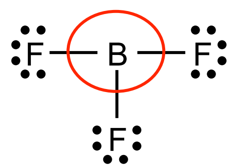
BeH_2

Be – $2e^-$
2H – $2x1e^-$
$4e^-$

BF_3



B – $3e^-$
3F – $3x7e^-$
$24e^-$



3 single bonds (3x2) = 6
9 lone pairs (9x2) = 18
Total = 24

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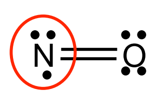
Exceptions to the Octet Rule

Odd-Electron Molecules

NO

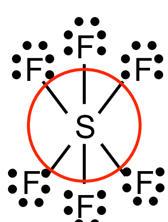
N – $5e^-$
O – $6e^-$
$11e^-$



The Expanded Octet (central atom with principal quantum number $n > 2$)

SF_6

S – $6e^-$
6F – $42e^-$
$48e^-$



6 single bonds (6x2) = 12
18 lone pairs (18x2) = 36
Total = 48

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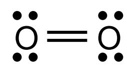
The enthalpy change required to break a particular bond in one mole of gaseous molecules is the ***bond enthalpy***.

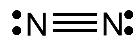
Bond Enthalpy

$H_{2\,(g)} \longrightarrow H_{(g)} + H_{(g)}$ $\Delta H^\circ = 436.4$ kJ

$Cl_{2\,(g)} \longrightarrow Cl_{(g)} + Cl_{(g)}$ $\Delta H^\circ = 242.7$ kJ

$HCl_{(g)} \longrightarrow H_{(g)} + Cl_{(g)}$ $\Delta H^\circ = 431.9$ kJ

$O_{2\,(g)} \longrightarrow O_{(g)} + O_{(g)}$ $\Delta H^\circ = 498.7$ kJ 

$N_{2\,(g)} \longrightarrow N_{(g)} + N_{(g)}$ $\Delta H^\circ = 941.4$ kJ 

Bond Enthalpies

Single bond < Double bond < Triple bond

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Average ***bond enthapy*** in polyatomic molecules

$H_2O_{(g)} \longrightarrow H_{(g)} + OH_{(g)}$ $\Delta H^\circ = 502$ kJ

$OH_{(g)} \longrightarrow H_{(g)} + O_{(g)}$ $\Delta H^\circ = 427$ kJ

$$\text{Average OH bond enthalpy} = \frac{502 + 427}{2} = 464 \text{ kJ}$$

Table 9.3 Some Bond Enthalpies of Diatomic Molecules* and Average Bond Enthalpies for Bonds in Polyatomic Molecules

Bond	Bond Enthalpy (kJ/mol)	Bond	Bond Enthalpy (kJ/mol)
H—H	436.4	C—S	255
H—N	393	C=S	477
H—O	460	N—N	193
H—S	368	N=N	418
H—P	326	N≡N	941.4
H—F	568.2	N—O	176
H—Cl	431.9	N=O	607
H—Br	366.1	O—O	142
H—I	298.3	O=O	498.7
C—H	414	O—P	502
C—C	347	O=S	469
C=C	620	P—P	197
C≡C	812	P=P	489
C—N	276	S—S	268
C=N	615	S=S	352
C≡N	891	F—F	156.9
C—O	351	Cl—Cl	242.7
C=O†	745	Br—Br	192.5
C—P	263	I—I	151.0

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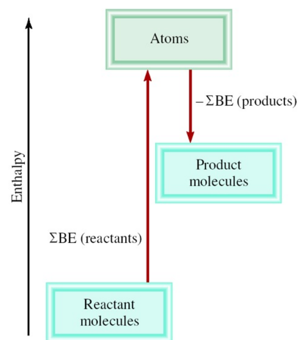
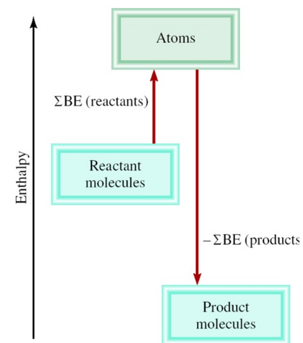
Bond Enthalpies (BE) and Enthalpy changes in reactions

Imagine reaction proceeding by breaking all bonds in the reactants and then using the gaseous atoms to form all the bonds in the products.

$$\Delta H^\circ = \text{total energy input} - \text{total energy released}$$
$$= \Sigma\text{BE(reactants)} - \Sigma\text{BE(products)}$$



endothermic



exothermic

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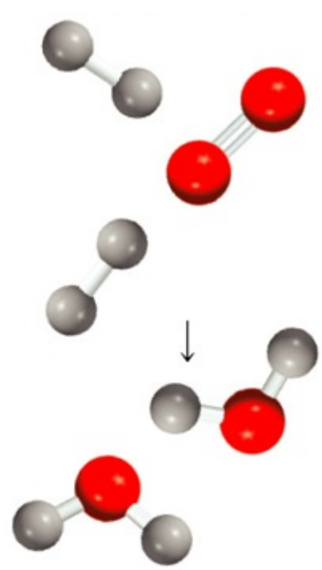
$$2H_2\ (g) + O_2\ (g) \longrightarrow 2H_2O\ (g)$$



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Use bond enthalpies to calculate the enthalpy change for:

$$H_{2\ (g)} + F_{2\ (g)} \longrightarrow 2HF_{\ (g)}$$

$$\Delta H^\circ = \Sigma BE(\text{reactants}) - \Sigma BE(\text{products})$$

Type of bonds broken	Number of bonds broken	Bond enthalpy (kJ/mol)	Enthalpy change (kJ/mol)
H—H	1	436.4	436.4
F—F	1	156.9	156.9
Type of bonds formed	**Number of bonds formed**	**Bond enthalpy (kJ/mol)**	**Enthalpy change (kJ/mol)**
H—F	2	568.2	1136.4

$$\Delta H^\circ = 436.4 + 156.9 - 2 \times 568.2 = -543.1 \text{ kJ/mol}$$

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