

Chemical Bonds
Formation of Compounds
from atoms

Preparation for College Chemistry
Columbia University
Department of Chemistry

Trends in the Periodic Table

Trends in the Periodic Table

Lewis Structures

VSEPR Model























Sizes of atoms and ions

Atomic radii (nm)

1	2	13	14	15	16	17	18
Li .152	Be .111	B .088	C .077	N .070	O .066	F .064	He .05
Na .186	Mg .160	Al .143	Si .117	P .110	S .104	Cl .099	Ar .094
K .231	Ca .197	Ga .122	Ge .122	As .121	Se .117	Br .114	Kr .109
Rb .244	Sr .215	In .162	Sn .140	Sb .141	Te .137	I .133	Xe .130
Cs .262	Ba .217	Tl .171	Pb .175	Bi .146	Po .165	At	Rn .140

Sizes of atoms and ions

Ionic radii (nm)

1	2	13	16	17
 Li ⁺ .060	 Be ²⁺ .031		 O ²⁻ .140	 F ⁻ .136
 Na ⁺ .095	 Mg ²⁺ .065	 Al ³⁺ .050	 S ²⁻ .184	 Cl ⁻ .181
 K ⁺ .133	 Ca ²⁺ .099	 Ga ³⁺ .062	 Se ²⁻ .198	 Br ⁻ .195
 Rb ⁺ .148	 Sr ²⁺ .113	 In ³⁺ .081	 Te ²⁻ .221	 I ⁻ .216
 Cs ⁺ .169	 Ba ²⁺ .135	 Tl ³⁺ .095		

Atomic and Ionic Radii

Sizes of atoms and ions

Atomic radii (nm)									
1	2	13	14	15	16	17	18		
Li	Be	B	C	N	O	F	Ne		
.152	.111	.088	.077	.070	.066	.064	.070		
Na	Mg	Al	Si	P	S	Cl	Ar		
.186	.160	.143	.117	.110	.104	.099	.094		
K	Ca	Ga	Ge	As	Se	Br	Kr		
.231	.197	.122	.122	.121	.117	.114	.109		
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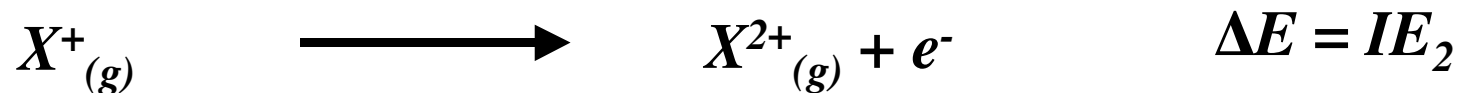
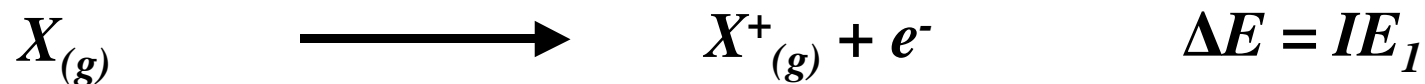
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.060	.031		.140	.136
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K ⁺	Ca ²⁺	Ga ³⁺	Se ²⁻	Br ⁻
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Rb ⁺	Sr ²⁺	In ³⁺	Te ²⁻	I ⁻
.148	.113	.081	.221	.216
Cs ⁺	Ba ²⁺	Tl ³⁺		
.169	.135	.095		

Decreases going across a period from left to right, increases going down group

Ionization Energy

Minimum energy necessary to remove an electron from a neutral gaseous atom in its ground state ($IE > 0$, ground state stable system)



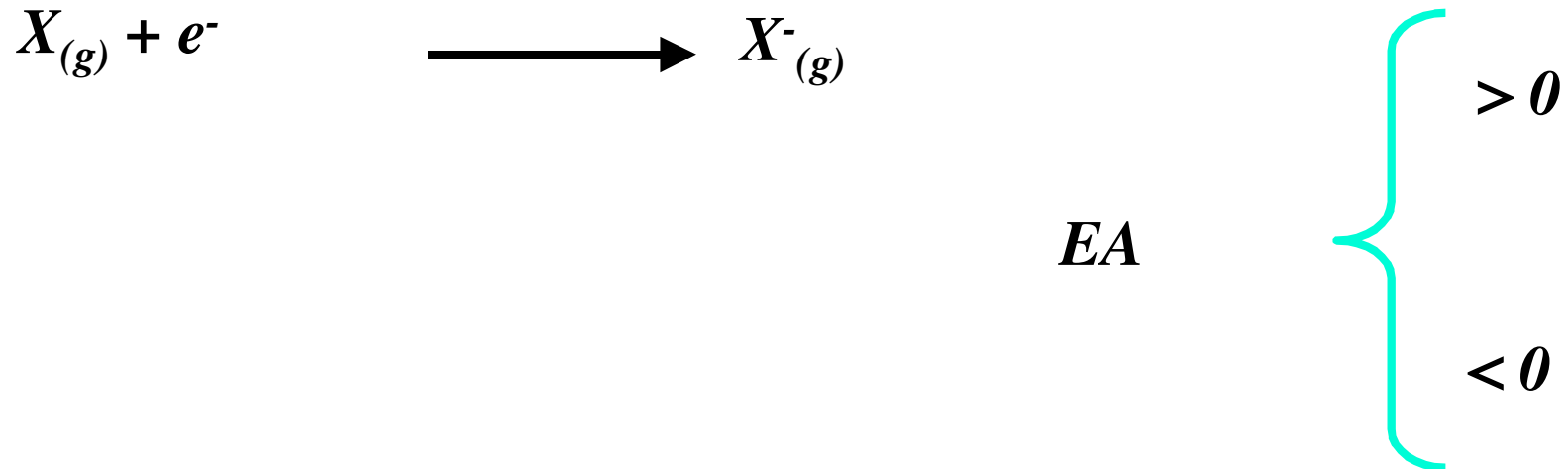
First Ionization Energies

Ionization energy increases

	1	2		13	14	15	16	17	18
	Li 520	Be 900		B 801	C 1086	N 1402	O 1314	H 1312	He 2372
	Na 496	Mg 738		Al 578	Si 786	P 1012	S 1000	F 1681	Ne 2081
	K 419	Ca 590		Ga 579	Ge 762	As 944	Se 941	Cl 1251	Ar 1520
	Rb 403	Sr 550		In 558	Sn 709	Sb 832	Te 869	Br 1140	Kr 1351
	Cs 376	Ba 503		Tl 589	Pb 716	Bi 703	Po 812	I 1009	Xe 1170
								At	Rn 1037

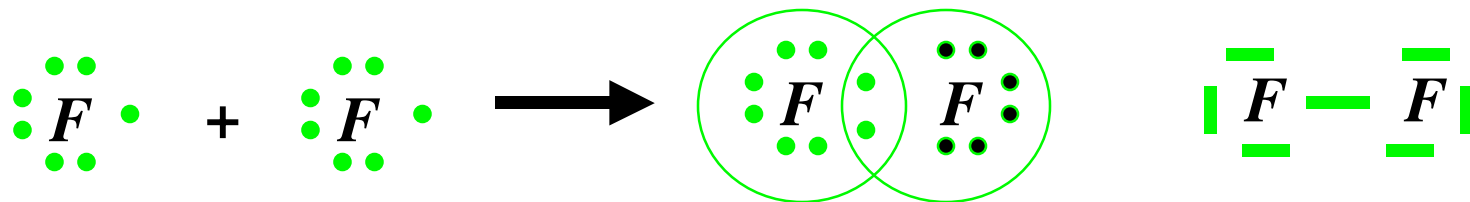
Electron Affinity EA

Electron attachment energy. Energy released when a gaseous atom in its ground state gains a single electron.

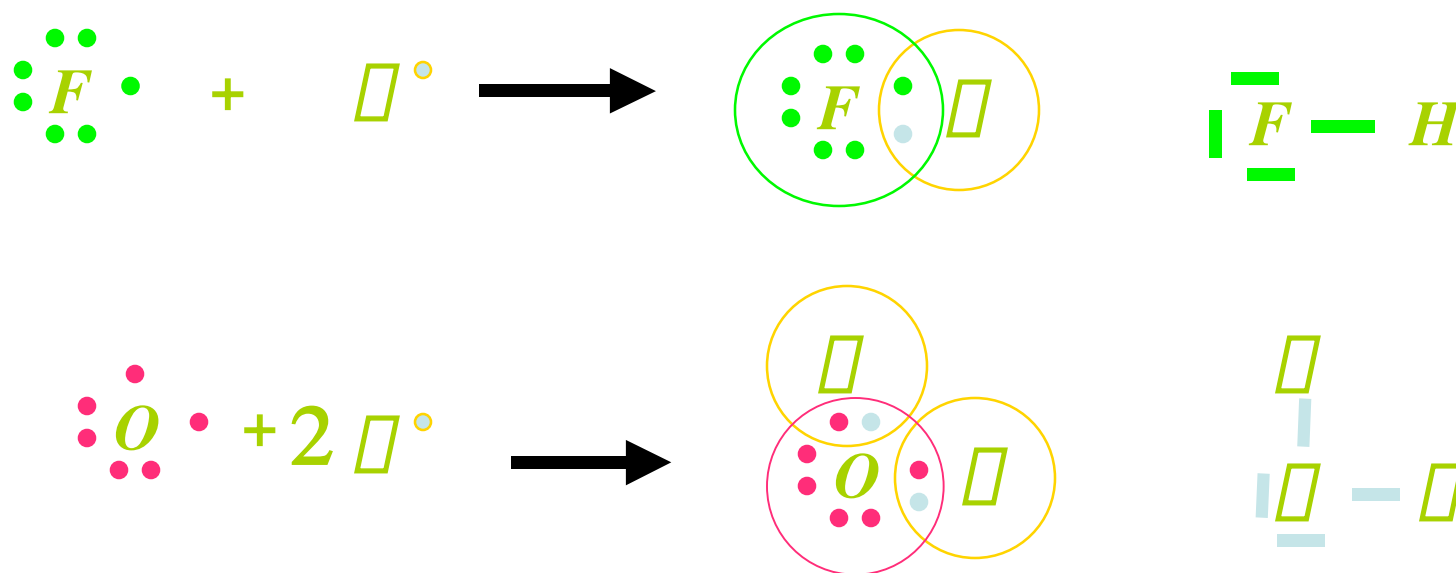


Lewis Structures of Atoms

Gilbert Lewis

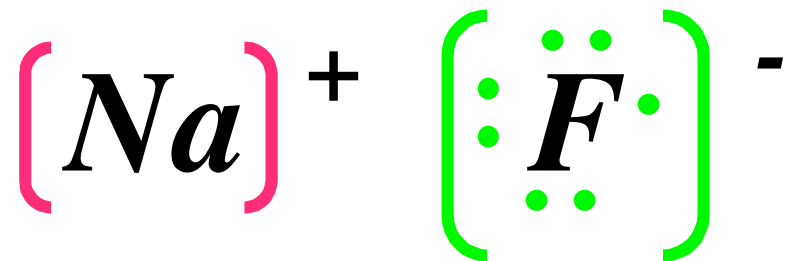
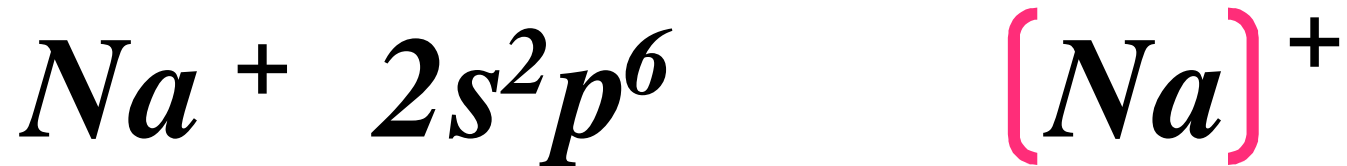


The Octet Rule

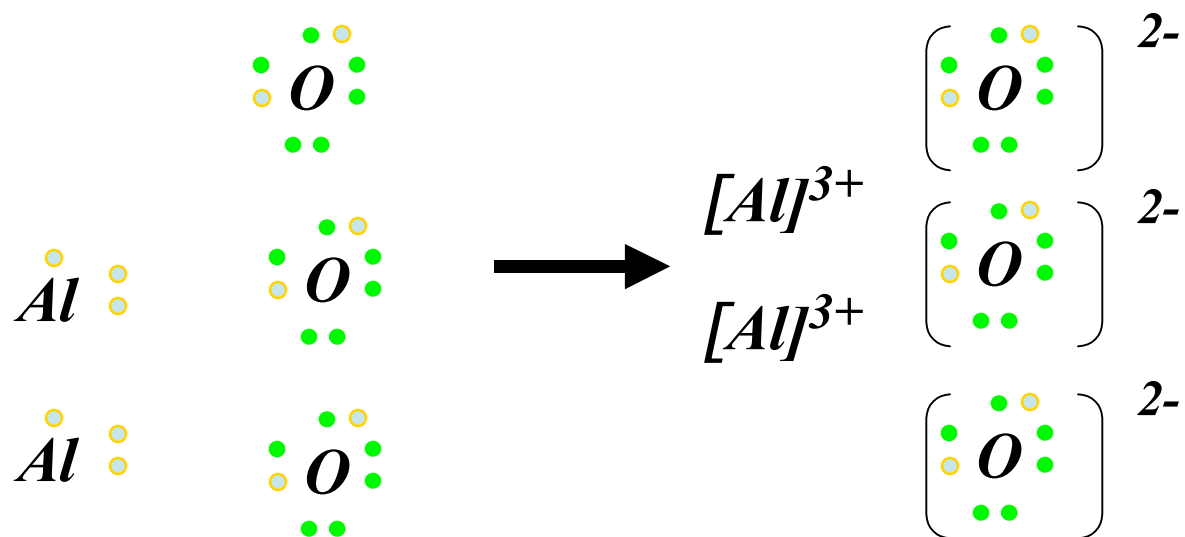
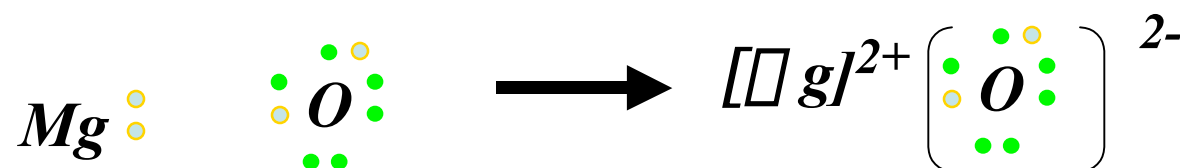
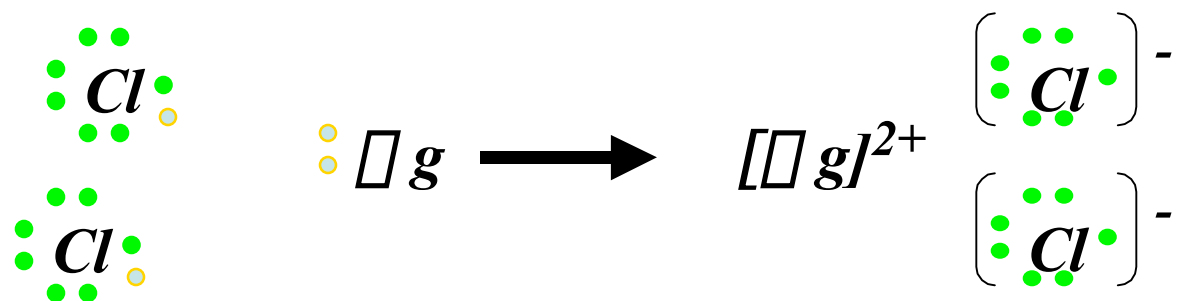


*In H₂O and HF, as in most molecules and polyatomic ions, **nonmetal atoms** except H are surrounded by 8 electrons (an octet). Each atom has a noble gas electronic configuration (ns^2p^6).*

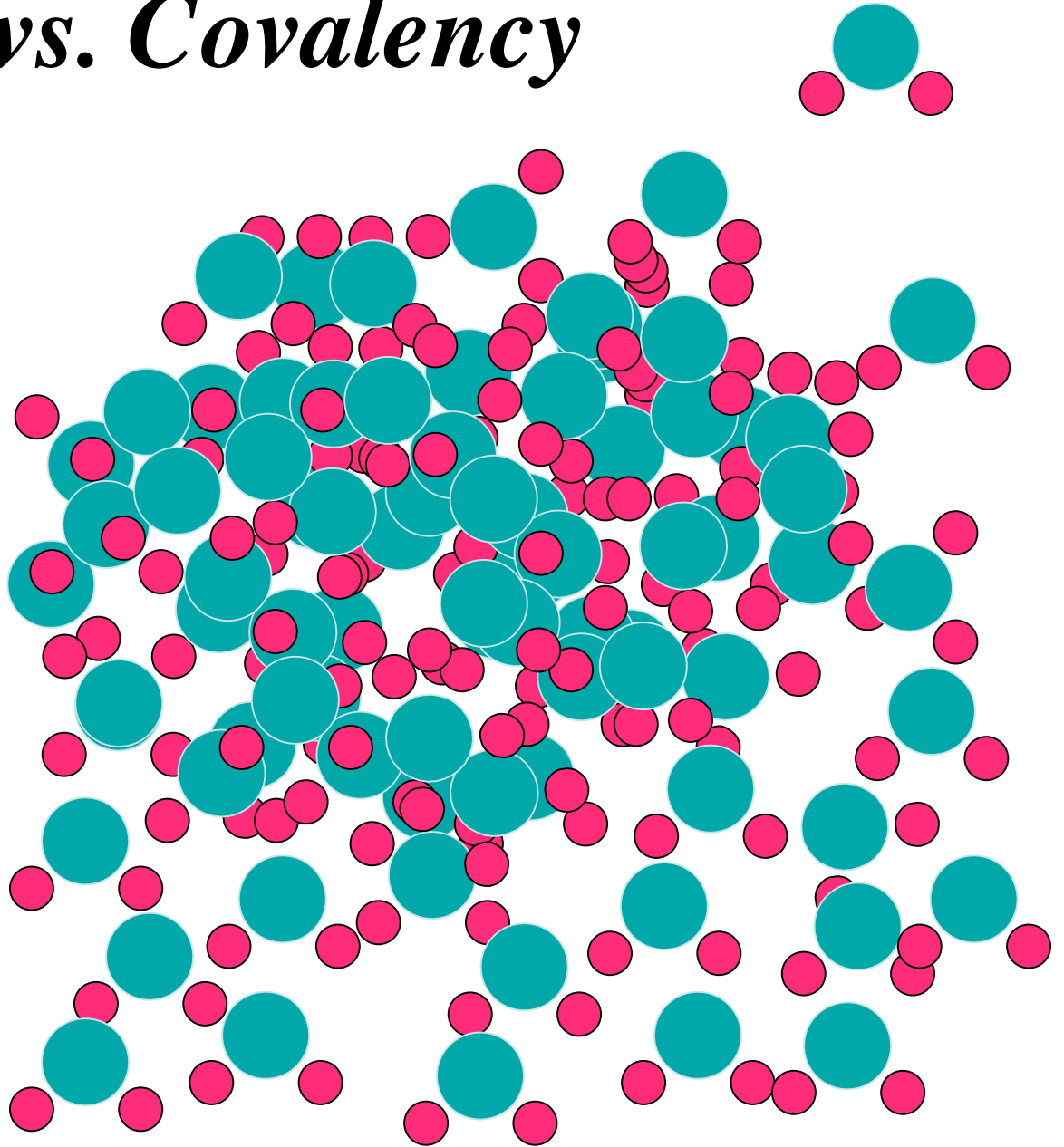
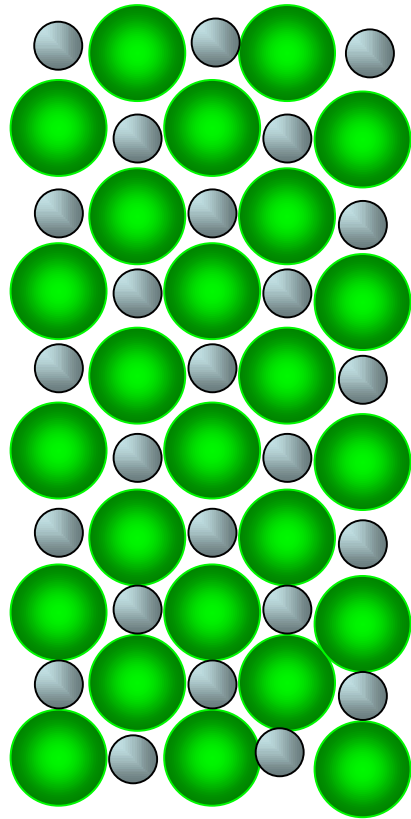
Ionic Bond. Electron Transfer



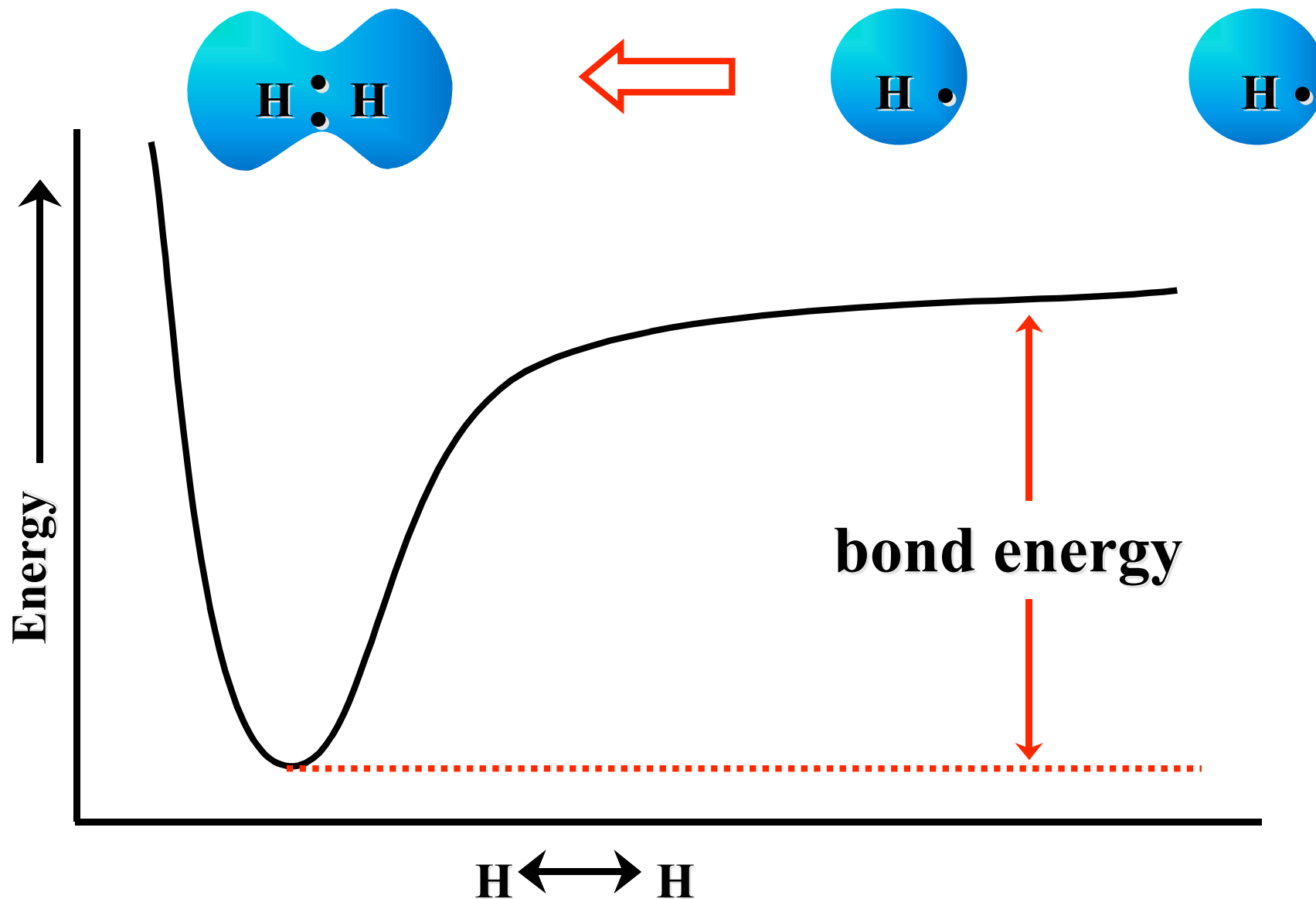
Ionic Bond. Electron Transfer



Ionicity vs. Covalency



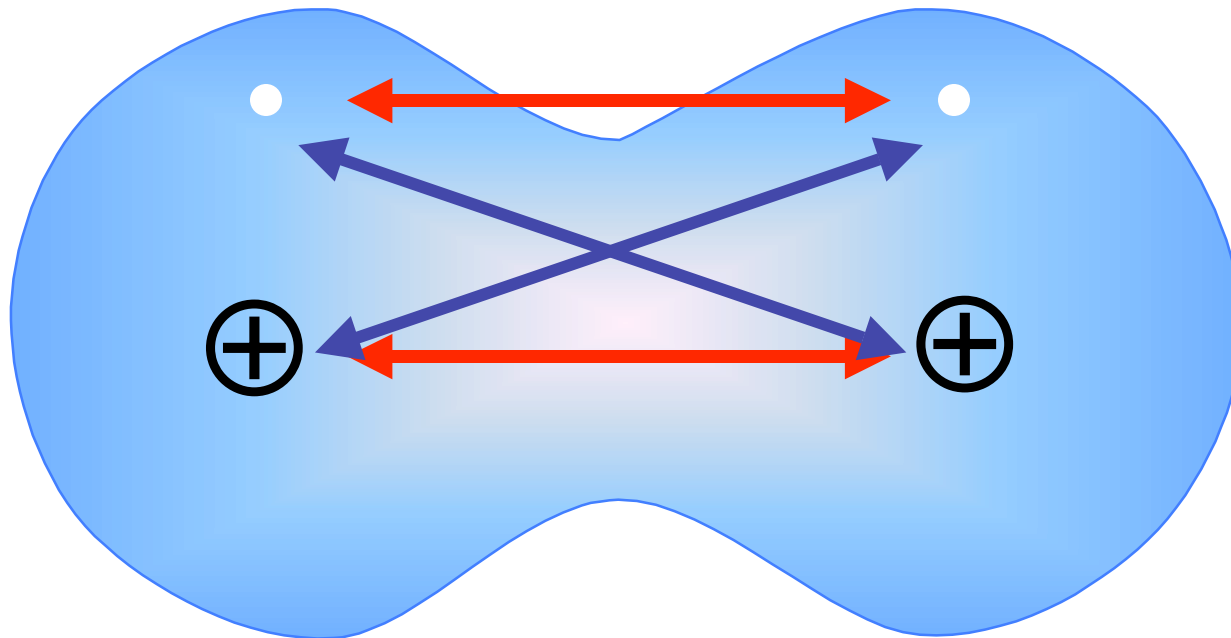
Potential Energy Diagram



Electrostatic forces in the H₂ molecule

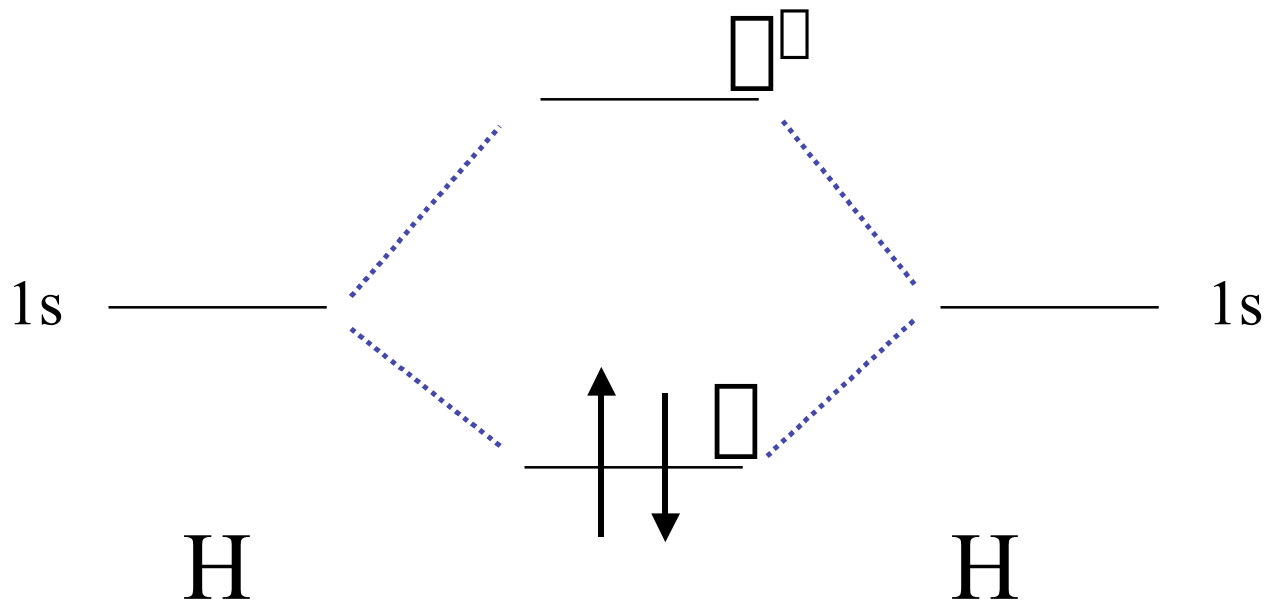
**electron repulsion
(destabilization)**

**nuclear repulsion
(destabilization)**



**electron-nuclear attraction
(stabilization)**

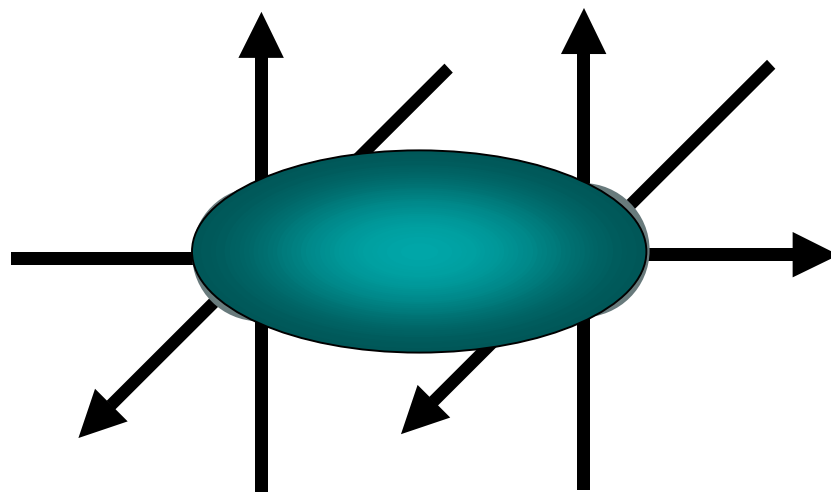
H₂ Electron Configuration: Bonding and Non-Bonding Orbitals



Two s atomic orbital = Two □ molecular orbital (MO)

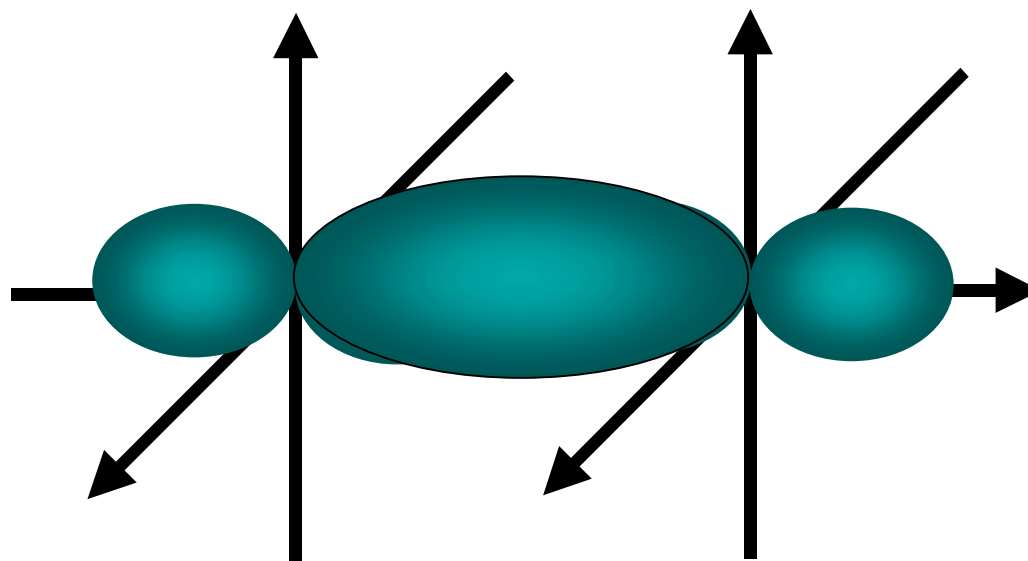
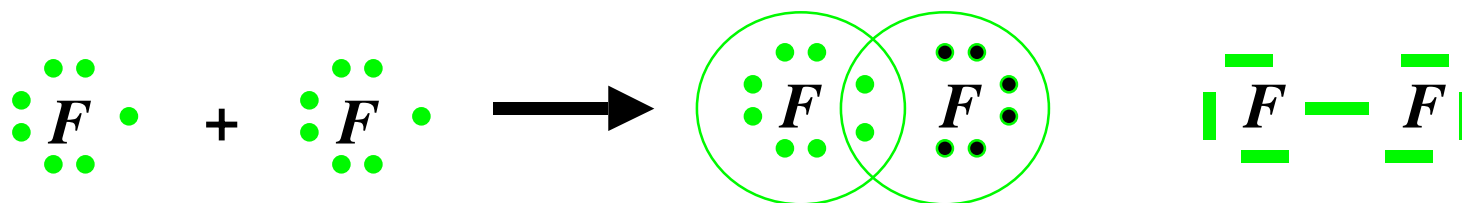
One bonding, one antibonding.

Covalent Bond. Sharing e^-



Only bonding MO shown

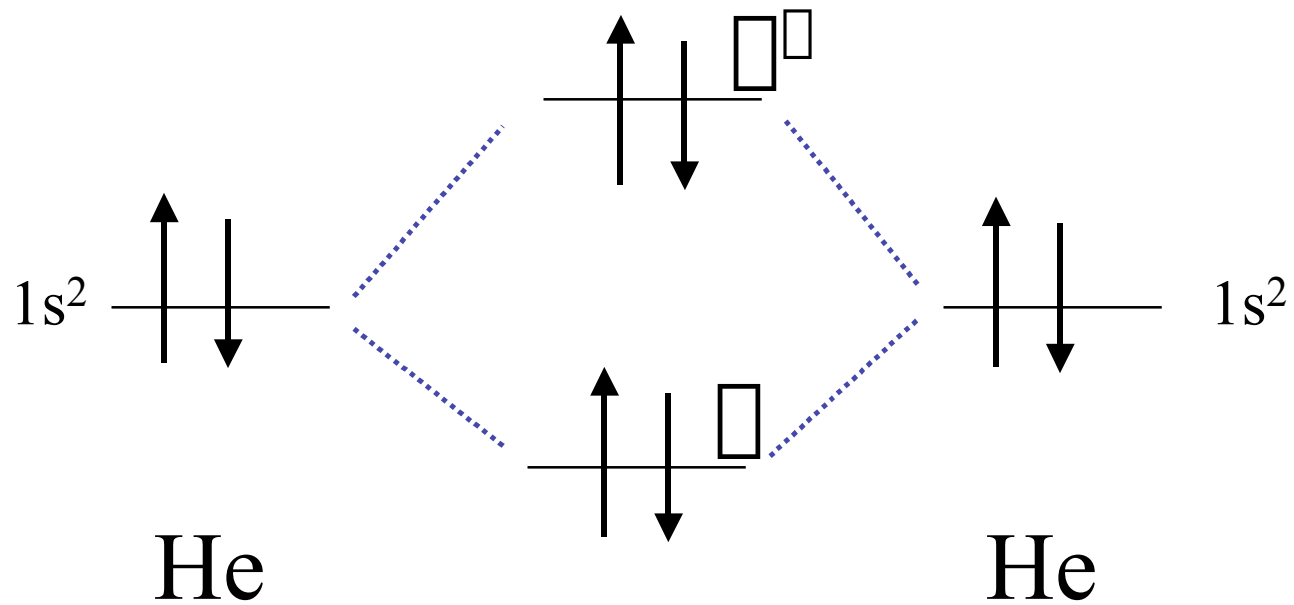
Collinear orbitals form σ bond



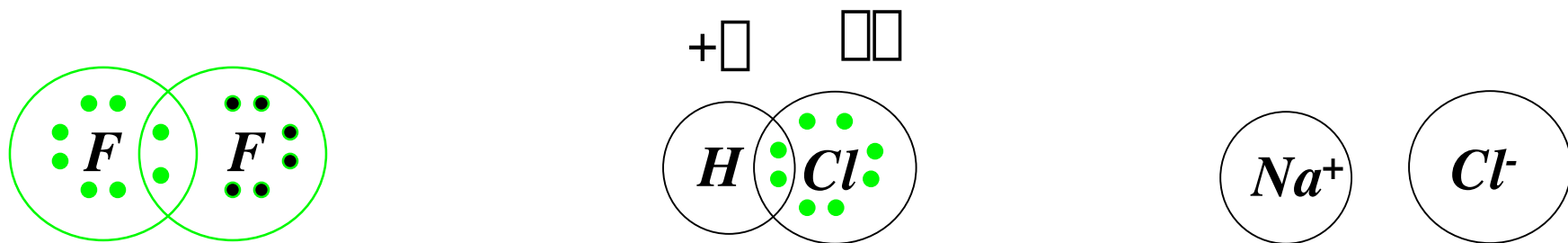
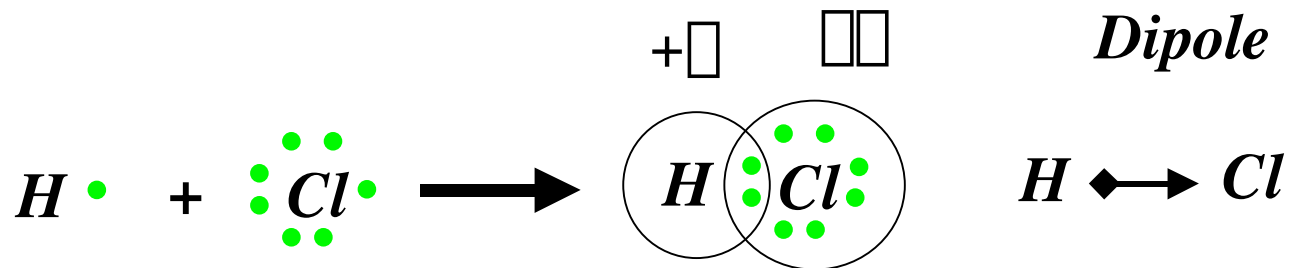
Two p AO = Two σ MO

Only bonding MO shown

He₂ Electron Configuration



Linus Pauling Electronegativity



Lewis Structures of Compounds

Count valence electrons available.

number of valence electrons contributed by nonmetal atom is equal to the last digit of its group number in the periodic table.

(H = 1)

Add electrons to take into account negative charge.

Ex.

OCl⁻ ion: 6 (O) + 7 (Cl) + 1 (charge) = 14 valence e⁻

CH₃OH molecule: 4 (C) + 4(H) + 6 (O) = 14 valence e⁻

Lewis Structures of Compounds

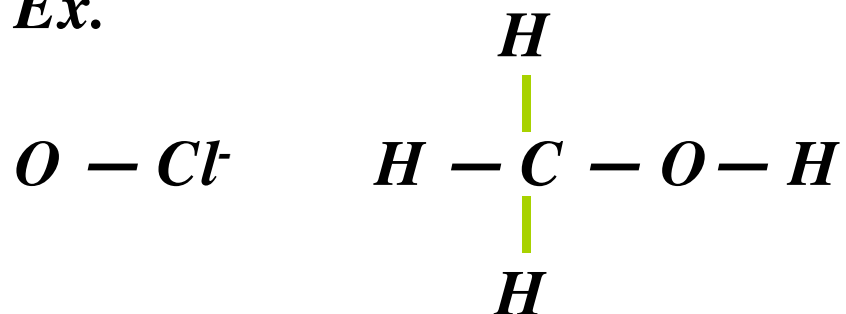
Draw skeleton structure using single bonds

Note that carbon almost always forms four bonds.

Central atom is written first in formula.

Terminal atoms are most often H, O, or a halogen.

Ex.



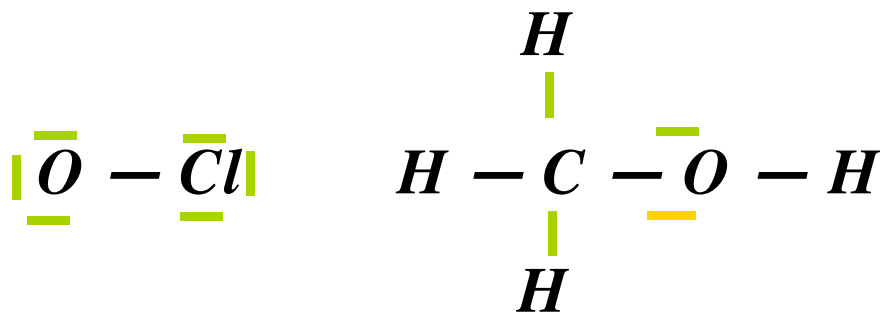
Lewis Structures of Compounds

Subtract two electrons for each single bond

O-Cl⁻ ion: 14 - 2 = 12 valence e⁻ left

CH₃OH molecule: 14 - 10 = 4 valence e⁻ left

Distribute remaining electrons to give each atom a noble gas structure (if possible).



Lewis Structures of Compounds

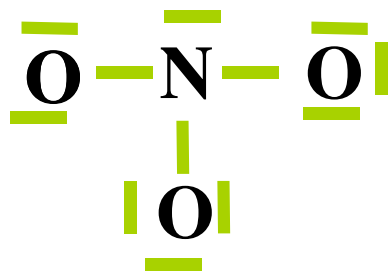
Too Few Electrons?

Form multiple bonds

Ex. What is the structure of the NO_3^- ion?

$$\text{valence } e^- = 5(\text{N}) + 18 (3\text{O}) + 1(\text{charge}) = 24 e^-$$

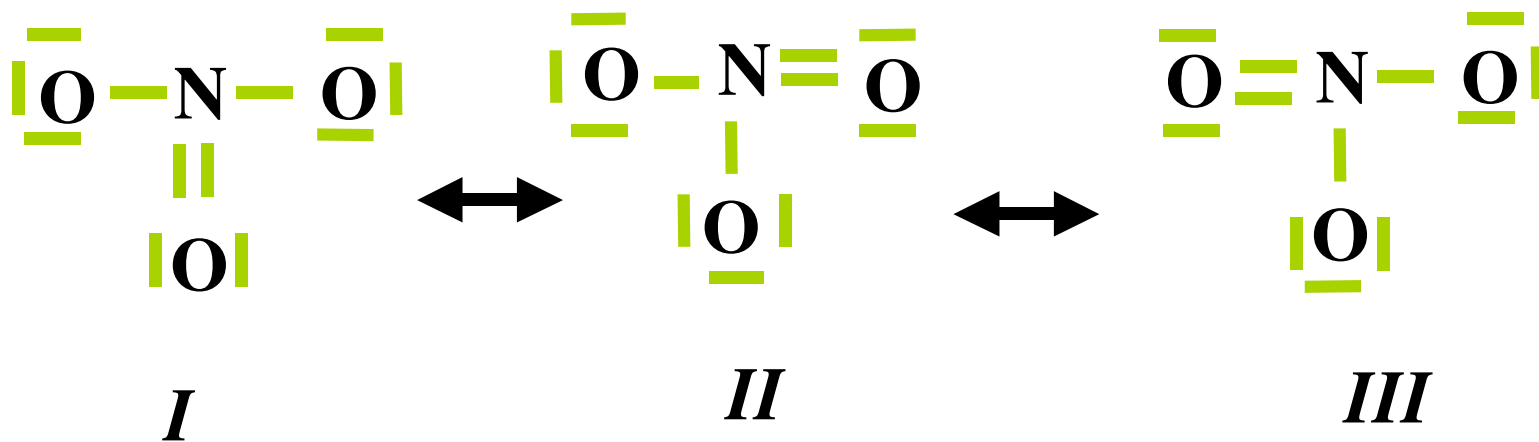
Skeleton:



Nitrate Ion (cont.)

valence e^- left = $24 - 6$ (3 single bonds) = $18 e^-$

Adding a double bond and rearranging:



Resonance Structures

Molecular Geometry

Molecular Geometry. VSEPR

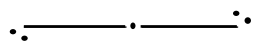
- 1. Electron pairs (lone and bonding pairs) around a central atom tend to be oriented so as to be as far apart as possible to minimize their repulsions*
- 2. The molecular geometry is hence determined by the relative locations of the electron pairs*
- 3. The SN (Steric Number) of the central atom is used to find the geometry that applies*

$$SN = \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \square \\ \hline \end{array} \# \text{ atoms bonded to } \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \square \\ \hline \end{array} + \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \square \\ \hline \end{array} \# \text{ lone pairs on } \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \square \\ \hline \end{array} \text{ central atom}$$

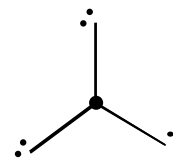
Molecular Geometry

In XY_n molecules in which there are no lone pairs, the SN is used to predict geometry

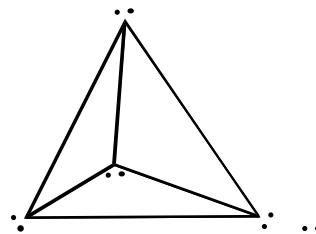
BeF_2 linear (SN = 2)



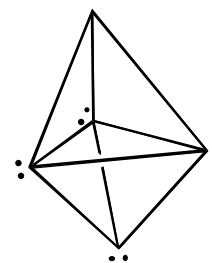
BF_3 trigonal planar (SN = 3)



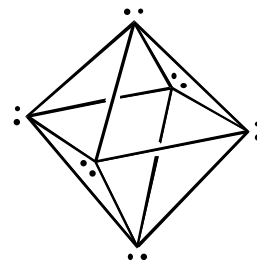
CF_4 tetrahedral (SN = 4)




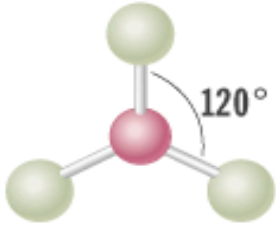
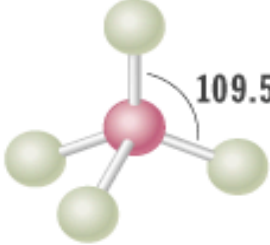
PF_5 trigonal bipyramid (SN = 5)



SF_6 octahedral (SN = 6)



Molecular Geometry

Species type	Orientation of electron pairs	Predicted bond angles	Example	Ball and stick model
AX_2	Linear	180°	BeF_2	
AX_3	Triangular planar	120°	BF_3	
AX_4	Tetrahedron	109.5°	CH_4	

VSEPR model

<i>Molecule</i>	<i>Lewis Str.</i>	<i>Pairs of e-</i>	<i>electron arrangem.</i>	<i>Molecular Shape</i>
H_2S	$H - \overset{\cdot\cdot}{\underset{\cdot\cdot}{S}} - H$	4	<i>tetrahedral</i>	<i>bent</i>
CCl_4	$\begin{array}{c} Cl \\ \\ Cl - C - Cl \\ \\ Cl \end{array}$	4	<i>tetrahedral</i>	<i>tetrahedral</i>