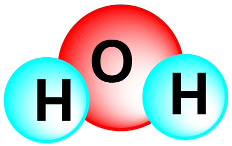
Ch 10. Chemical Bonding
(Representing Bonded Structures)

Types of Compounds

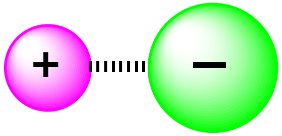
Molecular Compounds

- Covalent bond
- One unit: Molecule



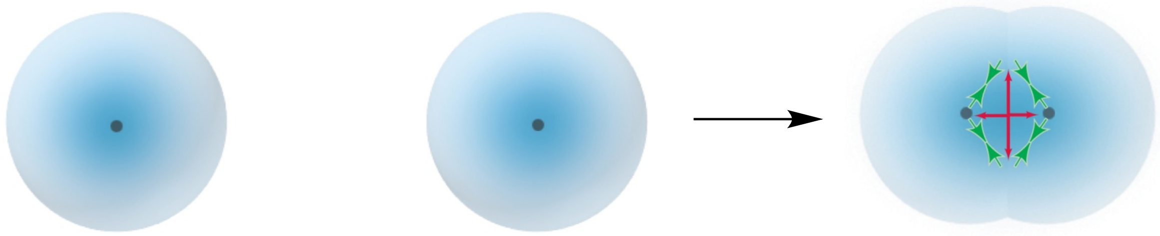
Ionic Compounds

- Ionic bond
- One unit: Formula unit



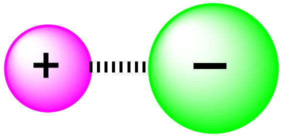
Molecular (Covalent) Compounds

- Held together through Covalent Bonds: Bonds in which electrons are <u>shared</u> between the bonded atoms.



Ionic Compounds

- Held together through Ionic Bonds: Bonds in which oppositely-charged ions are held together by electrostatic attraction between them.



Lewis Structures

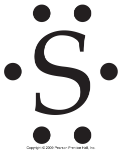
Lewis Symbols for Atoms and Ions

- Lewis Symbol: A way of showing the valence electrons of an atom or ion. Consists of the chemical symbol for element and a dot for each valence electron.

- eg. Sulfur

  Electron configuration [Ne]$3s^2 3p^4$

  Lewis symbol



- Each side can accommodate up to 2 electrons; all four sides are equivalent

Lewis Symbols for Some Main Group Elements

TABLE 2.5 Electron-Dot Symbols for Some Main Group Elements

1A	2A	3A	4A	5A	6A	7A	NOBLE GASES
H·							He:
Li·	·Be·	·B·	·C·	·N:	·O:	·F:	:Ne:
Na ·	·Mg·	·Al·	·Si·	·P:	·S:	·Cl:	:Ar:
K·	·Ca·	·Ga·	·Ge·	·As:	·Se:	·Br:	:Kr:

Ex Probs

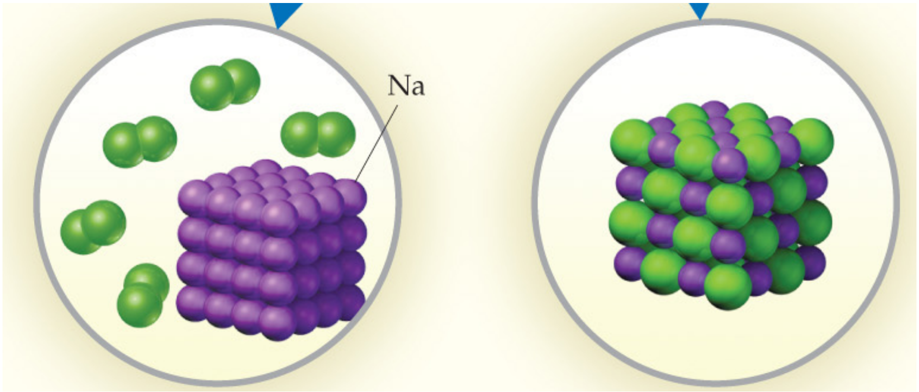
Lewis Structures

- Lewis structure: a representation of a compound that shows how the valence electrons are arranged among the atoms of the compound
- Lewis structures help us understand bonding in compounds.

Octet Rule

- Octet Rule: In reactions, atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons (attain noble gas configuration)
  - Noble gas electron configuration: Highest energy level orbitals (s and p) are completely filled. Very stable.
- Duet Rule: H and Li tend to gain/lose/share electrons until they are surrounded by two electrons.

Lewis Structures of Ionic Compounds



In ionic bonding, atoms transfer electrons until each atom is surrounded by eight valence electrons.

$$\mathrm{Na}\cdot + \cdot\ddot{\underset{\cdot\cdot}{\mathrm{Cl}}}: \longrightarrow \mathrm{Na}^{+} \quad [:\ddot{\underset{\cdot\cdot}{\mathrm{Cl}}}:]^{-}$$

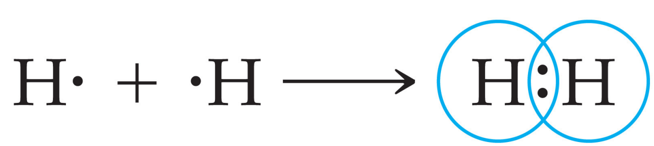
$[Ne]3s^1$ $[Ne]3s^23p^5$ [Ne] [Ar]

Ex Probs

Lewis Structures for Molecular Compounds

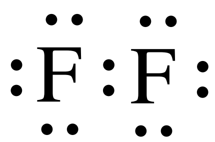
In covalent bonding, atoms share electrons until each atom is surrounded by eight valence electrons:

Cl [Ne]$3s^2 3p^5$

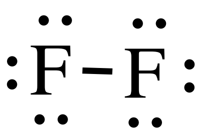
(or duet rule for H, Li): 

Lewis Structure Terminology

- A pair of shared electrons = bond
- A pair of unshared electrons = lone pairs



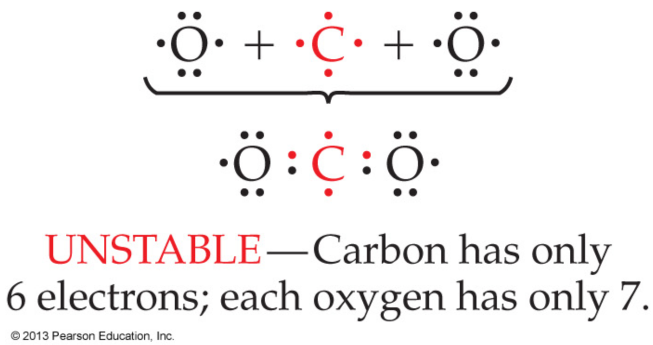
- A bond is represented by a line.

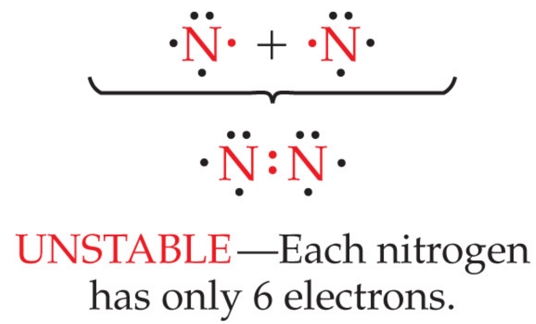


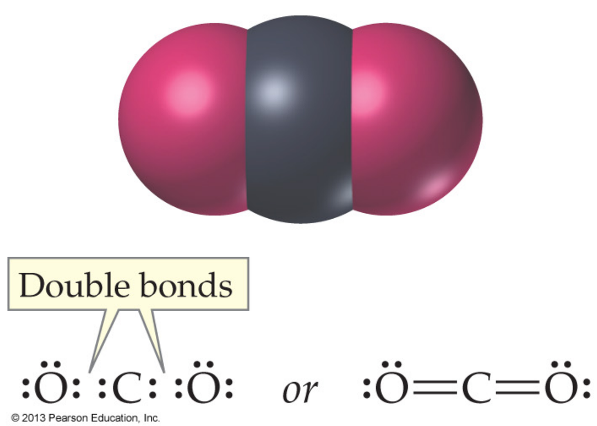
Multiple Covalent Bonds

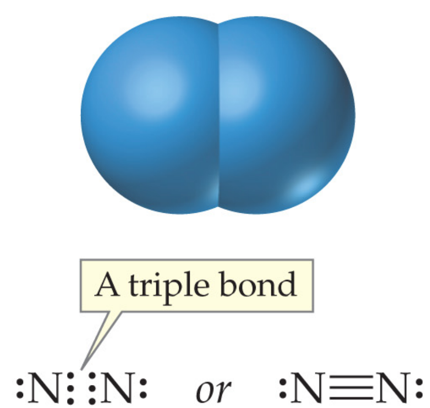
Sometimes, two atoms in a molecule need to share more than 2 electrons to achieve the octet.

→ Double and triple bonds









Single, Double, Triple Bonds

- Single bond – covalent bond in which 1 pair of electrons (2 electrons) is shared by two atoms.

  H–H

- Double bond – covalent bond in which 2 pairs of electrons are shared by two atoms.

  :Ö=C=Ö:

- Triple bond – covalent bond in which 3 pairs of electrons are shared by two atoms.

  :N≡N:

Steps to Drawing Lewis Structures

Goal is to get octet around each atom!

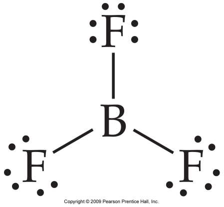
1. Add up valence electrons from all atoms.
2. Draw "skeleton structure": atoms connected by single bonds.
3. Arrange the remaining electrons as lone pairs on terminal atoms to satisfy the octet rule (or duet rule for hydrogen).
4. Place any left-over electrons as lone pairs on the central atom.
5. If there are not enough electrons to give the central atom an octet, use electrons from surrounding atoms to make multiple bonds.

Ex Probs

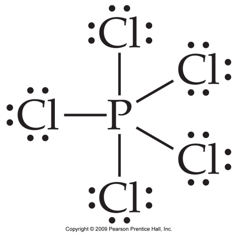
Exceptions to Octet Rule

Molecules containing :

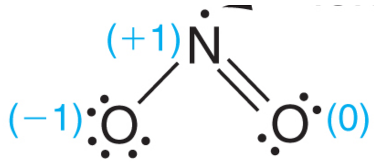
1. an atom with fewer than an octet of valence electrons



2. an atom with more than an octet of valence electrons ("expanded valence shell")



3. an odd number of electrons

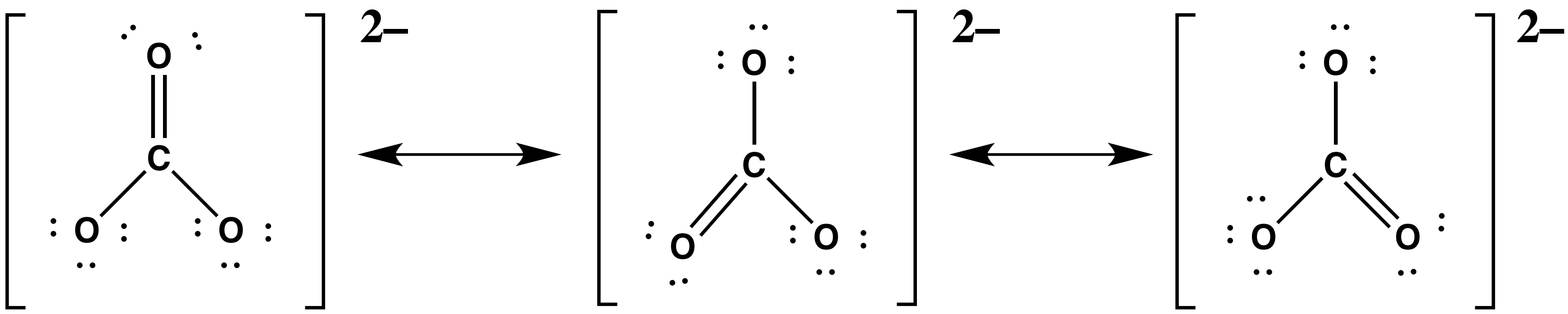


Multiple Lewis Structures

Sometimes, more than one Lewis structure that satisfies the octet rule can be drawn for a molecule: Resonance structure

Resonance Structures

- Resonance structures: the structures of a molecule whose average gives an accurate description of the real molecule

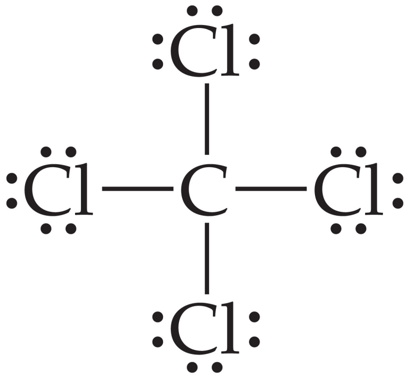


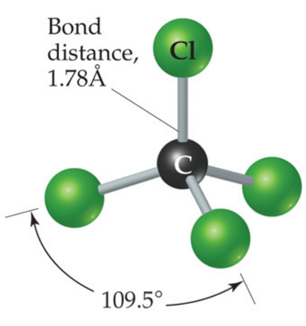
- Represents electron delocalization.

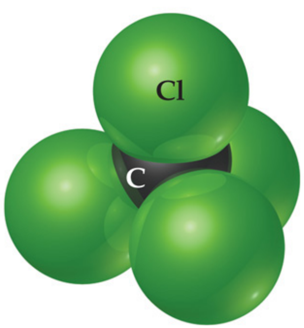
Molecular Shape

Molecular Shape

- Lewis structures show composition and atom-to-atom connectivity of molecules.
- But they don't show the 3D shapes of molecules (bond angles) → Use VSEPR Model







Predicting Molecular Structure: VSEPR Model

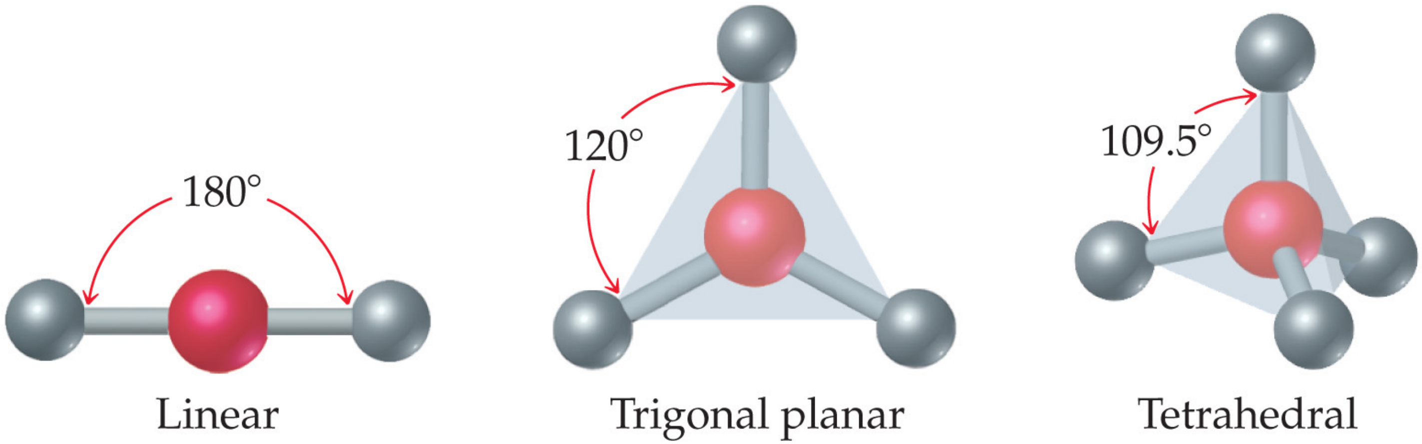
VSEPR Model (Valence-Shell Electron-Pair Repulsion Model):

The structure around a given atom is determined by minimizing repulsions between electron domains → Electron domains are as far apart as possible.

An electron domain can be:

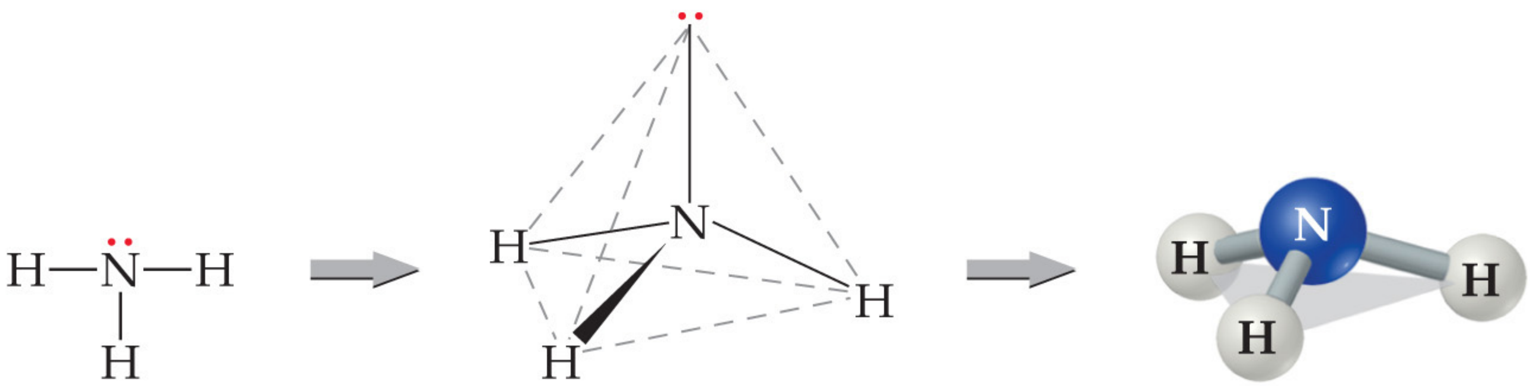
- a bond (single or multiple) OR a lone pair

Electron Domain Geometries that Minimize Repulsion



Electron Domain Geometry vs. Molecular Geometry

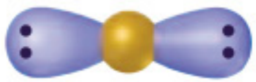
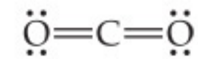
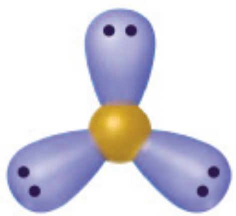
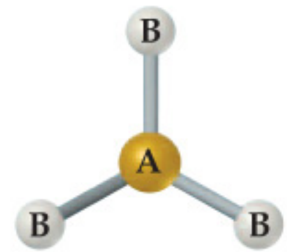
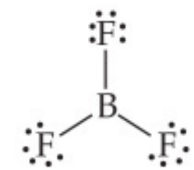
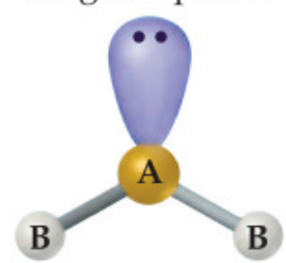
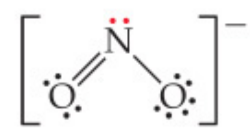
- Electron domain geometry: Geometry of the electron domains about a central atom
- Molecular geometry: Geometry of the bonded atoms about a central atom



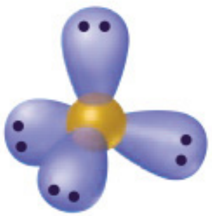
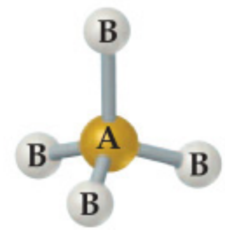
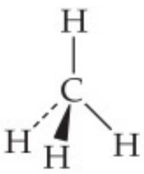
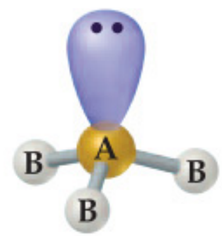
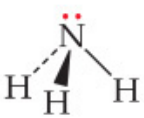
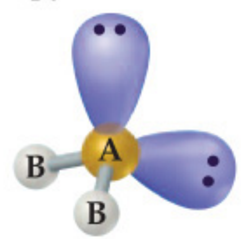
Electron domain Geometry
Tetrahedral

Molecular Geometry
Trigonal Pyramidal

Electron Domain and Molecular Geometry

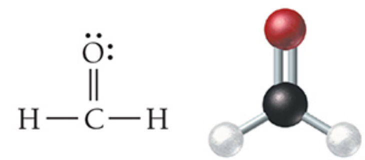
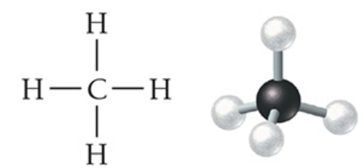
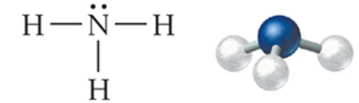
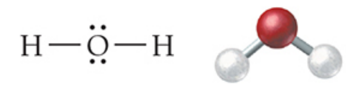
# Electron Domains	Electron Domain Geometry	No. of Bonds	No. of Lone Pairs	Molecular Geometry	Example
2	 Linear	2	0	 Linear	
3	 Trigonal planar	3	0	 Trigonal planar	
		2	1	 Bent	

Electron Domain and Molecular Geometry

# Electron Domains	Electron Domain Geometry	No. of Bonds	No. of Lone Pairs	Molecular Geometry	Example
4	 Tetrahedral	4	0	 Tetrahedral	
		3	1	 Trigonal pyramidal	
		2	2	 Bent	

Electron Domain and Molecular Geometry

TABLE 10.1 Electron and Molecular Geometries

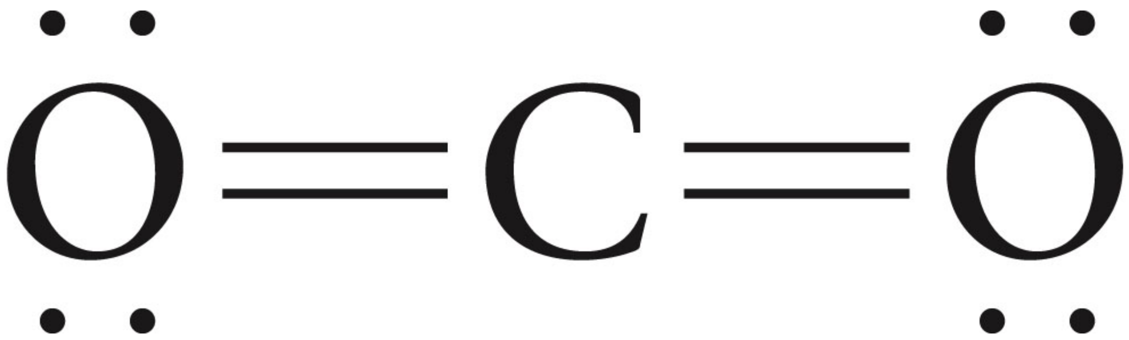
Electron Groups*	Bonding Groups	Lone Pairs	Electron Geometry	Angle between Electron Groups**	Molecular Geometry	Example
2	2	0	linear	180°	linear	
3	3	0	trigonal planar	120°	trigonal planar	
3	2	1	trigonal planar	120°	bent	
4	4	0	tetrahedral	109.5°	tetrahedral	
4	3	1	tetrahedral	109.5°	trigonal pyramidal	
4	2	2	tetrahedral	109.5°	bent	

* Count only electron groups around the *central* atom. Each of the following is considered one electron group: a lone pair, a single bond, a double bond, and a triple bond.

** Angles listed here are idealized. Actual angles in specific molecules may vary by several degrees. For example, the bond angles in ammonia are 107° and the bond angle in water is 104.5°.

Structures for Molecules with Double Bond

- Remember, an electron domain can be a single, double, or triple bond (or a lone pair).
  - Eg. Carbon in CO_2 has <u>two</u> electron domains.



Steps to Predict Molecular Structure Using VSEPR

1. Draw the Lewis structure for the molecule.
2. Count the <u>electron domains</u> and arrange them in the way that minimizes repulsion → electron domain geometry
3. Look at the <u>positions of the atoms</u> → molecular geometry

Ex Probs

Polar Covalent Bonds

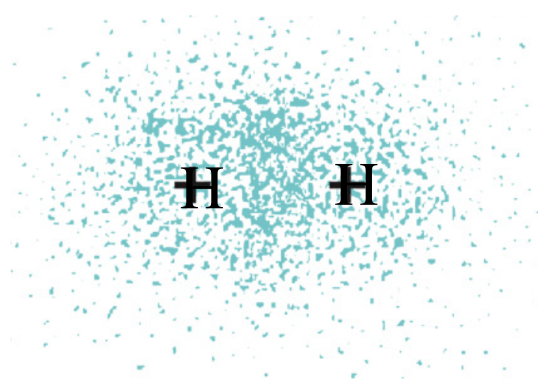
Polar Covalent Bonds

Types of Bonds

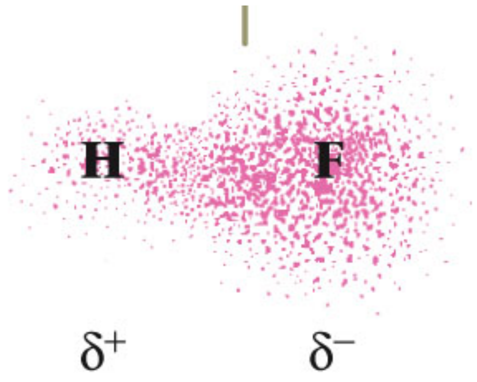
1. Ionic bond
2. Covalent bond
   a) Nonpolar covalent bond
   b) Polar covalent bond

Polar Covalent Bonding

- Nonpolar covalent bonding: Electrons are shared equally between two atoms.
- Polar covalent bonding: Electrons are shared unequally between two atoms (One atom attracts the electrons more than the other atom).
→ Results in a partial charge separation in the bond: polarity



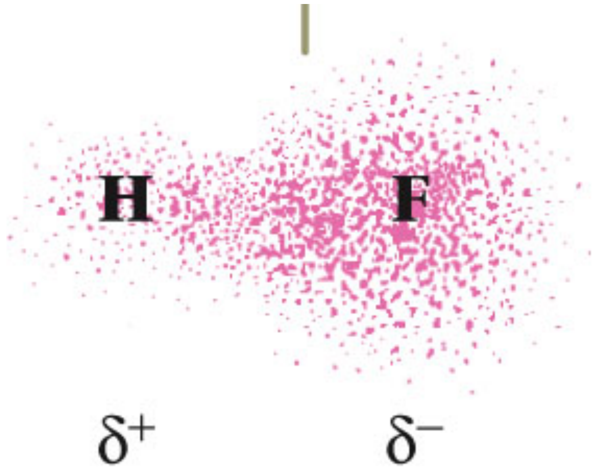
Nonpolar Covalent

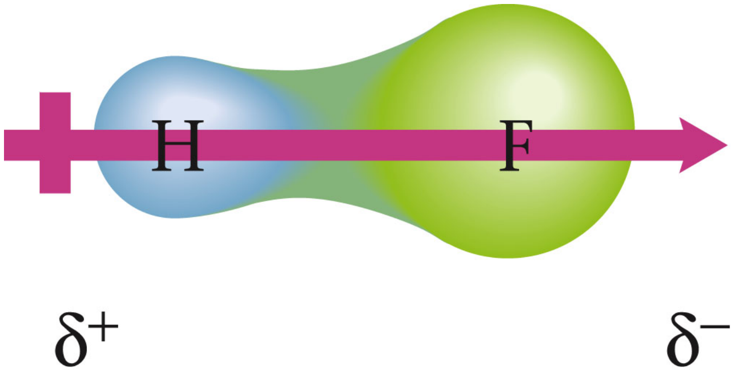


Polar Covalent

Bond Polarity Represented by a Dipole Moment

- Dipole moment: A measure of polarity (q x d)
- The dipole moment is a vector (has both magnitude and direction), represented by an arrow.



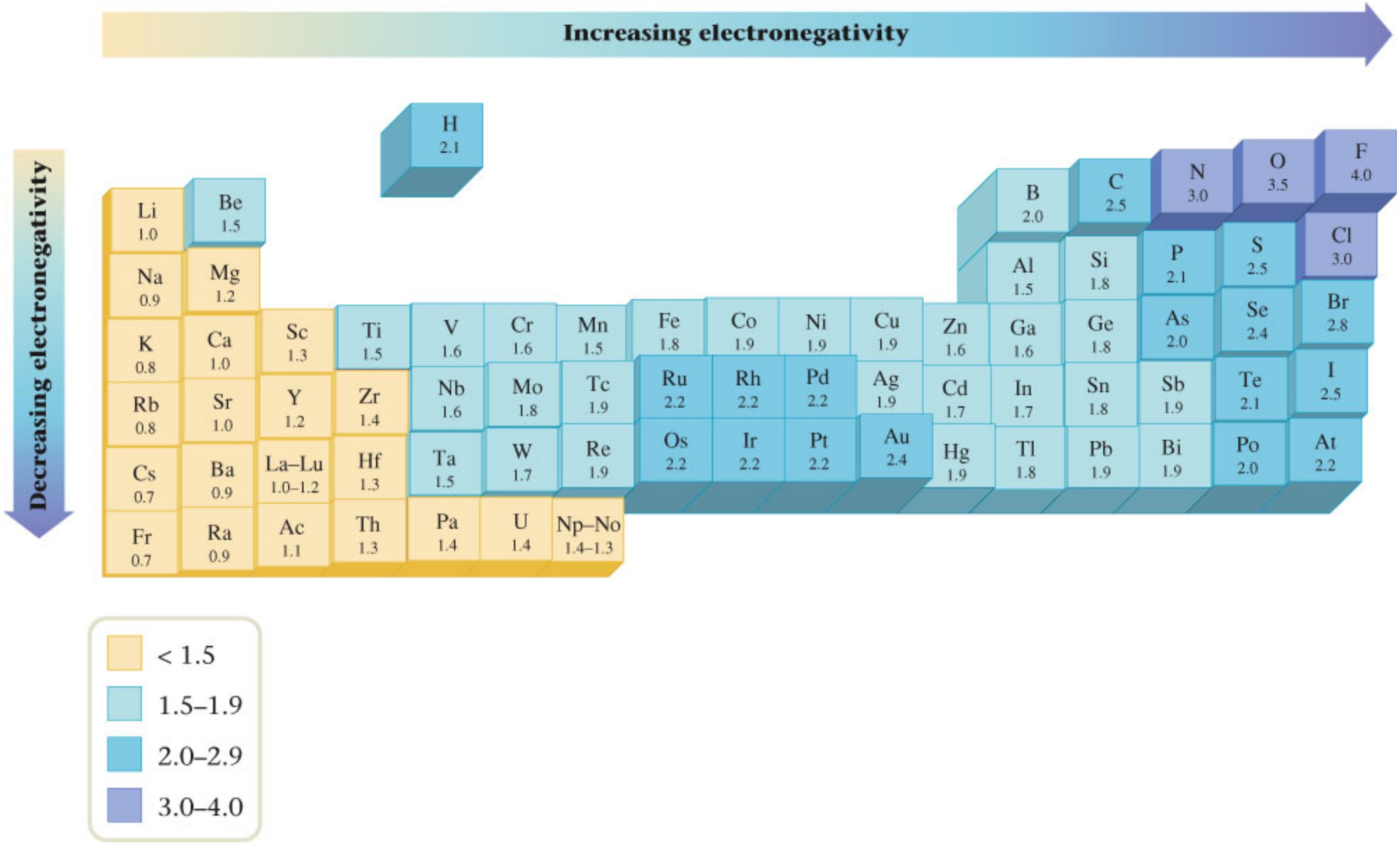


Electronegativity

- The polarity of a bond depends on the electronegativity of the atoms in the bond.

- Electronegativity: The relative ability of an atom in a molecule to attract shared electrons to itself.

Electronegativity Trend

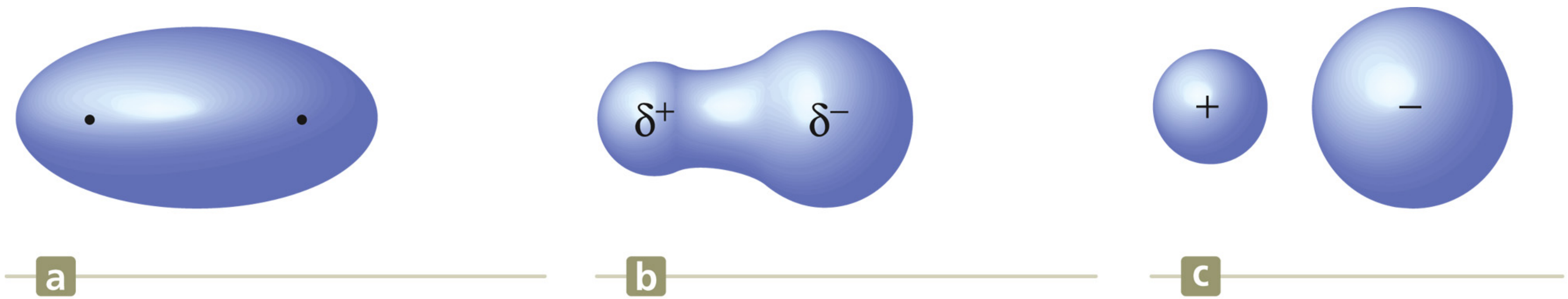


Range 0.7 – 4.0

Ex Probs

Electronegativity and Bond Type

The bond type is determined by the difference in the electronegativity of the atoms in the bond.



H-H	H-F	K^+ --- Cl^-
no or v. small electroneg difference	larger electroneg difference	v. large electroneg difference
nonpolar covalent bond	polar covalent covalent bond	ionic bond

General Guidelines: Electronegativity and Bond Type

TABLE 10.2 The Effect of Electronegativity Difference on Bond Type

Electronegativity Difference (ΔEN)	Bond Type	Example
zero (0–0.4)	pure covalent	Cl_2
intermediate (0.4–2.0)	polar covalent	HF
large (2.0+)	ionic	NaCl

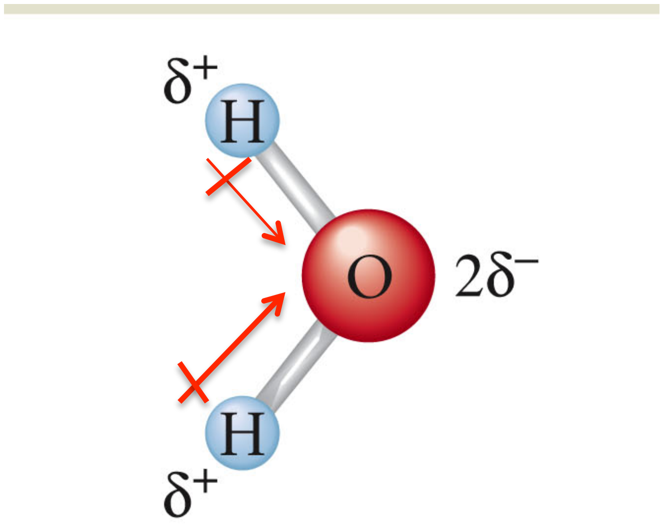
Observations: Electronegativity Diffs and Bond Polarity

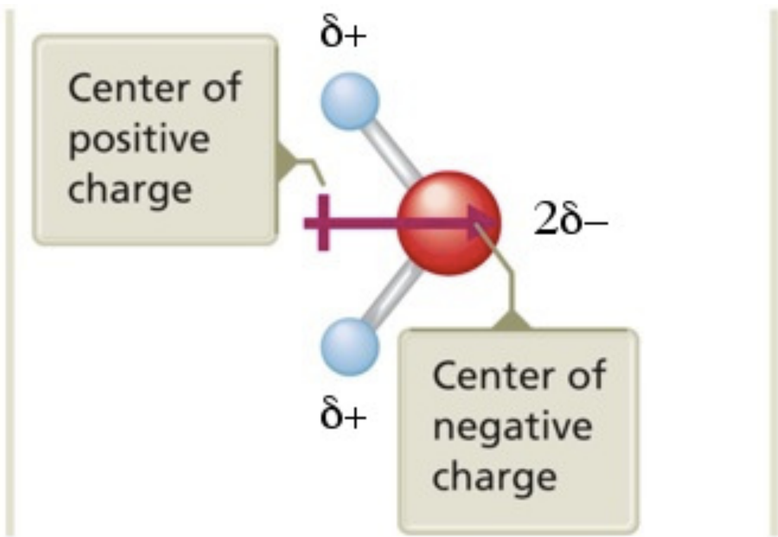
- Lower left corner of periodic table has lowest electronegativity values; upper right has highest electronegativity values.
- N, O, F, Cl have the highest electronegativity values.
- H and C have electronegativity values that are similar to each other, and that are significantly lower than those of N, O, F, or Cl.
- C-H bonds are nonpolar. C or H bonded to N, O, F, Cl are polar.

Ex Probs

Polar Molecules

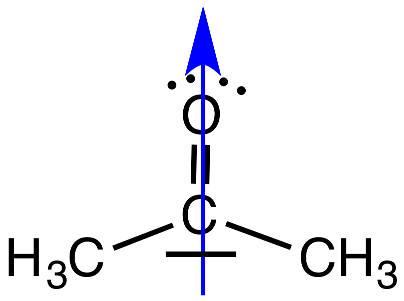
- Dipole moments of bonds in a molecule can add or subtract, to give a net molecular dipole moment.
- Polar molecule: A molecule with a net molecular dipole moment. Molecule as a whole has a partial + end and partial – end.

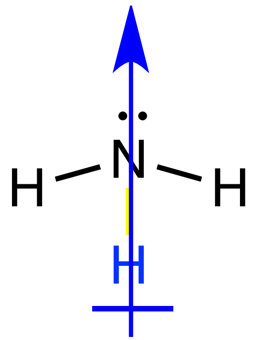


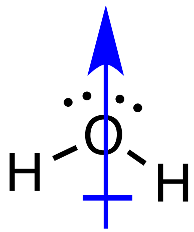


Polar Molecules

- Molecular polarity depends on both <u>bond dipole moments</u> and <u>molecular geometry!</u>



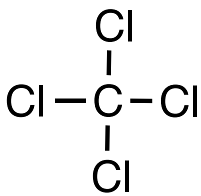


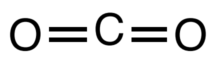


Nonpolar Molecules

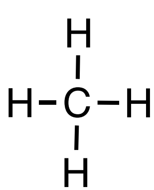
Nonpolar molecule: Has NO net dipole moment, b/c:

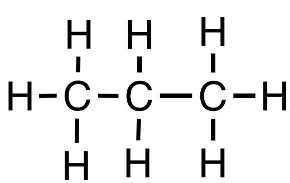
(1) has polar bonds whose dipole moments cancel, or

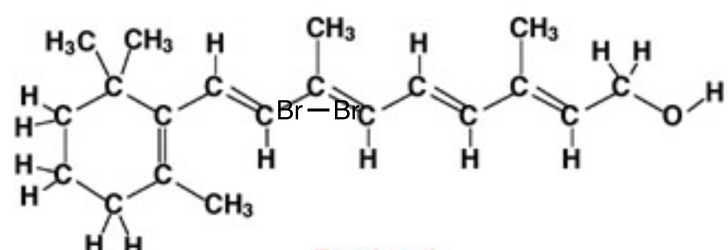




(2) has no polar bonds (think “oily” or “greasy”).







Retinol

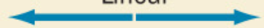
Any hydrocarbon molecules

Determining Whether a Molecule is Polar or Nonpolar

1. Determine the molecular geometry.
2. Determine whether each bond in the molecule is polar or nonpolar.
   - If there are no polar bonds, molecule is nonpolar.
3. Draw dipole moments for the polar bonds.
4. Add dipole moments:
   - If dipole moments cancel , molecule is nonpolar.
   - If there there is a net dipole moment, molecule is polar.

Common Cases of Adding Dipole Moments

Linear



Nonpolar

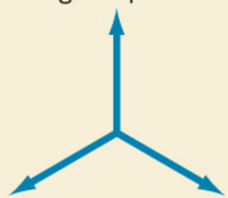
The dipole moments of two identical polar bonds pointing in opposite directions will cancel. The molecule is nonpolar.

Bent

Polar

The dipole moments of two polar bonds with an angle of less than 180° between them will not cancel. The resultant dipole moment vector is shown in red. The molecule is polar.

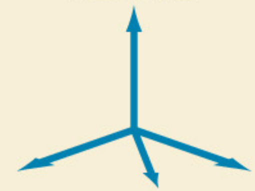
Trigonal planar



Nonpolar

The dipole moments of three identical polar bonds at 120° from each other will cancel. The molecule is nonpolar.

Tetrahedral



Nonpolar

The dipole moments of four identical polar bonds in a tetrahedral arrangement (109.5° from each other) will cancel. The molecule is nonpolar.

Trigonal pyramidal

Polar

The dipole moments of three polar bonds in a trigonal pyramidal arrangement (109.5° from each other) will not cancel. The resultant dipole moment vector is shown in red. The molecule is polar.

Ex Probs

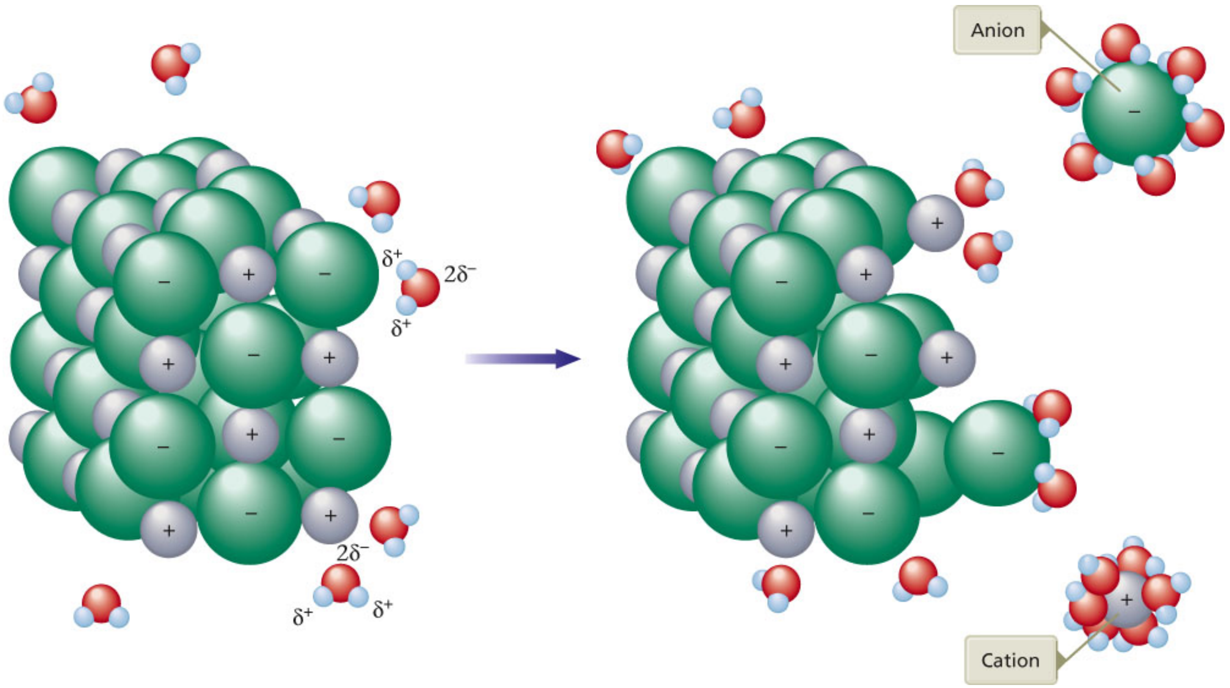
"Like Dissolves Like"

- Polar solvents dissolve polar solutes and ionic solutes.

- Nonpolar solvents dissolve nonpolar solutes.

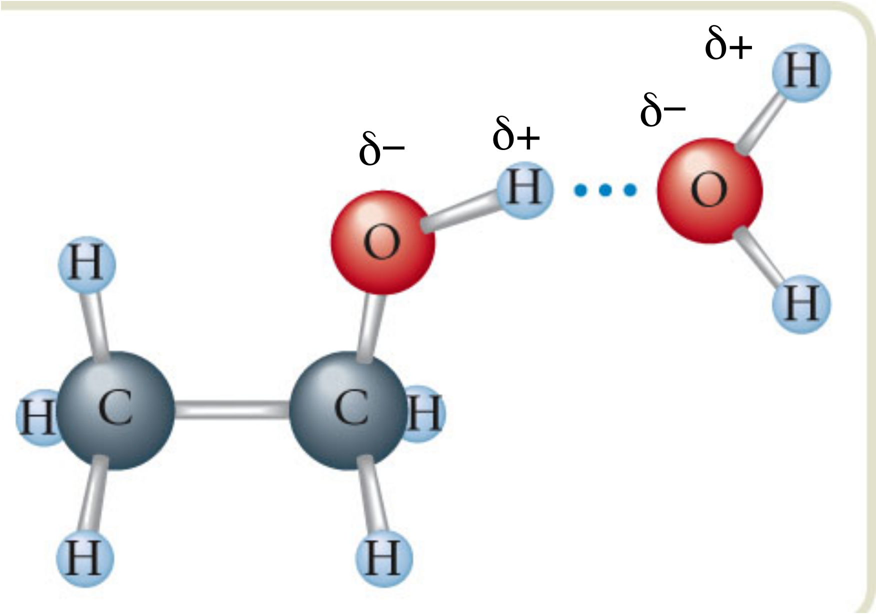
Ionic Solute is Soluble in Polar Solvent

- Polar solvent molecules are attracted to the cations and anions of an ionic solid, and help break up the ionic solid into individual cations and anions.



Polar Solute is Soluble in Polar Solvent

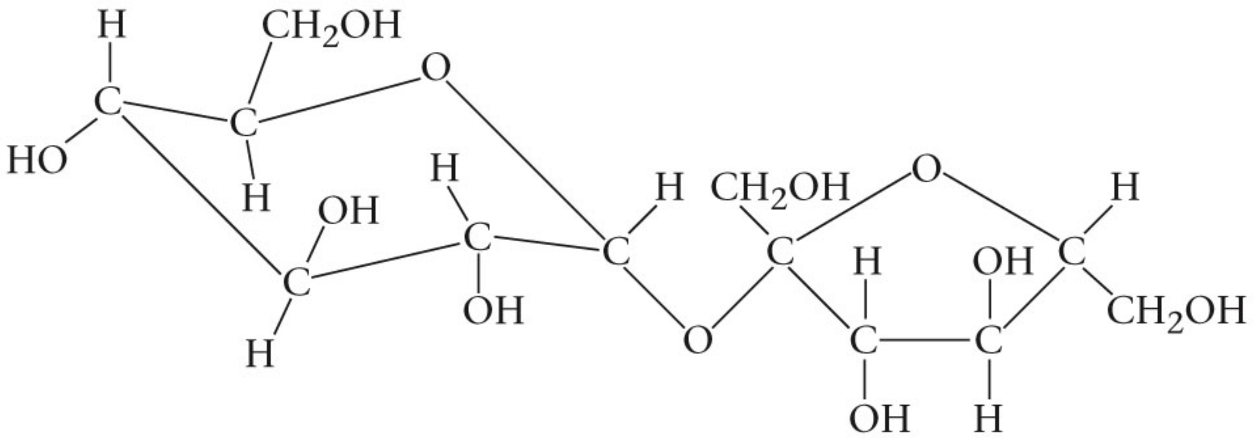
- Polar solute attracts polar solvent.



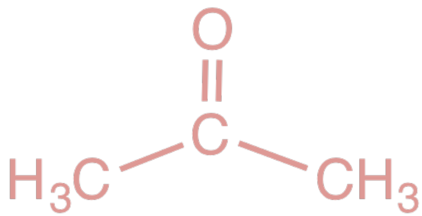
Eg. Water + Ethanol (C_2H_5OH)

Polar Solute is Soluble in Polar Solvent

- Why is solid sugar soluble in water?

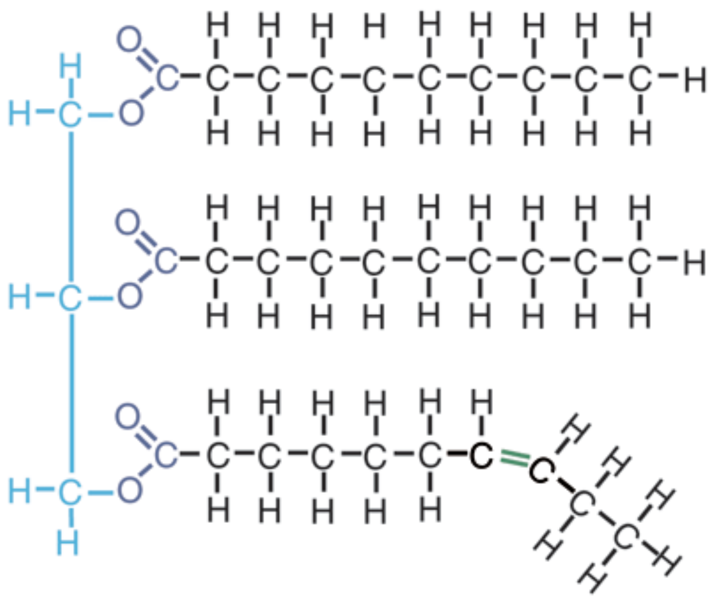


- Why is acetone soluble in water?

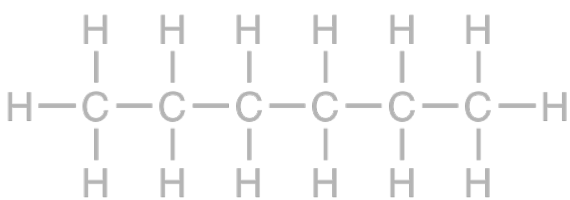


Nonpolar Solute is Soluble in Nonpolar Solvent

- Nonpolar solute attracts nonpolar solvent.



Eg. Fat



Hexane

Polar Solvent and Nonpolar Solute Do Not Mix

- Nonpolar substances do not have strong attraction to polar substances.
- Eg. Oil and water mixture: There are stronger attractions between the water molecules and between the oil molecules than between water and oil molecules.