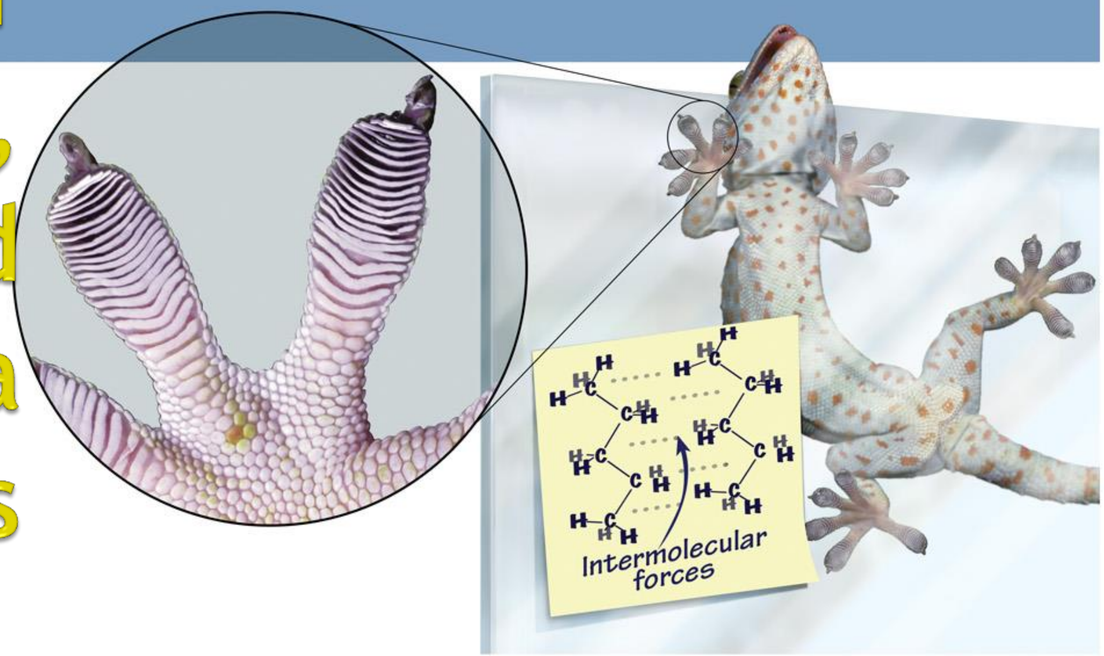
Chemistry: A Molecular Approach, 1st Ed.
Nivaldo Tro

Chapter 11 Liquids, Solids, and Intermolecular Forces



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2008, Prentice Hall

Comparisons of the States of Matter

- the solid and liquid states have a much higher density than the gas state
  - therefore the molar volume of the solid and liquid states is much smaller than the gas state
- the solid and liquid states have similar densities
  - generally the solid state is a little denser
    - notable exception: ice is less dense than liquid water
- the molecules in the solid and liquid state are in close contact with each other, while the molecules in a gas are far apart

Freedom of Motion

- the molecules in a gas have complete freedom of motion
  - their kinetic energy overcomes the attractive forces between the molecules
- the molecules in a solid are locked in place, they cannot move around
  - though they do vibrate, they don't have enough kinetic energy to overcome the attractive forces
- the molecules in a liquid have limited freedom – they can move around a little within the structure of the liquid
  - they have enough kinetic energy to overcome some of the attractive forces, but not enough to escape each other

Properties of the 3 Phases of Matter

State	*Shape*	*Volume*	*Compressible*	*Flow*	*Strength of Intermolecular Attractions*
Solid	*Fixed*	*Fixed*	*No*	*No*	*very strong*
Liquid	*Indef.*	*Fixed*	*No*	*Yes*	*moderate*
Gas	*Indef.*	*Indef.*	*Yes*	*Yes*	*very weak*

- Fixed = keeps shape when placed in a container
- Indefinite = takes the shape of the container

Gas Structure

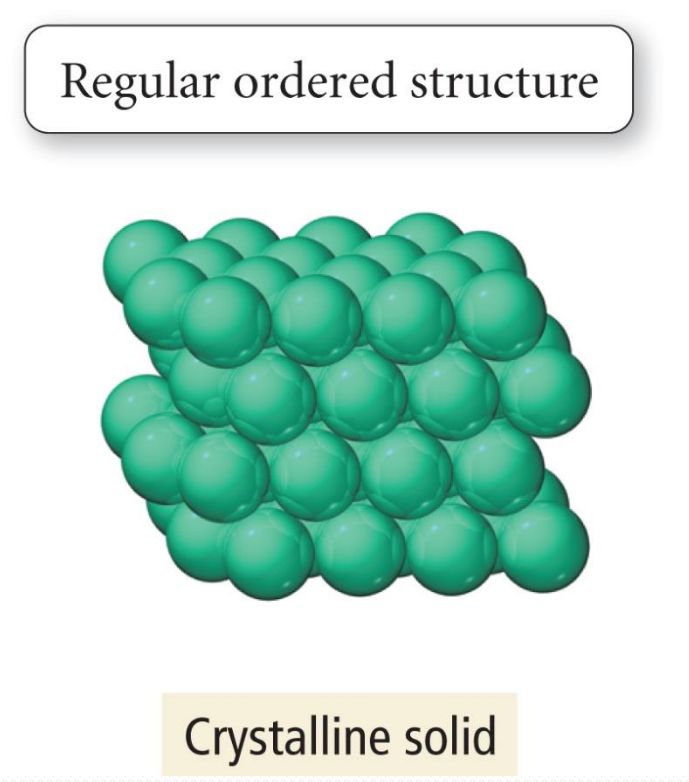
Gas molecules are rapidly moving in random straight lines and free from sticking to each other.

Explaining the Properties of Solids

- the particles in a solid are packed close together and are fixed in position
  - though they may vibrate
- the close packing of the particles results in solids being incompressible
- the inability of the particles to move around results in solids retaining their shape and volume when placed in a new container; and prevents the particles from flowing

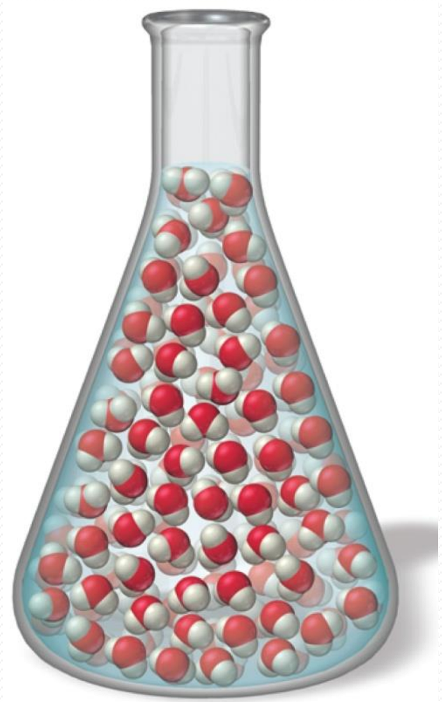
Solids

- some solids have their particles arranged in an orderly geometric pattern – we call these **crystalline solids**
  - salt and diamonds
- other solids have particles that do not show a regular geometric pattern over long range – we call these **amorphous solids**
  - plastic and glass

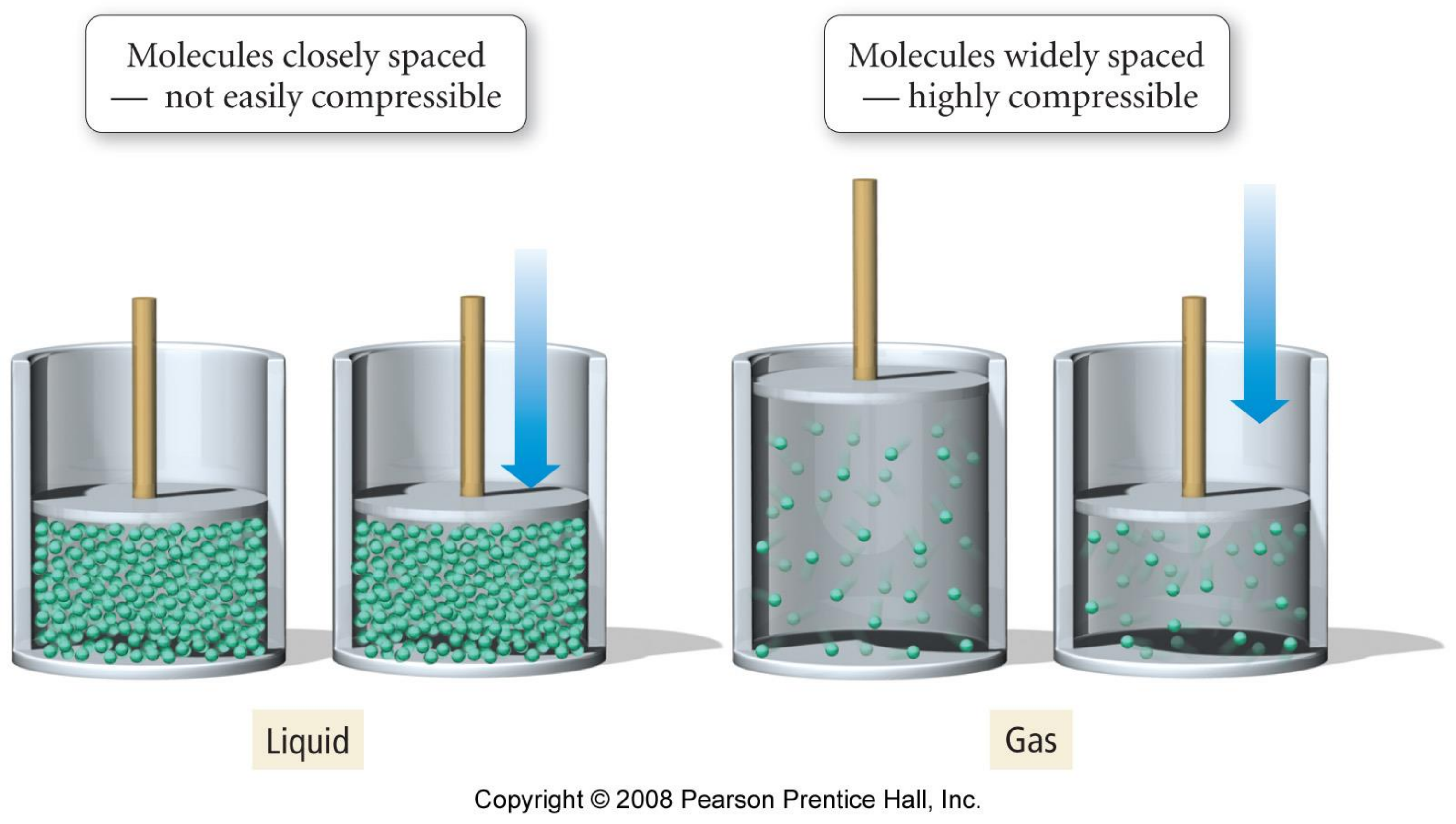


Explaining the Properties of Liquids

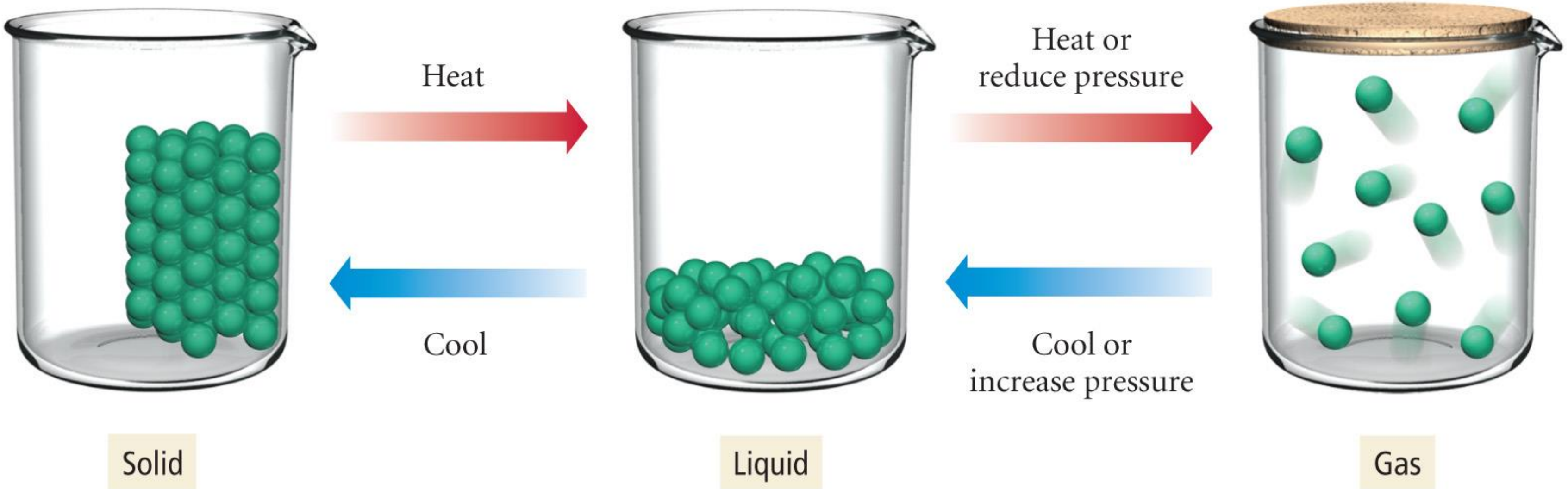
- they have higher densities than gases because the molecules are in close contact
- they have an indefinite shape because the limited freedom of the molecules allows them to move around enough to get to the container walls
- but they have a definite volume because the limit on their freedom keeps them from escaping the rest of the molecules



Compressibility

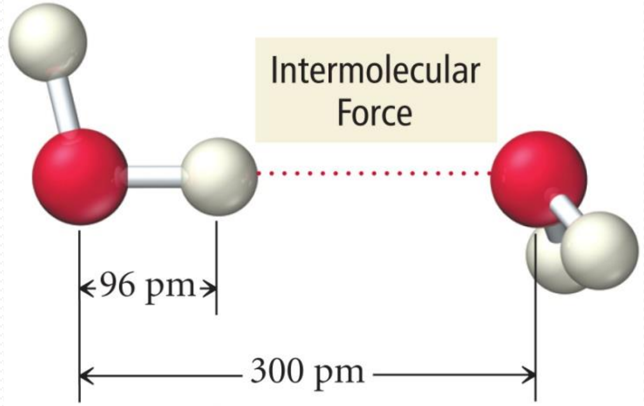


Phase Changes



Why are molecules attracted to each other?

- intermolecular attractions are due to attractive forces between opposite charges
  - + ion to - ion
  - + end of polar molecule to - end of polar molecule
    - H-bonding especially strong
  - even nonpolar molecules will have temporary charges
- **larger the charge = stronger attraction**
- **longer the distance = weaker attraction**
- however, these attractive forces are small relative to the bonding forces between atoms
  - generally smaller charges
  - generally over much larger distances



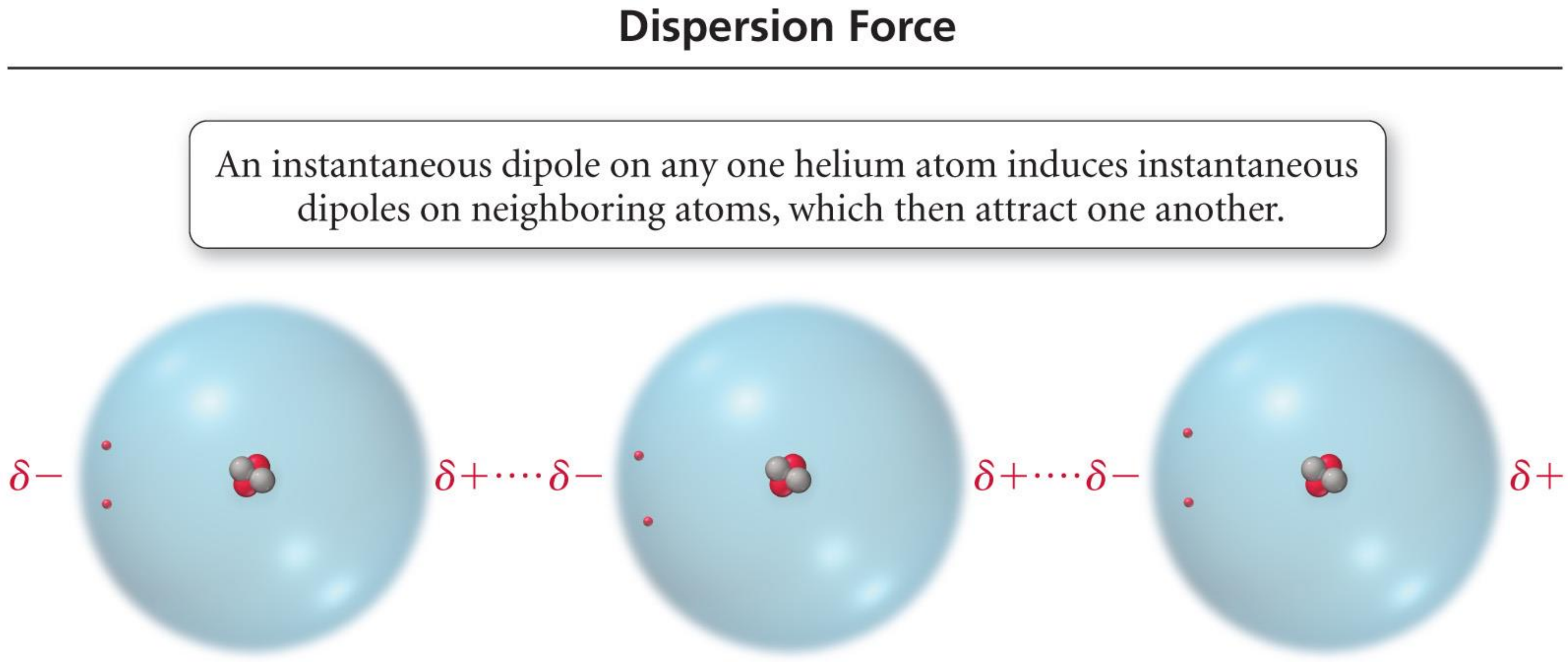
Trends in the Strength of Intermolecular Attraction?

- the stronger the attractions between the atoms or molecules, the more energy it will take to separate them
- boiling a liquid requires we add enough energy to overcome the attractions between the molecules or atoms
- **the higher the normal boiling point of the liquid, the stronger the intermolecular attractive forces**

Dispersion Forces

- fluctuations in the electron distribution in atoms and molecules result in a temporary dipole
  - region with excess electron density has partial (−) charge
  - region with depleted electron density has partial (+) charge
- the attractive forces caused by these temporary dipoles are called **dispersion forces**
  - aka London Forces
- all molecules and atoms will have them
- as a temporary dipole is established in one molecule, it induces a dipole in all the surrounding molecules

Dispersion Force



Size of the Induced Dipole

- the magnitude of the induced dipole depends on several factors
- polarizability of the electrons
  - volume of the electron cloud
  - **larger molar mass = more electrons = larger electron cloud = increased polarizability = stronger attractions**
- shape of the molecule
  - **more surface-to-surface contact = larger induced dipole = stronger attraction**

Effect of Molecular Size on Size of Dispersion Force

Noble Gases are all nonpolar atomic elements.

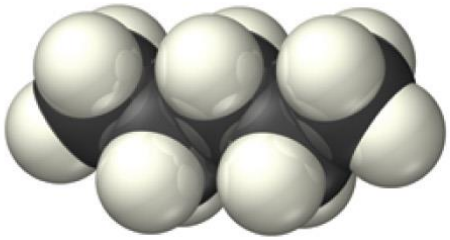
As the mass increases, the number of electrons increase. Therefore the strength of the dispersion forces increases.

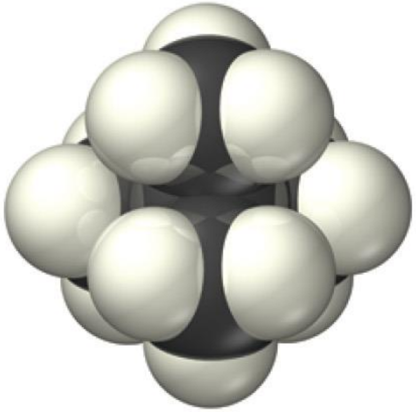
The stronger the attractive forces between the molecules, the higher the boiling point will be.

TABLE 11.3 Boiling Points of the Noble Gases

Noble Gas	Molar Mass (g/mol)	Boiling Point (K)
He	4.00	4.2
Ne	20.18	27
Ar	39.95	87
Kr	83.80	120
Xe	131.30	165

Effect of Molecular Shape on Size of Dispersion Force

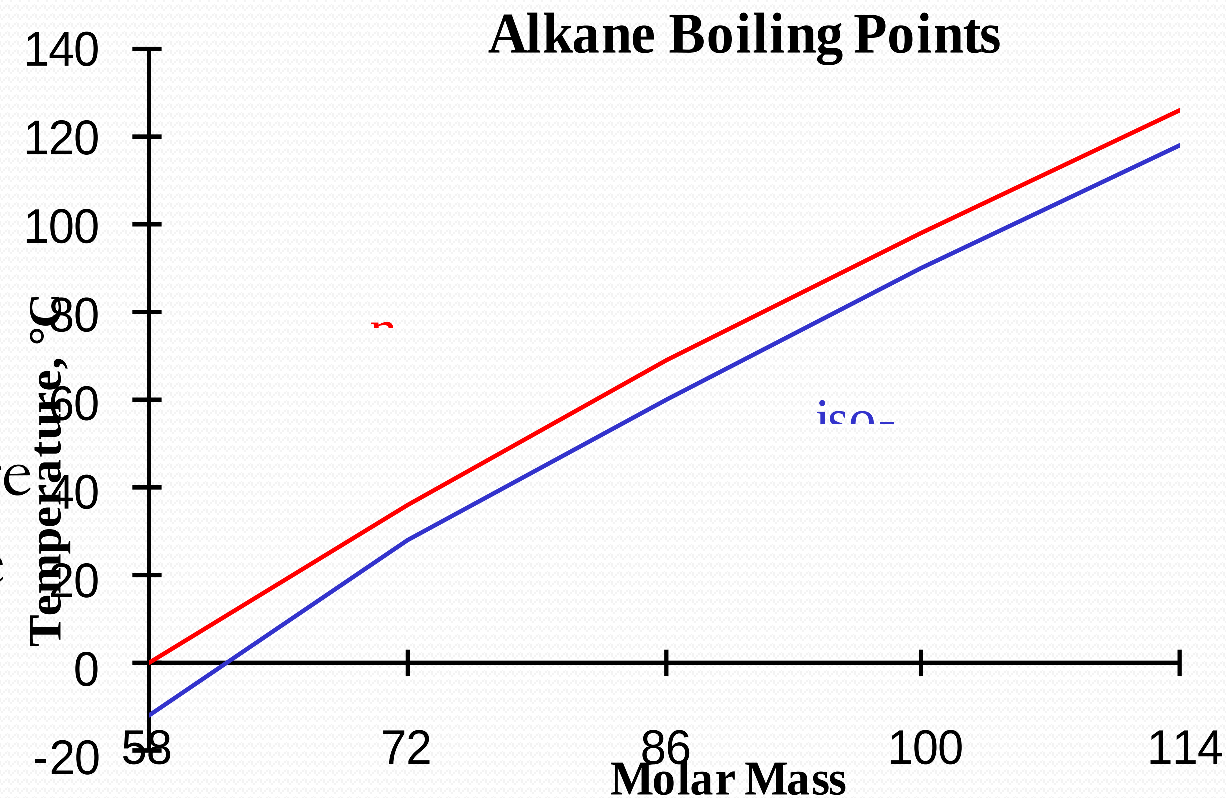




***n*-Pentane**	**Neopentane**
molar mass = 72.15 g/mol	molar mass = 72.15 g/mol
boiling point = 36.1 °C	boiling point = 9.5 °C

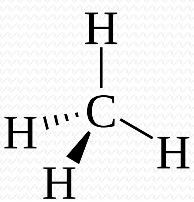
Alkane Boiling Points

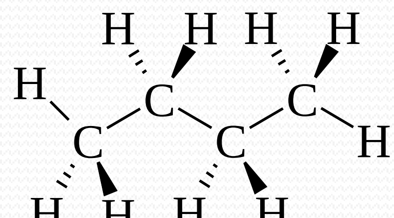
- branched chains have lower BPs than straight chains
- the straight chain isomers have more surface-to-surface contact



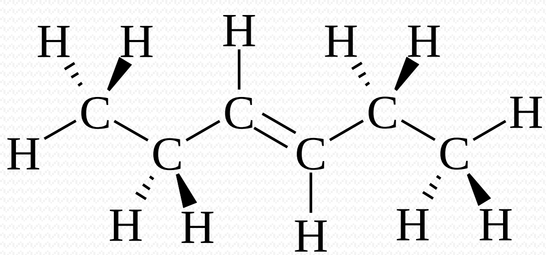
Practice – Choose the Substance in Each Pair with the Highest Boiling Point

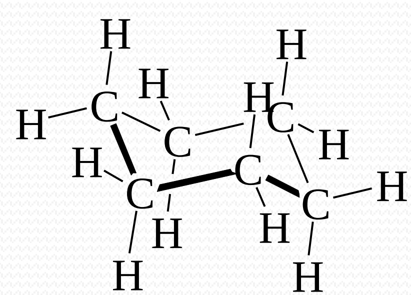
a) CH_4 $CH_3CH_2CH_2CH_3$





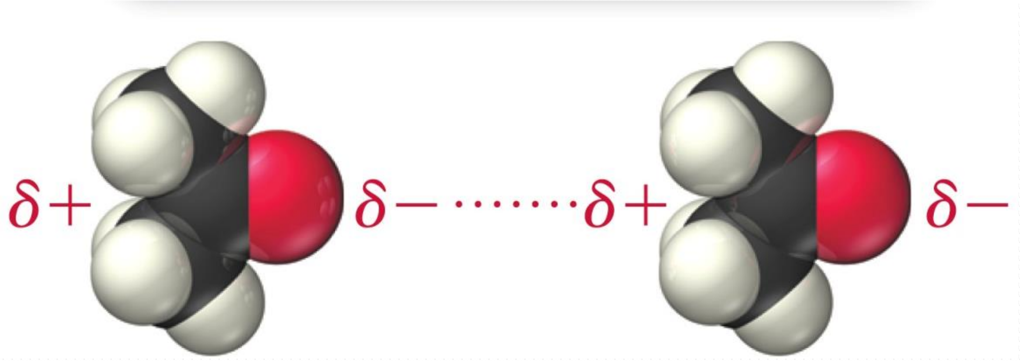
b) $CH_3CH_2CH{=}CHCH_2CH_3$ cyclohexane





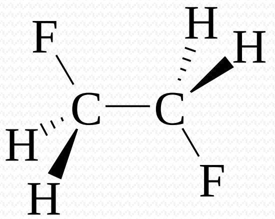
Dipole-Dipole Attractions

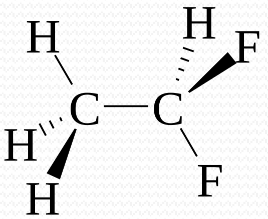
- polar molecules have a permanent dipole
  - because of bond polarity and shape
  - dipole moment
  - as well as the always present induced dipole
- the permanent dipole adds to the attractive forces between the molecules
  - raising the boiling and melting points relative to nonpolar molecules of similar size and shape



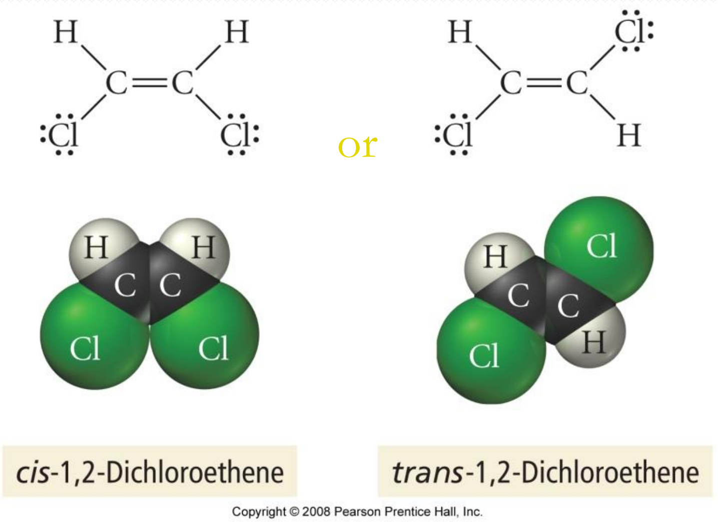
Practice – Choose the Substance in Each Pair with the Highest Boiling Point

a) CH_2FCH_2F CH_3CHF_2





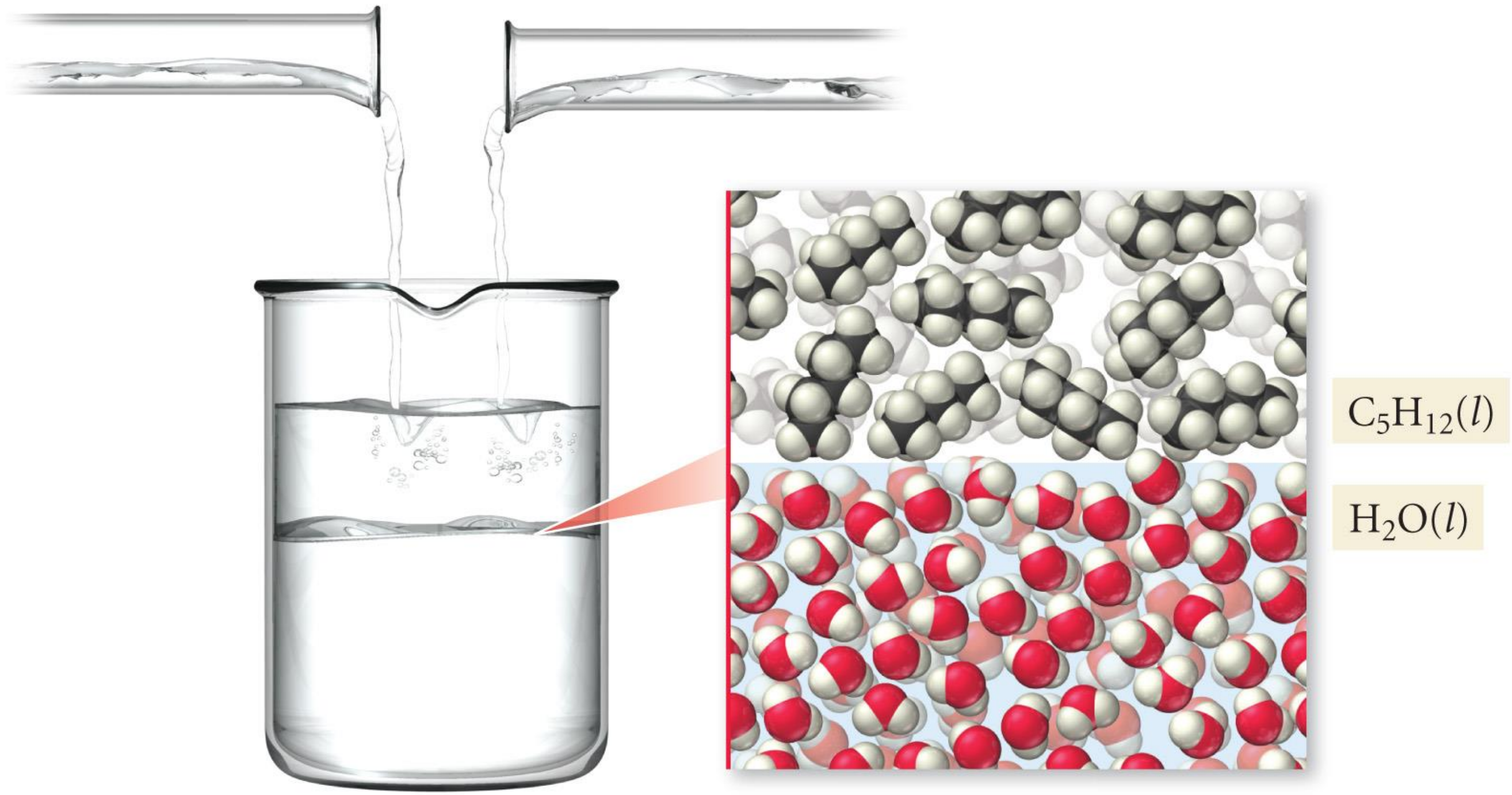
b)



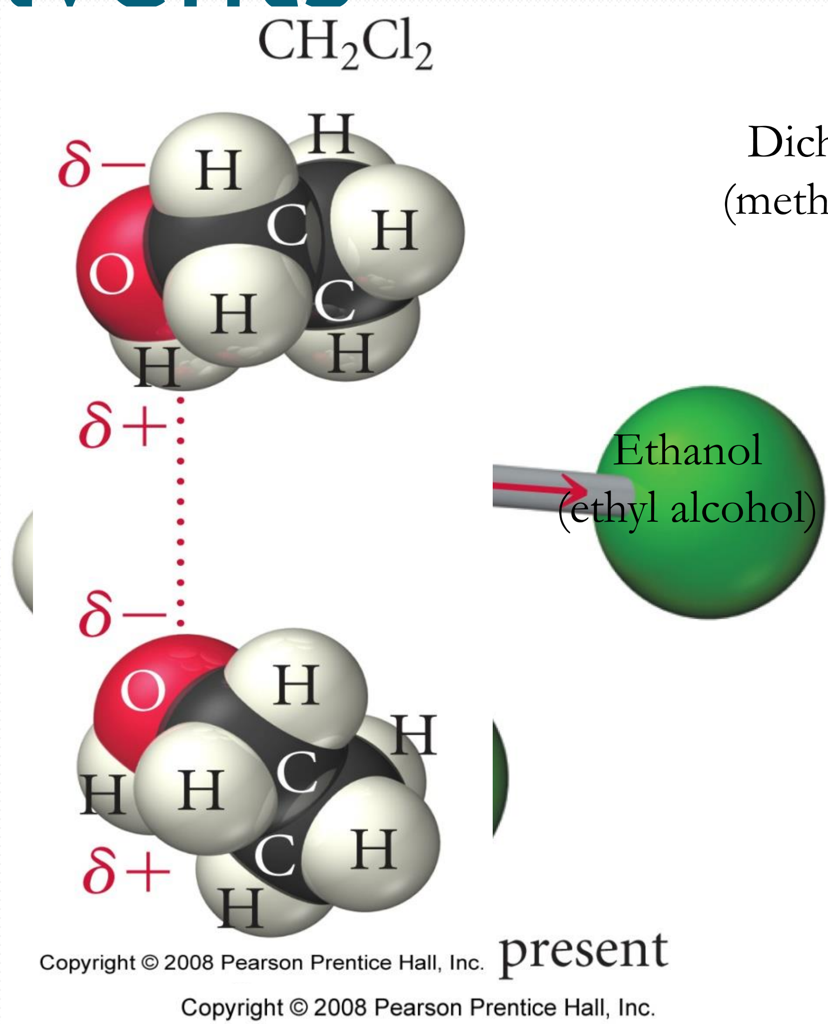
Attractive Forces and Solubility

- Solubility depends on the attractive forces of solute and solvent molecules
  - **Like dissolves Like**
  - **miscible liquids will always dissolve in each other**
- polar substance dissolve in polar solvents
  - **hydrophilic groups = OH, CHO, C=O, COOH, NH_2, Cl**
- nonpolar molecules dissolve in nonpolar solvents
  - **hydrophobic groups = C-H, C-C**
- Many molecules have both hydrophilic and hydrophobic parts - solubility becomes competition between parts

Immiscible Liquids



Polar Solvents

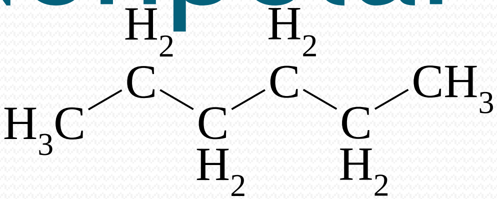


Dichloromethane
(methylene chloride)

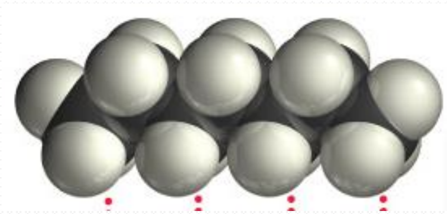
Water

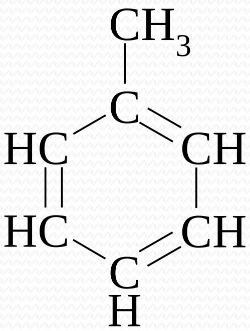
Ethanol
(ethyl alcohol)

Nonpolar Solvents

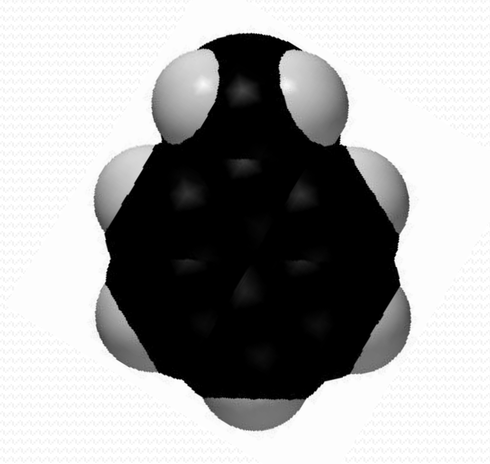


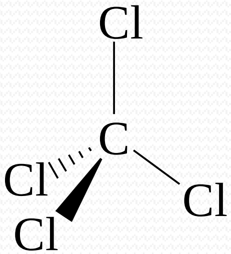
n-hexane

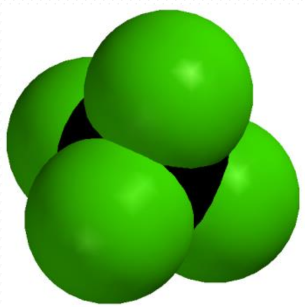




toluene







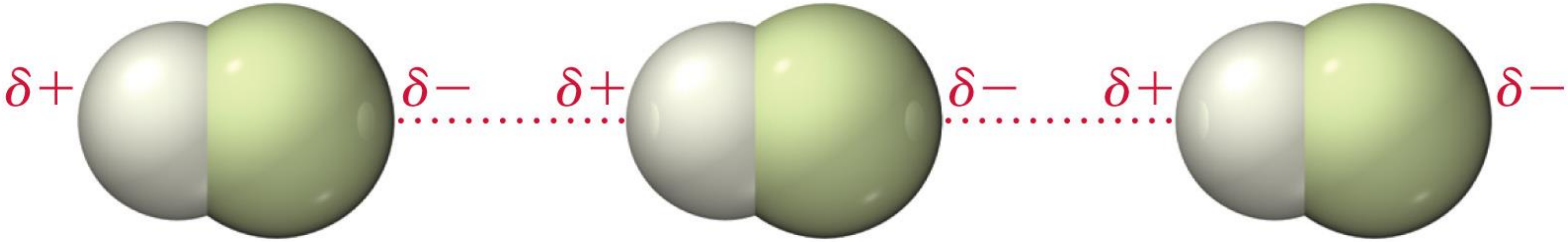
carbon tetrachloride

Hydrogen Bonding

- When a very electronegative atom is bonded to hydrogen, it strongly pulls the bonding electrons toward it
  - O-H, N-H, or F-H
- Since hydrogen has no other electrons, when it loses the electrons, the nucleus becomes deshielded
  - exposing the H proton
- The exposed proton acts as a very strong center of positive charge, attracting all the electron clouds from neighboring molecules

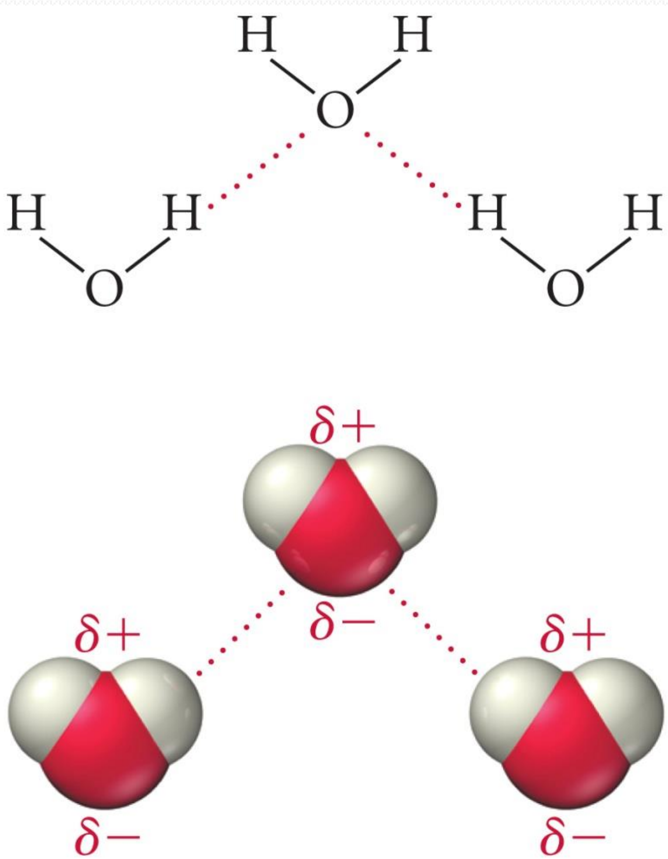
H-Bonding

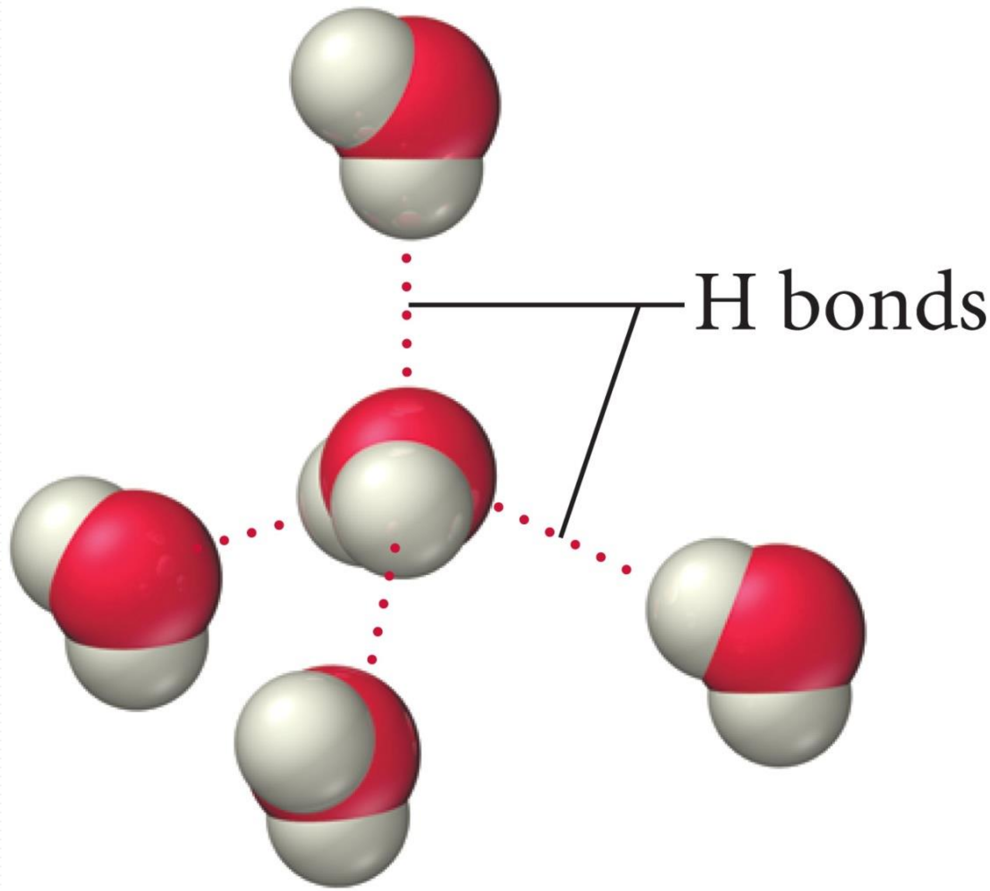
When H bonds directly to F, O, or N, the bonding atoms acquire relatively large partial charges, giving rise to strong dipole-dipole attractions between neighboring molecules.



HF

H-Bonding in Water





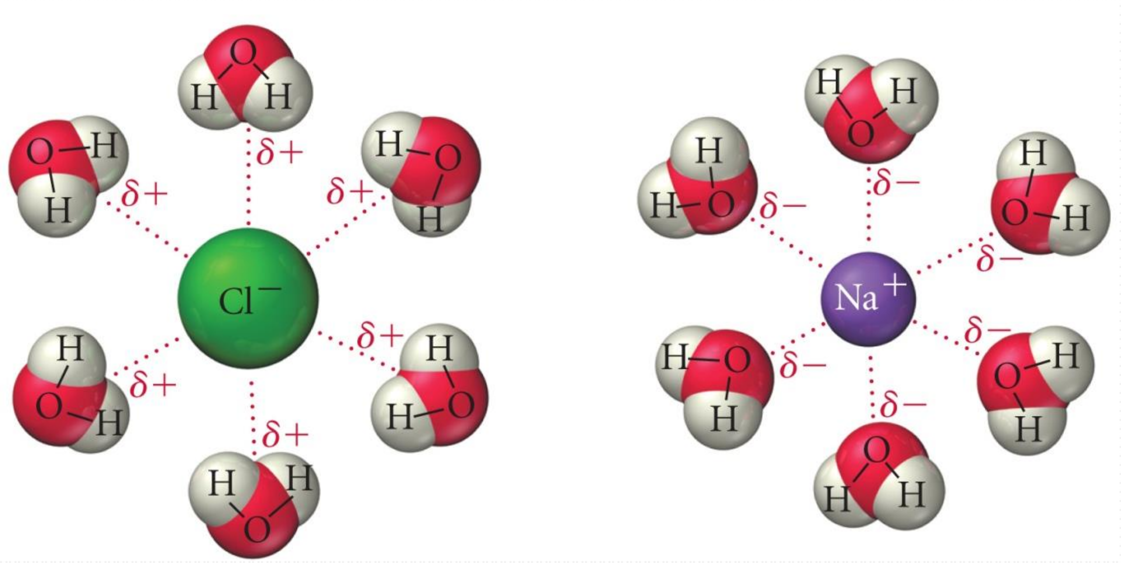
Practice – Choose the substance in each pair that is more soluble in water

a) CH_3OH CH_3CHF_2

b) $CH_3CH_2CH_2CH_3$ CH_3Cl

Ion-Dipole Attraction

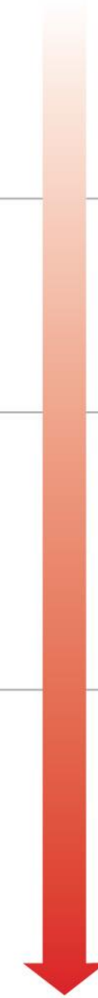
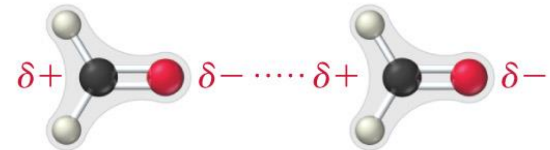
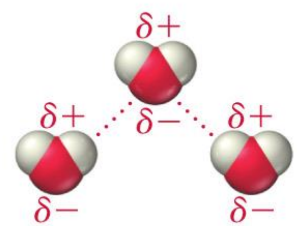
- in a mixture, ions from an ionic compound are attracted to the dipole of polar molecules
- the strength of the ion-dipole attraction is one of the main factors that determines the solubility of ionic compounds in water



Summary

- Dispersion forces are the weakest of the intermolecular attractions.
- Dispersion forces are present in all molecules and atoms.
- The magnitude of the dispersion forces increases with molar mass
- Polar molecules also have dipole-dipole attractive forces

TABLE 11.4 Types of Intermolecular Forces

Type	Present in	Molecular perspective	Strength
Dispersion	All molecules and atoms		
Dipole-dipole	Polar molecules		
Hydrogen bonding	Molecules containing H bonded to F, O, or N		
Ion-dipole	Mixtures of ionic compounds and polar compounds