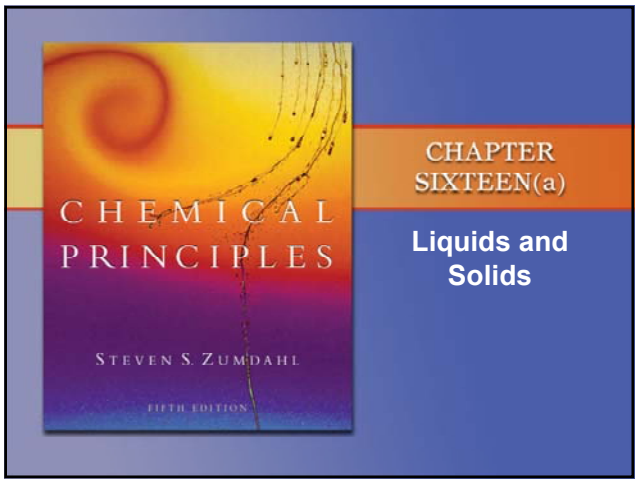
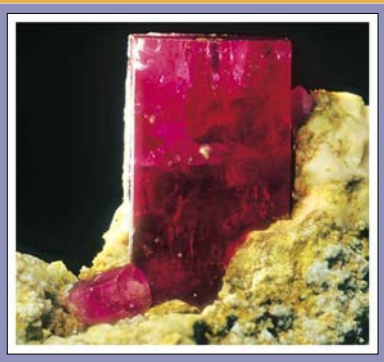


CHAPTER SIXTEEN(a)

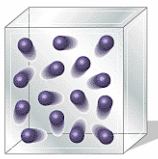
Liquids and Solids

Red Beryl, $Be_3Al_2Si_6O_{18}^-$



 16a–2

A Molecular Comparison of Liquids and Solids

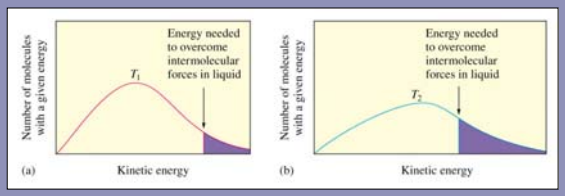
High Entropy, S^0_{gas}	Lower Entropy, S^0_{liquid}	Smallest Entropy, S^0_{solid}
		
Gas	Liquid	Crystalline solid
Total disorder; much empty space; particles have complete freedom of motion; particles far apart.	Disorder; particles or clusters of particles are free to move relative to each other; particles close together.	Ordered arrangement; particles are essentially in fixed positions; particles close together.

Cool or compress ⇄ Heat or reduce pressure

Cool ⇄ Heat

 16a–3

Figure 16.47: The number of molecules in a liquid with a given energy versus kinetic energy at two temperatures.



 16a–4

Figure 16.50: The heating curve for a given quantity of water where energy is added at a constant rate.

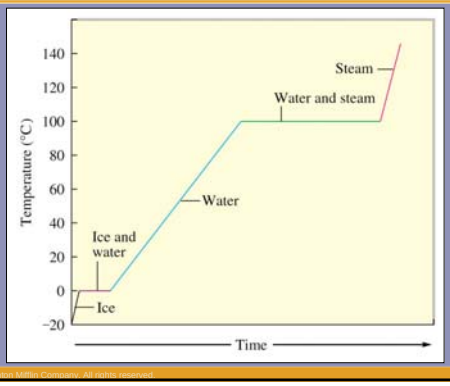
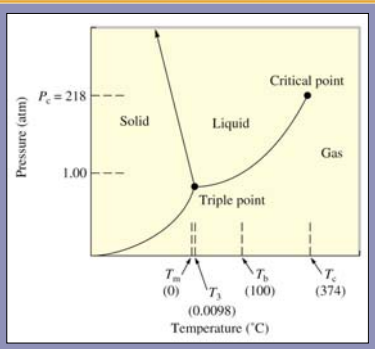
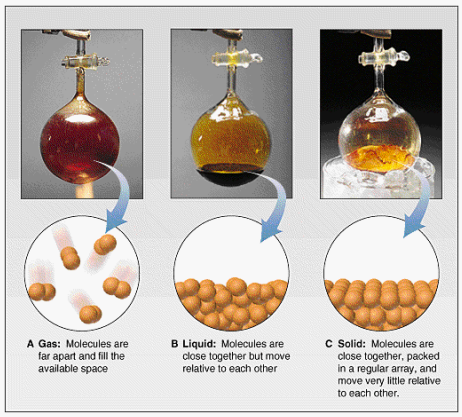


Figure 16.55: The phase diagram for water

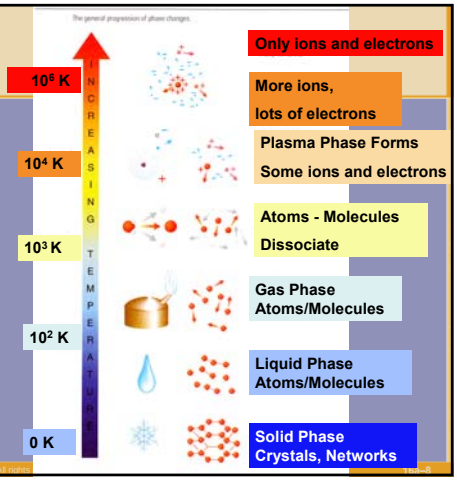


The 3 Most CommonStates

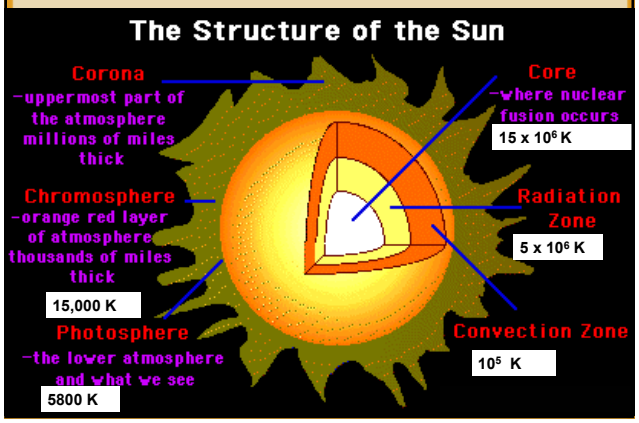
"of Earthbound Creatures"



Plasmas – The fourth phase of matter



The Sun – 99.8% Mass of Solar System, Plasma



Intermolecular Forces

- The covalent bond holding a molecule together is an **intra**molecular force.
- The attraction between molecules is an **inter**molecular force.
- Intermolecular forces are much weaker than intramolecular forces (e.g. 16 kJ/mol vs. 431 kJ/mol for HCl).
- When a substance melts or boils the intermolecular forces are broken (not the covalent bonds).
- When a substance condenses intermolecular forces are formed.

Larger INTERmolecular forces →

- Higher melting point
- Higher boiling point
- Larger enthalpy of fusion

Intermolecular Forces

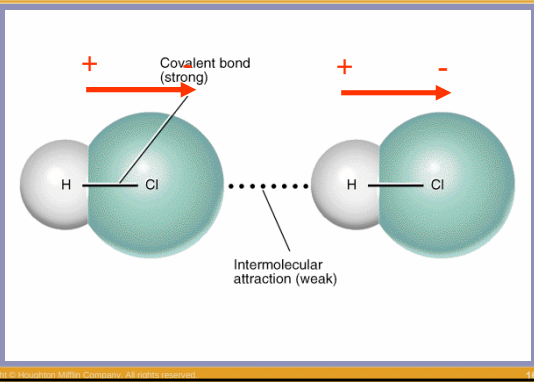
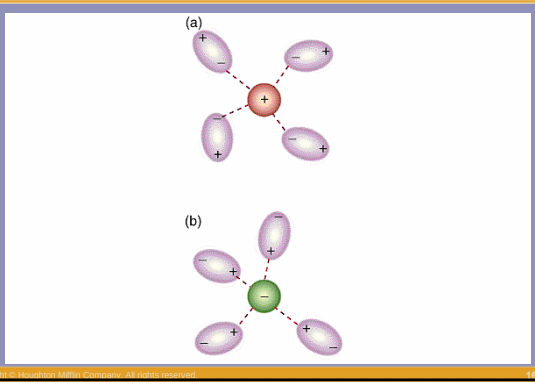


Table of Force Energies

Type of Force	Energy (kJ/mol)
Ionic Bond	300-600
Covalent	200-400
Hydrogen Bonding	20-40
Ion-Dipole	10-20
Dipole-Dipole	1-5
Instantaneous Dipole/ Induced Dipole	0.05-2

Intermolecular Forces



Intermolecular Forces

Ion-ion Forces

$$F = k\frac{Q_1Q_2}{d^2}$$

- F increases as Q increases and as d decreases:
  - the larger the charge and smaller the ion, the larger the attraction.

Intermolecular Forces

Ion-Dipole Forces

- Interaction between an ion (e.g. Na^+) and a dipole (e.g. water).

$$F = k\frac{Q_1Q_2}{d^2}$$

  - Since Q_1 is a full charge and Q_2 is a partial charge, F is comparatively large.
- F increases as Q increases and as d decreases:
  - the larger the charge and smaller the ion, the larger the ion-dipole attraction.

Intermolecular Forces

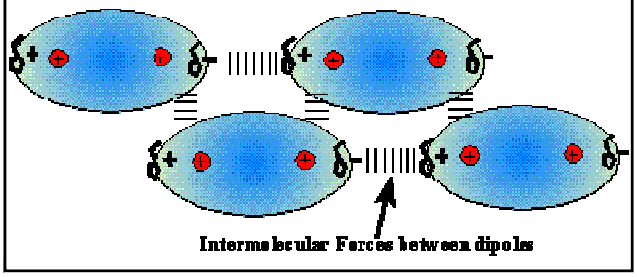
Dipole-Dipole Forces

- Dipole-dipole forces exist between neutral polar molecules.
- Polar molecules need to be close together.
- Weaker than ion-dipole forces:

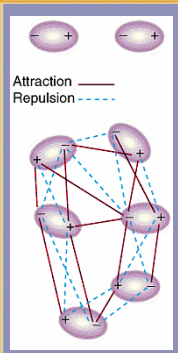
$$F = k\frac{Q_1 Q_2}{d^2}$$

  - Q_1 and Q_2 are *partial* charges.

Dipole-Dipole Forces



Intermolecular Forces



Dipole-Dipole Forces

- There is a mix of attractive and repulsive dipole-dipole forces as the molecules tumble.
- If two molecules have about the same mass and size, then dipole-dipole forces increase with increasing polarity.

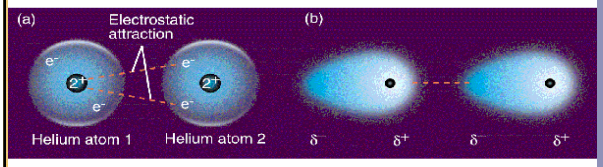
Intermolecular Forces

London Dispersion Forces

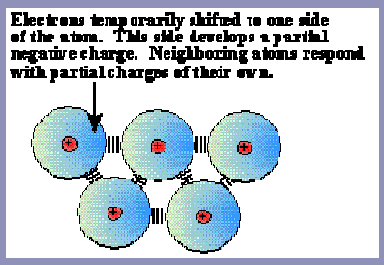
- Weakest of all intermolecular forces.
- The nucleus of one molecule (or atom) attracts the electrons of the adjacent molecule (or atom).
- For an instant, the electron clouds become distorted.
- In that instant a dipole is formed (called an instantaneous dipole).
- Polarizability is the ease with which an electron cloud can be deformed.
- The larger the molecule (the greater the number of electrons) the more polarizable.

Intermolecular Forces

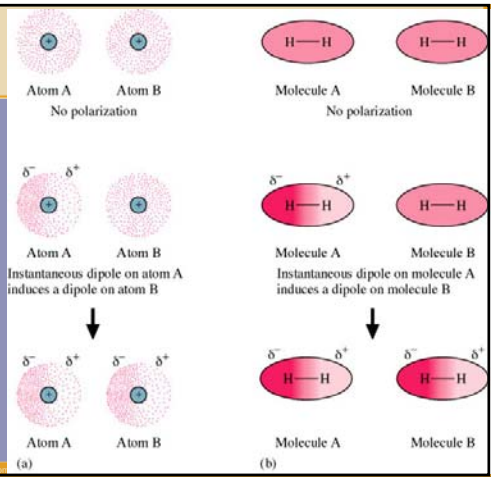
London Dispersion Forces



London Dispersion Forces



London Dispersion Forces



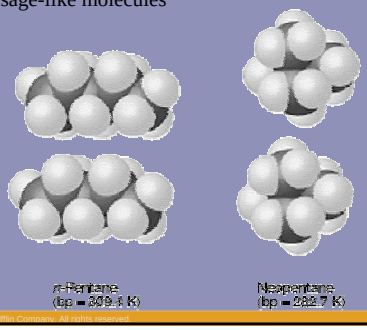
Intermolecular Forces

London Dispersion Forces

- London dispersion forces increase as molecular weight increases.
- London dispersion forces exist between all molecules.
- London dispersion forces depend on the shape of the molecule.
- The greater the surface area available for contact, the greater the dispersion forces.
- London dispersion forces between spherical molecules are lower than between sausage-like molecules.

Intermolecular Forces
London Dispersion Forces

London dispersion forces between spherical molecules are lower than between sausage-like molecules



H-Bonding

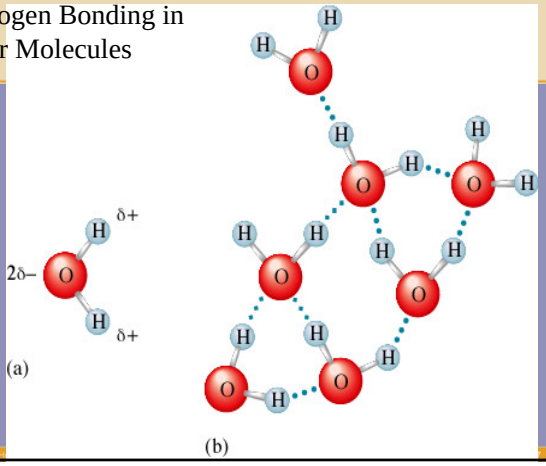
Occurs when Hydrogen is attached to a highly electronegative atom (O, N, F).

N-H···:N-	O-H···:N-	F-H···:N-
N-H···:O-	O-H···:O-	F-H···:O-
N-H···:F-	O-H···:F-	F-H···:F-

δ^+ δ^-

Requires Unshared Electron Pairs of Highly Electronegative Elements

Hydrogen Bonding in Water Molecules



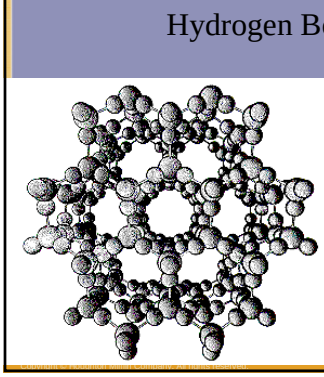
Why Does Ice Float?

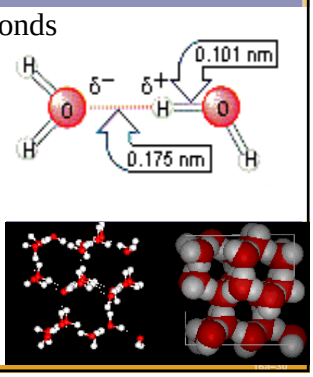
TABLE 16.1 Densities of the Three States of Water

State	Density (g/cm^3)
Solid (0°C, 1 atm)	0.9168
Liquid (25°C, 1 atm)	0.9971
Gas (400°C, 1 atm)	3.26×10^{-4}

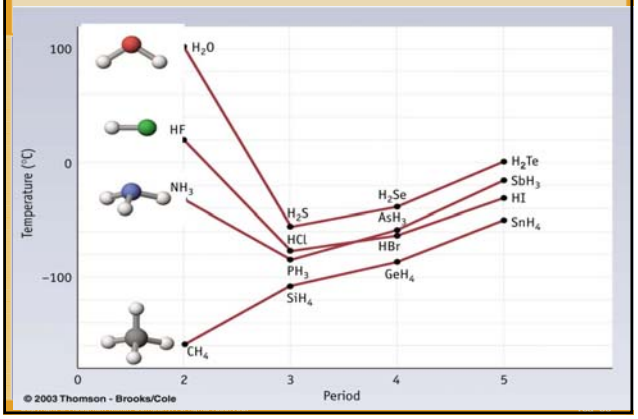
Structure of Ice

Observe the orientation of the Hydrogen Bonds

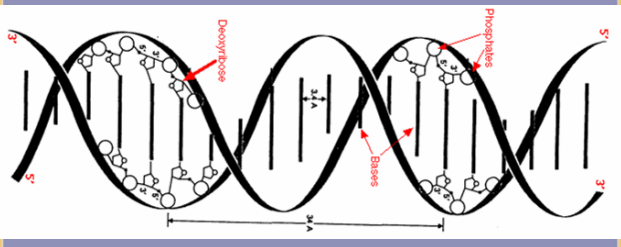




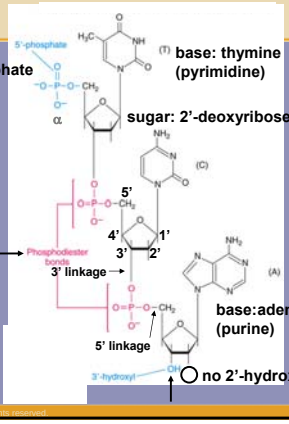
The Boiling Points of the Covalent Hydrides of the Elements in Groups 4A, 5A, 6A, and 7A



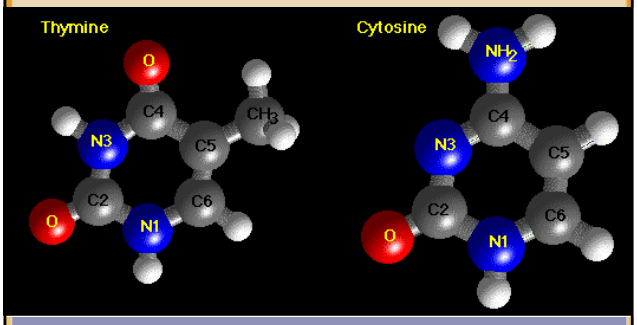
DNA Double Helix-Held Together with H-Bonds



Three Components of DNA Structure

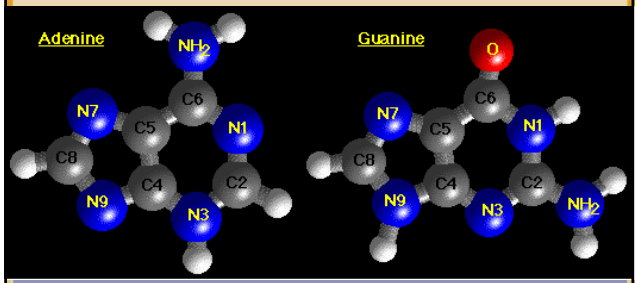


Pyrimidines used in Base Pairs, DNA



6-membered rings only

Purines used in Base Pairs, DNA

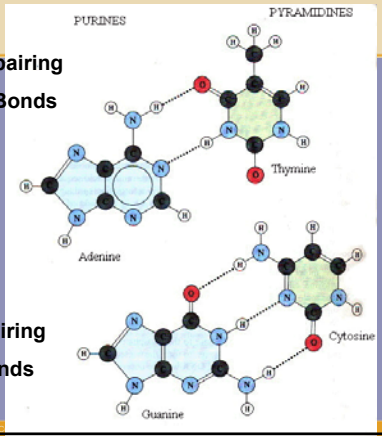


Fused 5 and 6 member rings

DNA Base Pairing

A-T pairing

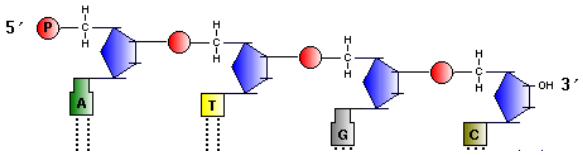
2 H-Bonds



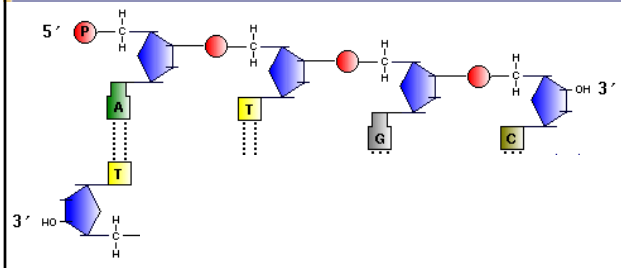
G-C pairing

3 H-bonds

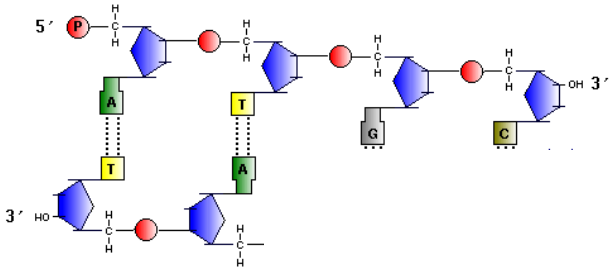
A-T and G-C Base Pairs Hold the DNA helices together



A-T and G-C Base Pairs Hold the DNA helices together



A-T and G-C Base Pairs Hold the DNA helices together



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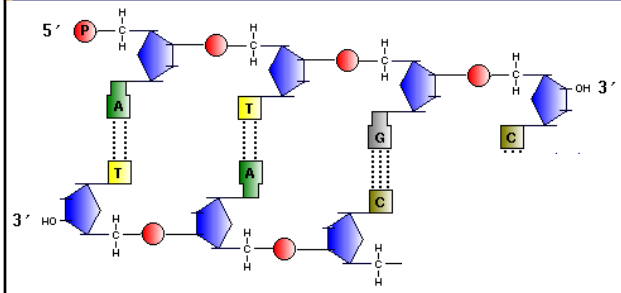
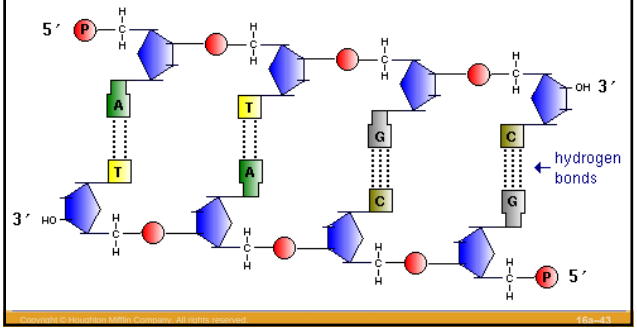
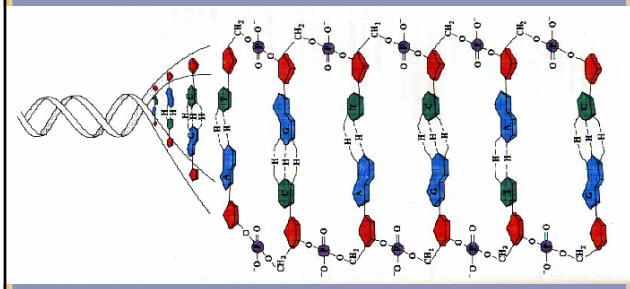


A-T and G-C Base Pairs Hold the DNA helices together



Base Pairs Double Helix



Hydrogen-Bonding's Role in DNA Structure

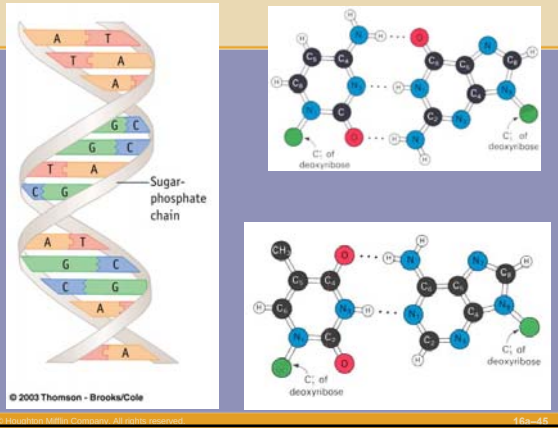


Table of Force Energies

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Covalent	200-400
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Ion-Dipole	10-20
Dipole-Dipole	1-5
Instantaneous Dipole/ Induced Dipole	0.05-2

Intermolecular Forces Summary

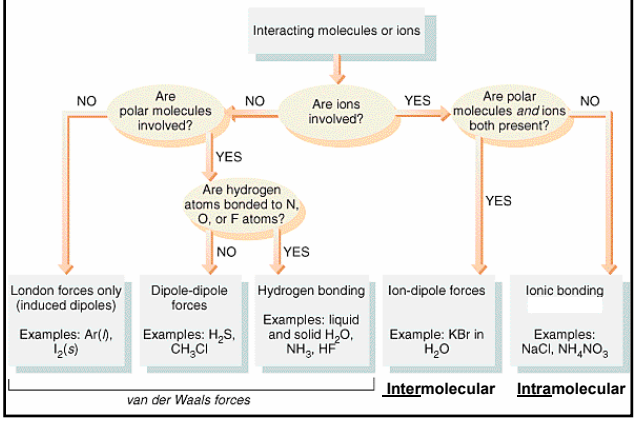


TABLE 16.2 The Freezing Points of the Group 8A Elements

Element	Freezing Point (°C)
Helium*	−269.7
Neon	−248.6
Argon	−189.4
Krypton	−157.3
Xenon	−111.9

*Helium is the only liquid that does not freeze when the temperature is lowered at 1 atm. It will freeze only if more pressure is applied.

Which forces?

	London	Dipole	H-bond	ionic
Xe	X			
CH_4	X			
CO_2	X			
CO	X	X		
HBr	X	X		
HF	X		X	
CH_3OH	X		X	
NaCl				X
$CaCl_2$				X

Relative forces

Larger London	I_2	>	Cl_2	
	H_2S	<	H_2O	H-bond
	CH_3OCH3	<	CH_3CH_2OH	H-bond
ionic	CsBr	>	Br_2	
	CO_2	<	CO	polar
polar	SF_2	>	SF_6	

Some Properties of Liquids

Viscosity

- Viscosity is the resistance of a liquid to flow.
- A liquid flows by sliding molecules over each other.
- The **stronger** the intermolecular forces, ……. the **higher** the viscosity.

Some Properties of Liquids

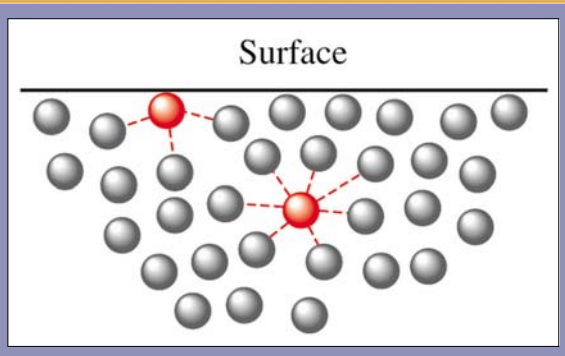
Viscosity

- Viscosity is the resistance of a liquid to flow.
- A liquid flows by sliding molecules over each other.
- The **stronger** the intermolecular forces, ……. the **higher** the viscosity.

Surface Tension

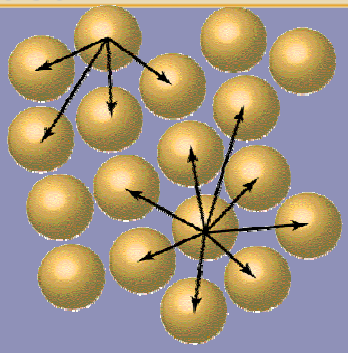
- Bulk molecules (those in the liquid) are equally attracted to their neighbors.

A molecule in the interior of a liquid is attracted to the molecules surrounding it, whereas a molecule at the surface of liquid is attracted only by molecules below it and on each side of it.



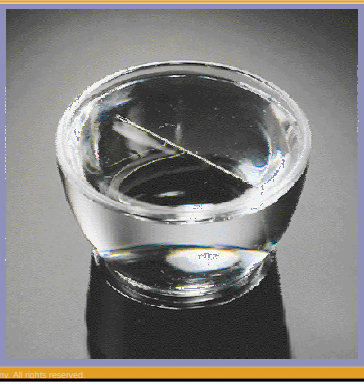
Some Properties of Liquids

Surface Tension



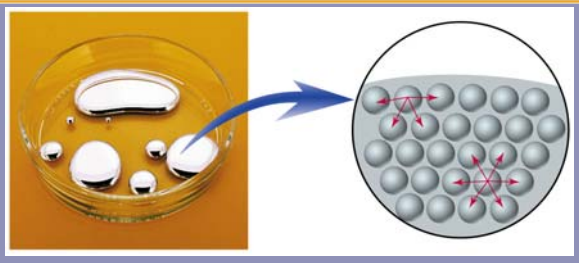
Some Properties of Liquids

Surface Tension



Water Strider (Hemiptera: Gerridae)

Surface Tension Mercury

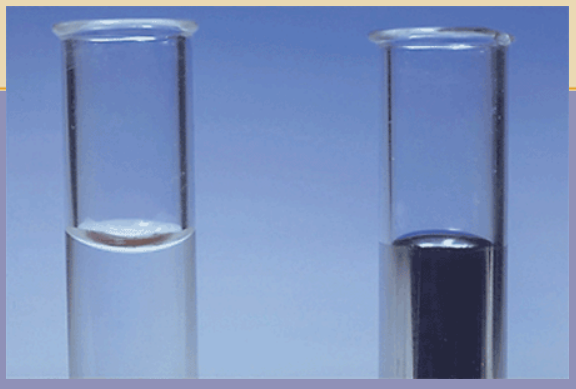


Surface tension is the amount of energy required to increase the surface area of a liquid.

Some Properties of Liquids

Surface Tension

- *Meniscus* is the shape of the liquid surface.
  - If adhesive forces are greater than cohesive forces, the liquid surface is attracted to its container more than the bulk molecules. Therefore, the meniscus is U-shaped (e.g. water in glass).
  - If cohesive forces are greater than adhesive forces, the meniscus is curved downwards.
- *Capillary Action:* When a narrow glass tube is placed in water, the meniscus pulls the water up the tube.

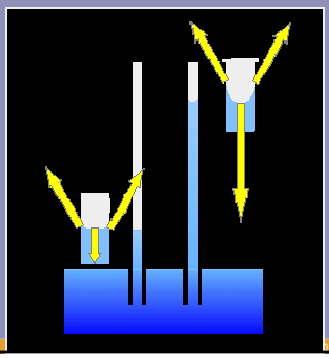


Water (left) has a downward curving meniscus.Mercury (right) has an upward curving meniscus

Capillary Action

The tendency of certain liquids to rise in a narrow tube.

There is a competition between adhesive and cohesive forces.



Larger INTERmolecular forces →

- Higher melting point
- Higher boiling point
- Larger enthalpy of fusion

- Larger viscosity
- Higher surface tension
- Smaller vapor pressure