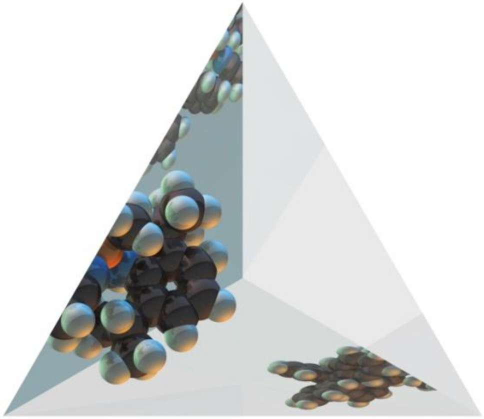


CHEMISTRY

The Central Science

8th Edition

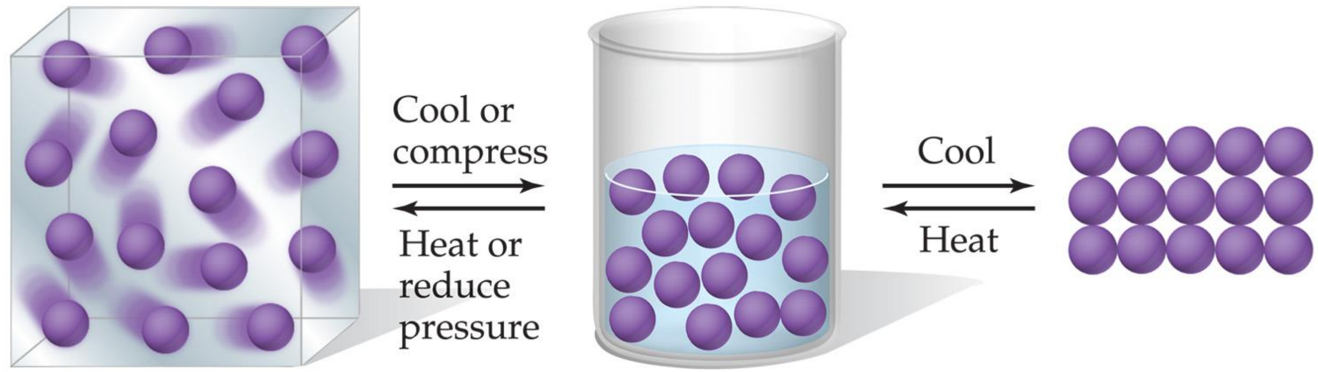
Chapter 11
Intermolecular Forces
Liquids and Solids

Kozet YAPSAKLI

States of Matter

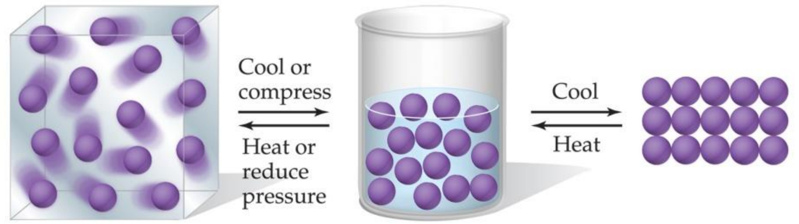
difference between states of matter is the distance between particles.

In the solid and liquid states particles are closer together, we refer to them as condensed phases.



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

The States of Matter



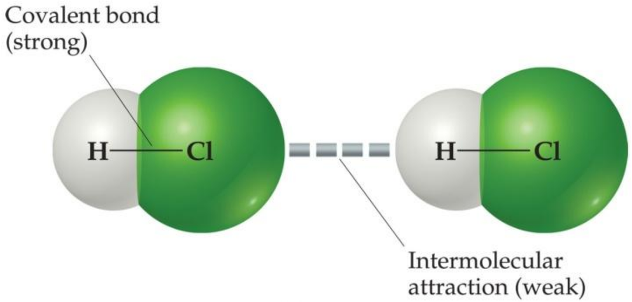
Gas	Liquid	Crystalline solid
Total disorder; much empty space; particles have complete freedom of motion; particles far apart	Disorder; particles or clusters of particles are free to move relative to each other; particles close together	Ordered arrangement; particles are essentially in fixed positions; particles close together

Gas	Assumes both the volume and shape of its container
	Is compressible
	Flows readily
	Diffusion within a gas occurs rapidly
Liquid	Assumes the shape of the portion of the container it occupies
	Does not expand to fill container
	Is virtually incompressible
	Flows readily
	Diffusion within a liquid occurs slowly
Solid	Retains its own shape and volume
	Is virtually incompressible
	Does not flow
	Diffusion within a solid occurs extremely slowly

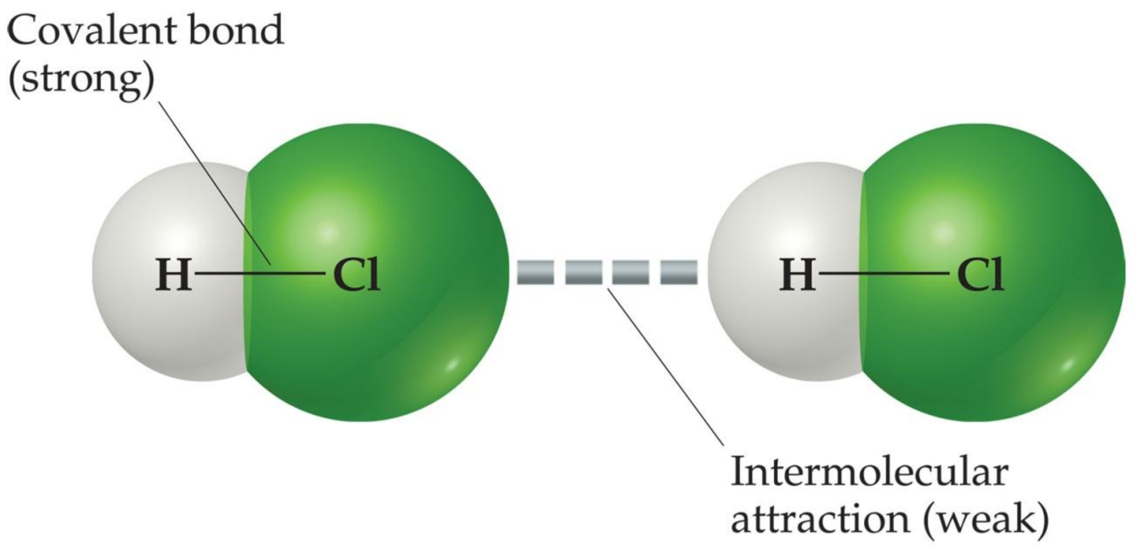
- The state of a substance at a particular temperature and pressure depends on :
  - The kinetic energy of the particles
  - The strength of the attractions between the particles

Intermolecular Forces

- Converting a gas into a liquid or solid requires the molecules to get closer to each other:
  - cool or compress.
- Converting a solid into a liquid or gas requires the molecules to move further apart:
  - heat or reduce pressure.
- The forces holding solids and liquids together are called ***intermolecular forces***.

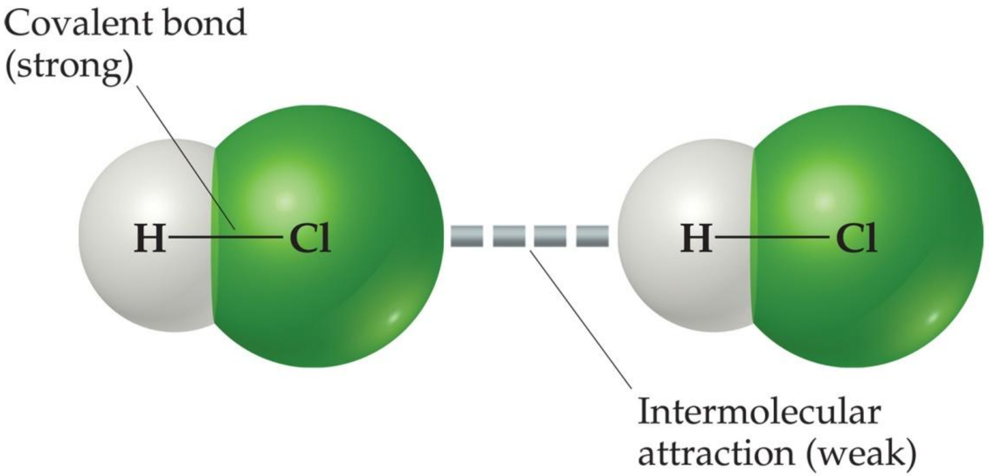


Intermolecular Forces



physical properties such as boiling and melting points, vapor pressures, and viscosities.

Intermolecular Forces



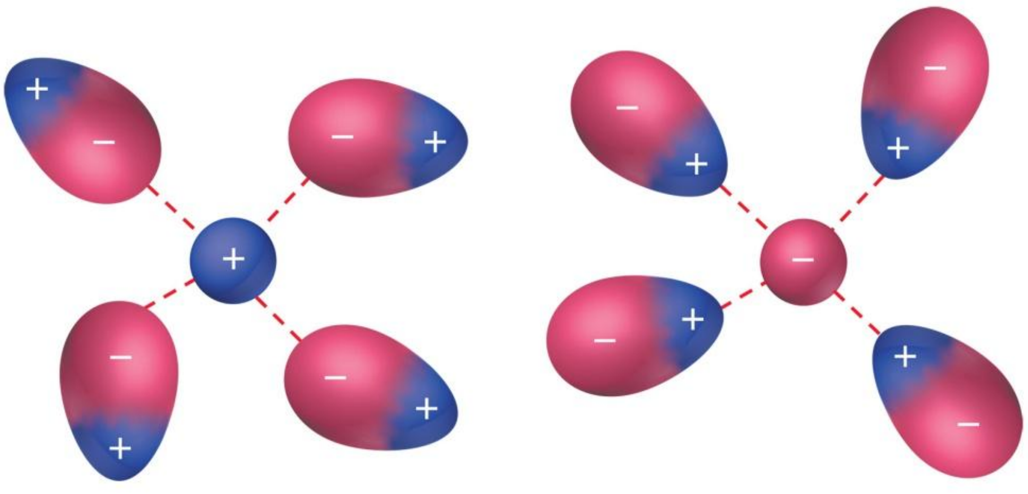
- The attraction between molecules is an **intermolecular** force.
- These intermolecular forces as a group are referred to as van der Waals forces.

van der Waals Forces

- Dipole-dipole interactions
- London dispersion forces
- Hydrogen bonding

Ion-Dipole Interactions

- An ion-dipole force exists between an ion and the partial charge on the end of a polar molecule.
- Ion-dipole interactions are an important force in solutions of ions.

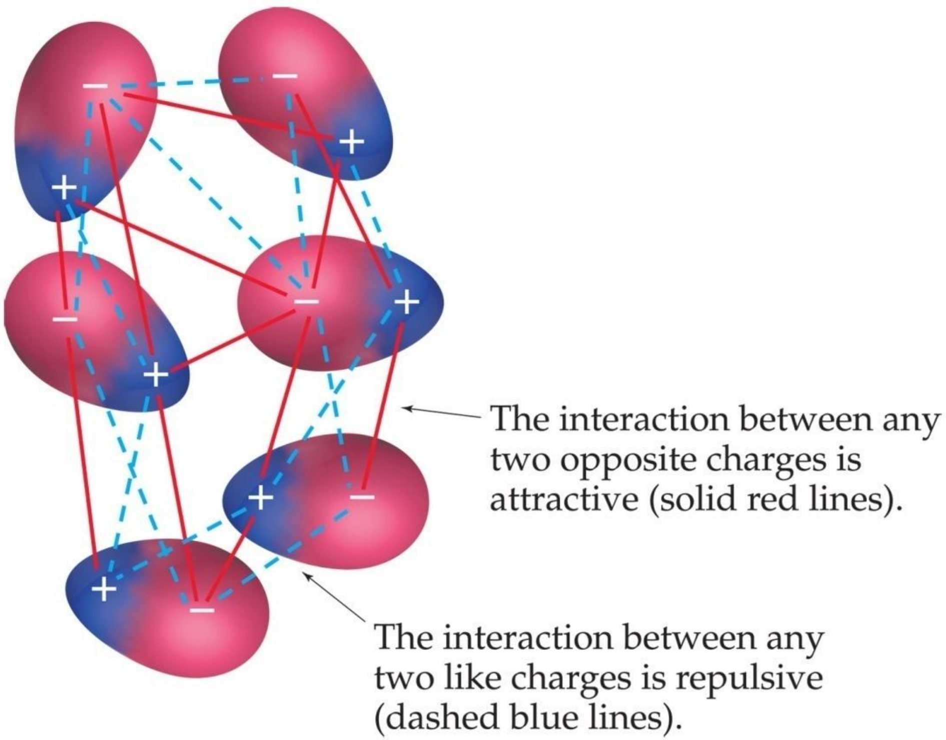


Cation-dipole attractions

Anion-dipole attractions

Dipole-Dipole Interactions

- Dipole-dipole forces exist between neutral polar molecules.



- Molecules that have regular dipoles are attracted to each other.
  - The positive end of one is attracted to the negative end of the other and vice-versa.
  - These forces are only important when the molecules are close to each other.

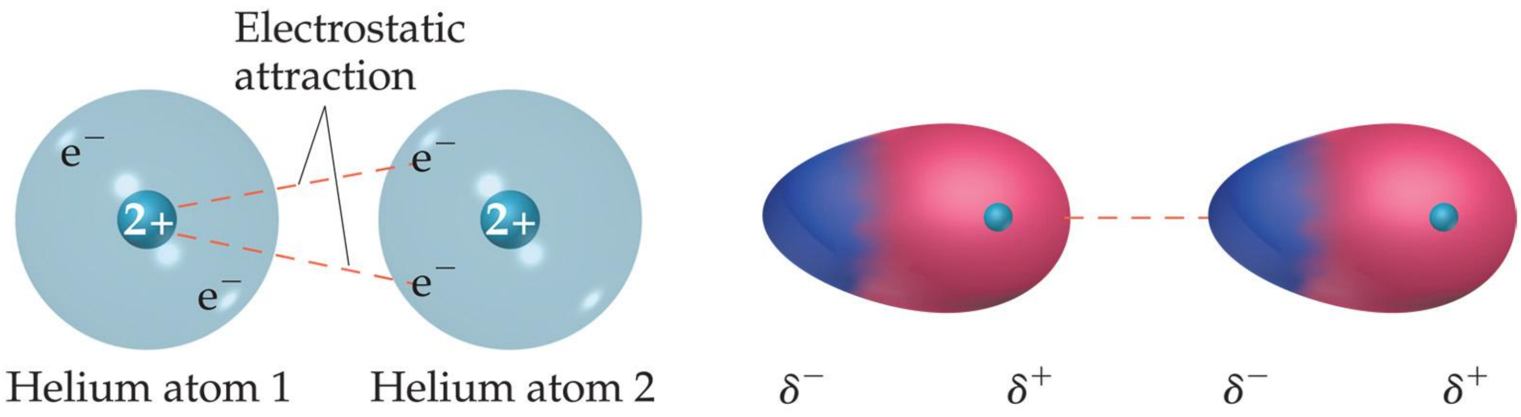
Dipole-Dipole Interactions

Substance	Molecular Weight (amu)	Dipole Moment μ (D)	Boiling Point (K)
Propane, $CH_3CH_2CH_3$	44	0.1	231
Dimethyl ether, CH_3OCH_3	46	1.3	248
Methyl chloride, CH_3Cl	50	1.9	249
Acetaldehyde, CH_3CHO	44	2.7	294
Acetonitrile, CH_3CN	41	3.9	355

- The greater the polarity of the molecules, the stronger the attractions between them.
- The more polar the molecule, the higher boiling point.

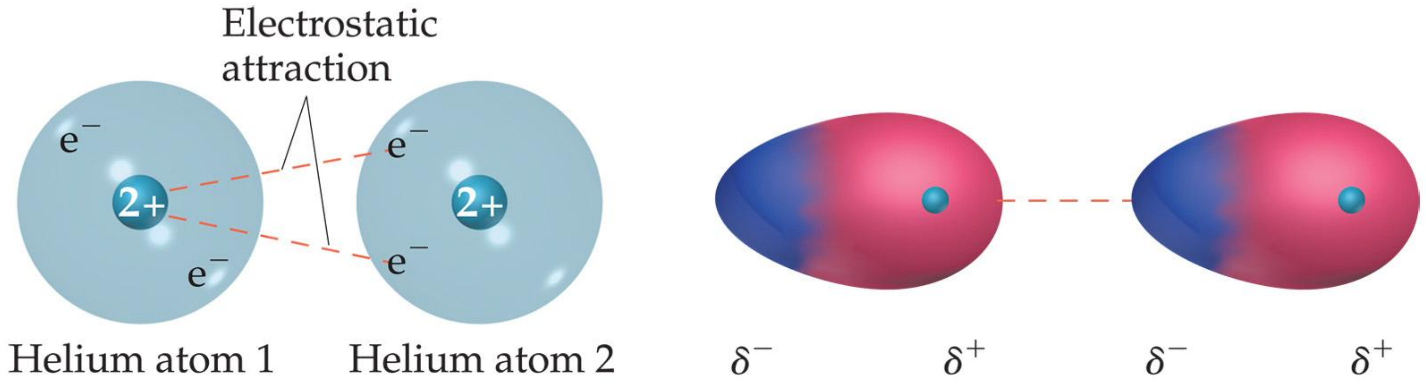
Intermolecular Forces

London Dispersion Forces



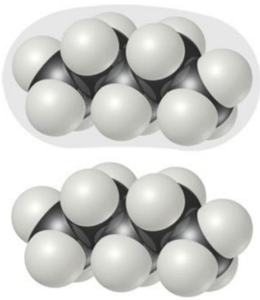
- It is possible for two adjacent neutral molecules to affect each other.
- The nucleus of one molecule (or atom) attracts the electrons of the adjacent molecule (or atom).
- ***London dispersion forces***, are attractions between an instantaneous dipole and an induced dipole.

London Dispersion Forces

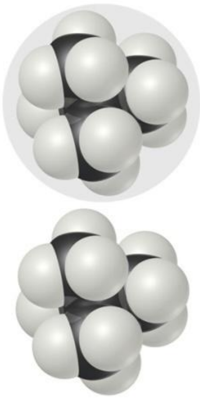


- These forces are present in *all* molecules, whether they are polar or nonpolar.
- The ease with which the electron distribution in a molecule is distorted is called polarizability.
- London dispersion forces depend on the shape of the molecule.

Factors Affecting London Forces



n-Pentane
(bp = 309.4 K)



Neopentane
(bp = 282.7 K)

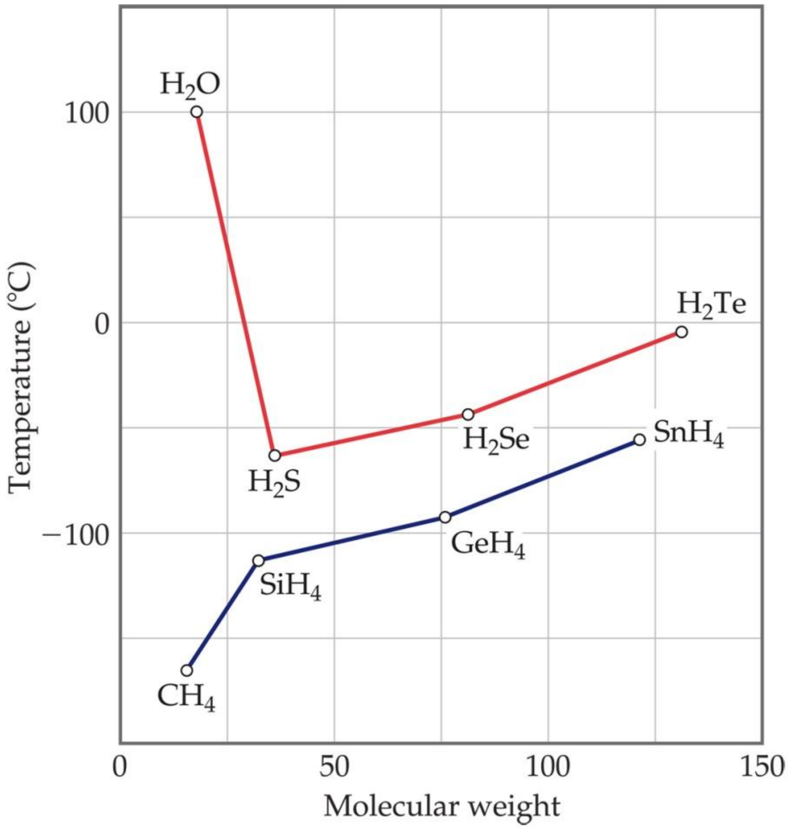
- The greater the surface area available for contact, the greater the dispersion forces.
- The shape of the molecule affects the strength of dispersion forces:
- The strength of dispersion forces tends to increase with increased molecular weight.
- Larger atoms have larger electron clouds, which are easier to polarize.

Halogen	Molecular Weight (amu)	Boiling Point (K)	Noble Gas	Molecular Weight (amu)	Boiling Point (K)
F_2	38.0	85.1	He	4.0	4.6
Cl_2	71.0	238.6	Ne	20.2	27.3
Br_2	159.8	332.0	Ar	39.9	87.5
I_2	253.8	457.6	Kr	83.8	120.9
			Xe	131.3	166.1

Which Have a Greater Effect:
Dipole-Dipole Interactions or Dispersion Forces?

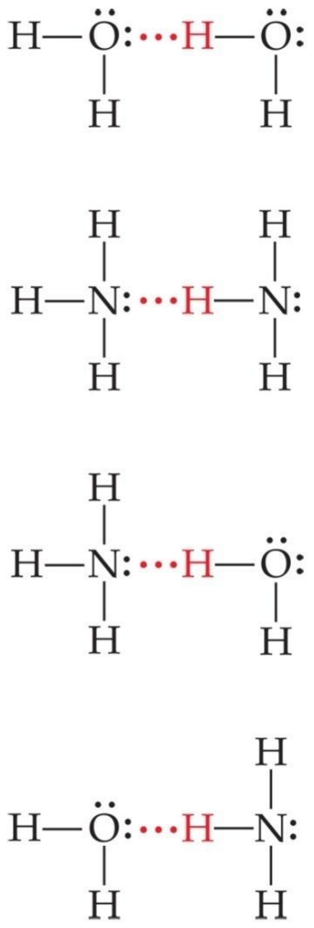
- If two molecules are of comparable size and shape, dipole-dipole interactions will likely be the dominating force.
- If one molecule is much larger than another, dispersion forces will likely determine its physical properties.

How Do We Explain This?



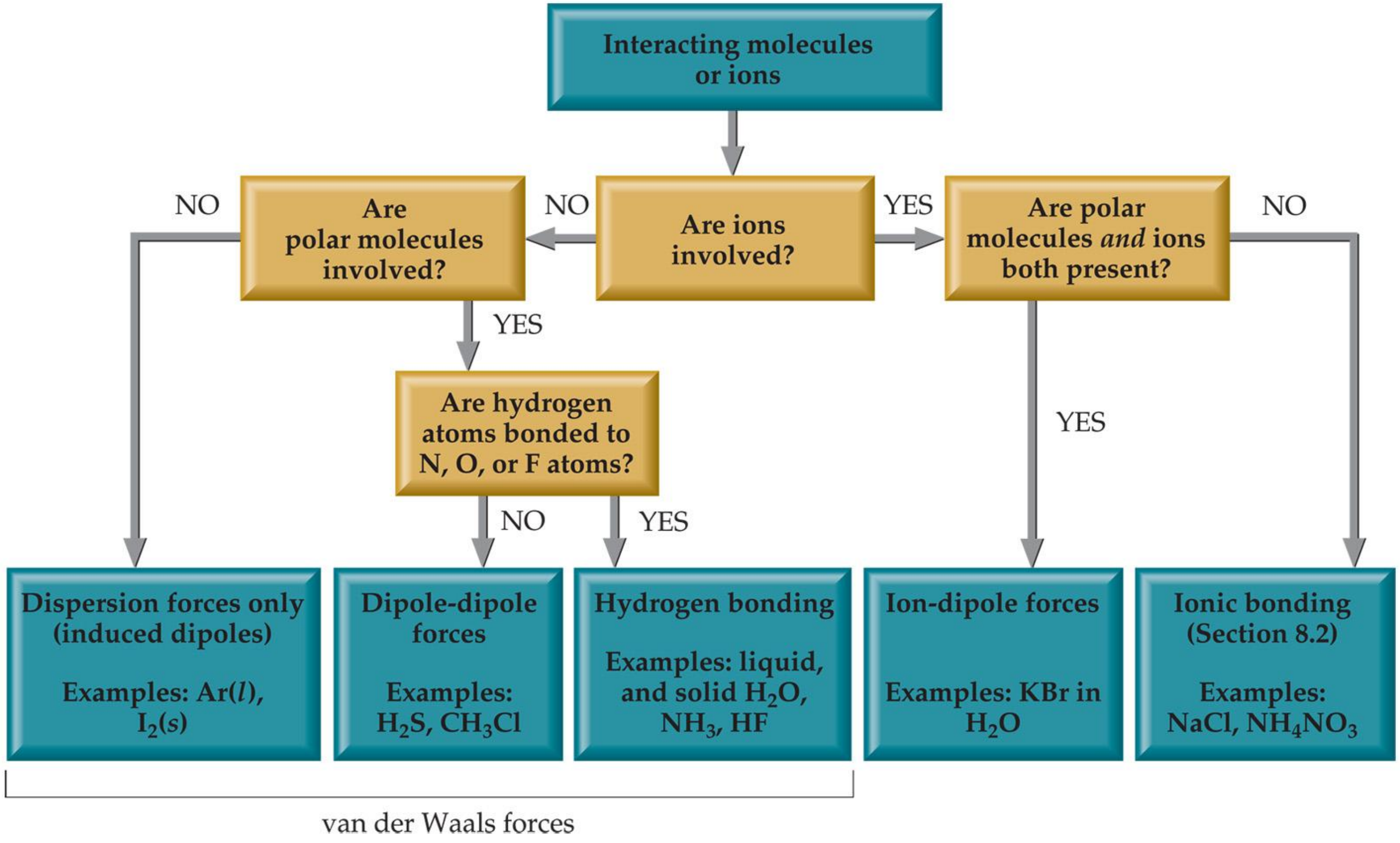
- The nonpolar series (SnH_4 to CH_4) follow the expected trend.
- The polar series follows the trend from H_2Te through H_2S, but water is quite an anomaly.

Hydrogen Bonding

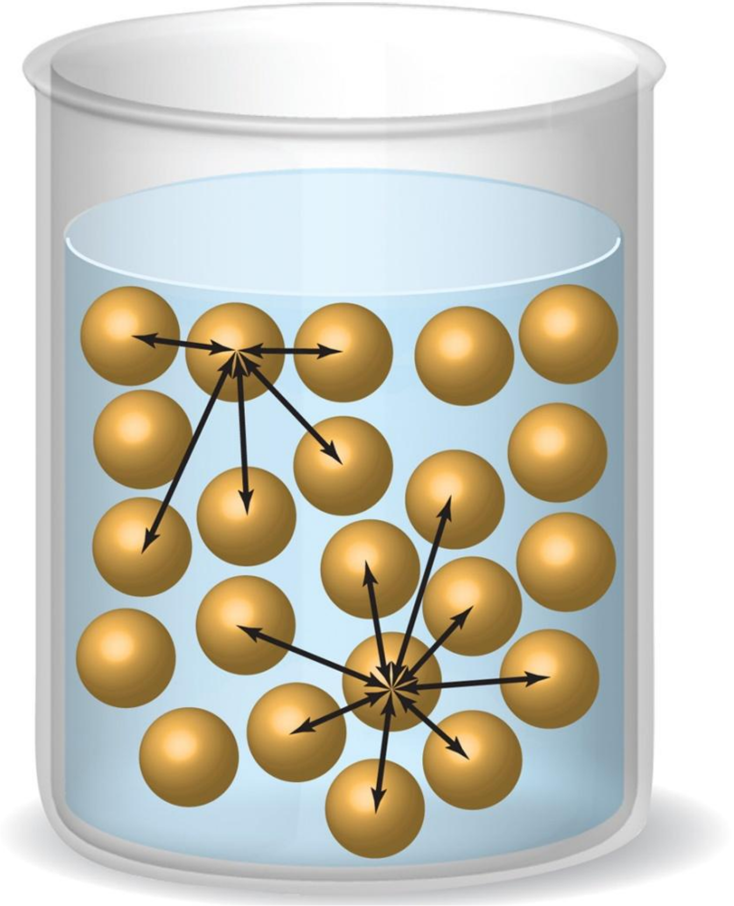


- is a special type of intermolecular attraction that exists btw the hydrogen atom in a polar bond.
- The dipole-dipole interactions experienced when H is bonded to N, O, or F are unusually strong.
- Among the strongest of the van der Waals forces are hydrogen bonds.

Summarizing Intermolecular Forces



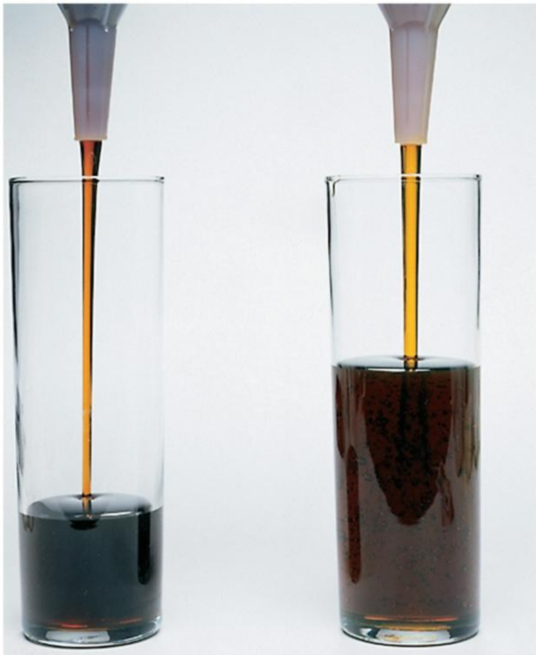
Intermolecular Forces Affect Many Physical Properties



The strength of the attractions between particles can greatly affect the properties of a substance or solution.

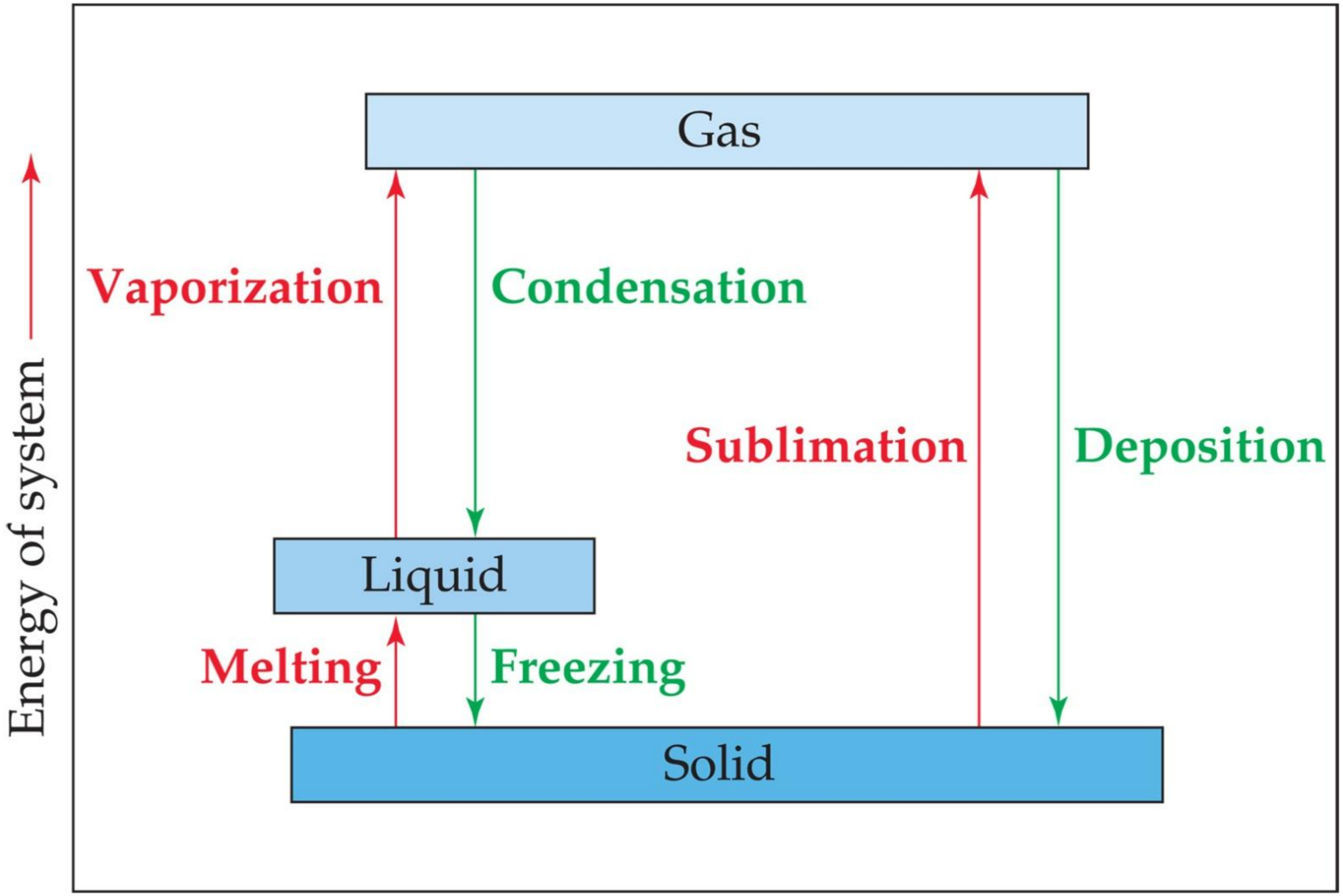
Viscosity

- Resistance of a liquid to flow is called viscosity.
- Viscosity increases with stronger intermolecular forces and decreases with higher temperature.

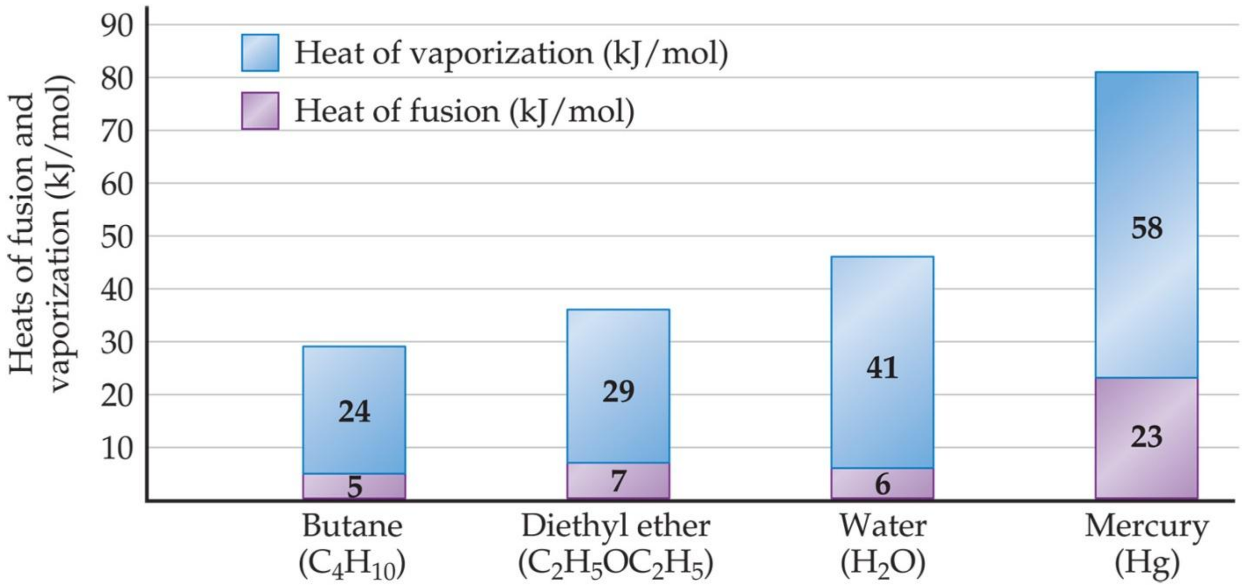


Substance	Formula	Viscosity (kg/m-s)
Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	$3.26 * 10^{-4}$
Heptane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	$4.09 * 10^{-4}$
Octane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	$5.42 * 10^{-4}$
Nonane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	$7.11 * 10^{-4}$
Decane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	$1.42 * 10^{-3}$

Phase Changes

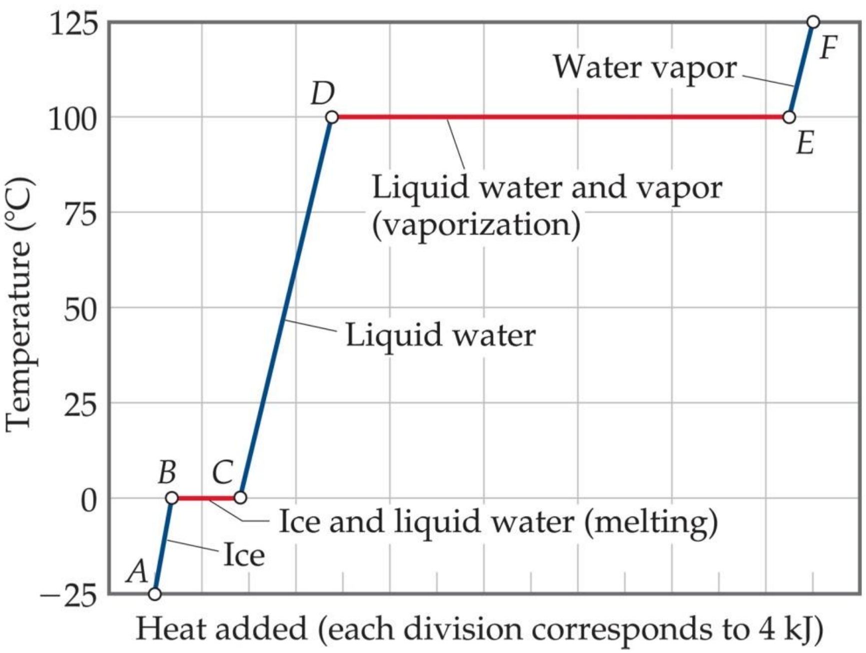


Energy Changes



- Heat of Fusion: Energy required to change a solid at its melting point to a liquid.
- Heat of Vaporization: Energy required to change a liquid at its boiling point to a gas.

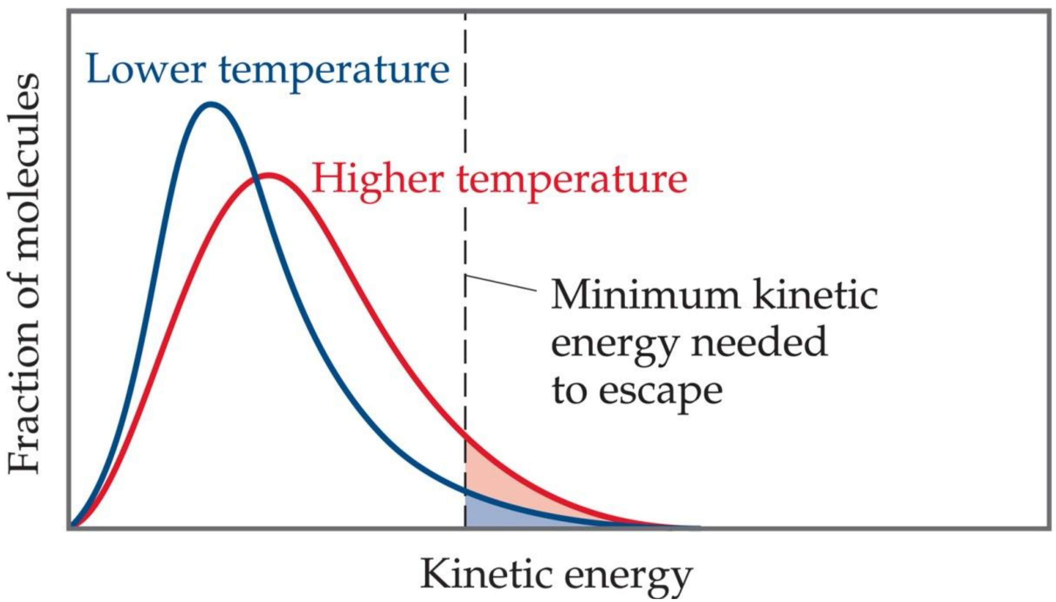
Energy Changes Associated with Changes of State



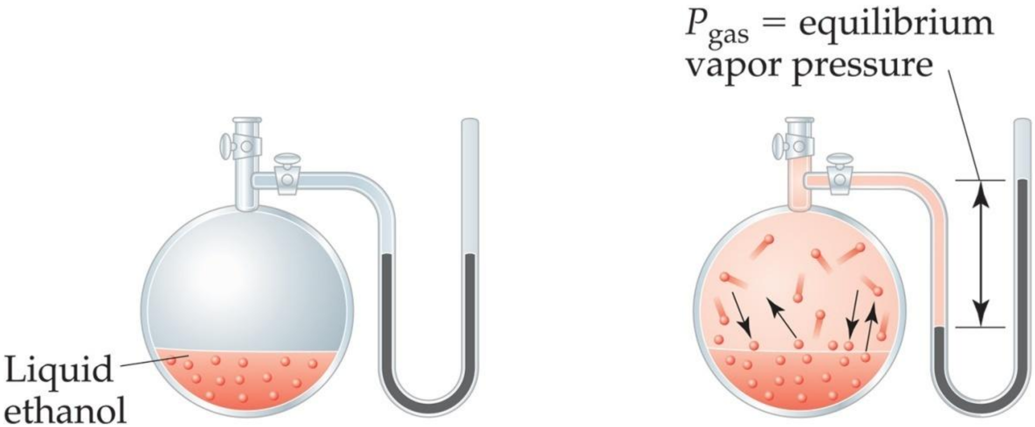
- The heat added to the system at the melting and boiling points goes into pulling the molecules farther apart from each other.
- The temperature of the substance does not rise during the phase change.

Vapor Pressure

- At any temperature, some molecules in a liquid have enough energy to escape.
- As the temperature rises, the fraction of molecules that have enough energy to escape increases.



Vapor Pressure

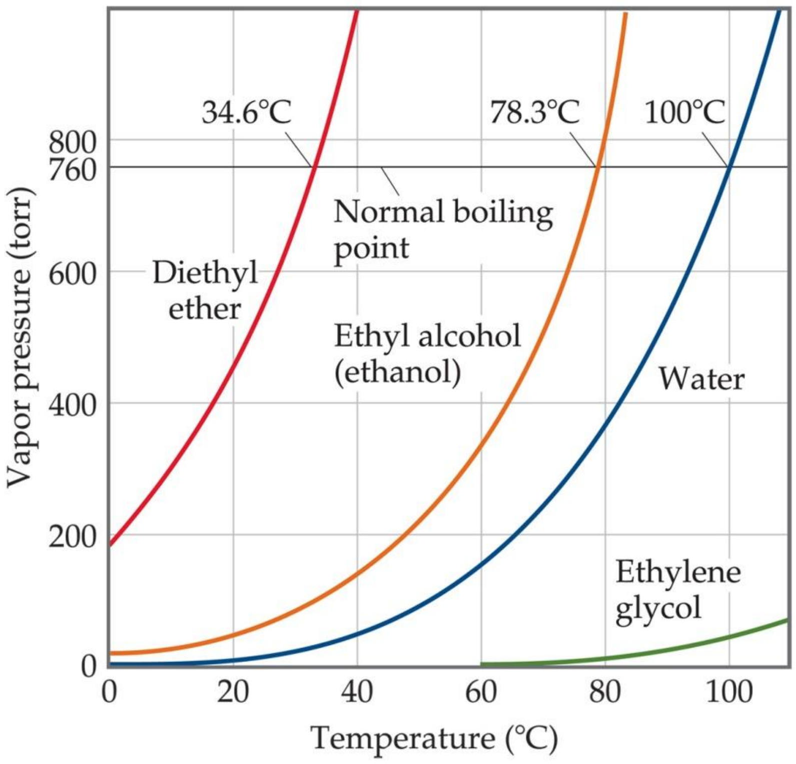


As more molecules escape the liquid, the pressure they exert increases.

The liquid and vapor reach a state of dynamic equilibrium: liquid molecules evaporate and vapor molecules condense *at the same rate*.

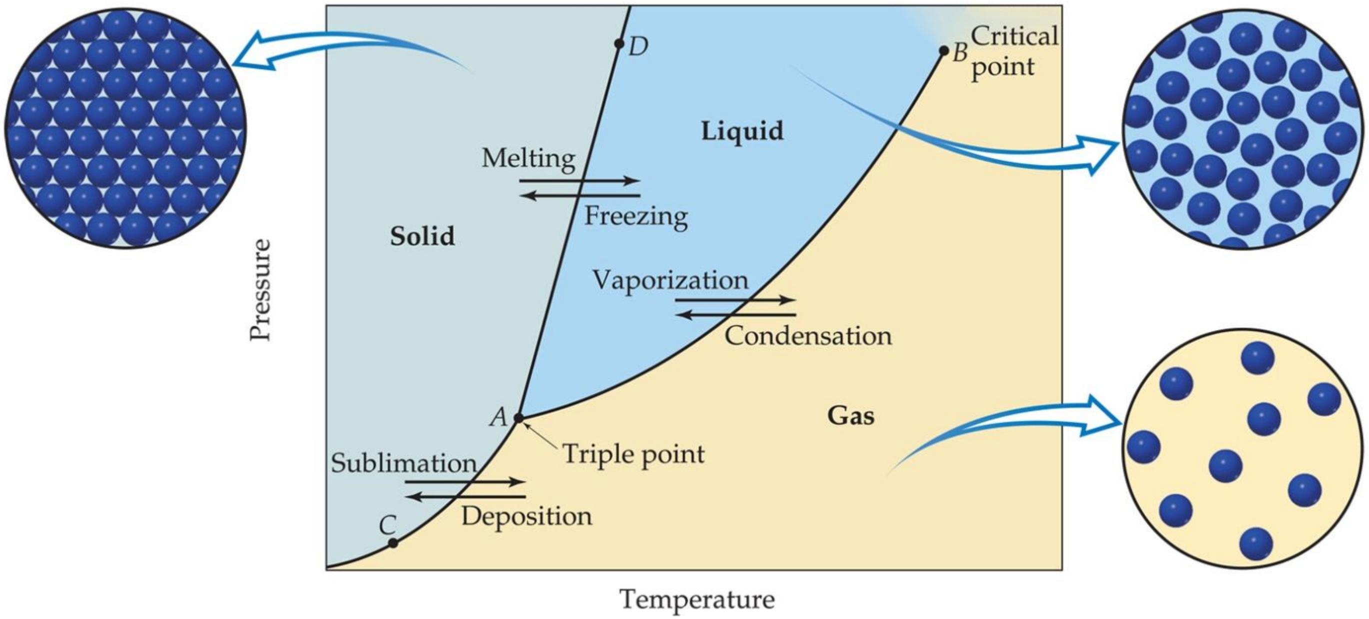
Vapor Pressure

- The boiling point of a liquid is the temperature at which its vapor pressure equals atmospheric pressure.
- The normal boiling point is the temperature at which its vapor pressure is 760 torr.
- Liquids boil when the external pressure equals the vapor pressure.



Phase Diagrams

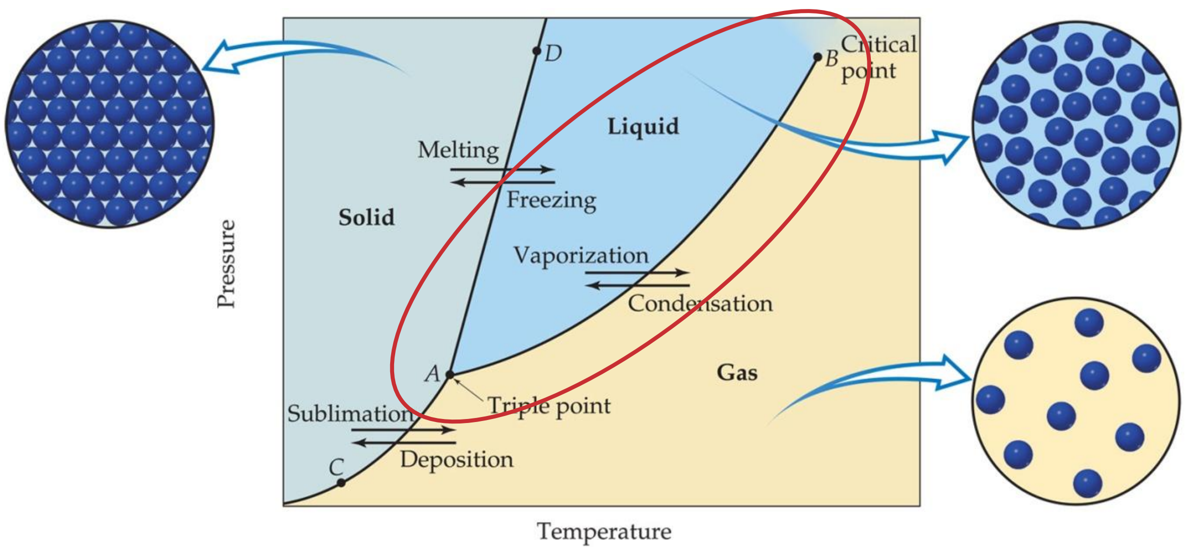
Phase diagrams display the state of a substance at various pressures and temperatures and the places where equilibria exist between phases.



Intermolecular Forces

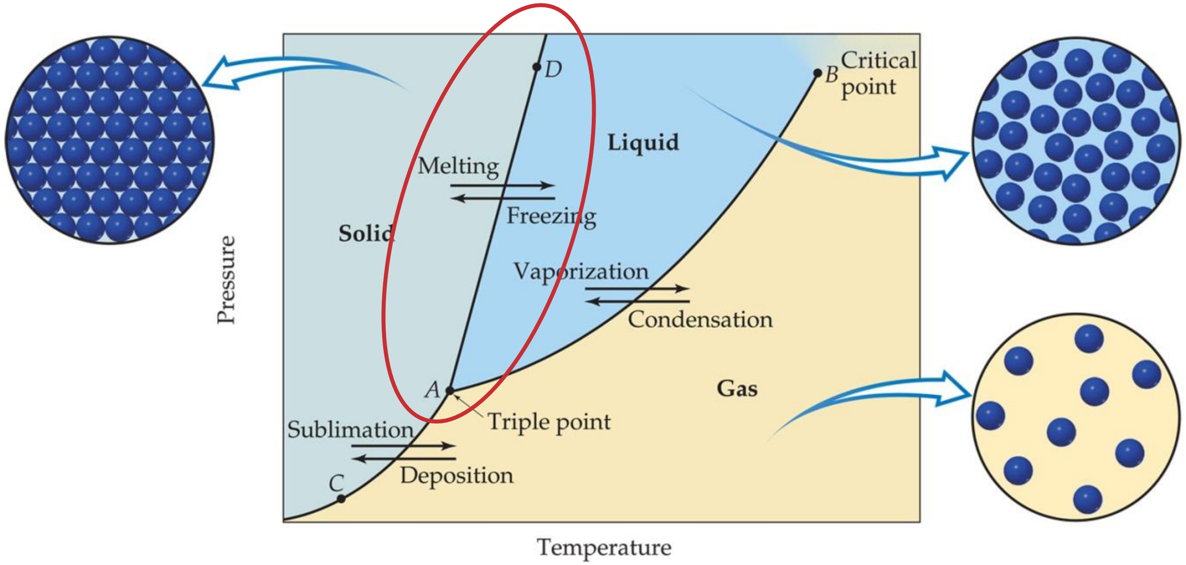
Phase Diagrams

- The *AB* line is the liquid-vapor interface. It starts at the triple point (*A*), the point at which all three states are in equilibrium.
- It ends at the critical point (*B*); above this critical temperature and pressure the liquid and vapor are indistinguishable from each other.
- Each point along this line is the boiling point

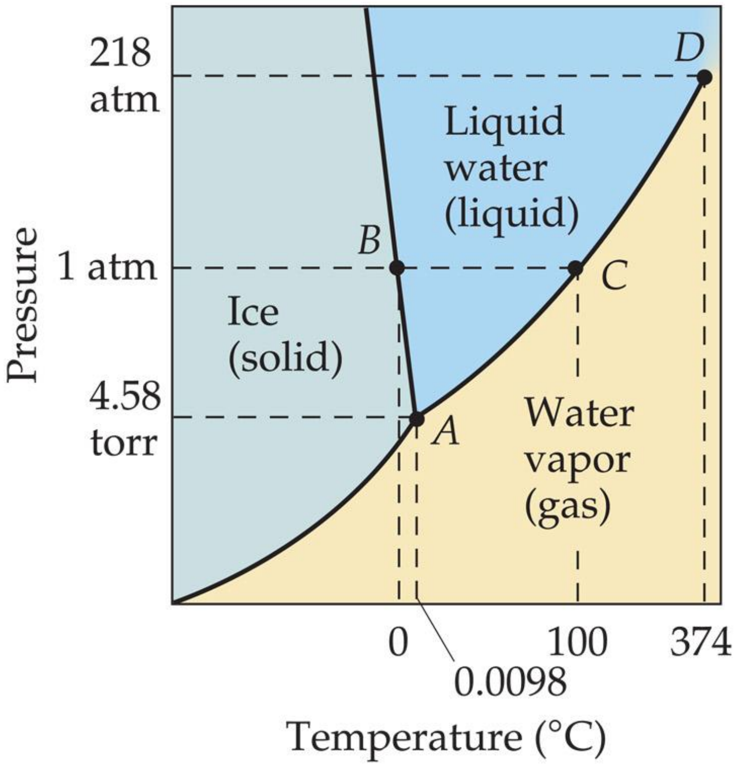


Phase Diagrams

- The *AD* line is the interface between liquid and solid.
- The melting point at each pressure can be found along this line.
- Below *A* the substance cannot exist in the liquid state.
- Along the *AC* line the solid and gas phases are in equilibrium; the sublimation point at each pressure is along this line.



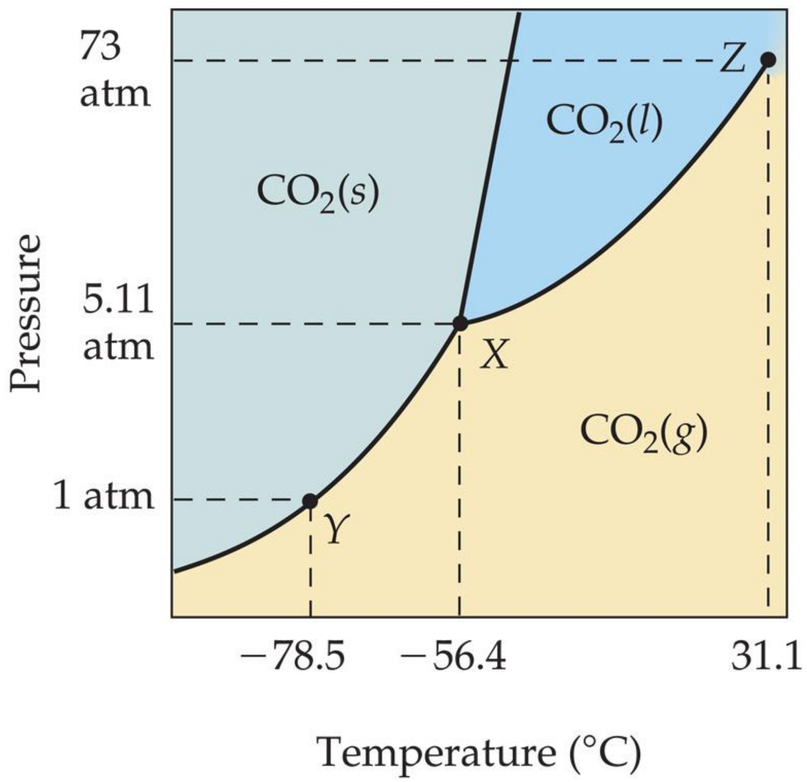
Phase Diagram of Water



- Note the high critical temperature and critical pressure:
  - These are due to the strong van der Waals forces between water molecules.

Phase Diagram of Carbon Dioxide

- Carbon dioxide cannot exist in the liquid state at pressures below 5.11 atm; CO_2 sublimes at normal pressures.
- The low critical temperature and critical pressure for CO_2 make supercritical CO_2 a good solvent for extracting nonpolar substances (such as caffeine).



Not responsible

- **Structures of Solids**
- **Bonding in Solids**