Chapter 11

Liquids and
Intermolecular Forces

Content

Hydrophobic, water repellent
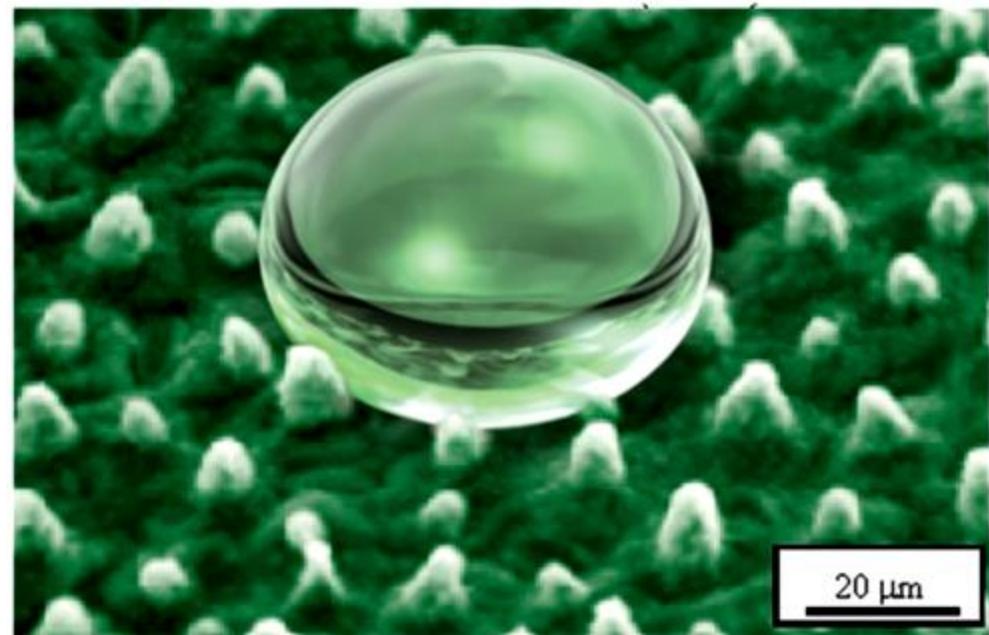
States of Matter

The fundamental difference between states of matter is the **distance between particles**.

Strength of intermolecular attractions increasing

Gas

Liquid

Crystalline solid

Chlorine, Cl_2
Particles far apart; possess complete freedom of motion

Bromine, Br_2
Particles are closely packed but randomly oriented; retain freedom of motion; rapidly change neighbors

Iodine, I_2
Particles are closely packed in an ordered array; positions are essentially fixed

States of Matter

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

20 μm

The States of Matter

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

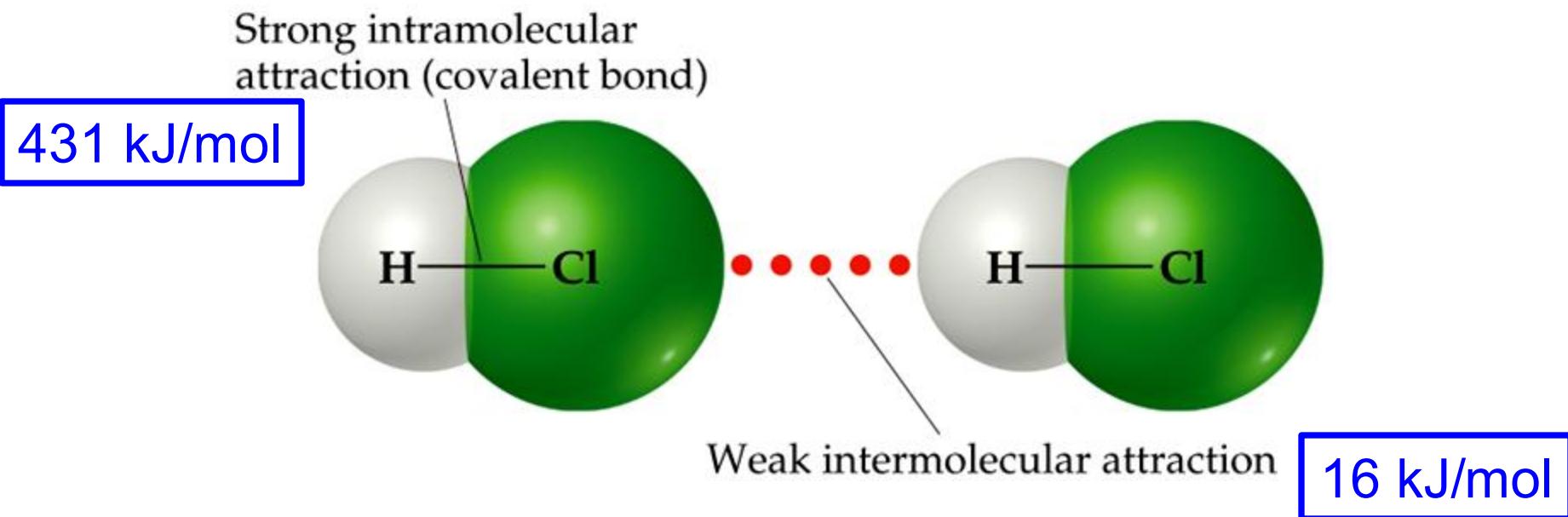| TABLE 11.1 • Some Characteristic Properties of the States of Matter	
Gas	Assumes both volume and shape of its container
	Expands to fill its container
	Is compressible (压缩)
	Flows readily
	Diffusion within a gas occurs rapidly
Liquid	Assumes shape of portion of container it occupies
	Does not expand to fill its container
	Is virtually incompressible
	Flows readily
	Diffusion within a liquid occurs slowly
Solid	Retains own shape and volume
	Does not expand to fill its container
	Is virtually incompressible
	Does not flow
	Diffusion within a solid occurs extremely slowly
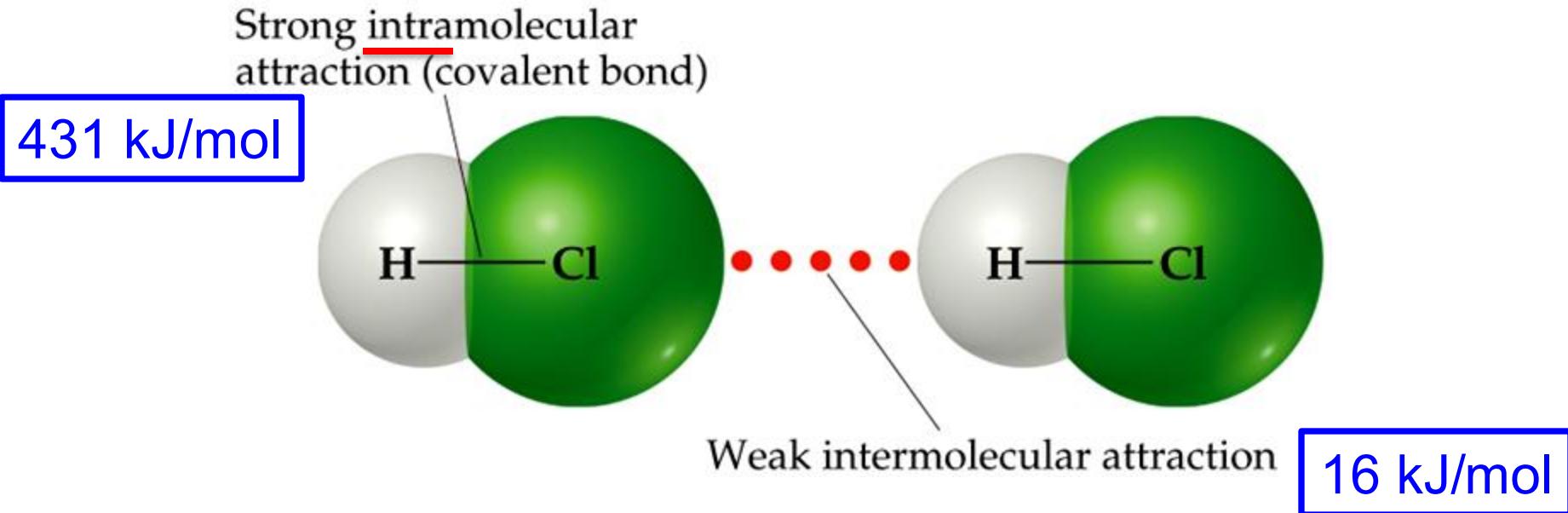
<u>Inter</u>molecular Forces 分子间力

Strong intramolecular
attraction (covalent bond)

431 kJ/mol

H — Cl ● ● ● ● ● ● ● H — Cl

Weak intermolecular attraction   16 kJ/mol

The attractions between molecules are not nearly as strong as the intramolecular attractions that hold compounds together.

<u>Inter</u>molecular Forces

Strong intramolecular
attraction (covalent bond)

431 kJ/mol

H——Cl

•••••

Weak intermolecular attraction

16 kJ/mol

These intermolecular attractions are, however, strong enough to control physical properties, such as boiling and melting points, vapor pressures, and viscosities (粘度).

van der Waals Forces (between neutral molecules 中性分子)

- London Disperse Forces (Dipole – induced dipole interactions)

- Dipole–dipole interactions
  （偶极−偶极相互作用）

- Hydrogen bonding

Johannes Diderik van der Waals
1837–1923

· **London Dispersion Forces** 色散力

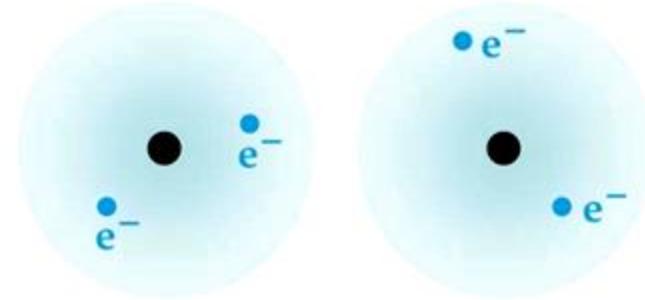## instantaneous dipole-induced dipole
瞬时偶极感应偶极子

非极性分子相互靠拢时，它们的瞬时偶极矩之间会产生很弱的吸引力，这种吸引力称为色散力。色散力存在于一切分子之间。任何一个分子，都存在着瞬间偶极，这种瞬间偶极也会诱导邻近分子产生瞬间偶极，于是两个分子可以靠瞬间偶极相互吸引在一起。这种瞬间偶极产生的作用力称为色散力（dispersion force），又叫做伦敦力。
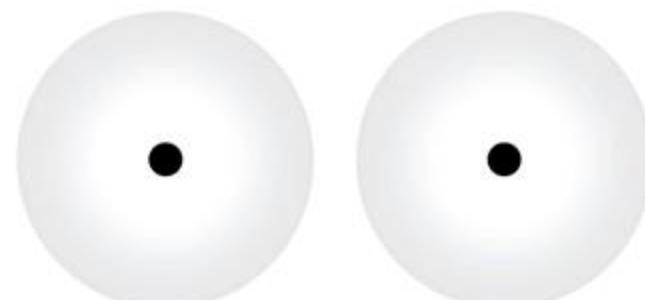

Fritz Wolfgang London
(1900–1954)

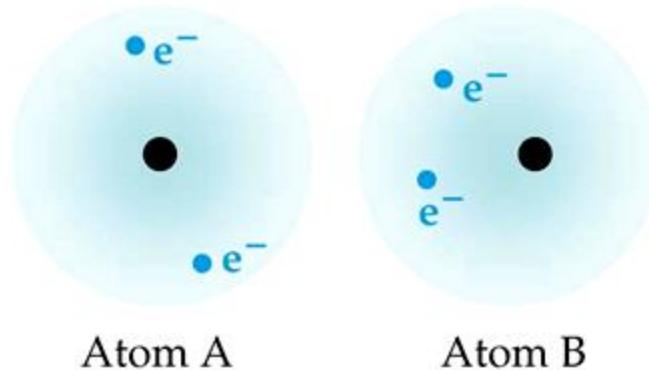# London Dispersion Forces

Atom A   Atom B

Atom A   Atom B

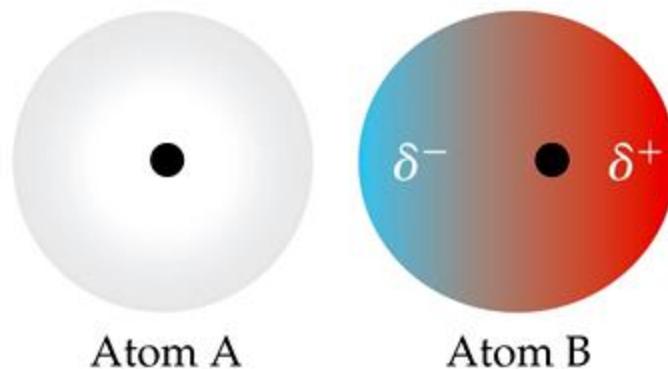(a) Two helium atoms, no polarization

While the electrons in the 1*s* orbital of helium would repel (排斥) each other (and, therefore, tend to stay far away from each other), it does happen that they occasionally wind up on the same side of the atom.

London Dispersion Forces

Subatomic particle view

Atom A   Atom B
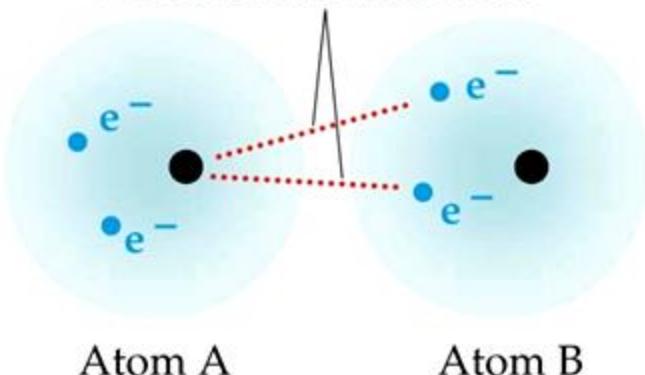
Polarization view

Atom A   Atom B

(b) Instantaneous dipole on atom B

At that instant, then, the helium atom is polar, with an excess of electrons on the left side and a shortage on the right side.
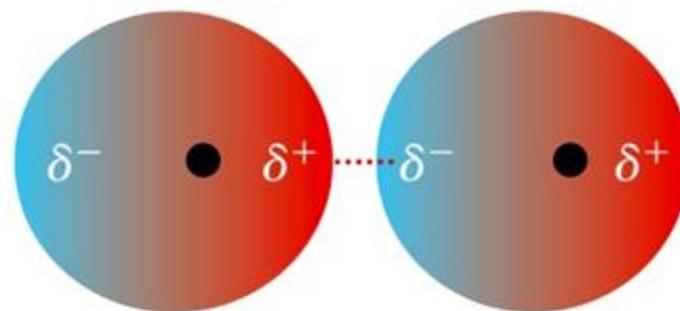
London Dispersion Forces

Electrostatic attraction

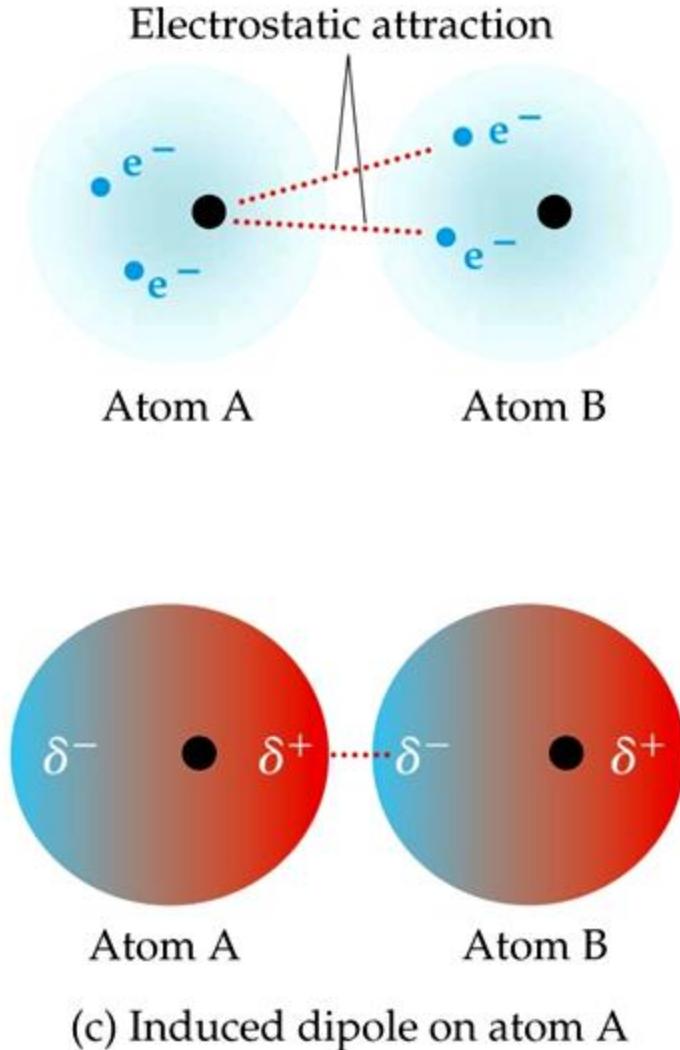Atom A   Atom B

(c) Induced dipole on atom A

Atom A   Atom B

Another helium atom nearby, then, would have a dipole induced in it, as the electrons on the left side of helium atom 2 repel the electrons in the cloud on helium atom 1.

London Dispersion Forces

Electrostatic attraction

Atom A   Atom B

δ^- δ^+ ···· δ^- δ^+
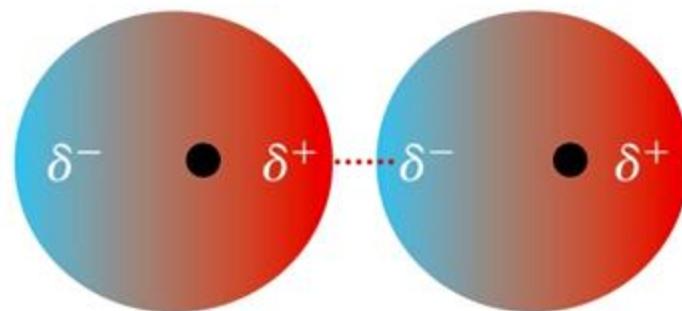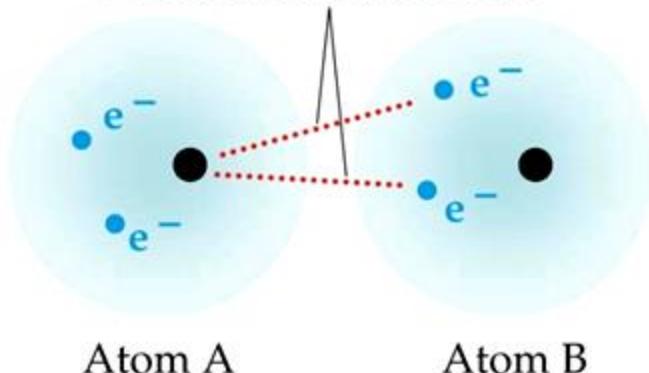
Atom A   Atom B

(c) Induced dipole on atom A

London dispersion forces, or dispersion forces (色散力), are **attractions** between an instantaneous dipole (瞬时偶极) and an induced dipole (感应偶极).

London Dispersion Forces

Electrostatic attraction
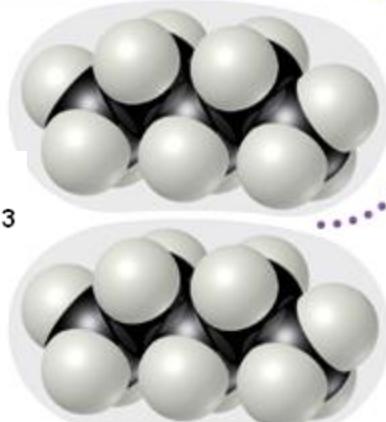
Atom A   Atom B

(c) Induced dipole on atom A

- These forces are present in *all* molecules, whether they are polar or nonpolar.

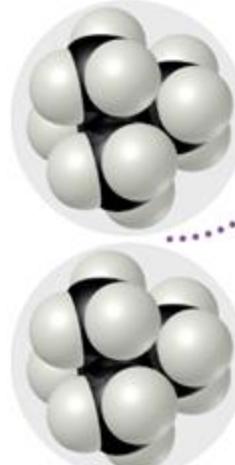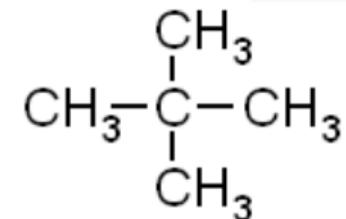- The tendency of an electron cloud to distort (扭曲) in this way is called **polarizability** (极化率).

Factors Affecting London Forces

Linear molecule, larger surface area enhances intermolecular contact and increases dispersion force ····•·
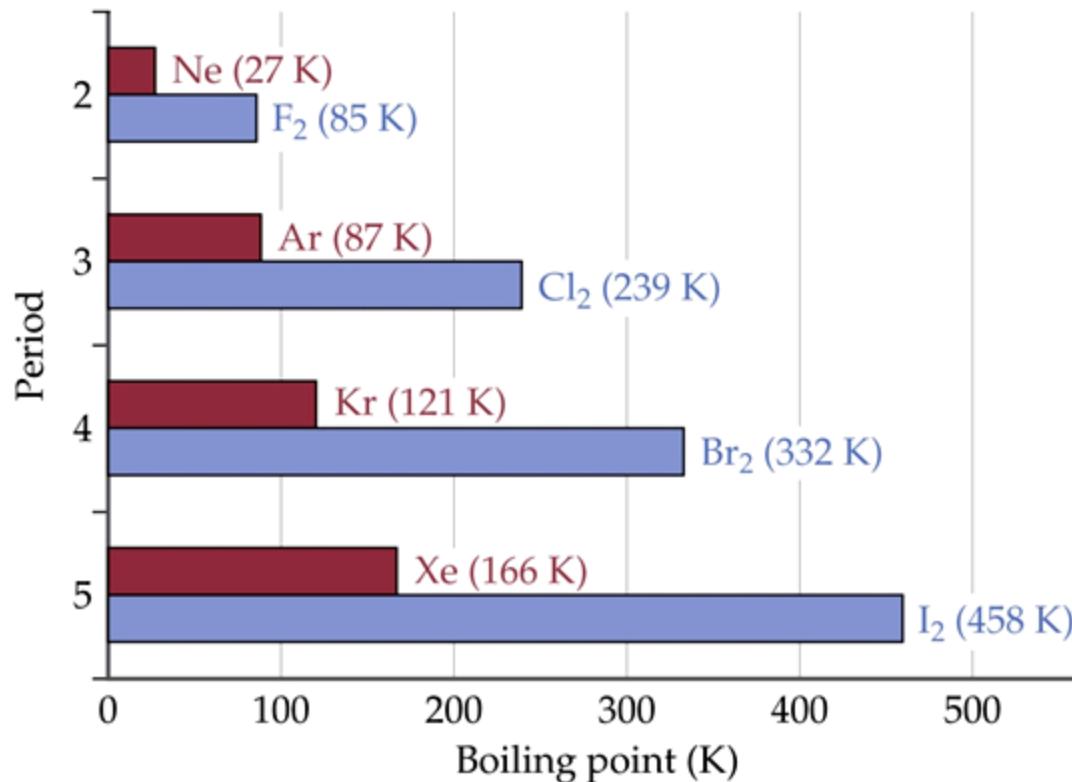
Spherical molecule, smaller surface area diminishes intermolecular contact and decreases dispersion force ·····

$CH_3-CH_2-CH_2-CH_2-CH_3$

n-Pentane (C_5H_{12})
bp = 309.4 K

Neopentane (C_5H_{12})
bp = 282.7 K

$$CH_3-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$$

- The shape of the molecule affects the strength of dispersion forces: long, skinny (细长) molecules (like *n*-pentane) tend to have stronger dispersion forces than short, fat ones (like neopentane 新戊烷).
- This is due to the increased surface area in *n*-pentane.

Factors Affecting London Forces

- The strength of dispersion forces tends to increase with increased molecular weight.

- Larger atoms have larger electron clouds that are easier to polarize.

List the substances CCl_4, CBr_4, and CH_4 in order of increasing boiling point.

A. $CH_4 < CBr_4 < CCl_4$

B. $CCl_4 < CH_4 < CBr_4$
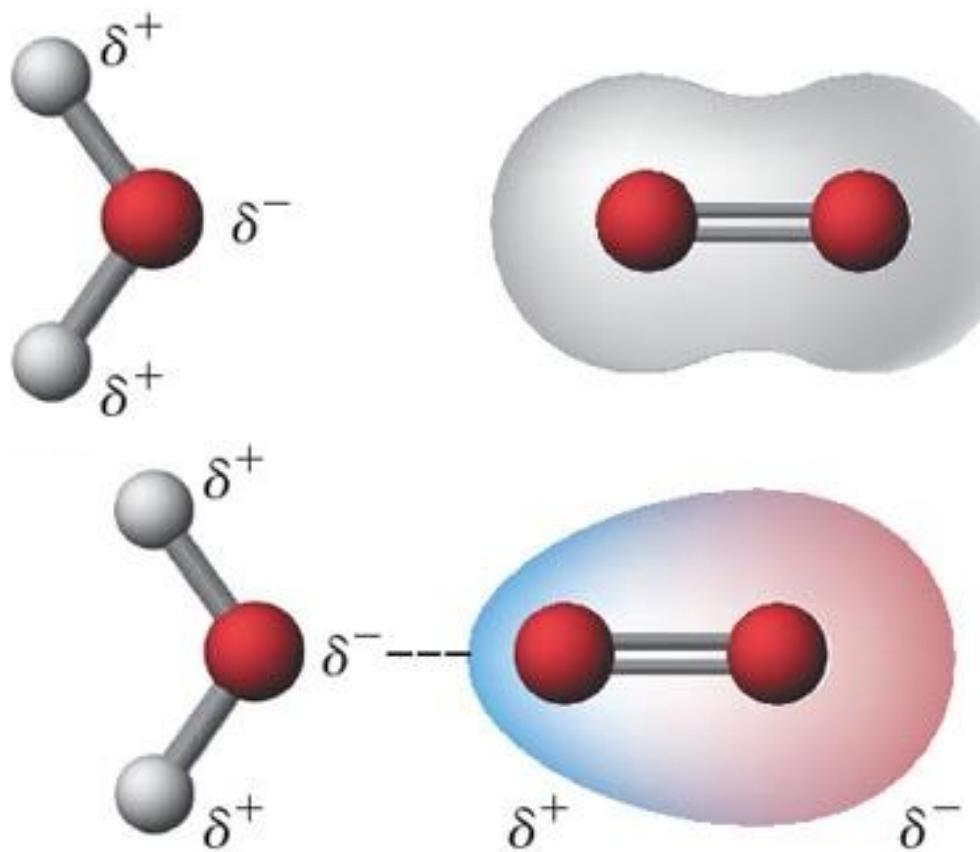
C. $CH_4 < CCl_4 < CBr_4$

D. $CBr_4 < CCl_4 < CH_4$

List the substances CCl_4, CBr_4, and CH_4 in order of increasing boiling point.

A. $CH_4 < CBr_4 < CCl_4$

B. $CCl_4 < CH_4 < CBr_4$

C. $CH_4 < CCl_4 < CBr_4$

D. $CBr_4 < CCl_4 < CH_4$

Dipole – Induced Dipole Interactions

- A weak attraction that results when a polar molecule induces a dipole in an atom or in a nonpolar molecule by disturbing the arrangement of electrons in the nonpolar species.
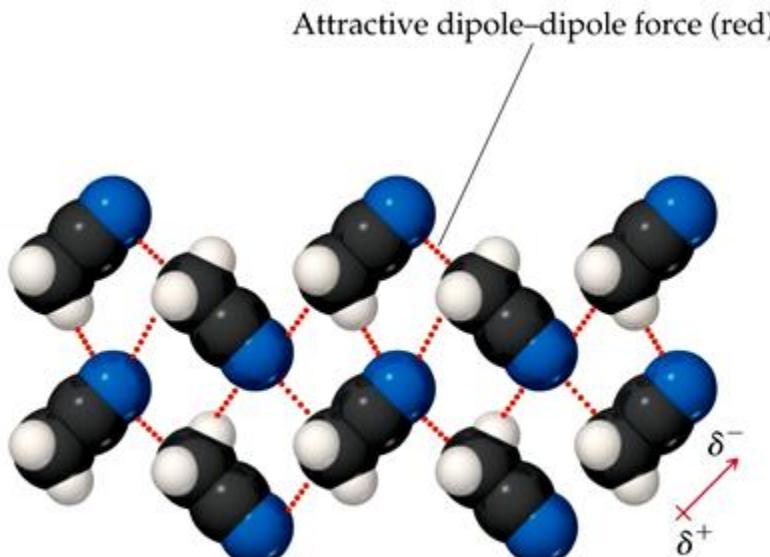
Oxygen dissolves in water:
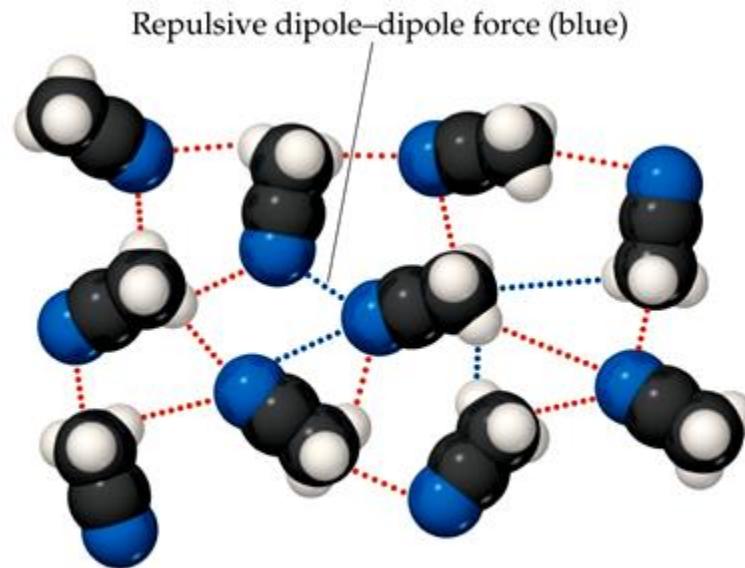
The dipole of water induces a dipole in O_2 by distorting the O_2 electron cloud.

Dipole–Dipole Interactions

- Molecules that have permanent dipoles (固有偶极) 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.

Attractive dipole–dipole force (red)

Repulsive dipole–dipole force (blue)

δ^-
δ^+
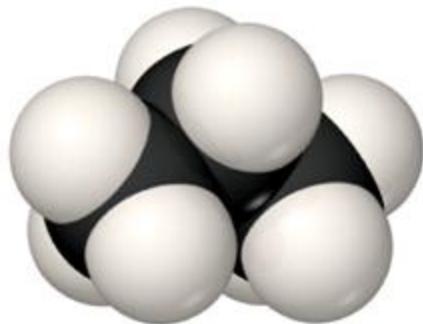
(a) Solid CH_3CN

(b) Liquid CH_3CN

Dipole–Dipole Interactions

Propane
$CH_3CH_2CH_3$
MW = 44 amu
μ = 0.1 D
bp = 231 K

Dimethyl ether
CH_3OCH_3
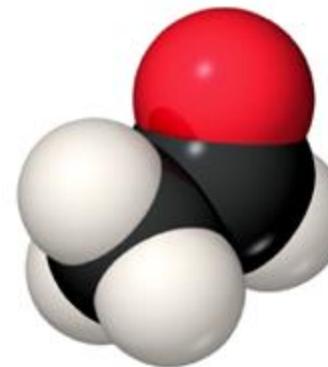MW = 46 amu
μ = 1.3 D
bp = 248 K

Acetaldehyde
CH_3CHO
MW = 44 amu
μ = 2.7 D
bp = 294 K

Acetonitrile
CH_3CN
MW = 41 amu
μ = 3.9 D
bp = 355 K

Increasing polarity
Increasing strength of dipole–dipole forces
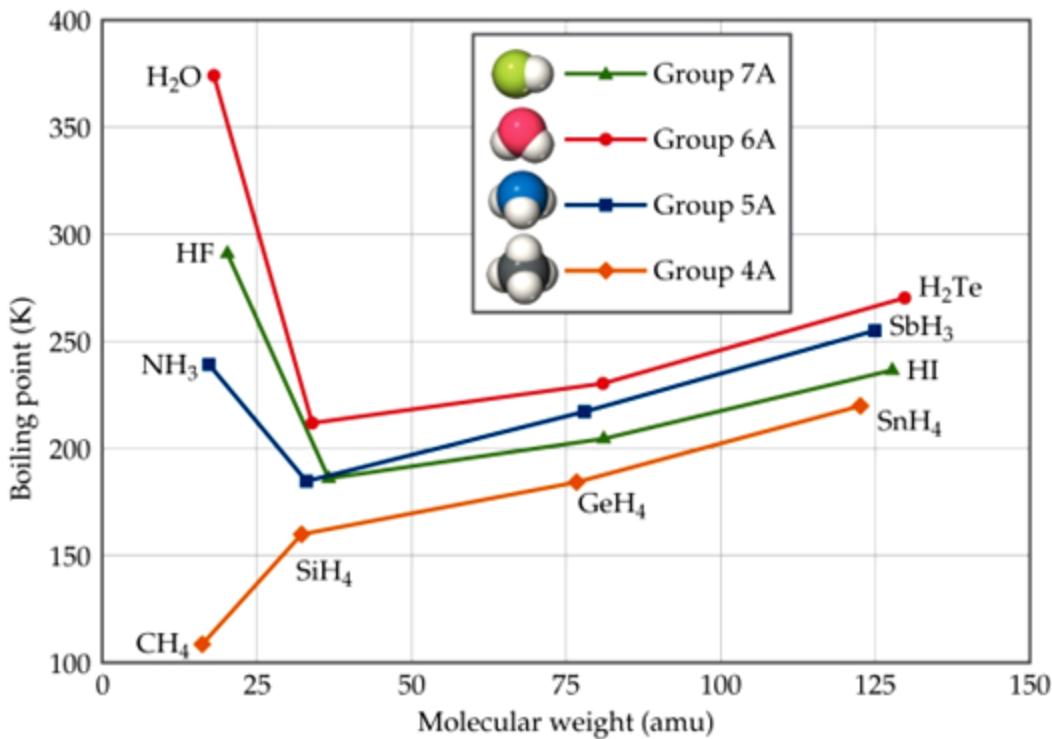
The more polar the molecule, the higher its boiling point.

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?
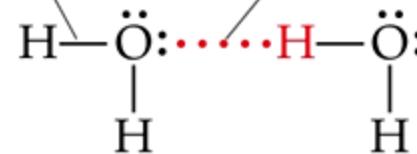
- The nonpolar series (SnH_4 to CH_4) follow the expected trend.
- The polar series follow the trend until you get to the smallest molecules in each group.

Hydrogen Bonding
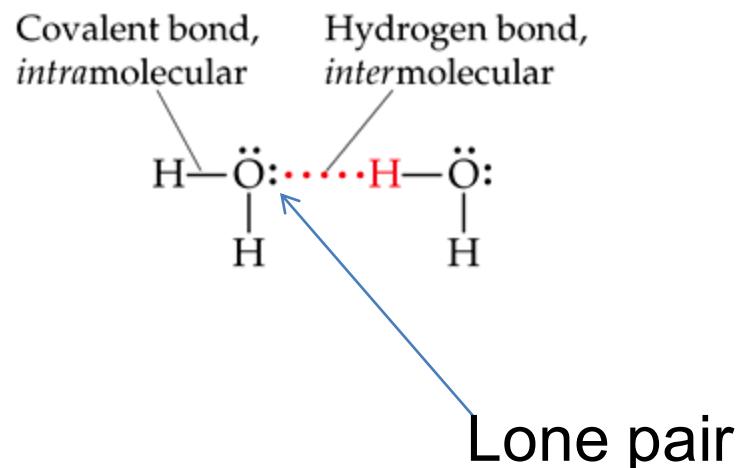
- The dipole–dipole interactions experienced when H is bonded to N, O, or F are unusually strong.
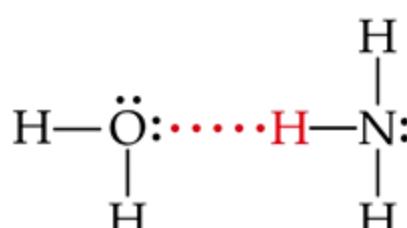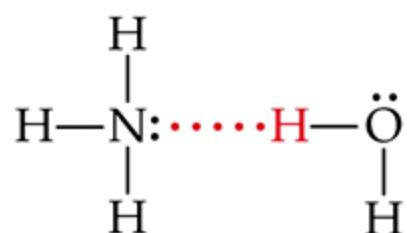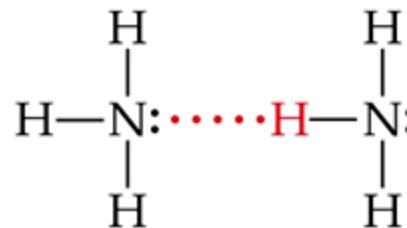- We call these interactions **hydrogen bonds**.

To form a hydrogen bond what must the non-hydrogen atom (N, O, or F) involved in the bond possess?

A. The non-hydrogen atom must have a nonbonding electron pair.
B. The non-hydrogen atom must have low electronegativity.
C. The non-hydrogen atom must have a large atomic size.
D. The non-hydrogen atom must have a small electron affinity.

Covalent bond, *intra*molecular

Hydrogen bond, *inter*molecular

$$H—\ddot{\underset{\cdot\cdot}{O}}:\cdots H—\ddot{\underset{\cdot\cdot}{O}}:$$
$$\overset{|}{H} \qquad\qquad \overset{|}{H}$$

Lone pair

To form a hydrogen bond what must the non-hydrogen atom (N, O, or F) involved in the bond possess?

A. The non-hydrogen atom must have a nonbonding electron pair.
B. The non-hydrogen atom must have low electronegativity.
C. The non-hydrogen atom must have a large atomic size.
D. The non-hydrogen atom must have a small electron affinity.

Covalent bond, *intra*molecular

Hydrogen bond, *inter*molecular

H—Ö:·····H—Ö:
    | |
    H   H

Lone pair

Hydrogen Bonding

- Hydrogen bonding arises in part from the **high electronegativity** of nitrogen, oxygen, and fluorine.

  Also, when hydrogen is bonded to one of those very electronegative elements, the hydrogen nucleus is exposed.
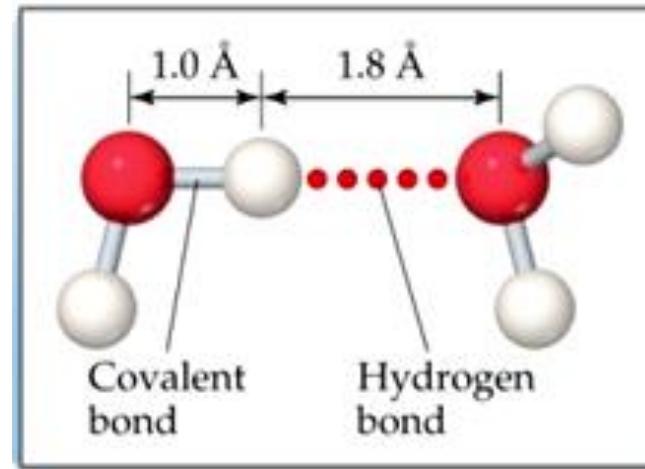
What is the approximate H—O•••H bond angle in ice, where H—O is the covalent bond and O•••H is the hydrogen bond?

A. Approximately 90°
B. Approximately 109°
C. Approximately 120°
D. Approximately 180°

1.0 Å   1.8 Å

Covalent bond   Hydrogen bond

What is the approximate H—O••••H bond angle in ice, where H—O is the covalent bond and O••••H is the hydrogen bond?

A. Approximately 90°
B. Approximately 109°
C. Approximately 120°
D. Approximately 180°

1.0 Å   1.8 Å
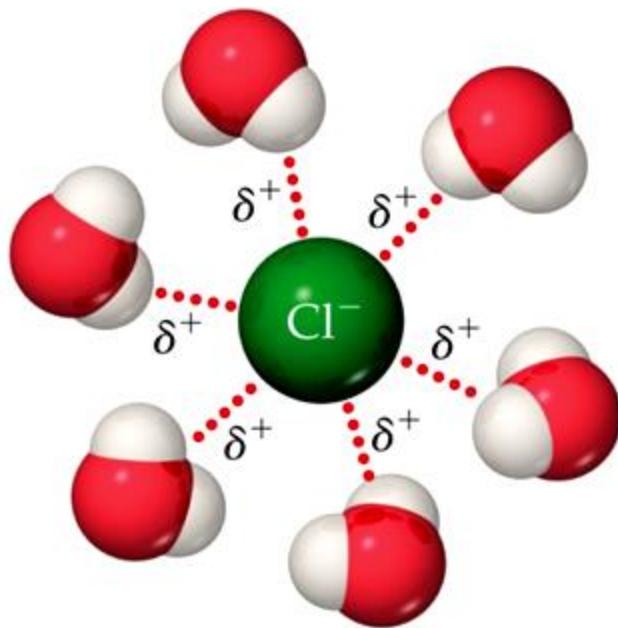
Covalent bond   Hydrogen bond
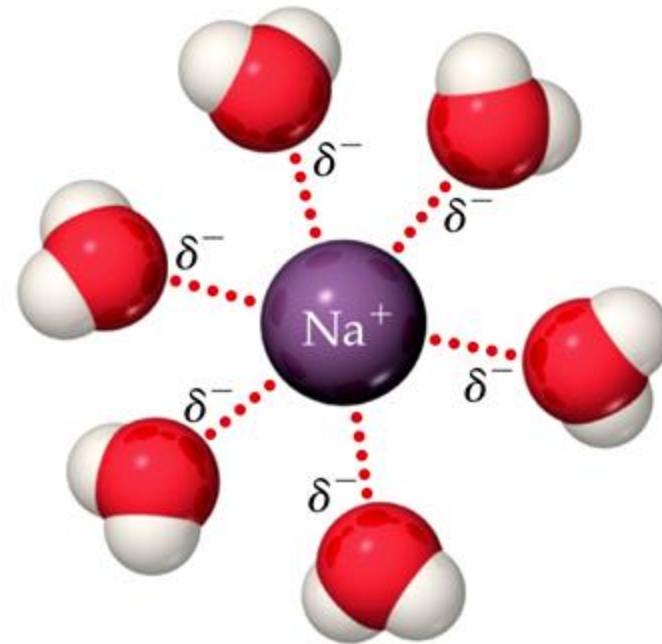
Ion–Dipole Interactions

- Ion–dipole interactions (a fourth type of force) are important in solutions of ions.

- The strength of these forces is what makes it possible for **ionic substances to dissolve in polar solvents**.

Positive ends of polar molecules are oriented toward negatively charged anion

Negative ends of polar molecules are oriented toward positively charged cation

In which mixture do you expect to find ion–dipole forces: CH_3OH in water or $Ca(NO_3)_2$ in water?

A. CH_3OH in water, because CH_3OH is a strong electrolyte and forms ions.

B. $Ca(NO_3)_2$ in water, because $Ca(NO_3)_2$ is a strong electrolyte and forms ions.

C. CH_3OH in water, because CH_3OH is a weak electrolyte and forms ions.

D. $Ca(NO_3)_2$ in water, because $Ca(NO_3)_2$ is a weak electrolyte and forms ions.

In which mixture do you expect to find ion–dipole forces: CH_3OH in water or $Ca(NO_3)_2$ in water?

A. CH_3OH in water, because CH_3OH is a strong electrolyte and forms ions.

B. $Ca(NO_3)_2$ in water, because $Ca(NO_3)_2$ is a strong electrolyte and forms ions.

C. CH_3OH in water, because CH_3OH is a weak electrolyte and forms ions.

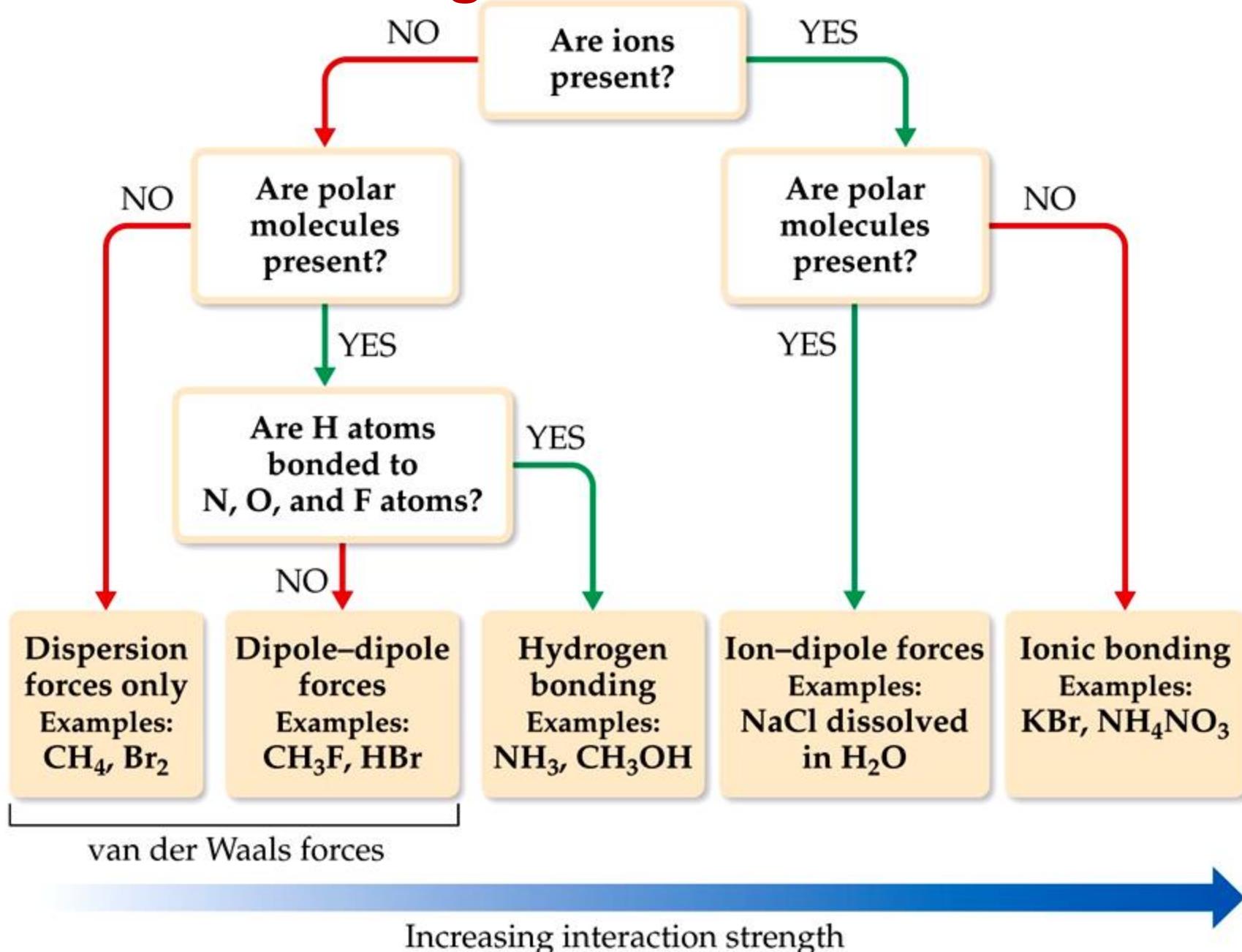D. $Ca(NO_3)_2$ in water, because $Ca(NO_3)_2$ is a weak electrolyte and forms ions.

Summarizing Intermolecular Forces

Each molecule can form two
hydrogen bonds with a neighbor

Acetic acid, CH_3COOH
MW = 60 amu
bp = 391 K

Each molecule can form one
hydrogen bond with a neighbor

1-Propanol, $CH_3CH_2CH_2OH$
MW = 60 amu
bp = 370 K

Intermolecular Forces Affect Many Physical Properties

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

Exercise Predicting Types and Relative Strengths of Intermolecular Attractions

List the substances $BaCl_2$, H_2, CO, HF, and Ne in order of increasing boiling point.

Solution

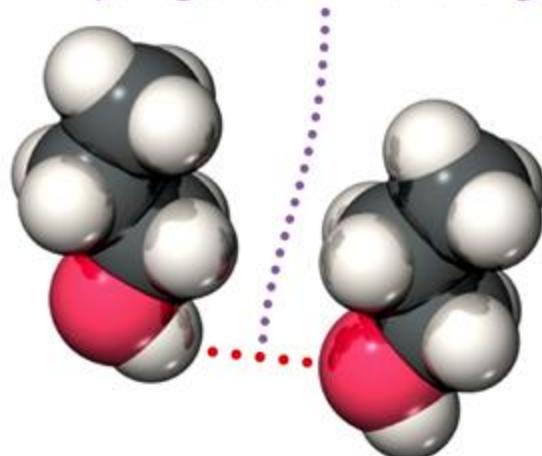**Plan** The boiling point depends in part on the attractive forces in each substance. We need to order these according to the relative strengths of the different kinds of intermolecular attractions.

Solve

(1) The attractive forces are stronger for ionic substances than for molecular ones, so $BaCl_2$ should have the highest boiling point.

(2) The intermolecular forces of the remaining substances depend on molecular weight, polarity, and hydrogen bonding. The molecular weights are H_2 (2), CO (28), HF (20), and Ne (20).

(3) The boiling point of H_2 should be the lowest because it is nonpolar and has the lowest molecular weight. The molecular weights of CO, HF, and Ne are similar.

(4) Because HF can hydrogen bond, however, it should have the highest boiling point of the three. Next is CO, which is slightly polar and has the highest molecular weight. Finally, Ne, which is nonpolar, should have the lowest boiling point of these three.

Exercise Predicting Types and Relative Strengths of Intermolecular Attractions

List the substances $BaCl_2$, H_2, CO, HF, and Ne in order of increasing boiling point.

Solution

Plan The boiling point depends in part on the attractive forces in each substance. We need to order these according to the relative strengths of the different kinds of intermolecular attractions.

Solve The predicted order of boiling points is, therefore,

$$H_2 < Ne < CO < HF < BaCl_2$$

Check The boiling points reported in the literature are H_2 (20 K), Ne (27 K), CO (83 K), HF (293 K), and $BaCl_2$ (1813 K)—in agreement with our predictions.

Viscosity 粘度

TABLE 11.4 • Viscosities of a Series of Hydrocarbons at 20 °C

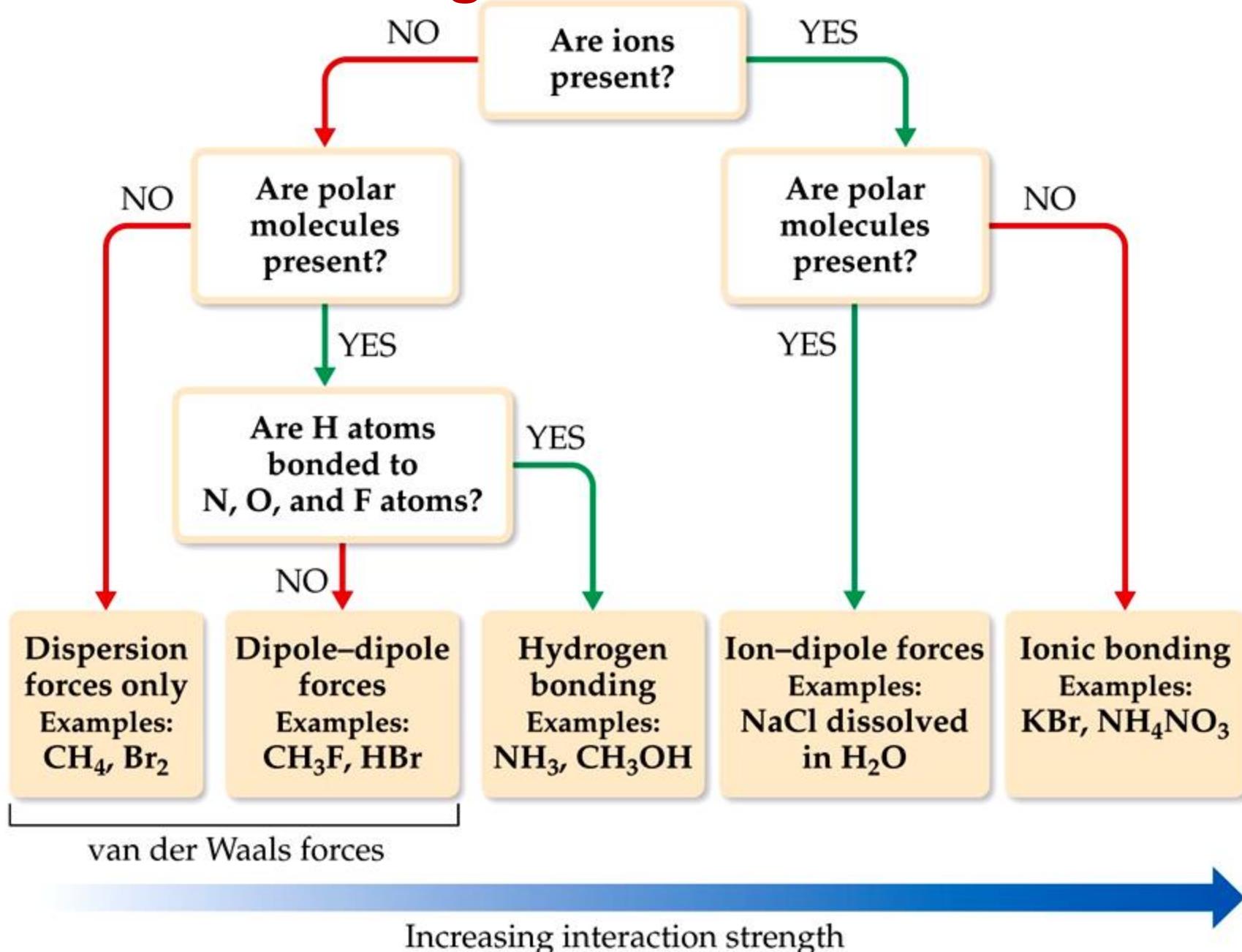| Substance	Formula	Viscosity (kg/m-s)
Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	3.26×10^{-4}
Heptane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	4.09×10^{-4}
Octane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	5.42×10^{-4}
Nonane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	7.11×10^{-4}
Decane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$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

SAE 40
higher number
higher viscosity
slower pouring

SAE 10
lower number
lower viscosity
faster pouring

- Resistance of a liquid to flow is called **viscosity**.

- It is related to the ease with which molecules can move past each other.

- Viscosity increases with stronger intermolecular forces and decreases with higher temperature.

- **London Disperse Forces (Dipole-induced dipole interactions)**
- **Dipole–dipole interactions**
- **Hydrogen bonding**
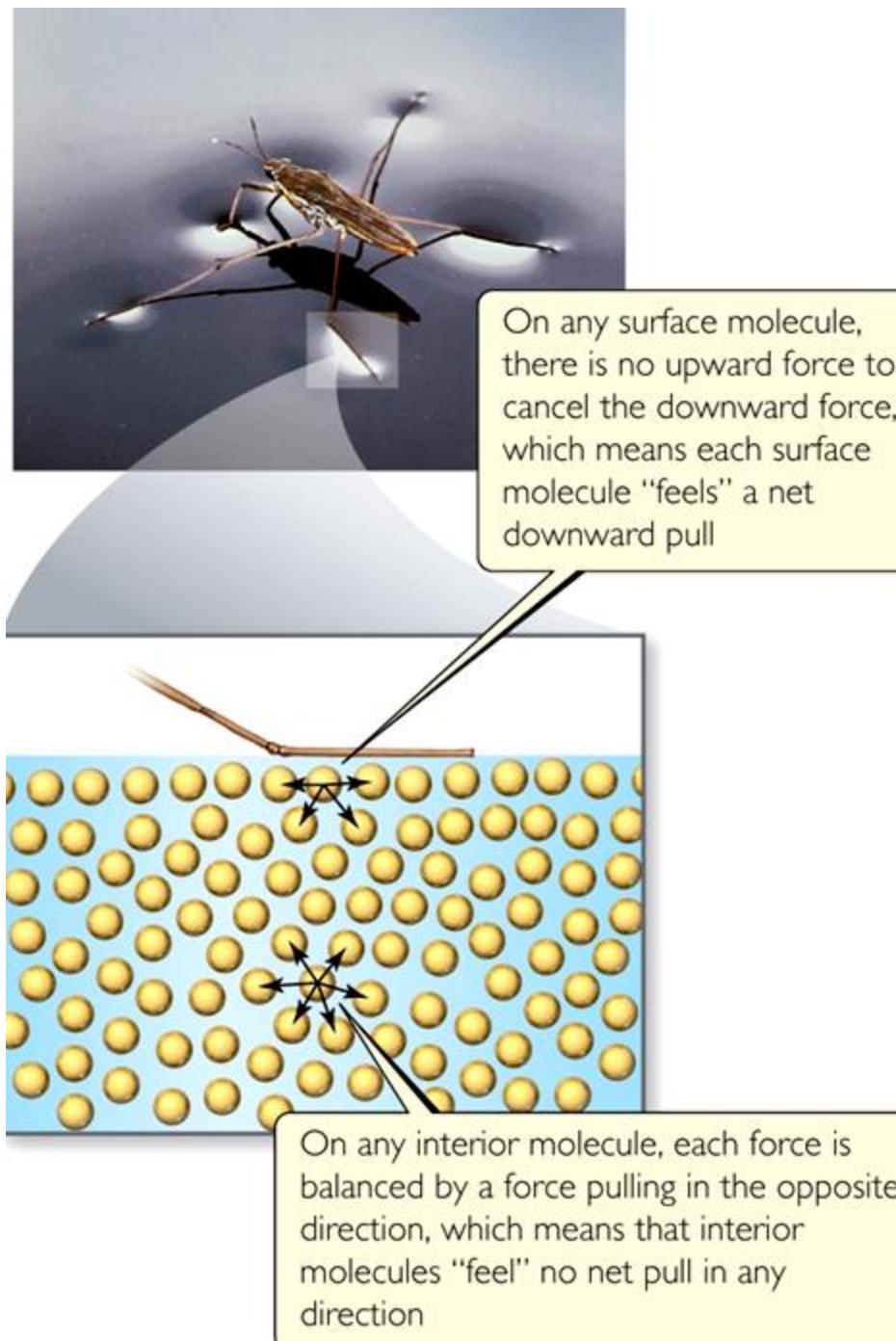- **Ion–Dipole Interactions**

Summarizing Intermolecular Forces

41

Surface Tension
表面张力

On any surface molecule, there is no upward force to cancel the downward force, which means each surface molecule "feels" a net downward pull

On any interior molecule, each force is balanced by a force pulling in the opposite direction, which means that interior molecules "feel" no net pull in any direction

Surface tension results from the net inward force experienced by the molecules on the surface of a liquid.

It is the energy required to increase area of a liquid by a unit amount (J/m^2)

表面张力指液体表面任意二相邻部分之间垂直于它们的单位长度分界线相互作用的拉力。

How do viscosity and surface tension change
a. as temperature increases,
b. as intermolecular forces of attraction become stronger?

A. Viscosity increases as intermolecular forces increase while surface tension decreases. Both viscosity and surface tension increase with increasing temperature.

B. Viscosity decreases as intermolecular forces increase while surface tension increases. Both viscosity and surface tension increase with decreasing temperature

C. Both viscosity and surface tension increase as intermolecular forces increase and temperature decreases.

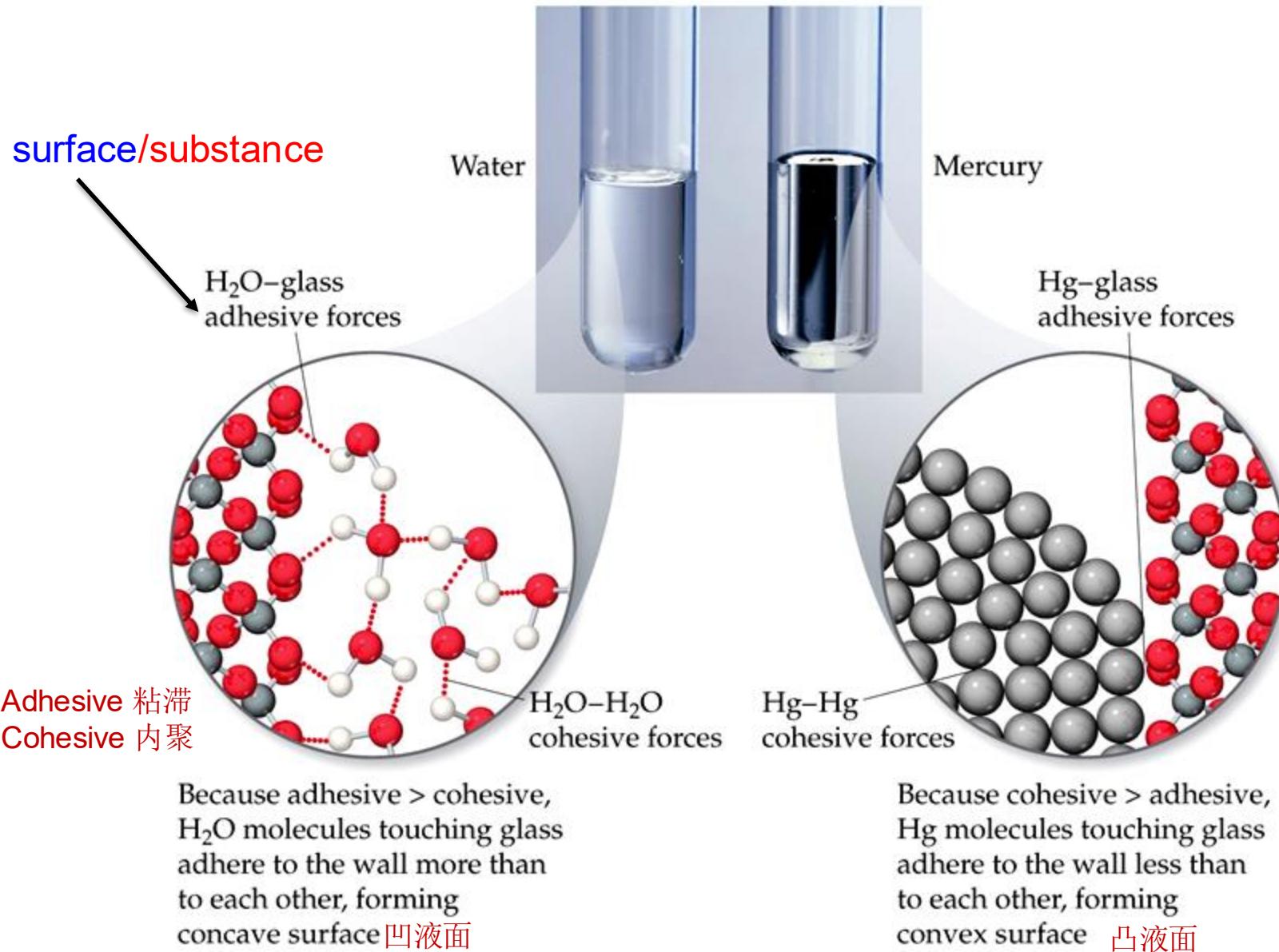D. Both viscosity and surface tension decrease as intermolecular forces increase and temperature increases.

GIVE IT SOME THOUGHT

How do viscosity and surface tension change
a. as temperature increases,
b. as intermolecular forces of attraction become stronger?

A. Viscosity increases as intermolecular forces increase while surface tension decreases. Both viscosity and surface tension increase with increasing temperature.

B. Viscosity decreases as intermolecular forces increase while surface tension increases. Both viscosity and surface tension increase with decreasing temperature

C. Both viscosity and surface tension increase as intermolecular forces increase and temperature decreases.

D. Both viscosity and surface tension decrease as intermolecular forces increase and temperature increases.

Wetting and Non-Wetting

surface/substance

Water

Mercury

H_2O–glass
adhesive forces

Hg–glass
adhesive forces

Adhesive 粘滞
Cohesive 内聚

H_2O–H_2O
cohesive forces

Hg–Hg
cohesive forces

Because adhesive > cohesive,
H_2O molecules touching glass
adhere to the wall more than
to each other, forming
concave surface 凹液面

Because cohesive > adhesive,
Hg molecules touching glass
adhere to the wall less than
to each other, forming
convex surface 凸液面

If the inside surface of each tube were coated with wax (蜡), would the general shape of the water meniscus(弯月面) change? Would the general shape of the mercury (汞) meniscus change?

Shape of Water Meniscus	Shape of Hg Meniscus
A. Yes, Inverted U	Yes, downward U
B. No change	Yes, downward U
C. No change	No change
D. Yes, Inverted U	No change

If the inside surface of each tube were coated with wax (蜡), would the general shape of the water meniscus change? Would the general shape of the mercury (汞) meniscus change?
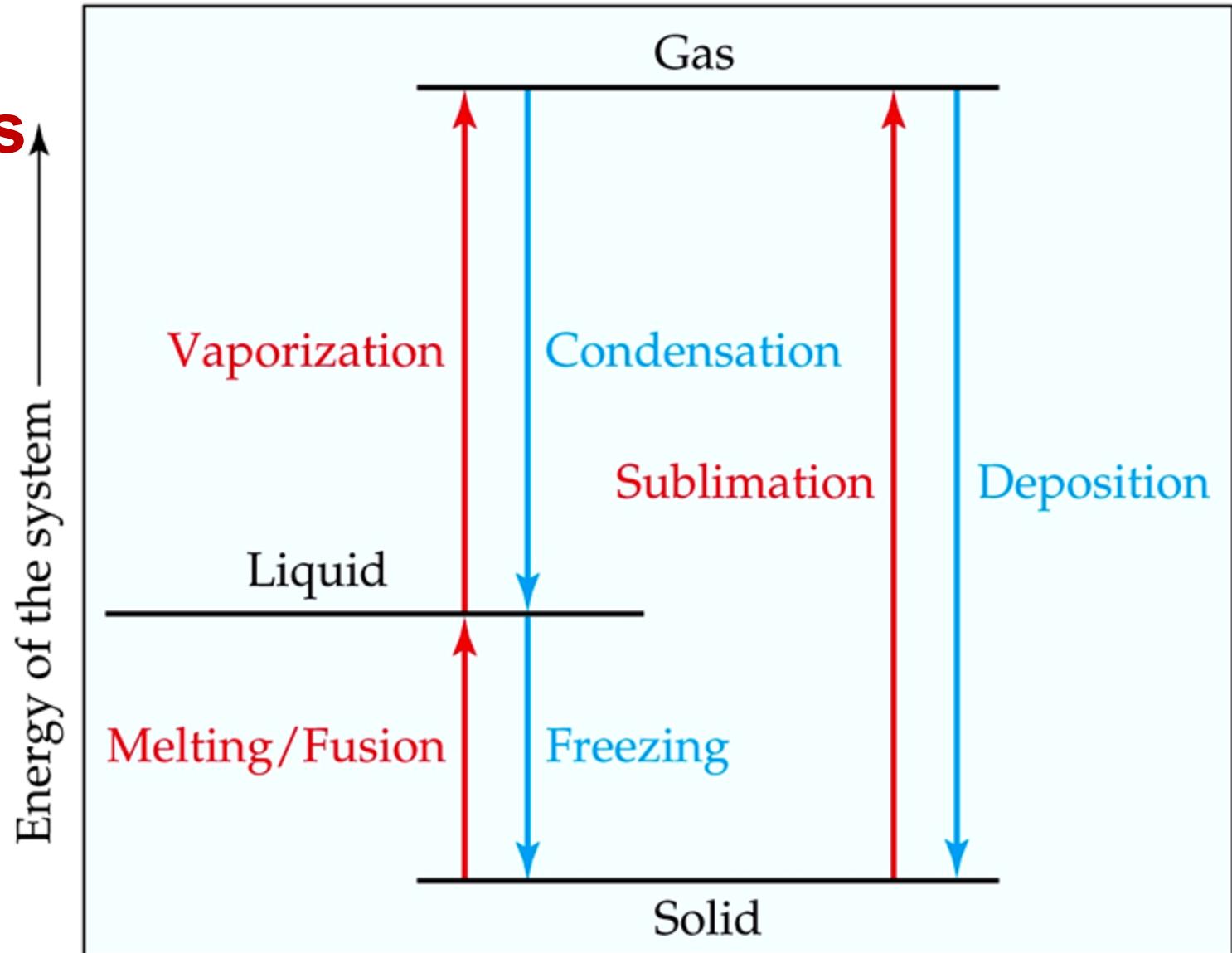
	Shape of Water Meniscus	Shape of Hg Meniscus
A.	Yes, Inverted U	Yes, downward U
B.	No change	Yes, downward U
C.	No change	No change
D.	Yes, Inverted U	No change

Water-Repellent Legs of Water Striders

Water striders (*Gerris remigis*) have remarkable non-wetting legs that enable them to stand effortlessly and move quickly on water, a feature believed to be due to a surface-tension effect caused by secreted wax (蜡).

Phase Changes

Energy of the system

Gas

Vaporization | Condensation

Sublimation | Deposition

Liquid

Melting/Fusion | Freezing
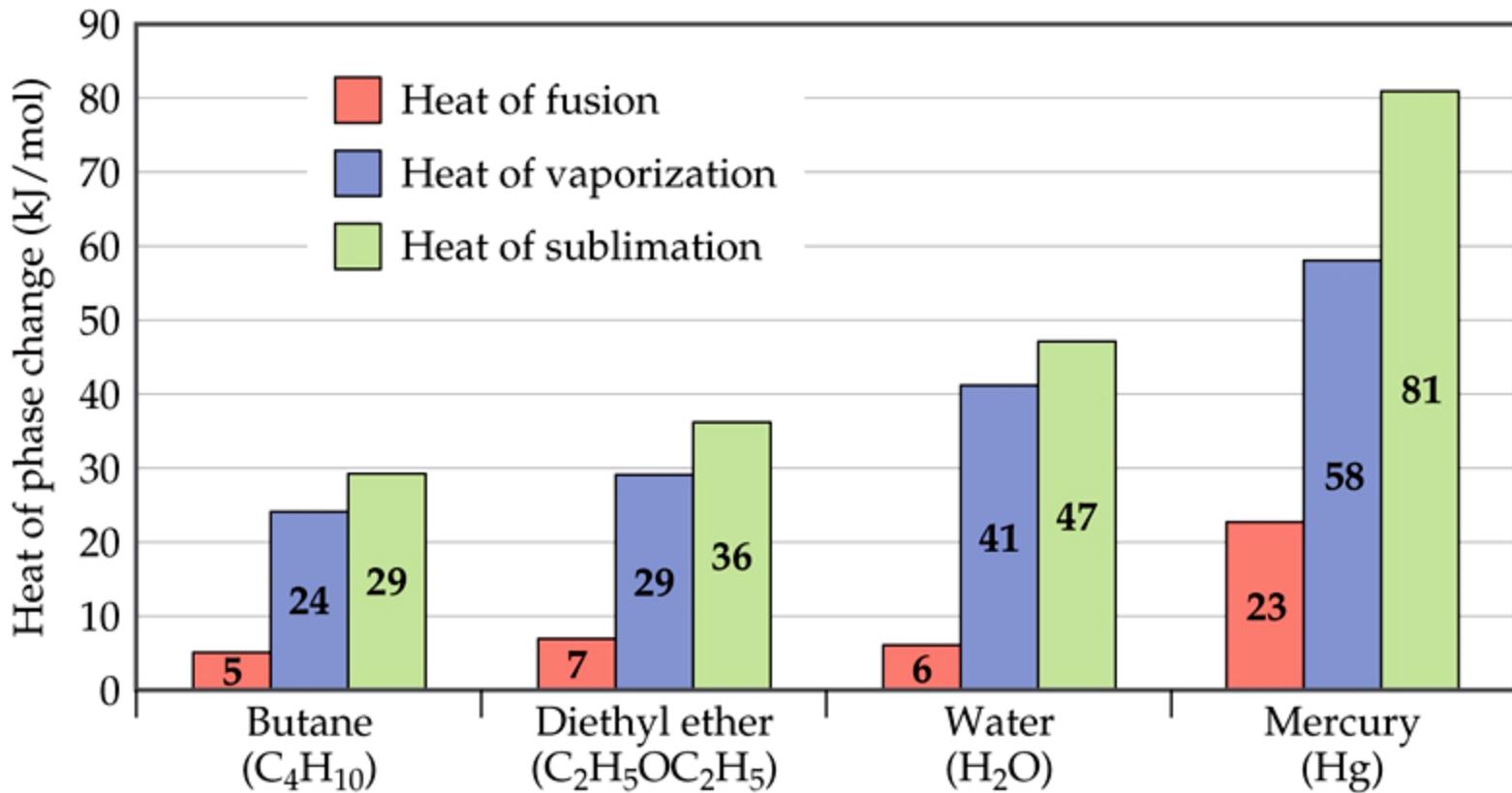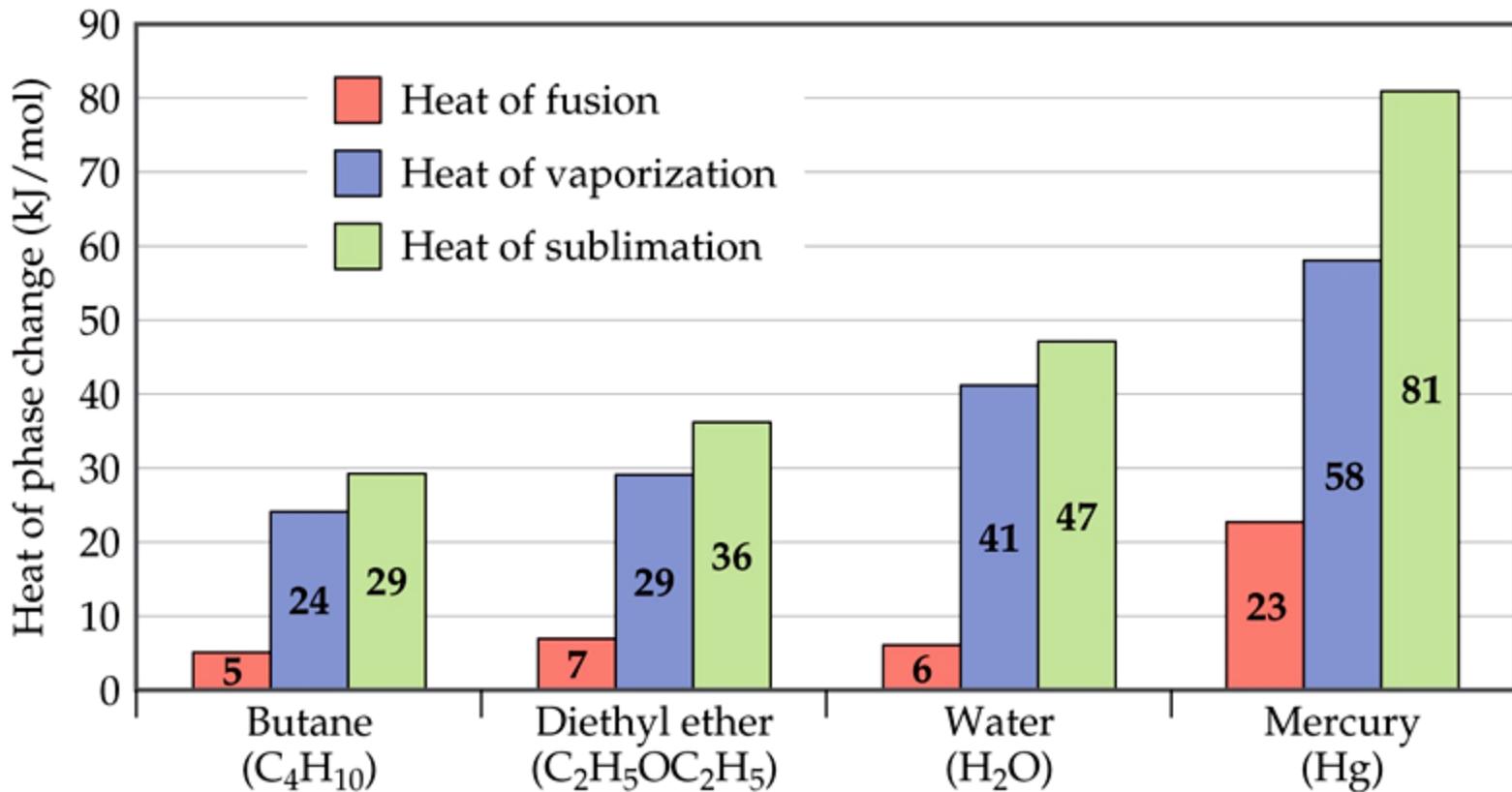
Solid

—— Endothermic process (energy added to substance)

—— Exothermic process (energy released from substance)

Energy Changes Associated with Changes of State
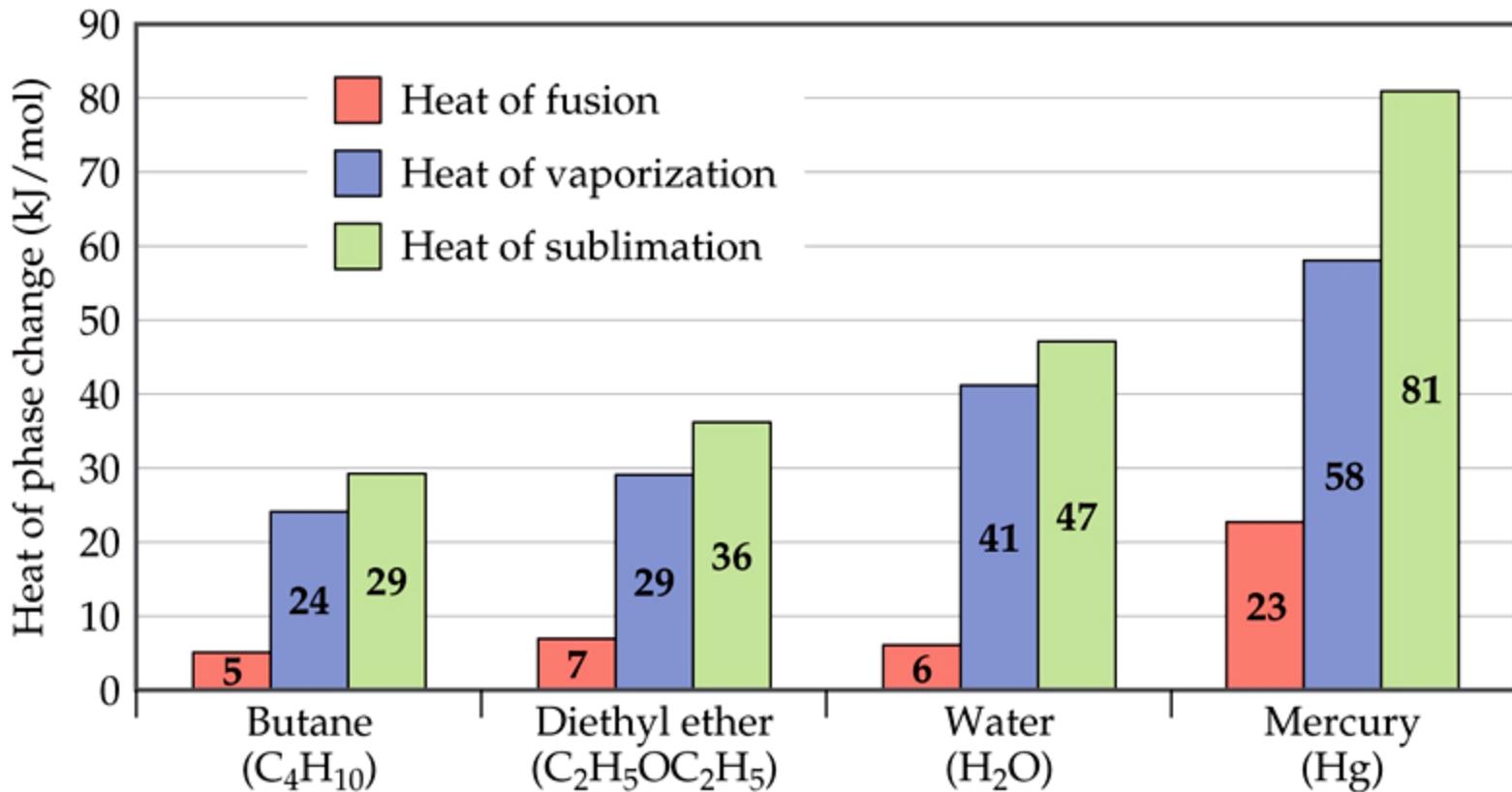
The **heat of fusion** (熔化热) is the energy required to change a solid at its melting point to a liquid.

Energy Changes Associated with Changes of State

The **heat of vaporization** (蒸发热) is defined as the energy required to change a liquid at its boiling point to a gas.

Energy Changes Associated with Changes of State

The **heat of sublimation** (升华热) is defined as the energy required to change a solid directly to a gas.
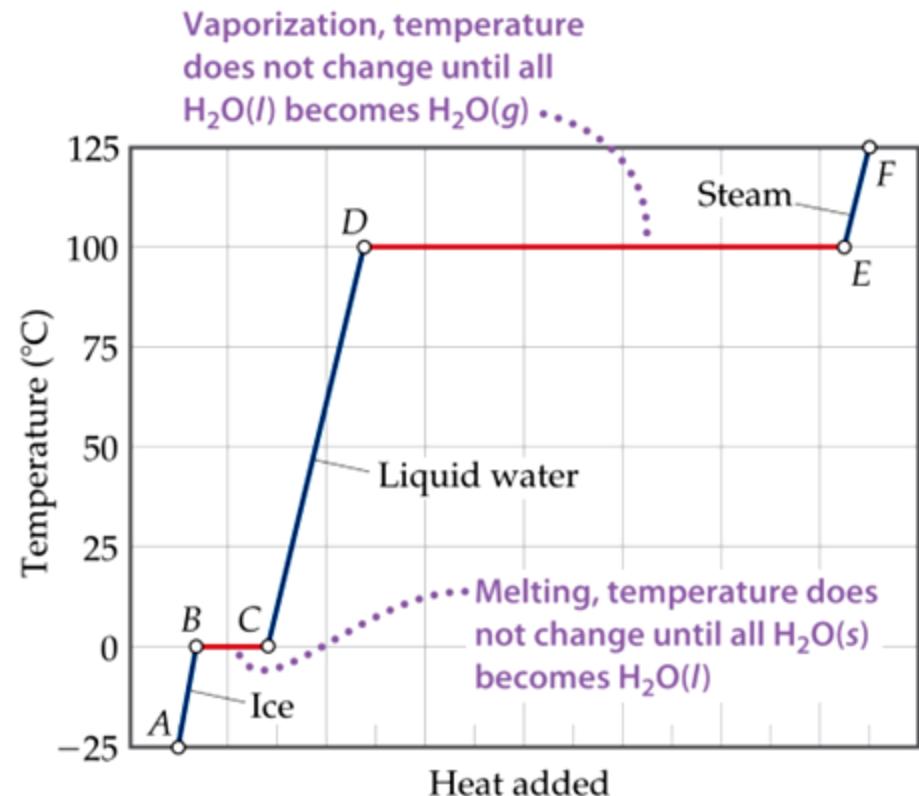
Is it possible to calculate the heat of sublimation for a substance given its heats of vaporization and fusion? If so, what is the relationship?

A. No, because we are not dealing with state functions.
B. No, because we need heat of melting.
C. Yes, $\Delta H_{sub} = \Delta H_{fus} + \Delta H_{vap}$
D. Yes, $\Delta H_{sub} = \Delta H_{fus} - \Delta H_{vap}$

Is it possible to calculate the heat of sublimation for a substance given its heats of vaporization and fusion? If so, what is the relationship?

A. No, because we are not dealing with state functions.
B. No, because we need heat of melting.
C. Yes, $\Delta H_{sub} = \Delta H_{fus} + \Delta H_{vap}$
D. Yes, $\Delta H_{sub} = \Delta H_{fus} - \Delta H_{vap}$

Energy Changes Associated with Changes of State

Vaporization, temperature does not change until all $H_2O(l)$ becomes $H_2O(g)$ · · ·

Steam

Liquid water

Melting, temperature does not change until all $H_2O(s)$ becomes $H_2O(l)$

Ice

Temperature (°C)

Heat added

- 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 a phase change.

Exercise Calculating ΔH for Temperature and Phase Changes
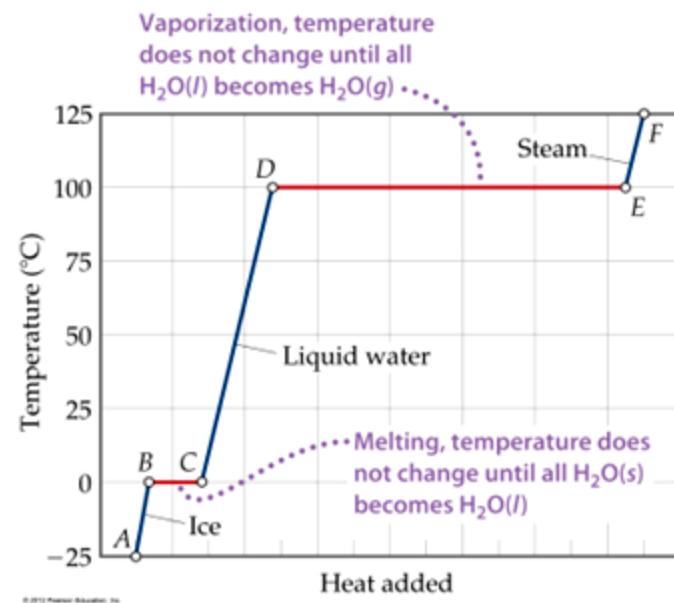
Calculate the enthalpy change upon converting 1.00 mol of ice at -25 °C to steam at 125 °C under a constant pressure of 1 atm. The specific heats of ice, liquid water, and steam are 2.03 J/g-K, 4.18 J/g-K, and 1.84 J/g-K, respectively. For H_2O, $\Delta H_{fus} = 6.01$ kJ/mol and $\Delta H_{vap} = 40.67$ kJ/mol.

Solution

Plan We can calculate the enthalpy change for each segment and then sum them to get the total enthalpy change (Hess's law, Section 5.6).

Solve For segment AB in Figure 11.22, we are adding enough heat to ice to increase its temperature by 25 °C. A temperature change of 25 °C is the same as a temperature change of 25 K, so we can use the specific heat of ice to calculate the enthalpy change during this process:

AB: $\Delta H = (1.00 \text{ mol})(18.0 \text{ g/mol})(2.03 \text{ J/g-K})(25 \text{ K}) = 914 \text{ J} = 0.91 \text{ kJ}$

Exercise Calculating ΔH for Temperature and Phase Changes (continued)

For segment *BC* in Figure 11.22, in which we convert ice to water at 0 °C, we can use the molar enthalpy of fusion directly:

BC: $\Delta H = (1.00 \text{ mol})(6.01 \text{ kJ/mol}) = 6.01 \text{ kJ}$

The enthalpy changes for segments *CD*, *DE*, and *EF* can be calculated in similar fashion:
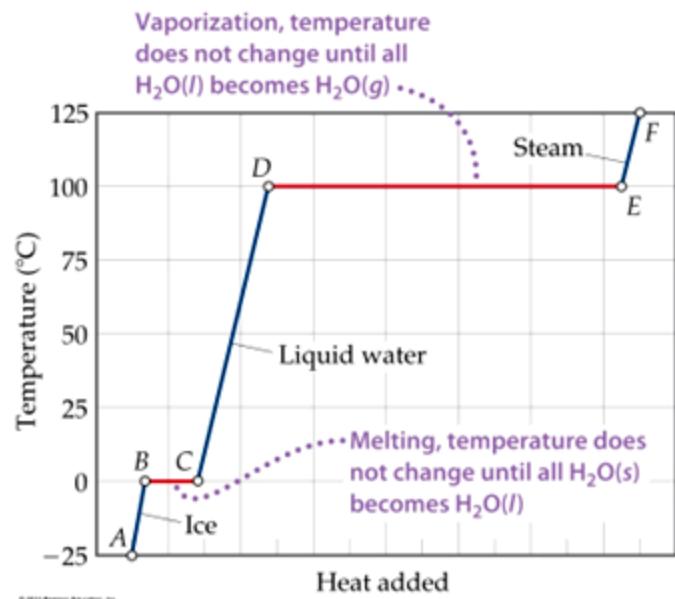
CD: $\Delta H = (1.00 \text{ mol})(18.0 \text{ g/mol})(4.18 \text{ J/g-K})(100 \text{ K})$
$= 7520 \text{ J} = 7.52 \text{ kJ}$
DE: $\Delta H = (1.00 \text{ mol})(40.67 \text{ kJ/mol}) = 40.7 \text{ kJ}$
EF: $\Delta H = (1.00 \text{ mol})(18.0 \text{ g/mol})(1.84 \text{ J/g-K})(25 \text{ K}) = 830 \text{ J} = 0.83 \text{ kJ}$
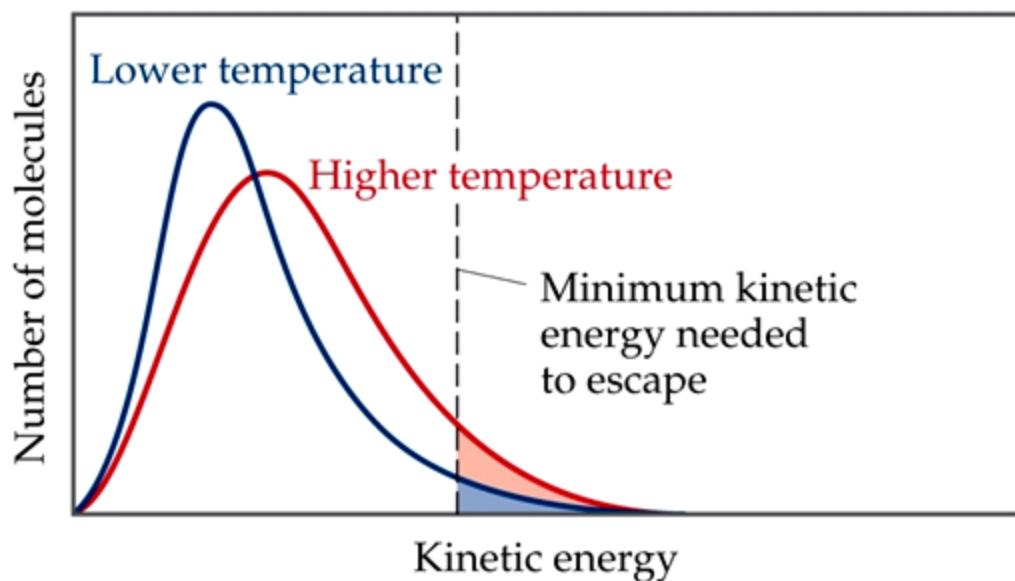
The total enthalpy change is the sum of the changes of the individual steps:

$\Delta H = 0.91 \text{ kJ} + 6.01 \text{ kJ} + 7.52 \text{ kJ} + 40.7 \text{ kJ} + 0.83 \text{ kJ}$
$= 56.0 \text{ kJ}$

Vapor Pressure
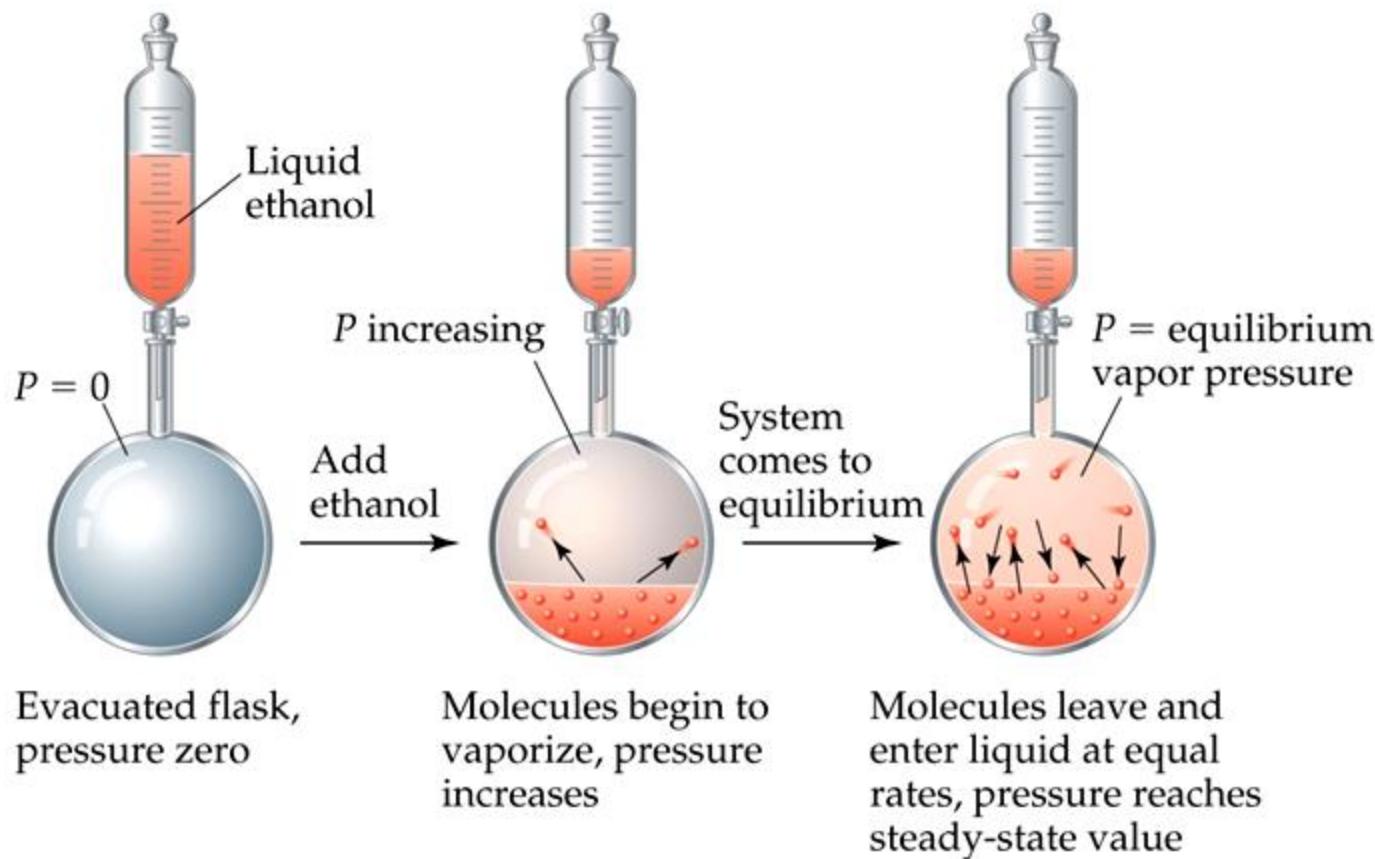
- At any temperature some molecules in a liquid have enough energy to break free.

- As the temperature rises, the fraction of molecules that have enough energy to break free increases.

Blue area = number of molecules having enough energy to evaporate at lower temperature
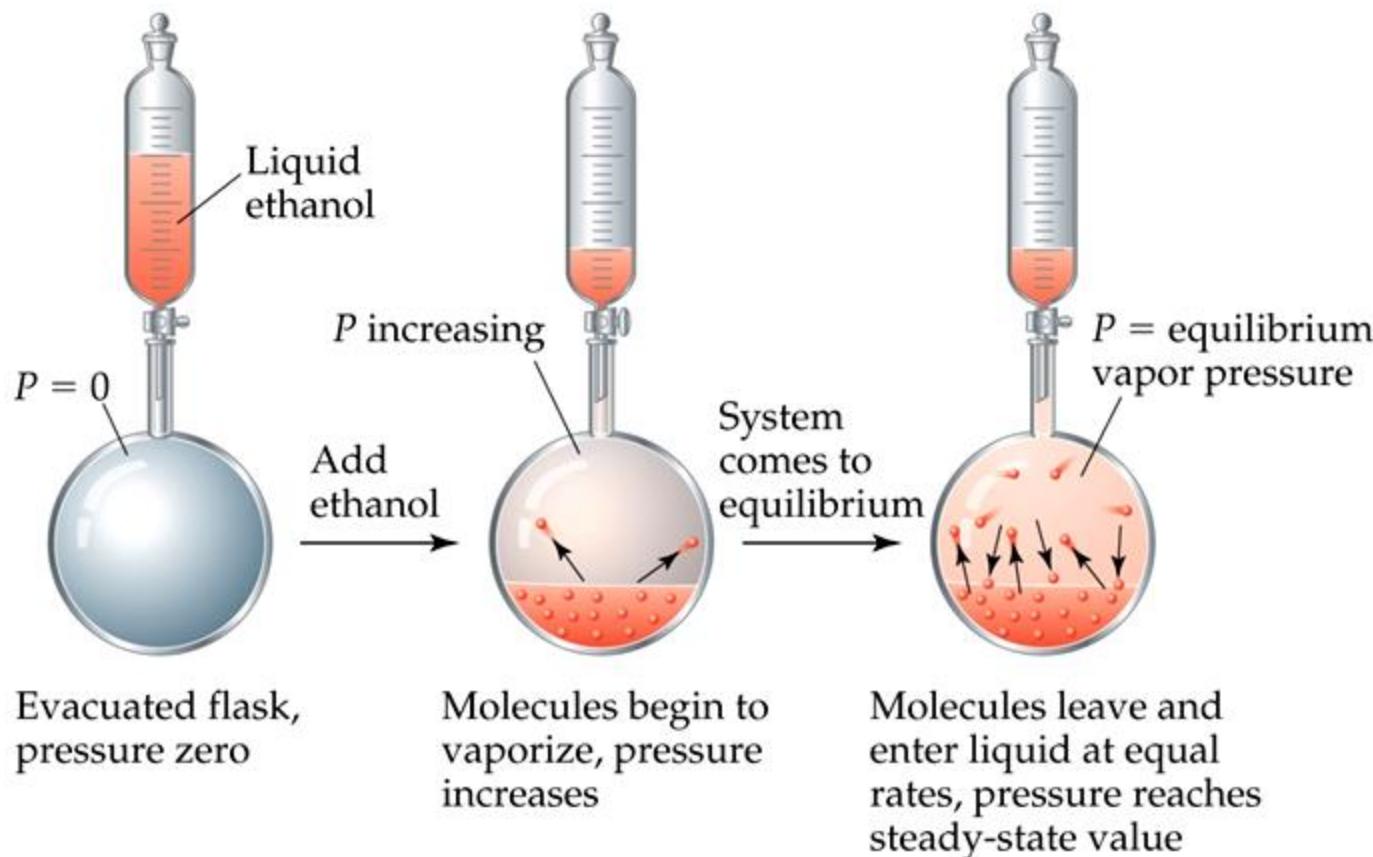
Red + blue areas = number of molecules having enough energy to evaporate at higher temperature

Vapor Pressure

As more molecules escape the liquid, the pressure they exert increases.
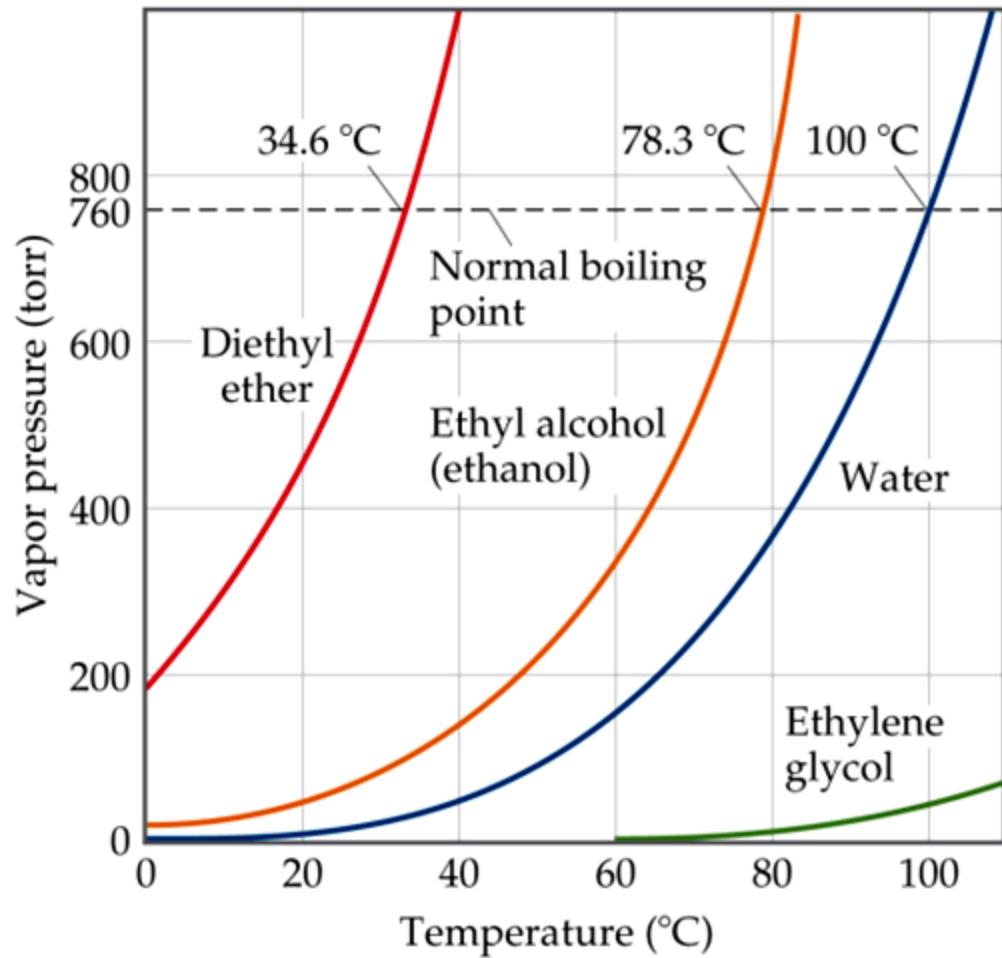
Vapor Pressure
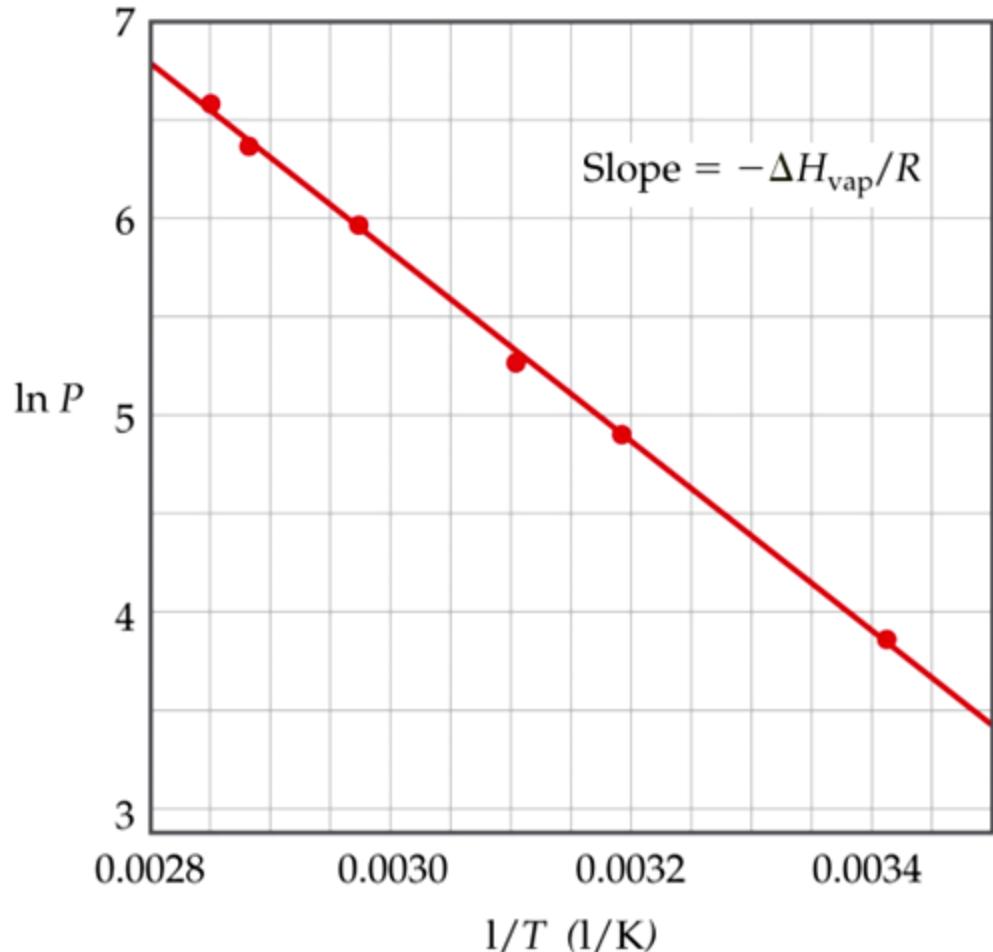
The liquid and vapor reach a state of dynamic equilibrium: liquid molecules evaporate and vapor molecules condense *at the same rate.*

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.
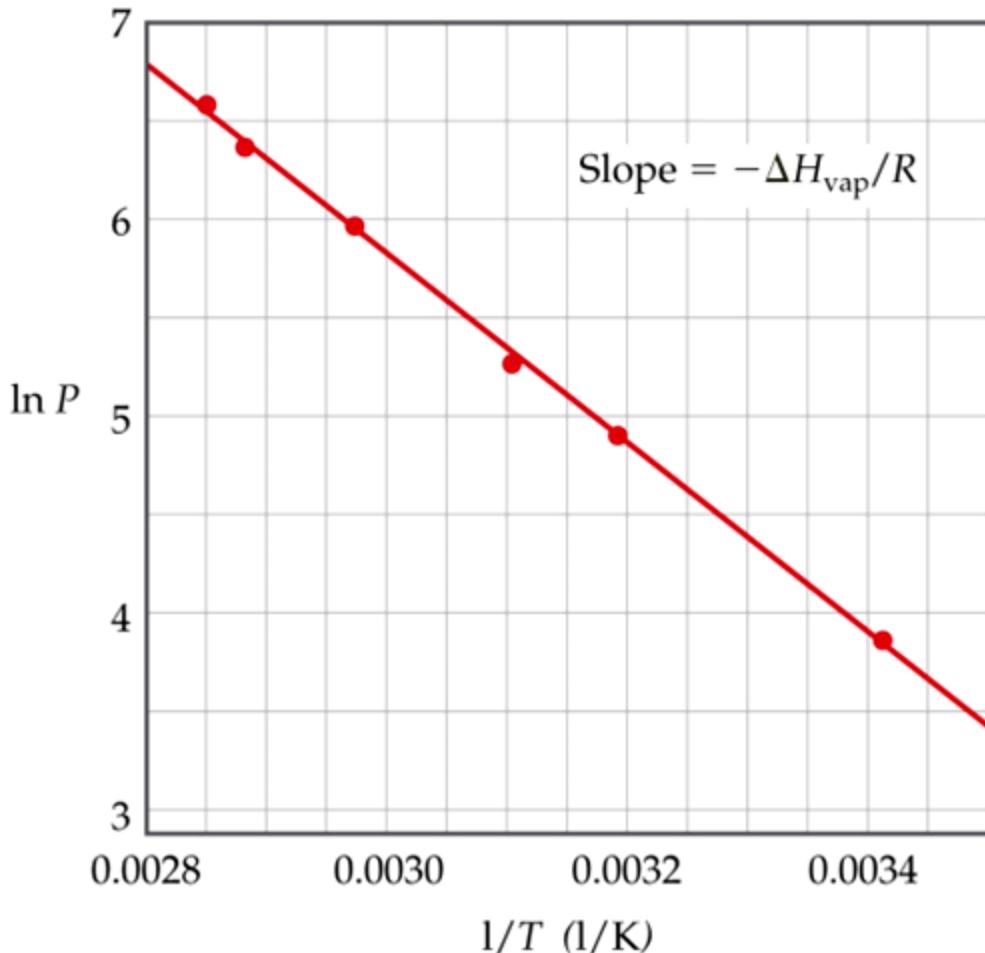
Vapor Pressure

The natural log of the vapor pressure of a liquid is inversely proportional to its temperature.

Vapor Pressure

Slope $= -\Delta H_{vap}/R$
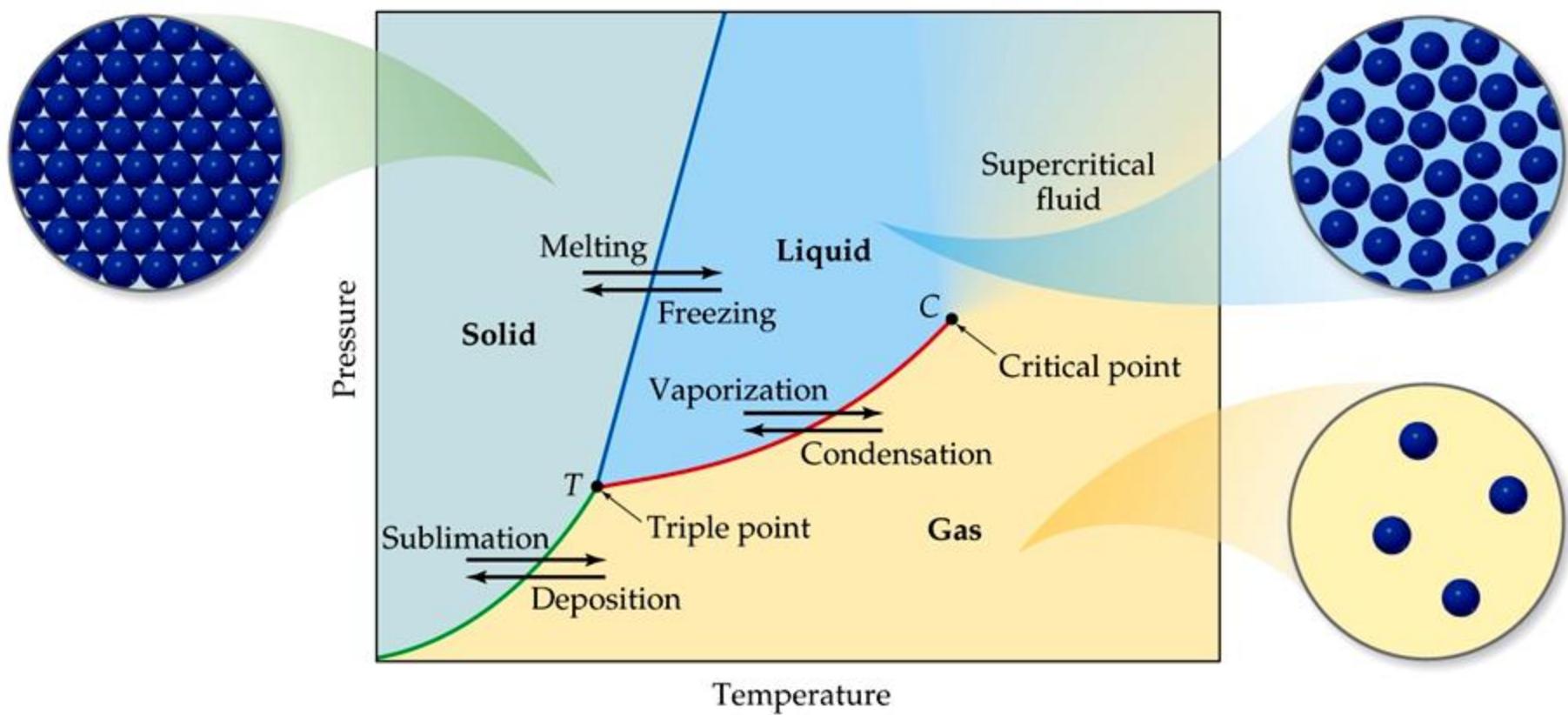
This relationship is quantified in the **Clausius–Clapeyron equation:**

$$\ln P = -\Delta H_{vap}/RT + C,$$

where C is a constant.
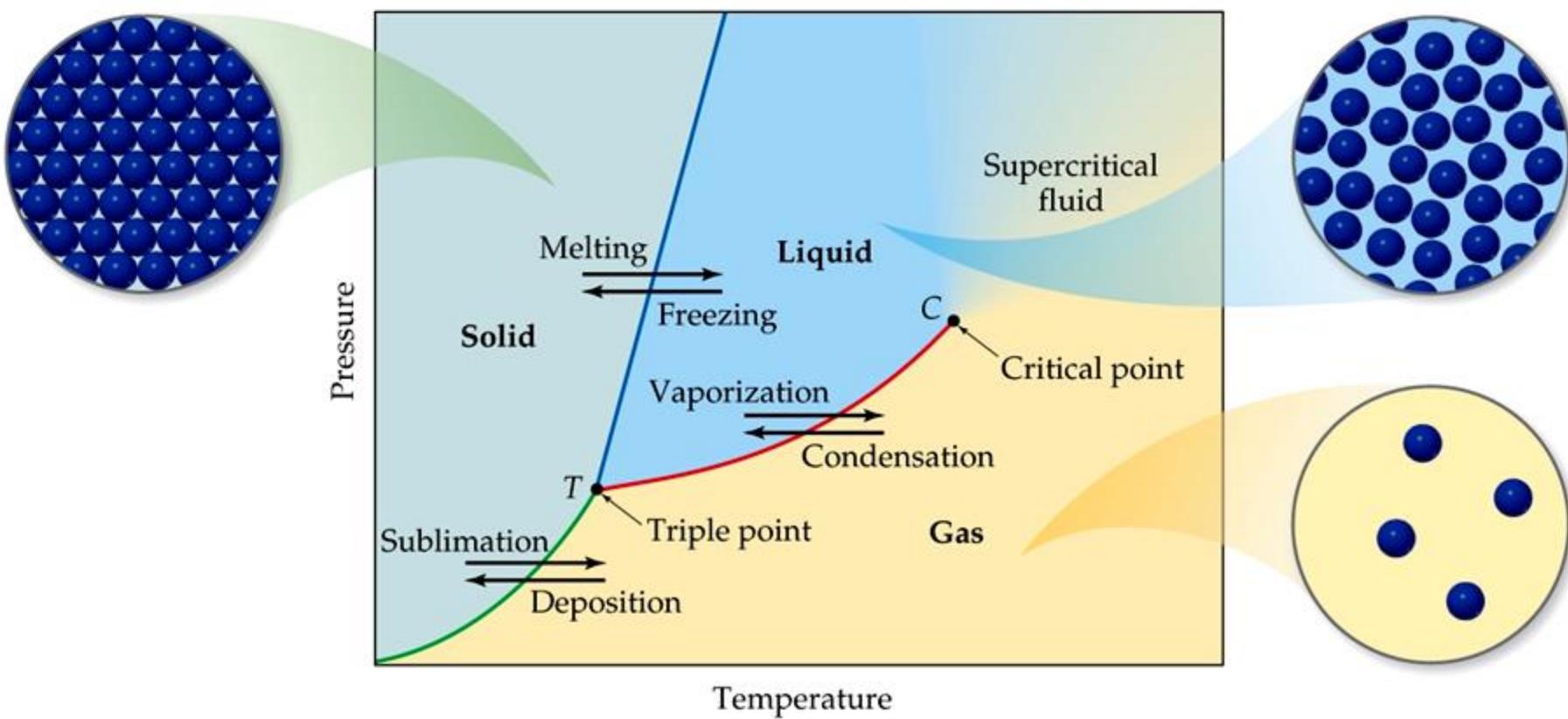
Phase Diagrams

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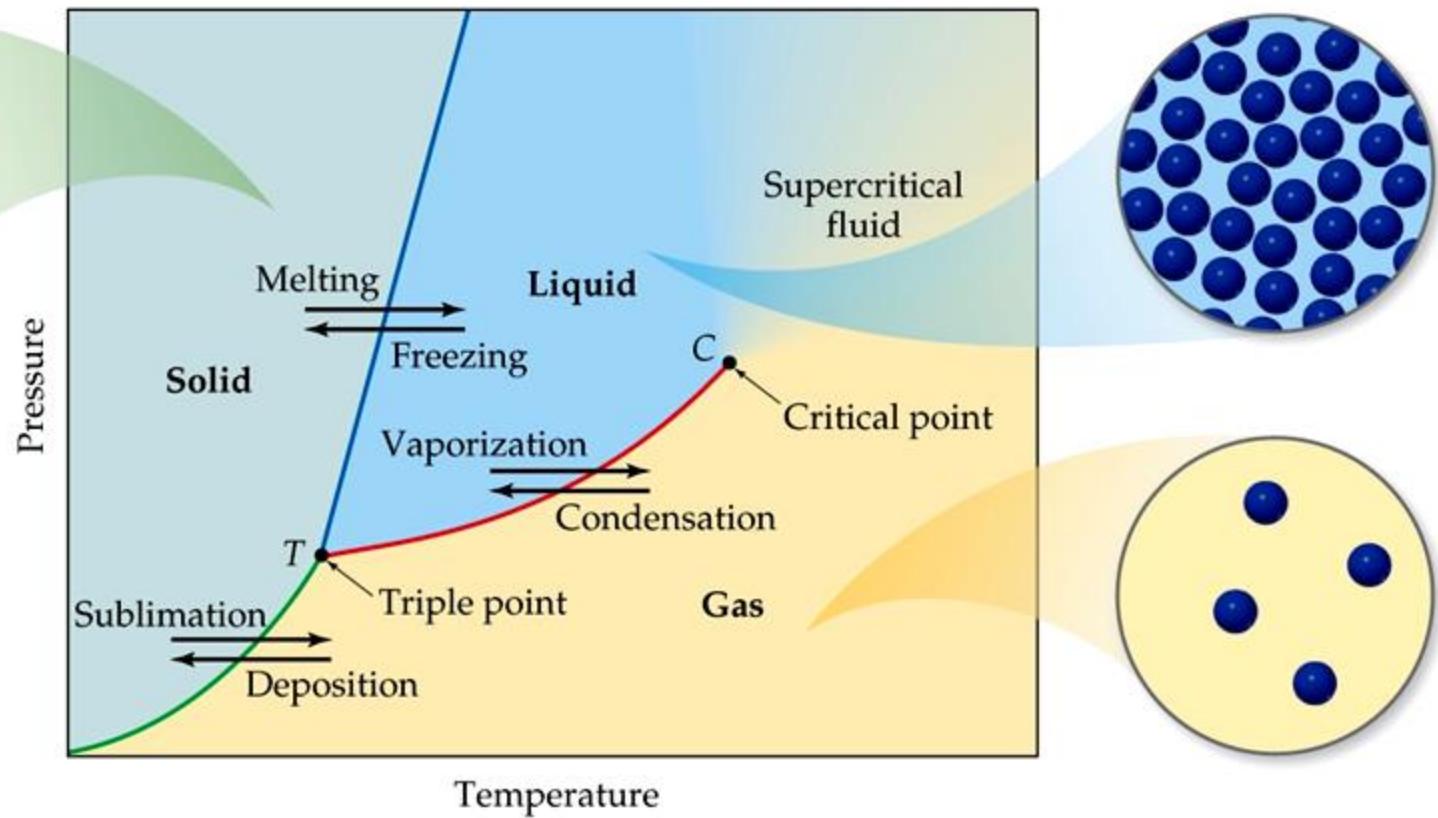
Phase Diagrams

The liquid–vapor interface starts at the triple point (*T*), at which all three states are in equilibrium, and ends at the critical point (*C*), above which the liquid and vapor are indistinguishable from each other.
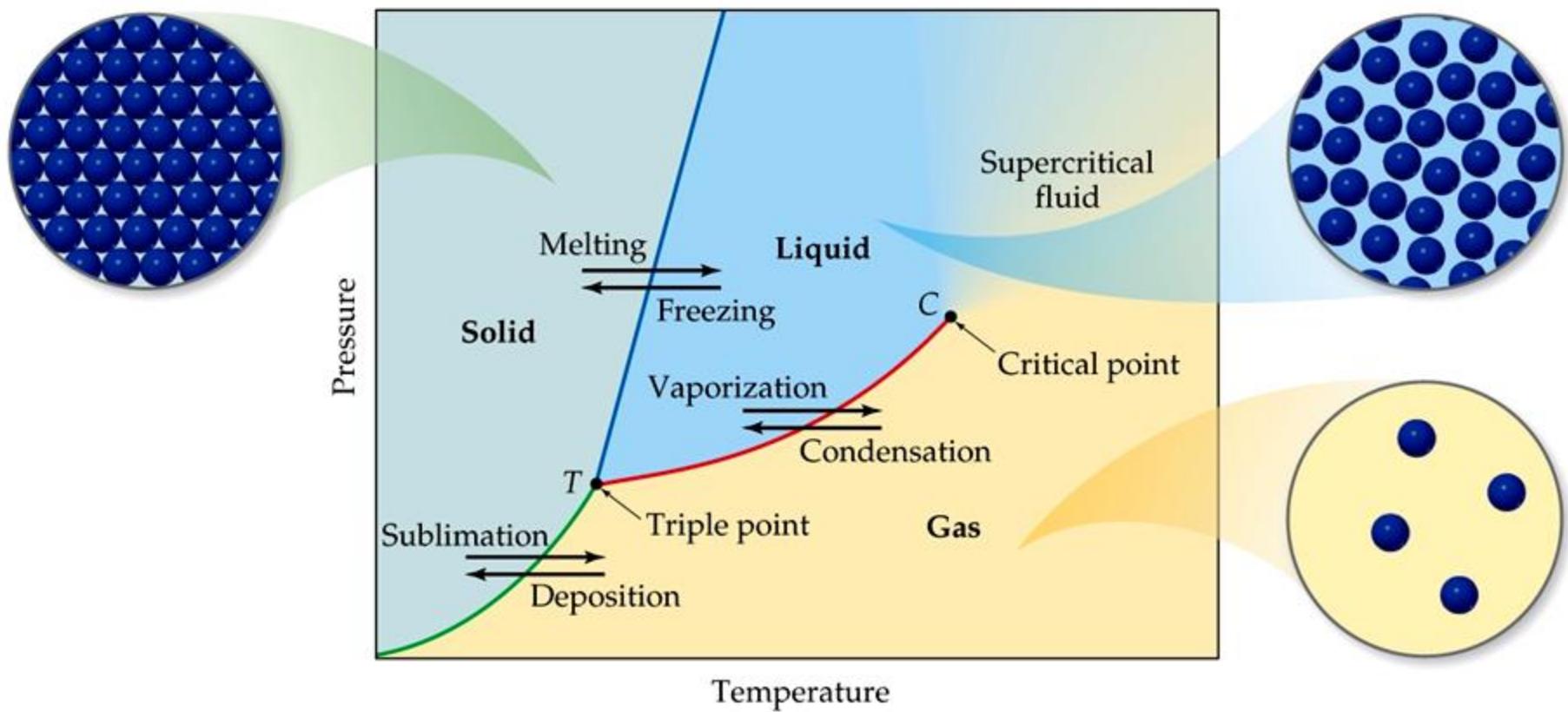
Phase Diagrams

Each point along this line is the boiling point of the substance at that pressure.
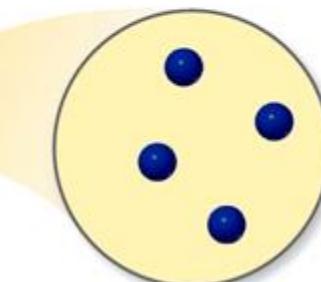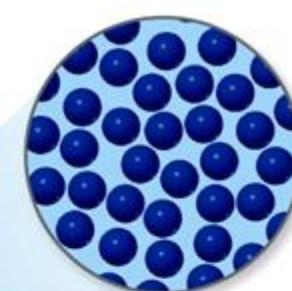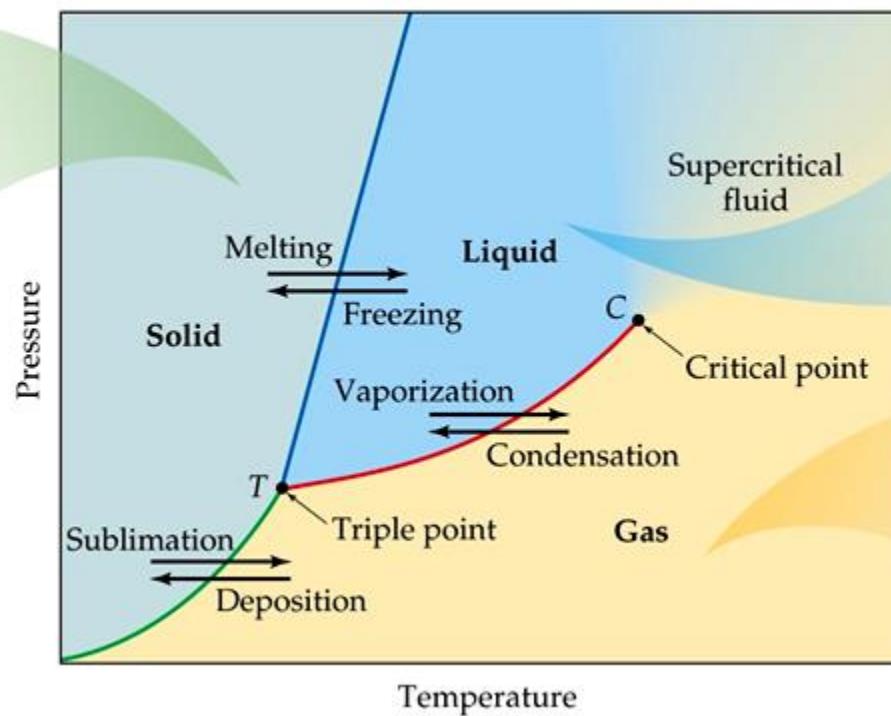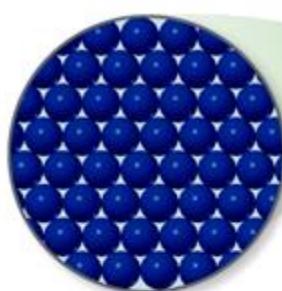
Phase Diagrams

The interface between liquid and solid marks the melting point of a substance at each pressure.
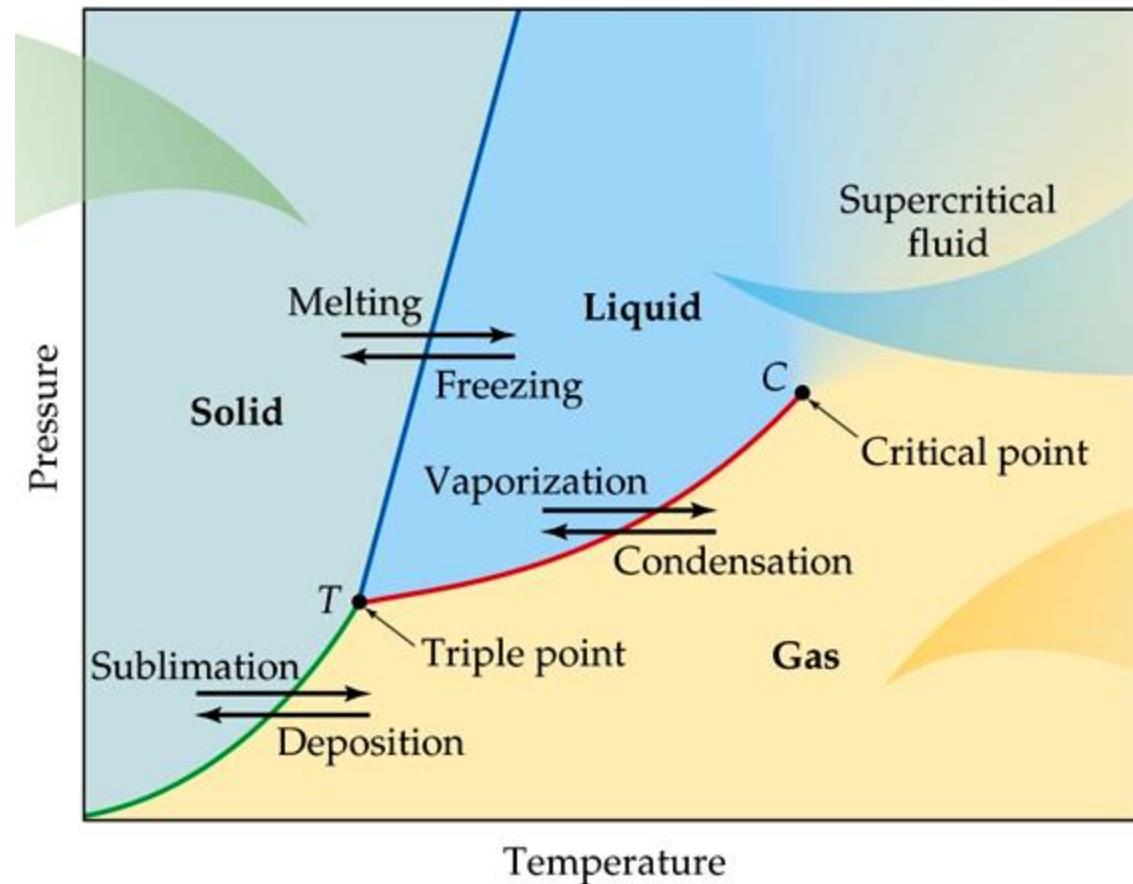
Phase Diagrams

- Below the triple point the substance cannot exist in the liquid state.

- Along the solid–gas line those two phases are in equilibrium; the sublimation point at each pressure is along this line.
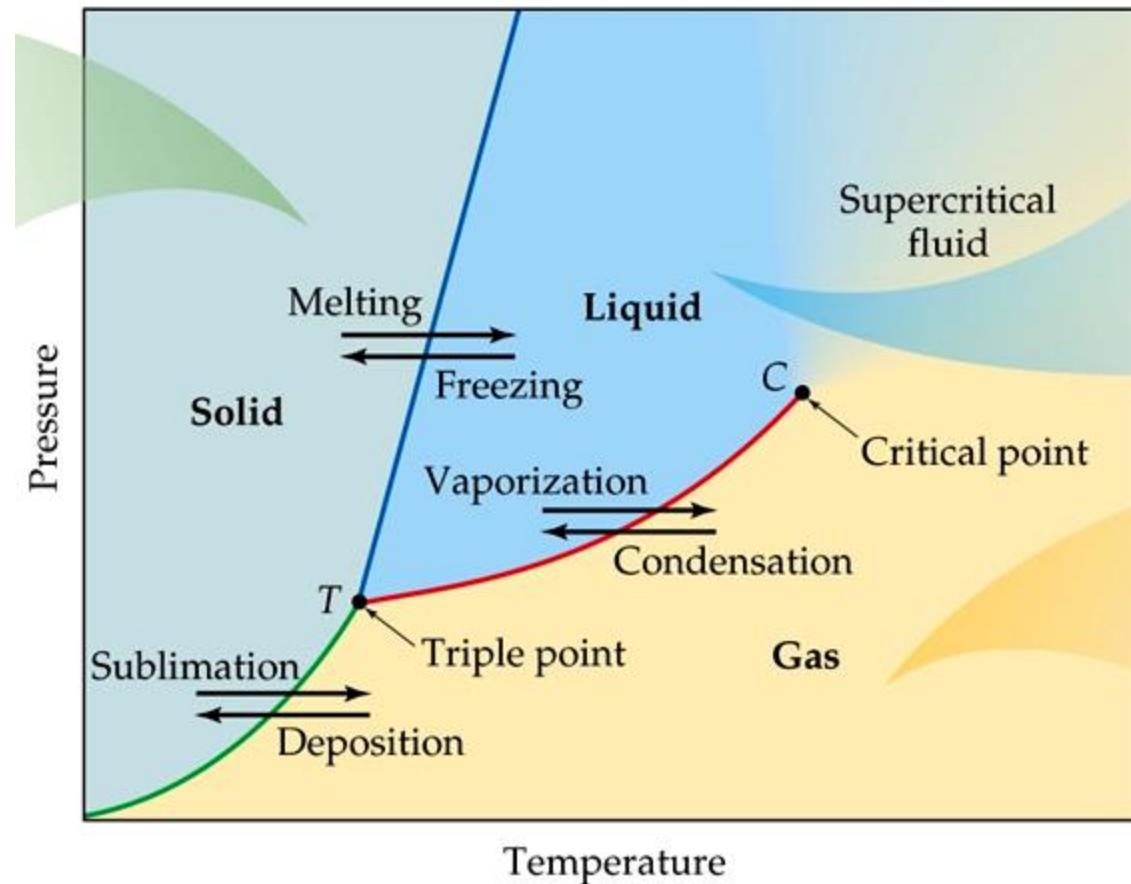
If the pressure exerted on a liquid is increased, while the temperature is held constant, what type of phase transition will eventually occur?

A. Freezing
B. Melting
C. Vaporization
D. Condensation
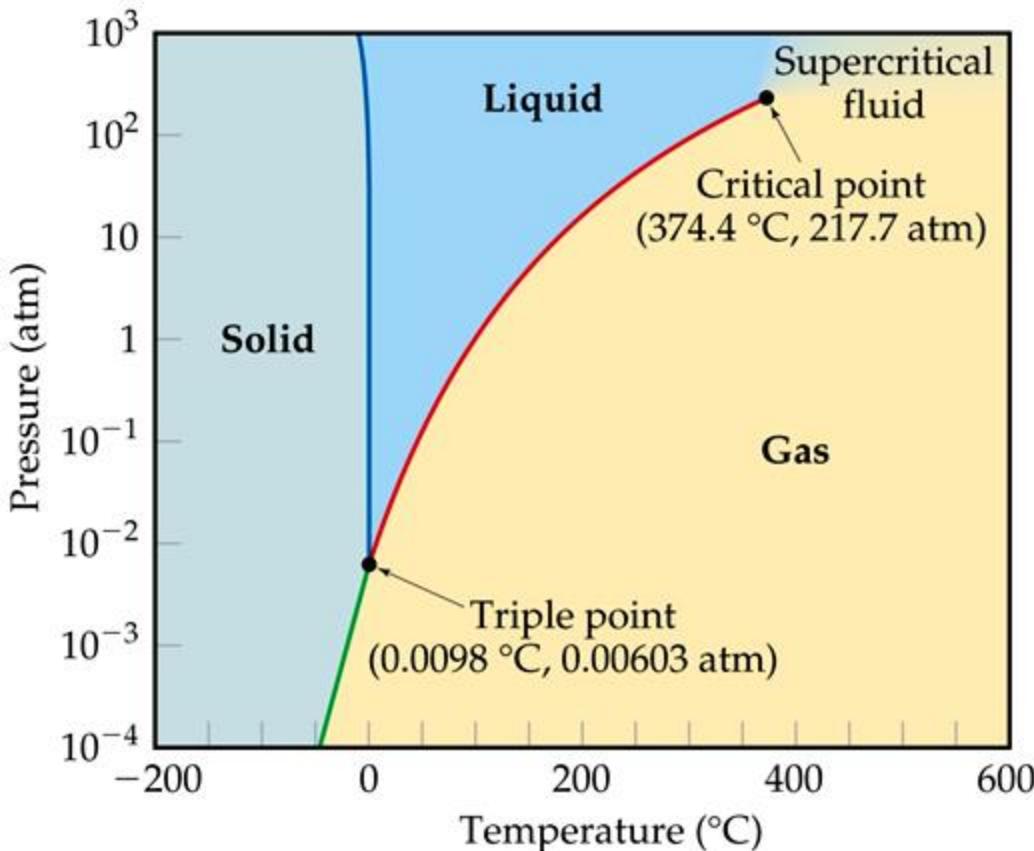
If the pressure exerted on a liquid is increased, while the temperature is held constant, what type of phase transition will eventually occur?

A. Freezing
B. Melting
C. Vaporization
D. Condensation
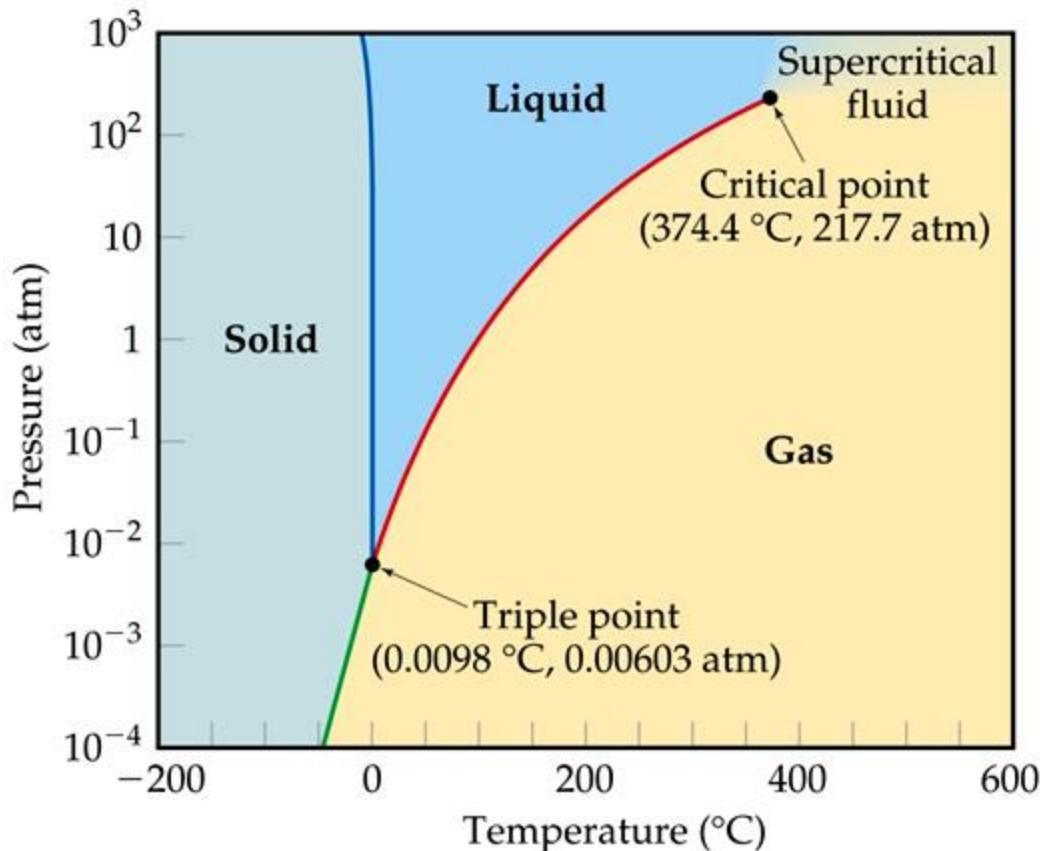
Phase Diagram of Water

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

Phase Diagram of Water
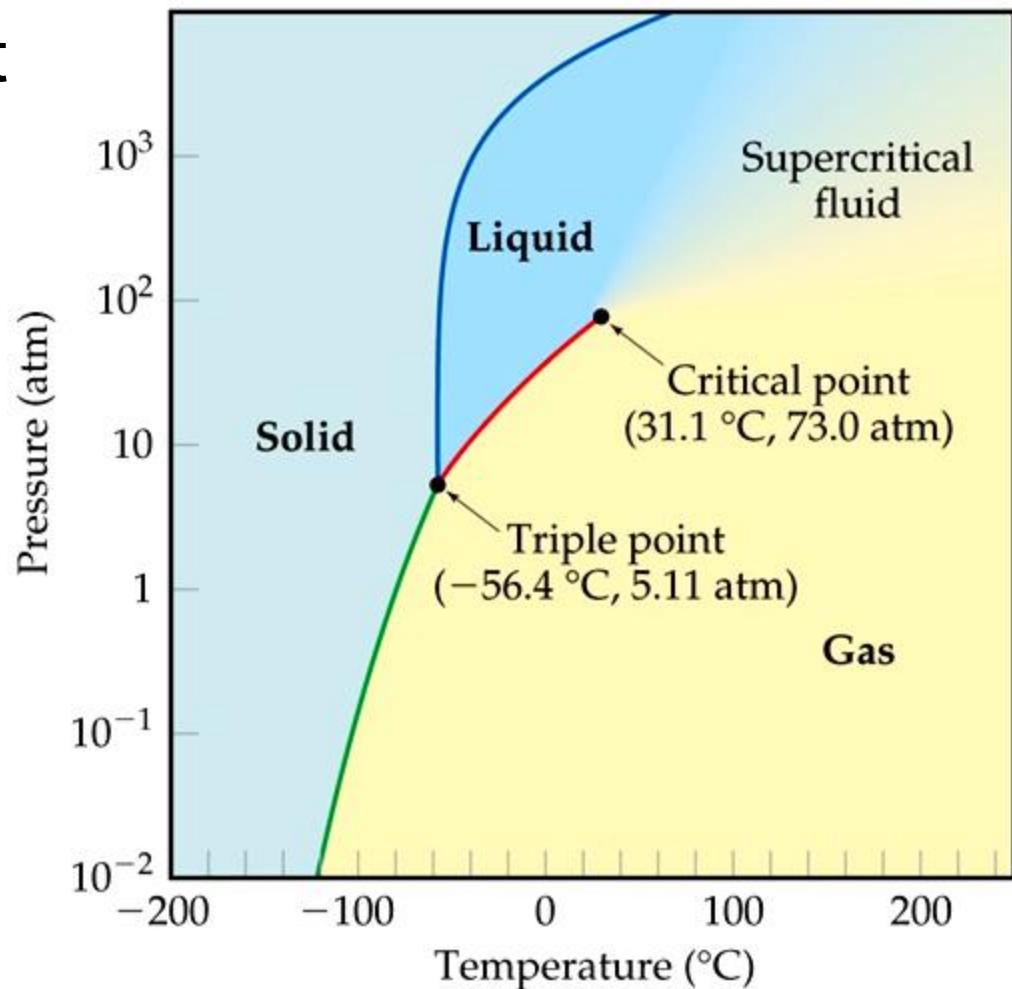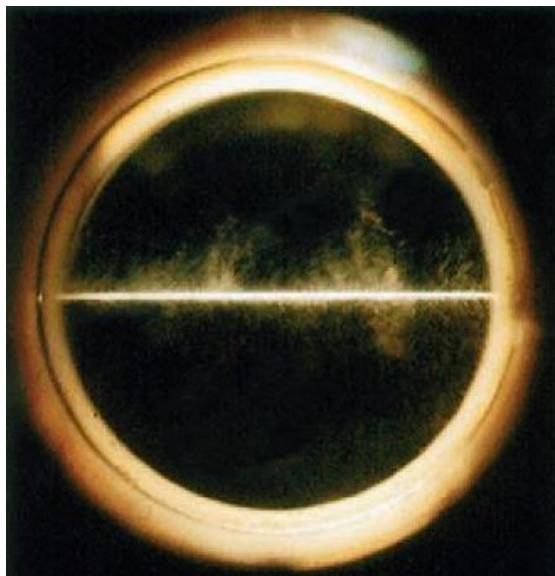
The slope of the solid–liquid line is negative.

– This means that as the pressure is increased at a temperature just below the melting point, water goes from a solid to a liquid.
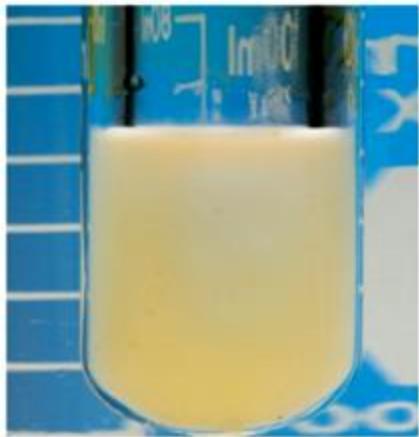
Phase Diagram of Carbon Dioxide

Carbon dioxide cannot exist in the liquid state at pressures below 5.11 atm; CO_2 sublimes at normal pressures.
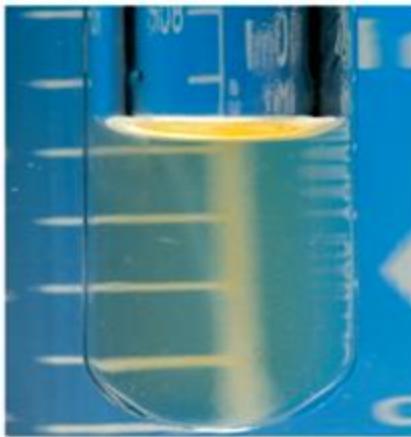
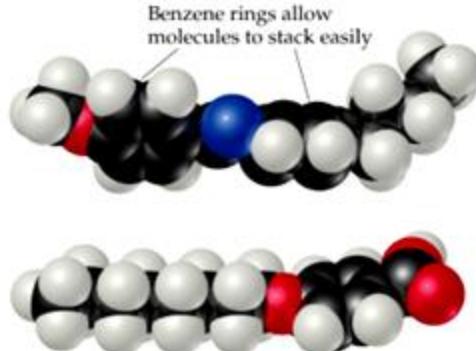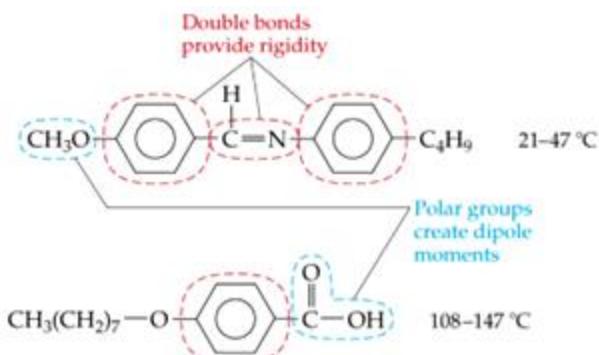Supercritical Fluid of CO_2

Liquid Crystals

145 °C < T < 179 °C
Liquid crystalline phase

T > 179 °C
Liquid phase

Double bonds
provide rigidity

H

CH_3O —[⬡]— C=N —[⬡]— C_4H_9 21–47 °C

Polar groups
create dipole
moments

$CH_3(CH_2)_7$ —O —[⬡]— C—OH   108–147 °C

O

Benzene rings allow
molecules to stack easily
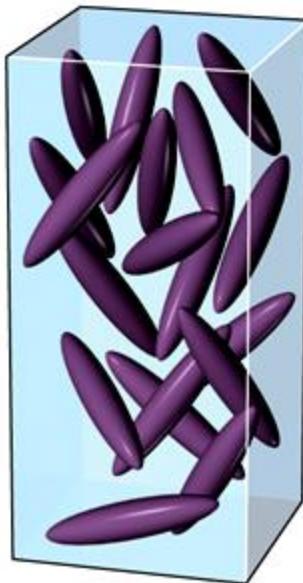
- Some substances do not go directly from the solid state to the liquid state.

- In this intermediate state, liquid crystals have some traits of solids and some of liquids.
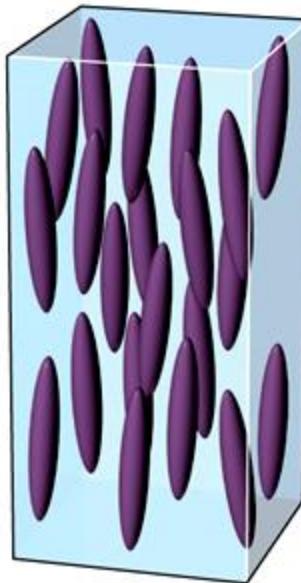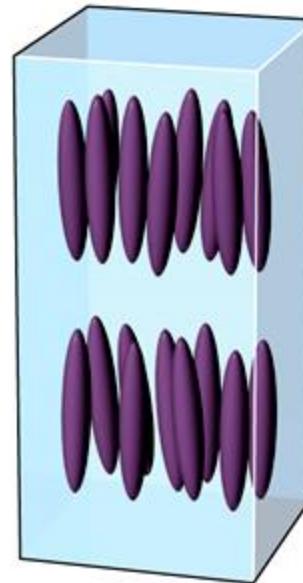
Liquid Crystals

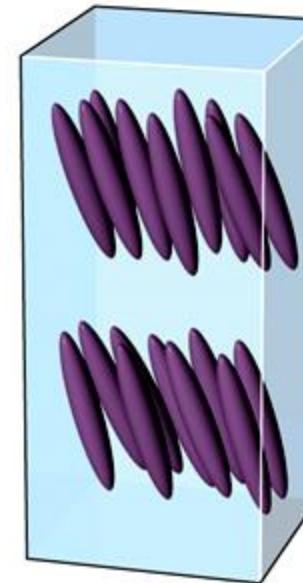**Liquid phase**

Molecules arranged randomly

Nematic liquid crystalline phase

Long axes of molecules aligned, but ends are not aligned

Smectic A liquid crystalline phase

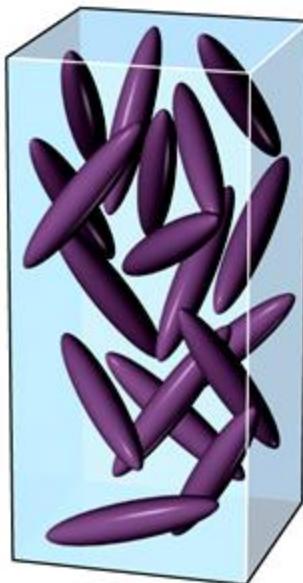Molecules aligned in layers, long axes of molecules perpendicular to layer planes

Smectic C liquid crystalline phase

Molecules aligned in layers, long axes of molecules inclined with respect to layer planes
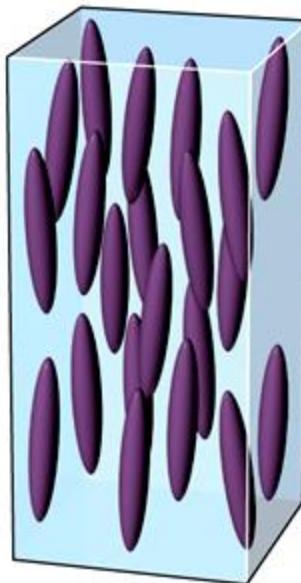
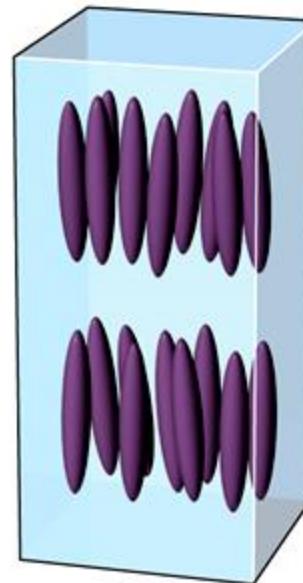Unlike liquids, molecules in liquid crystals have some degree of order.

Liquid Crystals

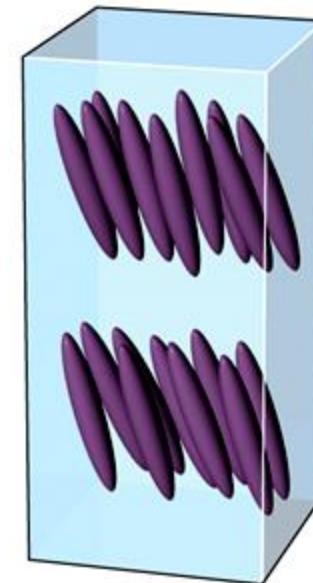**Liquid phase**

Molecules arranged randomly

Nematic liquid crystalline phase

Long axes of molecules aligned, but ends are not aligned

Smectic A liquid crystalline phase

Molecules aligned in layers, long axes of molecules perpendicular to layer planes
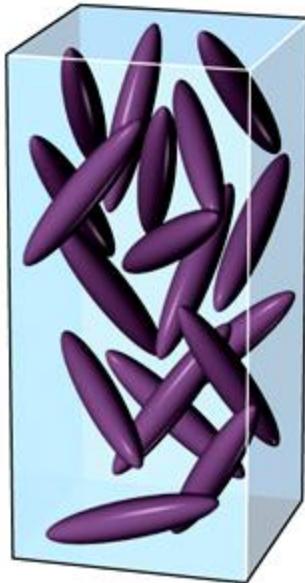
Smectic C liquid crystalline phase

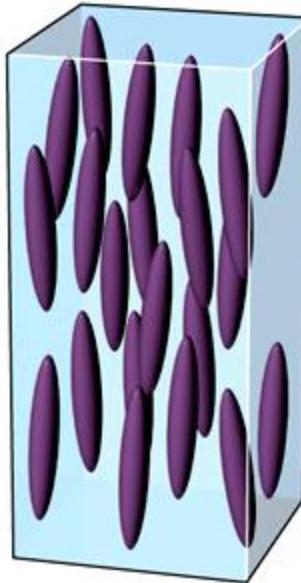Molecules aligned in layers, long axes of molecules inclined with respect to layer planes

In **nematic liquid crystals** (向列液晶), molecules are only ordered in one dimension, along the long axis.
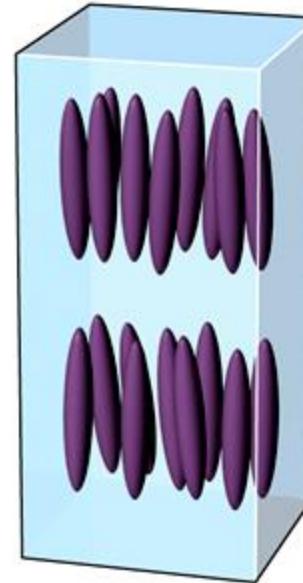
Liquid Crystals

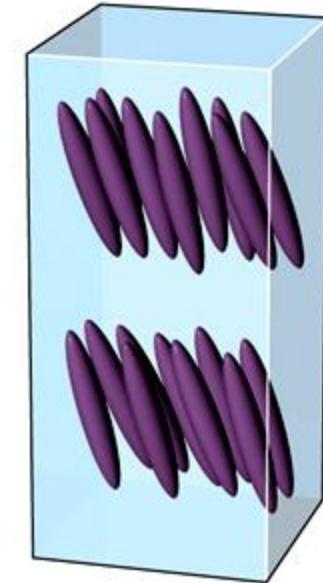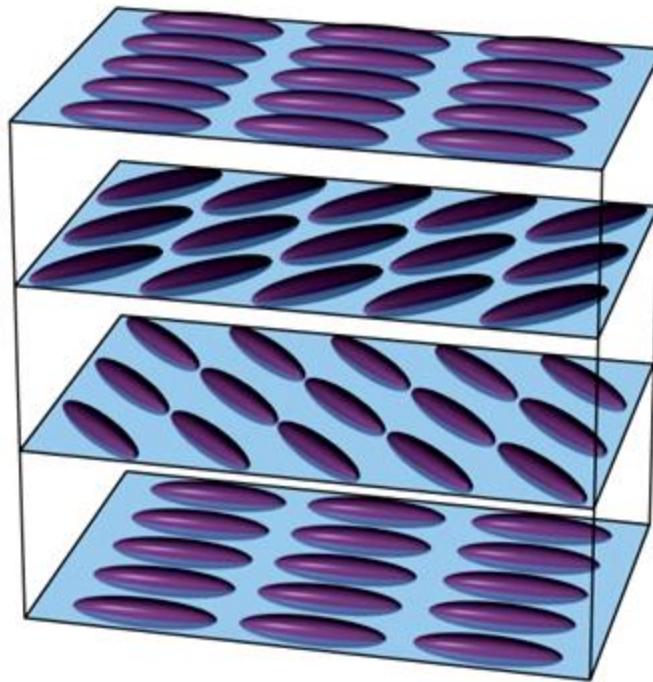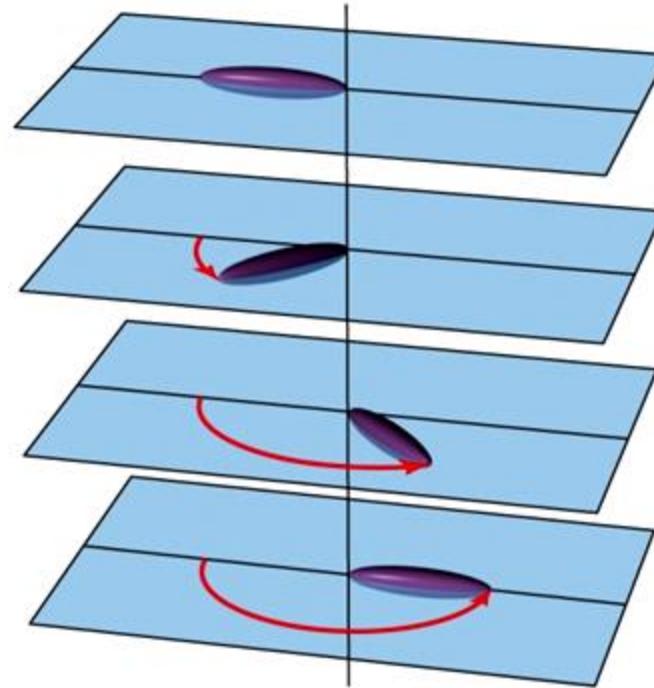| Liquid phase	Nematic liquid crystalline phase	Smectic A liquid crystalline phase	Smectic C liquid crystalline phase
Molecules arranged randomly	Long axes of molecules aligned, but ends are not aligned	Molecules aligned in layers, long axes of molecules perpendicular to layer planes	Molecules aligned in layers, long axes of molecules inclined with respect to layer planes

In **smectic liquid crystals** (近晶型), molecules are ordered in two dimensions, along the long axis and in layers.

Liquid Crystals
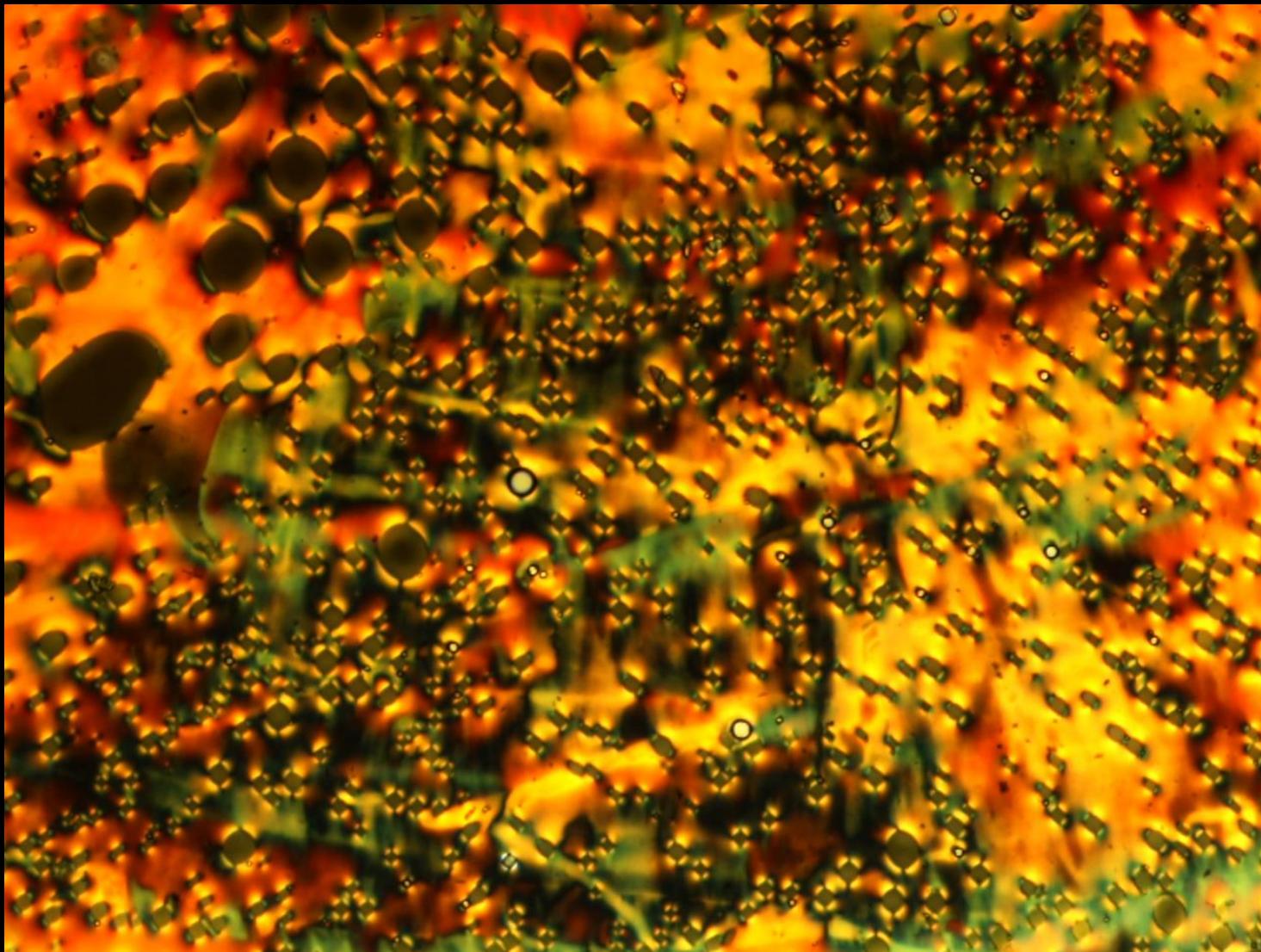
In a cholesteric liquid crystal the molecules pack into layers; the long axis of each molecule is oriented parallel to its neighbors within the same layer

The direction along which the molecules point rotates from one layer to the next, resulting in a spiraling pattern resembling the threads of a screw

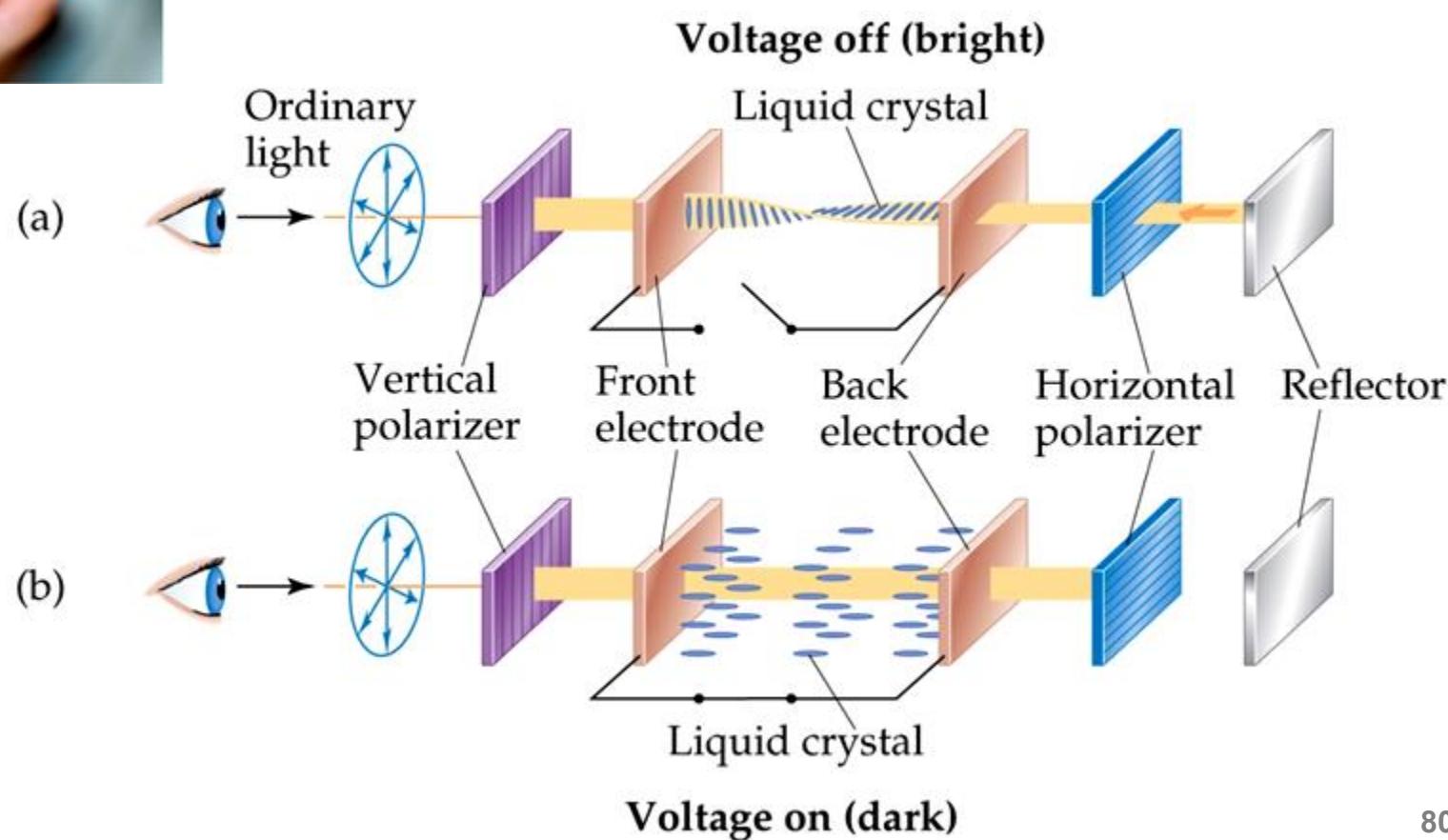In **cholesteryl** (胆固醇) **liquid crystals**, nematic-like crystals are layered at angles to each other.

The Beauty of Liquid Crystals

Liquid Crystals

These crystals can exhibit color changes with changes in temperature.

Voltage off (bright)

Ordinary light — Vertical polarizer — Front electrode — Liquid crystal — Back electrode — Horizontal polarizer — Reflector

(a)

(b)

Liquid crystal

Voltage on (dark)

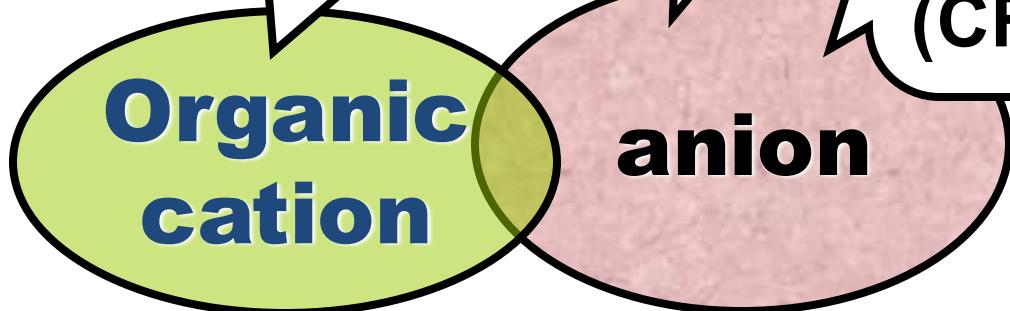# Ionic Liquids - Green Solvents for the Future

➢ Salts that are liquid at ambient temperatures.

➢ Low melting organic salts
➢ Very low vapor pressure
➢ Non-flammable
➢ Wide liquid range (300 °C)
➢ Moderate to high viscosity (bad)
➢ Solvent properties different from molecular solvents
➢ Solvent properties can be controlled by selection of anion and cation – hence often termed designer solvents (good).

Ionic Liquids - Green Solvents for the Future

Halide-based (Cl^-, Br^-, F^-)
Halogeno-based (BF_4^-, PF_6^-)
Halogenoaluminium(III)
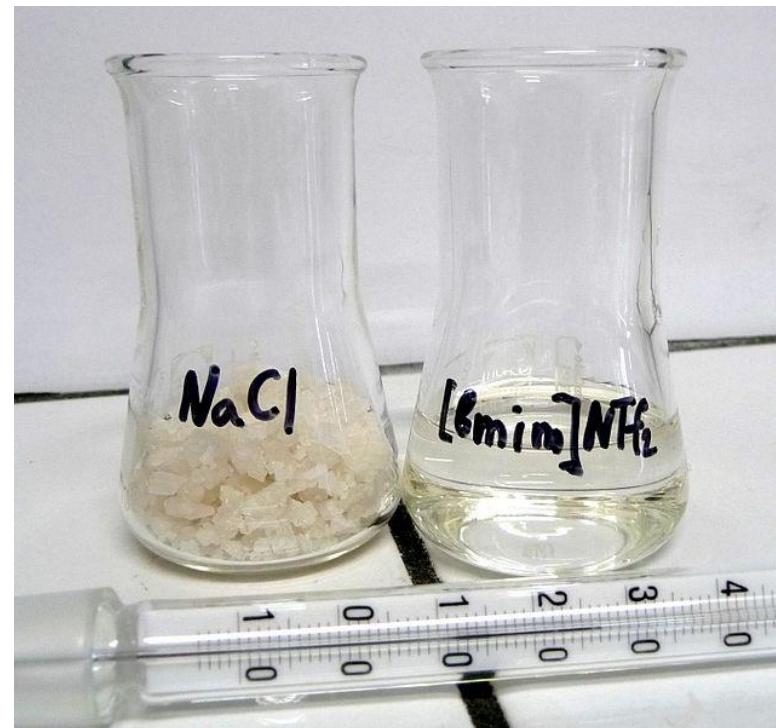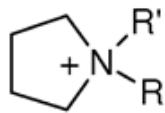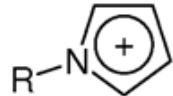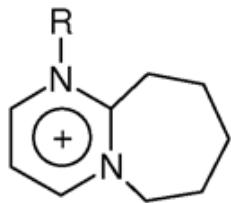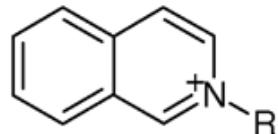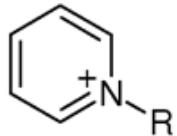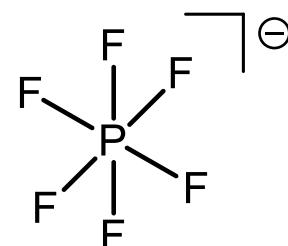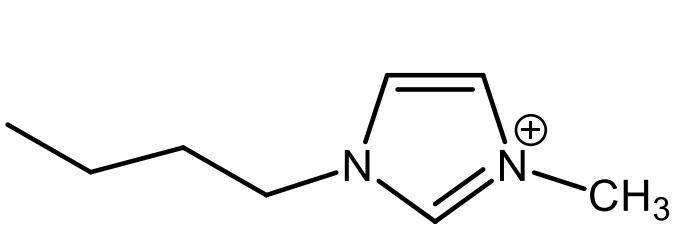
Alkylammonium
Alkylphosphonium
Alkylnitride
***N,N'*-dialkylimidazolium**
***N*-alkylpyridinium**

NO_3^-, ClO_4^-, HSO_4^-
SO_3^-, $CF_3SO_3^-$
$(CF_3SO_2)_2N^-$
$(CF_3SO_2)_3C^-$

Organic cation

anion

Ionic Liquids - Green Solvents for the Future

Which force below is the strongest intermolecular attractive force ?

   a. Hydrogen bonding

   b. Ion-dipole forces

   c. Dipole-dipole forces

   d. London dispersion forces

Which force below is the strongest intermolecular attractive force ?

    a. Hydrogen bonding
    b. Ion-dipole forces
    c. Dipole-dipole forces
    d. London dispersion forces

Which force below increases in strength as the molecular weight of the compound increases?

a. Hydrogen bonding

b. Ion-dipole forces

c. Dipole-dipole forces

d. London dispersion forces

Which force below increases in strength as the molecular weight of the compound increases?

a. Hydrogen bonding

b. Ion-dipole forces

c. Dipole-dipole forces

d. London dispersion forces

Which compound below is not capable of forming hydrogen bonds?

a. CH_4

b. NH_3

c. H_2O

d. HF

Which compound below is not capable of forming hydrogen bonds?

a. CH_4

b. NH_3

c. H_2O

d. HF

Which compound below has the highest boiling point?

a. H_2O

b. H_2S

c. H_2Se

d. H_2Te

Which compound below has the highest boiling point?

    a. H_2O

    b. H_2S

    c. H_2Se

    d. H_2Te

Which element below has the highest boiling point?

a. Kr

b. F_2

c. Cl_2

d. Br_2

Which element below has the highest boiling point?

a. Kr

b. F_2

c. Cl_2

d. Br_2

Which substance below has a greater density in its liquid state than in its solid state?

a. Iron
b. Glass
c. Water
d. Carbon dioxide

Which substance below has a greater density in its liquid state than in its solid state?

a. Iron

b. Glass

c. Water

d. Carbon dioxide

The resistance of a liquid to flow is called the _____ of the liquid.

a. density

b. viscosity

c. potential energy

d. flow rate

The resistance of a liquid to flow is called the _____ of the liquid.

a. density
b. viscosity
c. potential energy
d. flow rate

The energy required to cause a liquid to boil is called the _____ of the liquid.

a. boiling point

b. freezing point

c. heat of vaporization

d. heat of fusion

The energy required to cause a liquid to boil is called the _____ of the liquid.

a. boiling point

b. freezing point

c. heat of vaporization

d. heat of fusion

Isopropyl alcohol feels cool to the touch because it has an (X) heat of (Y).

a. X = exothermic,   Y = vaporization

b. X = endothermic,   Y = vaporization

c. X = exothermic,   Y = fusion

d. X = endothermic,   Y = fusion

When heat is added to ice at zero degrees Celsius, what will happen?

a. The temperature will increase.

b. The temperature will decrease.

c. The temperature will not change.

d. A supercritical fluid will form.

The highest temperature at which a substance can exist in its liquid state is called its _____ point.

a. boiling

b. freezing

c. triple

d. critical

The temperature and pressure at which all three phases exist simultaneously is called the _____ point of a substance.

a. boiling
b. freezing
c. triple
d. critical

At high altitudes (海拔), the boiling point of water is

    a. 100 degrees Celsius.

    b. greater than 100 degrees Celsius.

    c. less than 100 degrees Celsius.

    d. equal to its freezing point.

Substance X has a boiling point of 150 degrees Celsius and a freezing point of 15 degrees Celsius. The condensation point of X

a. is 150 degrees Celsius.

b. is 15 degrees Celsius.

c. is 165 degrees Celsius.

d. is 135 degrees Celsius.

Which of the terms below does NOT describe a type of liquid crystal?

a. Eutectic (共晶)

b. Nematic

c. Smectic

d. Cholesteric