# Liquids and Intermolecular Forces (Slide 2)

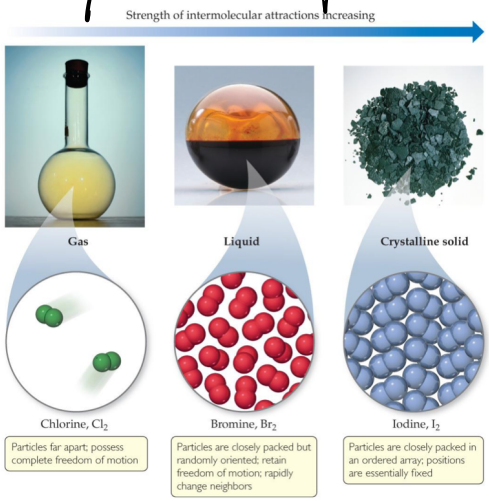
## §1 State of Matter

### 1. Basic Information

1° The fundamental difference between states of matter is the strength of the intermolecular forces of attraction.

2° Stronger force brings molecules closer together.

3° Solids and liquids are referred to as the condensed phases.




### 2. Differences in the States of Matter

**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 可压缩的 |
| | Flows readily |
| 扩散 | 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 |

*The atoms in a solid are able to vibrate in place. As the temperature of the solid increases, the vibrational motion increases. 振动

### 3. The Determination of State of Matter

1° Balance between the kinetic energies (动能) of the particles.

2° Interparticle energies of attraction.

**Table 11.2 Comparing Kinetic Energies and Energies of Attractions for States of Matter**

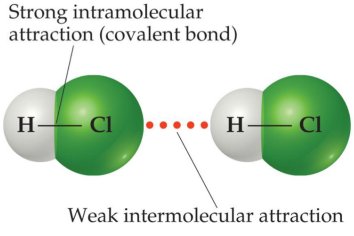
| | |
|---|---|
| Gas | Kinetic energies >> energies of attraction |
| Liquid | Comparable kinetic energies and energies of attraction |
| Solid | Energies of attraction >> kinetic energies |

## §2 Intermolecular Forces

### 1. Basic Information

1° Not as strong as the intramolecular attractions (bonds)

2° Reflected by physical properties, like boiling points, melting points, viscosity, surface tension, and capillary action.




### 2. Types of Intermolecular Force

Weakest to strongest forces:

1° (London) dispersion forces } van der Waals forces

2° dipole-dipole forces }

3° hydrogen bonding (a special dipole-dipole force)

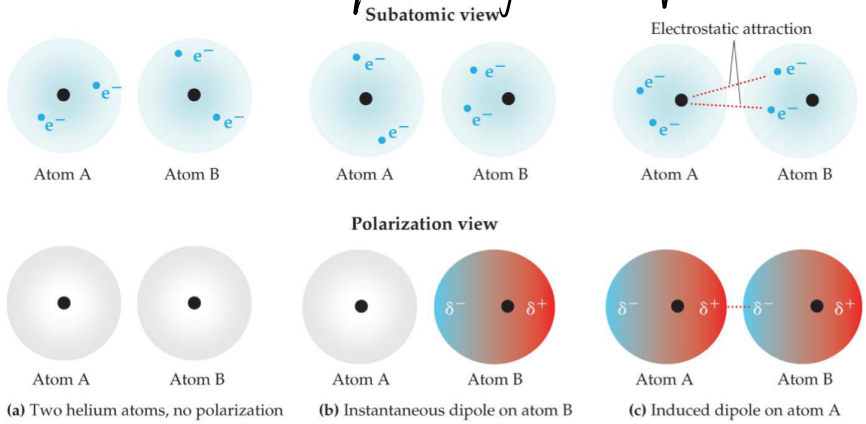
4° ion-dipole forces

5° ionic interactions

## §3 Dispersion Forces (色散力)

## 1. Basic Information

The figure below shows how a nonpolar particle can be temperarily polarized to allow dispersion force to form.



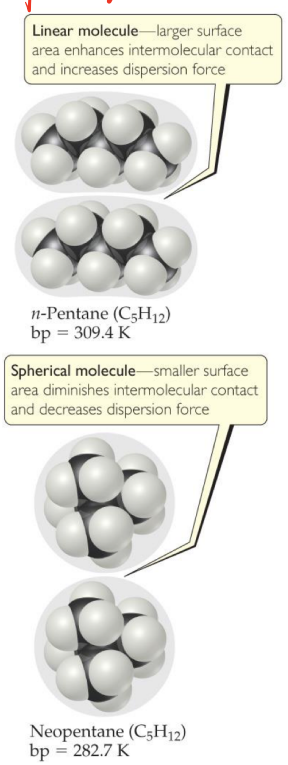

The tendency of an electron cloud to distort (扭曲) is called its polarizability.

## 2. Factors Which Affect Amount of Dispersion Force in a Molecule

1° Number of electrons in an atom (more electrons, more dispersion force)

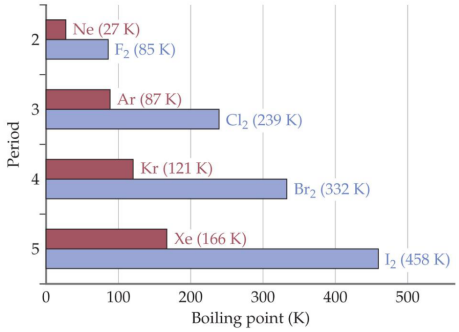
2° size of atom or molecule / molecular weight

3° shape of molecules with similar masses (more compact, less dispersion force)



### 3. Polarizability & Boiling Point

If something is more difficult to polarize (smaller molecule, lower molecular weight, fewer electrons), it has a lower boiling point.

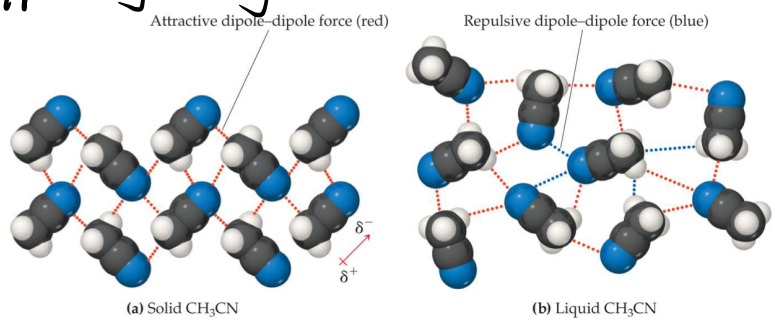



## §4 Dipole-Dipole Interactions (偶极-偶极相互作用)(取向力)

### 1. The Formation

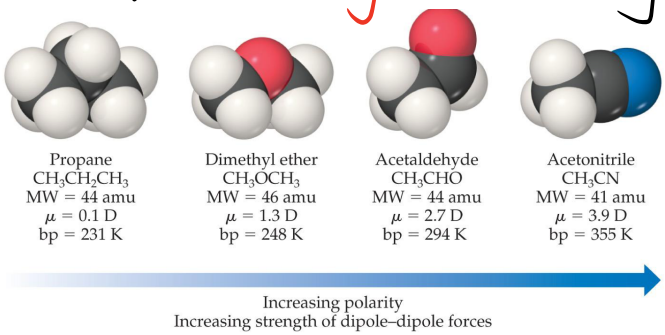
Polar molecules have a more positive and a more negative end — a dipole (two poles, $\delta^+$ and $\delta^-$)

The oppositely charged ends attract each other.




### ✡ 2. Factors Which Affect Amount of Dipole-Dipole Interactions

For molecules of approximately equal mass and size, the more polar the molecule, the higher its boiling points.



## 3. The Comparison Between Dipole-Dipole Interactions and Dispersion Forces

1° Comparable size and shape: dipole-dipole interactions will likely be the dominating force.

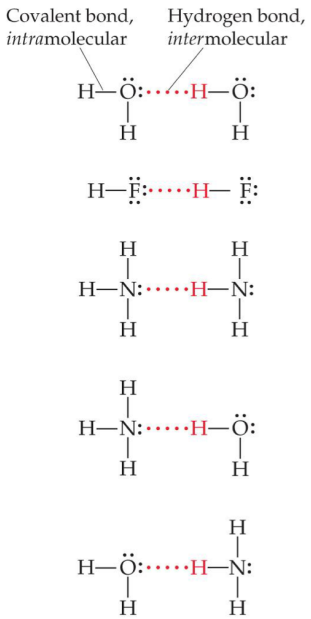
2° One is much larger than another: dispertion force will likely determine its physical properties.

# §5 Hydrogen Bonding

## 1. Basic Information

(1) The dipole-dipole interactions experienced when H is bonded to N, O, F are usually strong.

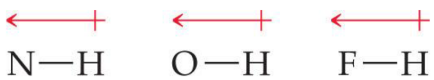
(2) A hydrogen bond is an attraction between a hydrogen atom attached to a highly electronegative atom and a nearby small electronegative atom in another molecule or chemical group.

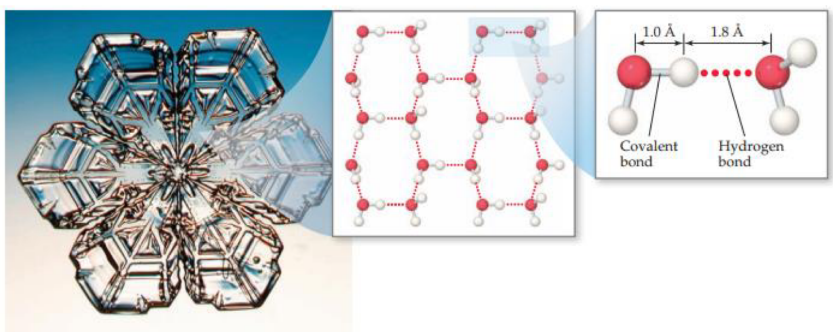



## 2. What Forms Hydrogen Bonds

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

These atoms interact with a nearby bare nucleus (which contains one proton.)

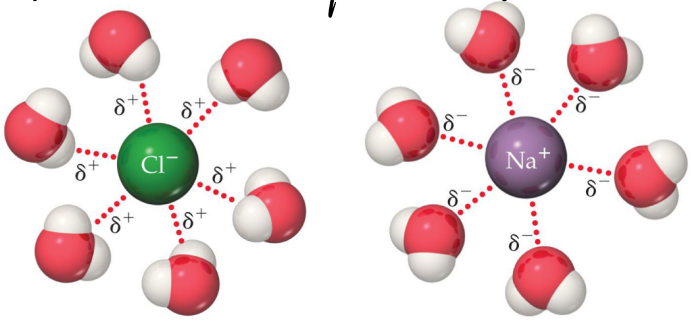



▲ Figure 11.11 **Hydrogen bonding in ice.** The empty channels in the structure of ice make water less dense as a solid than as a liquid.

## §6 Ion-Dipole Interactions

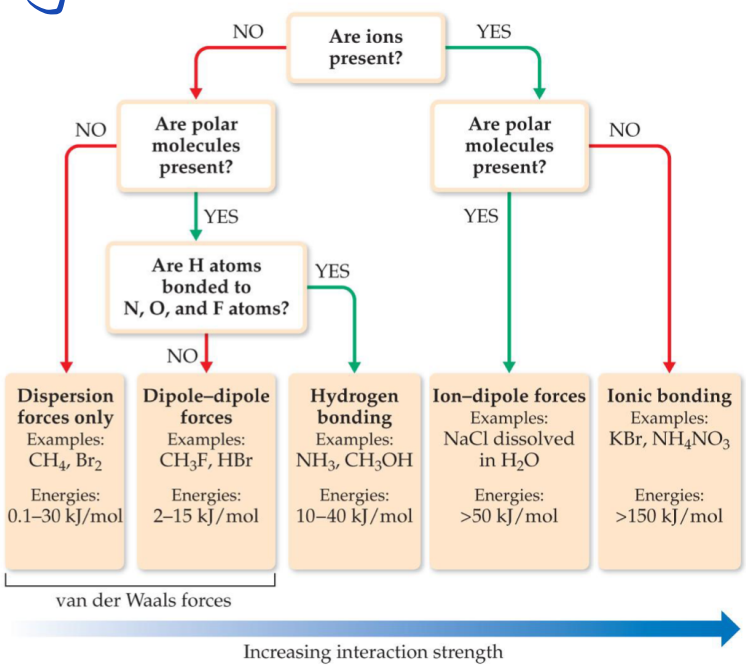
Ion-Dipole interactions are found in solutions of ions.
The strength of these forces is what makes it possible for ionic substances to dissolve in polar solvents.




Positive ends of polar molecules are oriented toward negatively charged anion

Negative ends of polar molecules are oriented toward positively charged cation

## §7 Summarizing Intermolecular Forces




## §8 Liquid Properties Affected by Intermolecular Forces

### 1. Viscosity

1° Resistance of a liquid to flow is called viscosity.

2° It's related to the ease with which molecules can move past each other.

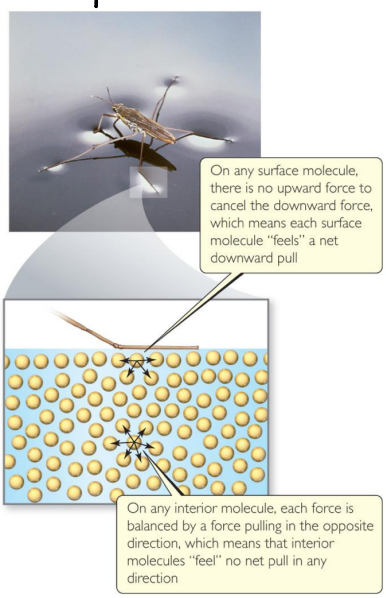
3° Viscosity increases with stronger intermolecular forces and decreases with higher temperature.

Table 11.5 Viscosities of a Series of Hydrocarbons at 20 °C

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

## 2. Surface Tension

Water act as if it has a "skin" on it due to extra inward forces on its surface. Those are called the surface tension.




## 3. Capillary Action (毛细现象)

1° Intermolecular forces that bind similar molecules to one another are called cohesive forces (内聚力)

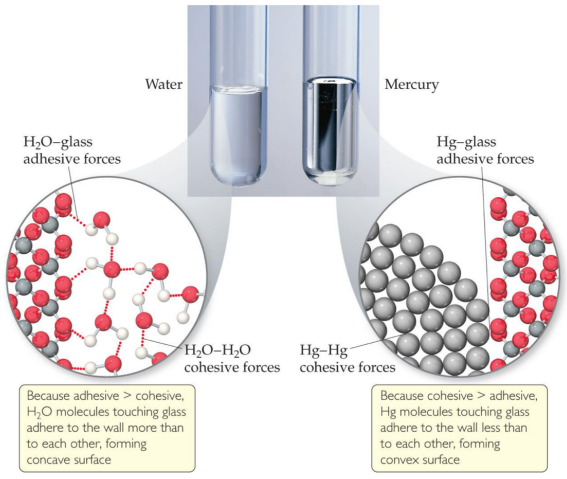
2° Intermolecular forces that bind a substance to a surface are called adhesive forces (附着力)

3° The rise of liquids up narrow tubes is called capillary action.

4° Adhesive forces attract the liquid to the wall of the tube.

5° Cohesive forces attract the liquid to itself.

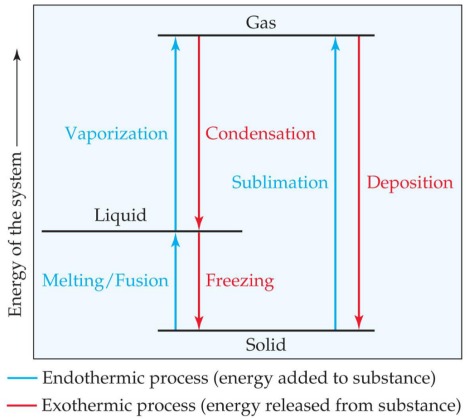
6° Water has stronger adhesive forces with glass;
Mercury has stronger cohesive forces with itself




# §9 Phase Changes

## 1. Types

- melting / freezing
- vaporizing / condensing
- subliming / depositing

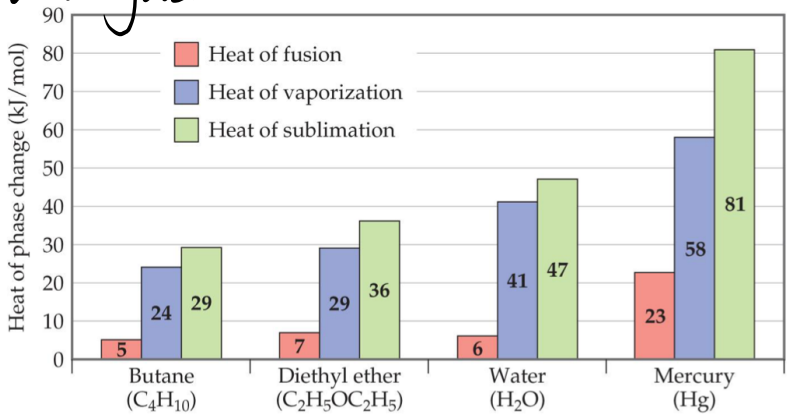



## 2. Energy Change

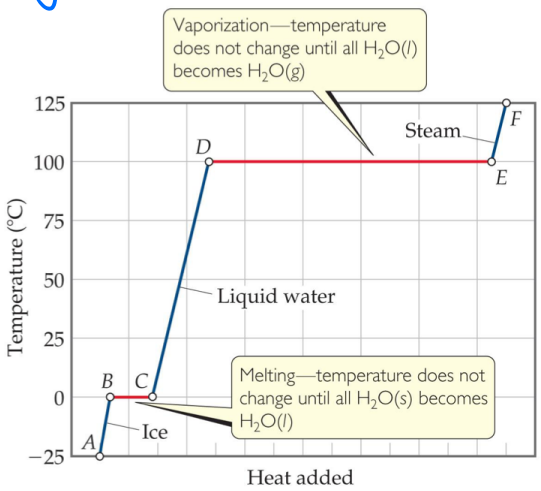
1° The heat of fusion is the energy required to change a solid at its melting point to a liquid.

2° The heat of vaporization is the energy required to change a liquid at its boiling point to a gas.

3° The heat of sublimation is the energy required to change a solid directly to a gas.




## 3. Heating Curve

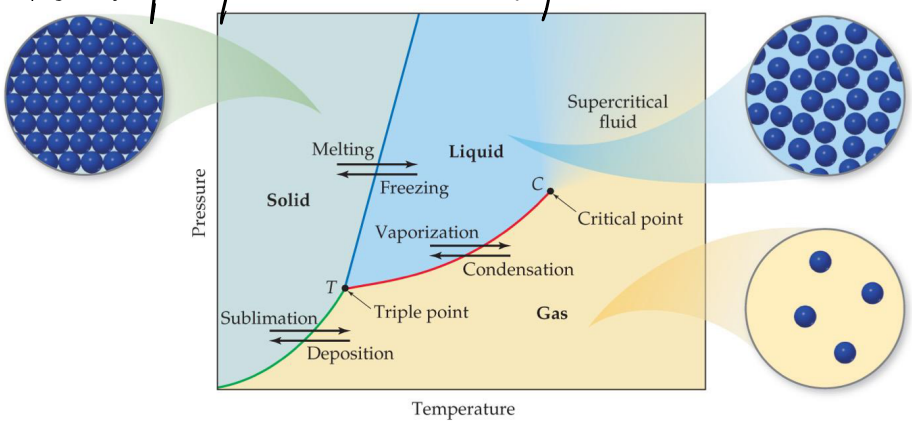


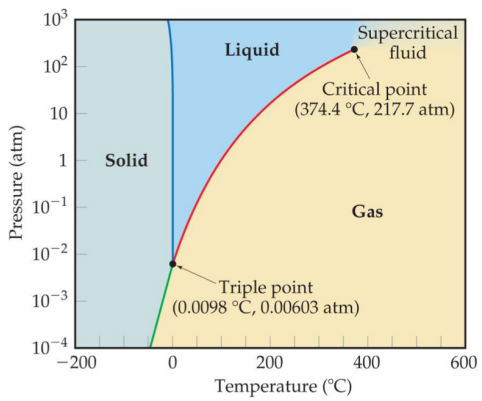

# 4. Phase Diagram

It shows:

1° melting, boiling, and sublimation points at different pressures.

2° the triple point and critical point




- Unusual feature for water:
  - ➢ The slope of the solid–liquid line is negative.
  - ✓ This means that as the pressure is increased, the melting point decreases.

- Unusual features for carbon dioxide:
  - ➢ cannot exist in the liquid state at pressures below 5.11 atm (triple point)
  - ✓ $CO_2$ sublimes at normal pressures.