Chapter 13
LIQUIDS AND SOLIDS

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Kinetic-Molecular Description of Liquids and Solids

- Solids and liquids are ***condensed states*.**
  - The atoms, ions, or molecules in solids and liquids are much closer to one another than in gases.
- Liquids and gases are ***fluids*.**
- The ***intermolecular attractions*** in liquids and solids are strong.

Kinetic-Molecular Description of Liquids and Solids

- If we compare the **strengths of interactions** among particles and the **degree of ordering** of particles, we see that

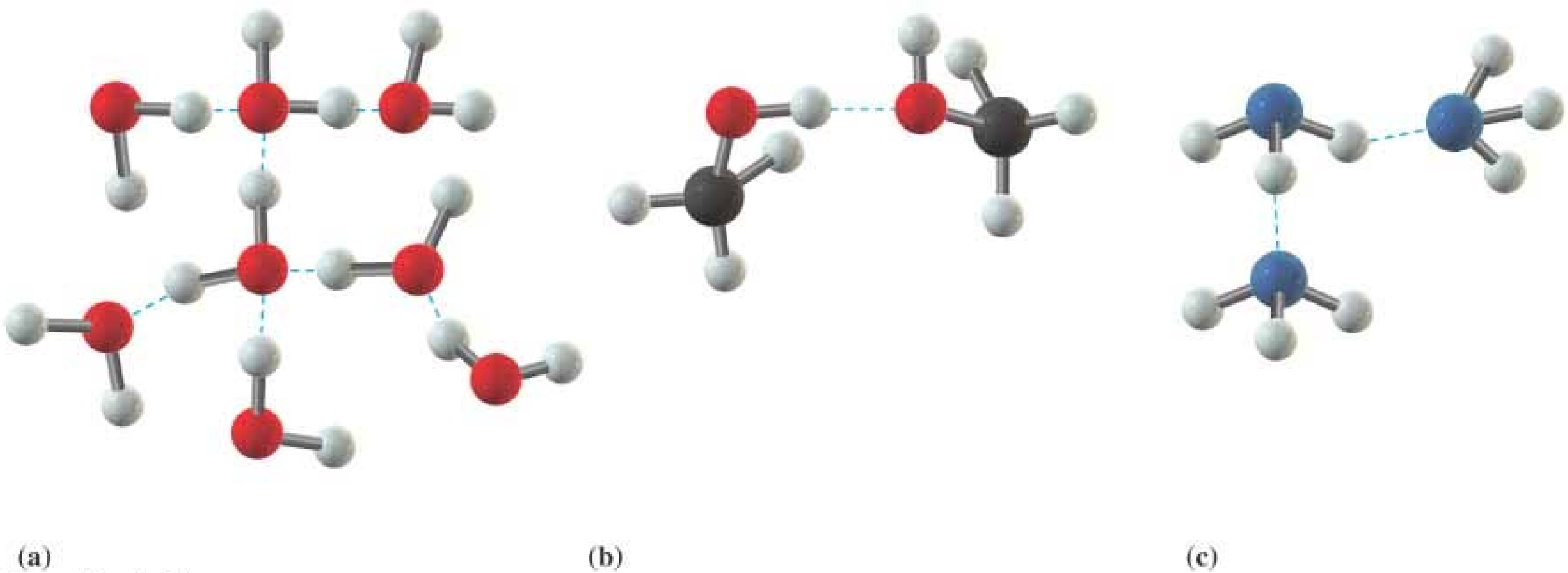
  Gases< Liquids < Solids

- **Miscible liquids** are soluble in each other.
  - Examples of miscible liquids:
    - Water dissolves in alcohol.
    - Gasoline dissolves in motor oil.
- **Immiscible liquids** are insoluble in each other.
  - Two examples of immiscible liquids:
    - Water does not dissolve in oil.
    - Water does not dissolve in cyclohexane.

Intermolecular Attractions and Phase Changes

- There are four important intermolecular attractions.
  - *This list is from strongest attraction to the weakest attraction.*

1. **Ion-ion interactions**
   - The force of attraction between two oppositely charged ions is governed by Coulomb's law.
2. **Hydrogen bonding**
   - Occurs among polar covalent molecules containing H and one of the three small, highly electronegative elements-F, O, or N. Ex. H_2O, CH_3OH and NH_3.

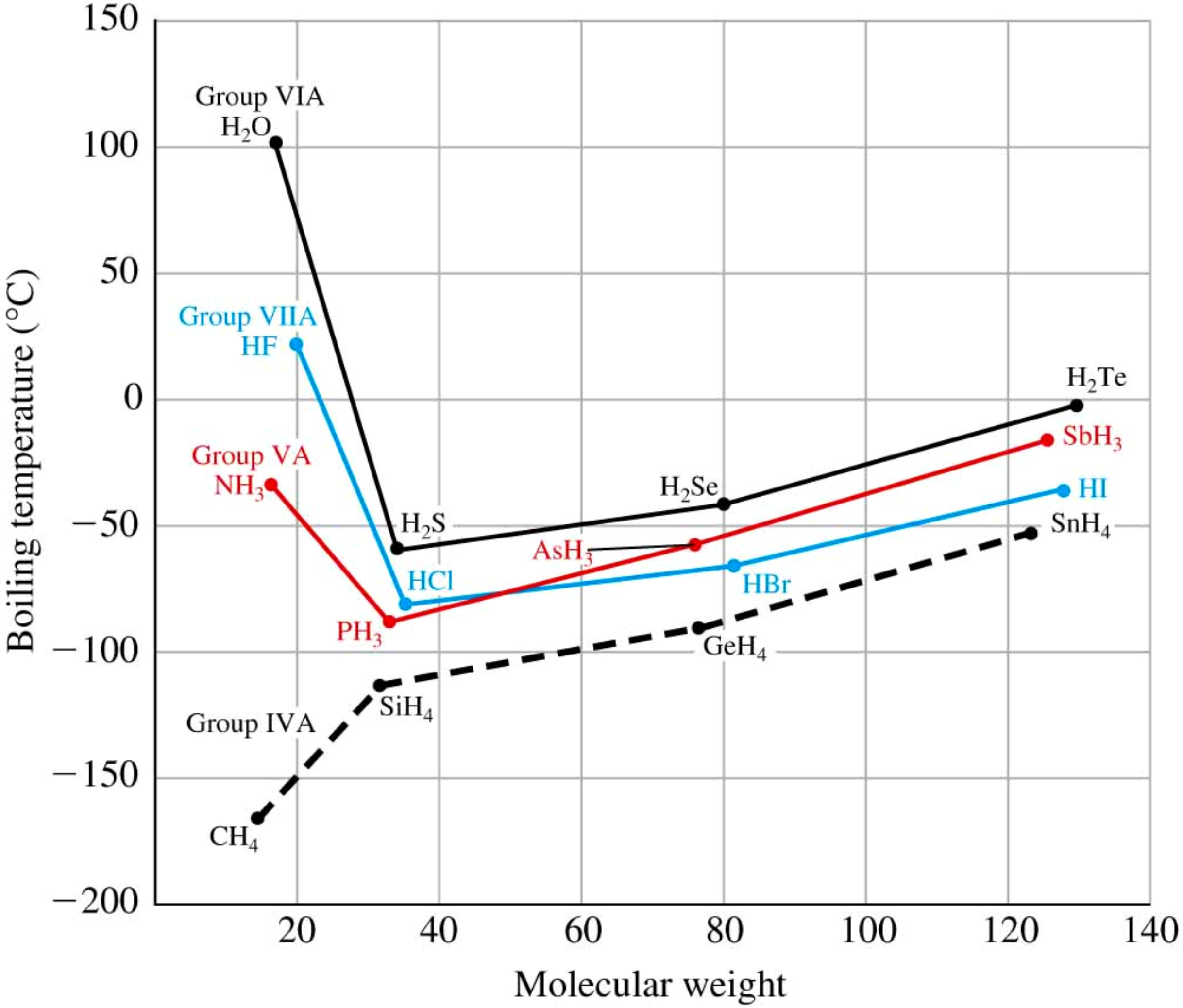


Hydrogen bonding in water molecules

Hydrogen bonding in methanol molecules

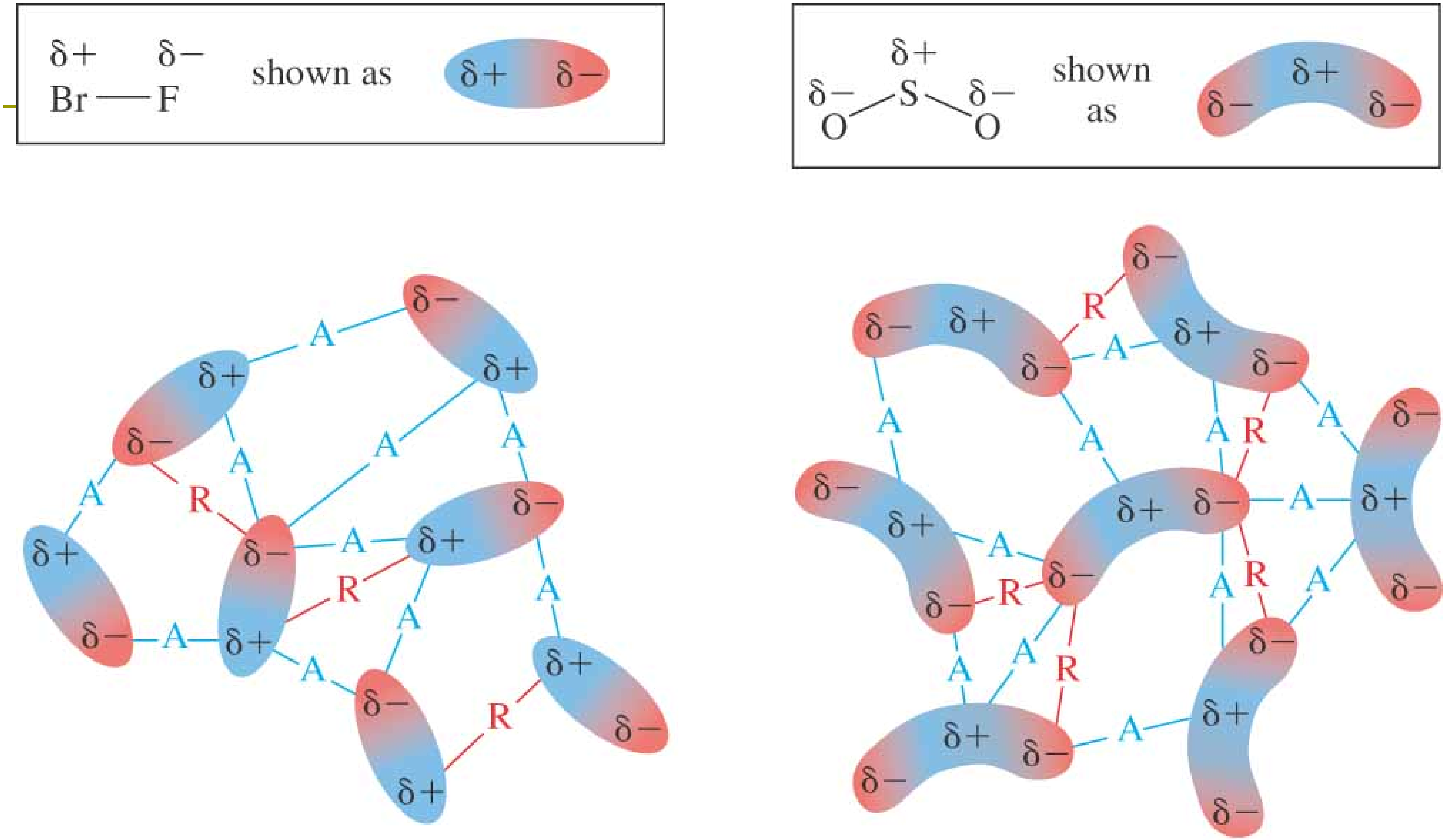
Hydrogen bonding in ammonia molecules

Intermolecular Attractions and Phase Changes



Intermolecular Attractions and Phase Changes

3. **Dipole-dipole interactions**
   - Occurs between polar covalent moecules because of the attraction of the $\delta+$ atoms of one molecule to the $\delta-$ atoms of another molecule.
   - Consider BrF and SO_2 molecules.

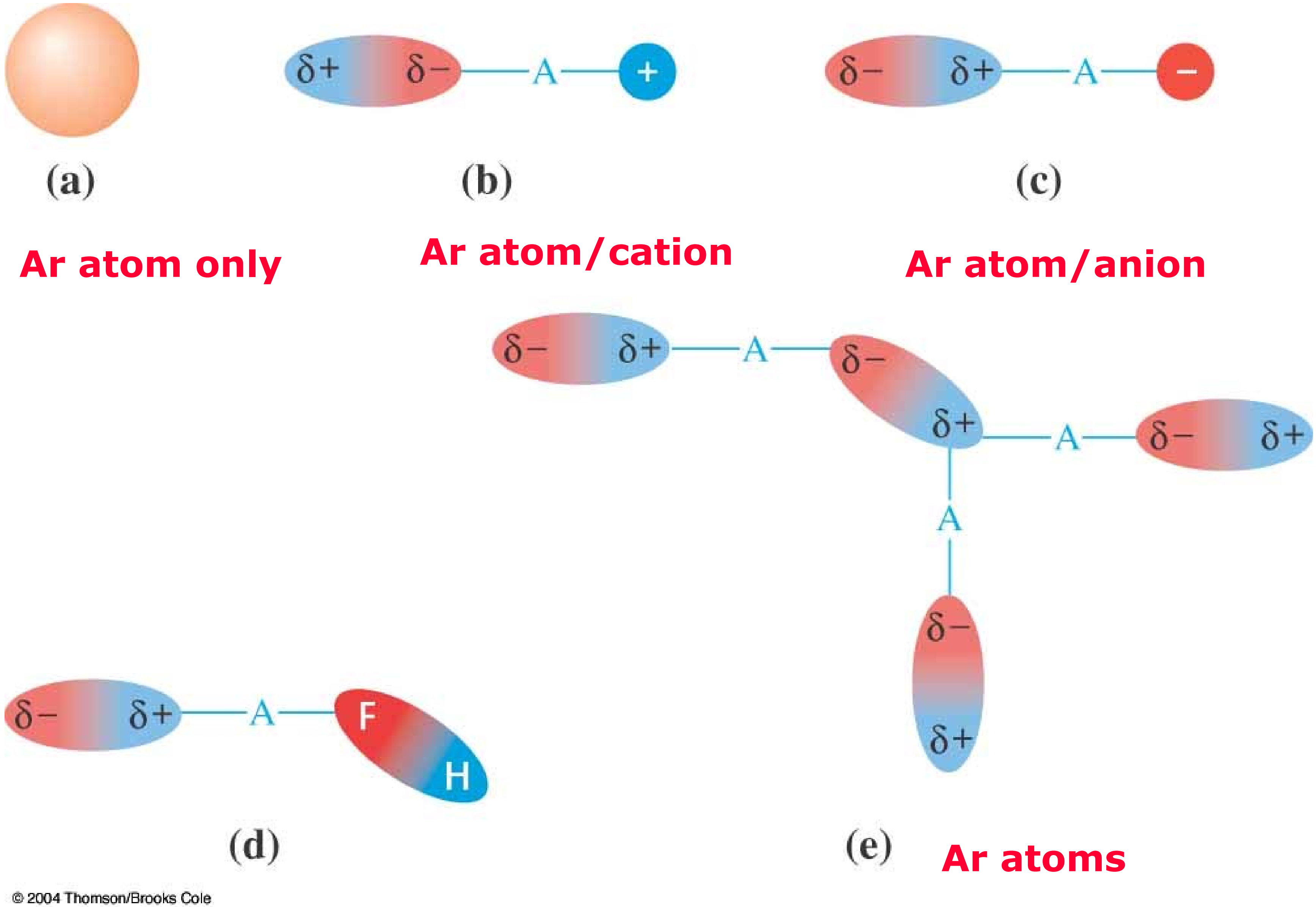


(a) (b)

Intermolecular Attractions and Phase Changes

4. **London Forces are very weak (dispersion forces).**
   - They are the weakest of the intermolecular forces.
   - This is the only attractive force in nonpolar molecules.

- Consider Ar as an isolated atom.
- In a group of Ar atoms the temporary dipole in one atom induces other atomic dipoles.
- Similar effects occur in a group of I_2 molecules.



Ar atom only

Ar atom/cation

Ar atom/anion

Ar atoms

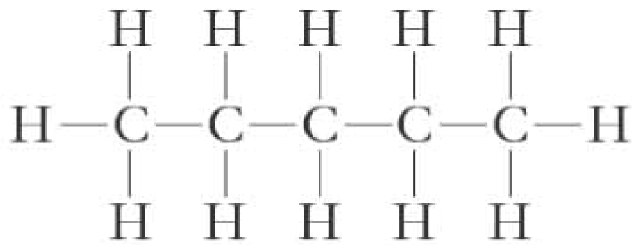
Ar atom/HF

The Liquid State

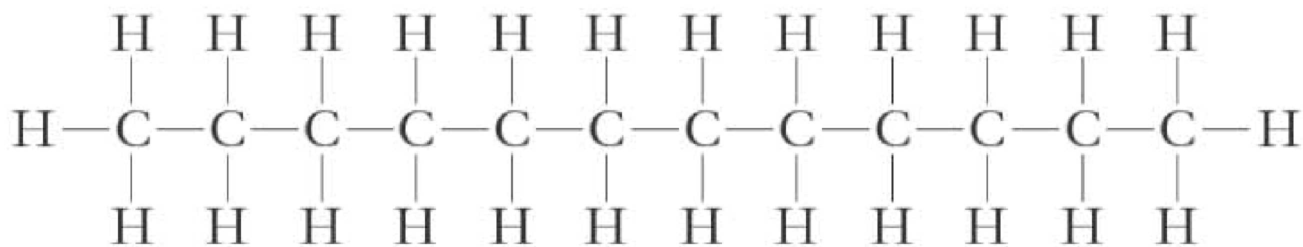
Viscosity

- Viscosity is the resistance to flow.
  - For example, compare how water pours out of a glass compared to molasses, syrup or honey.
- Oil for your car is bought based on this property.
  - 10W30 or 5W30 describes the viscosity of the oil at high and low temperatures.

pentane, C_5H_{12}
viscosity = 0.215
centipoise at 25°C



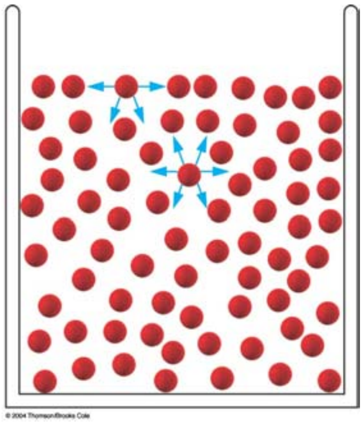
dodecane, $C_{12}H_{26}$
viscosity = 1.38
centipoise at 25°C



The Liquid State

Surface Tension

- Surface tension is a measure of the unequal attractions that occur at the surface of a liquid.
- The molecules at the surface are attracted unevenly.



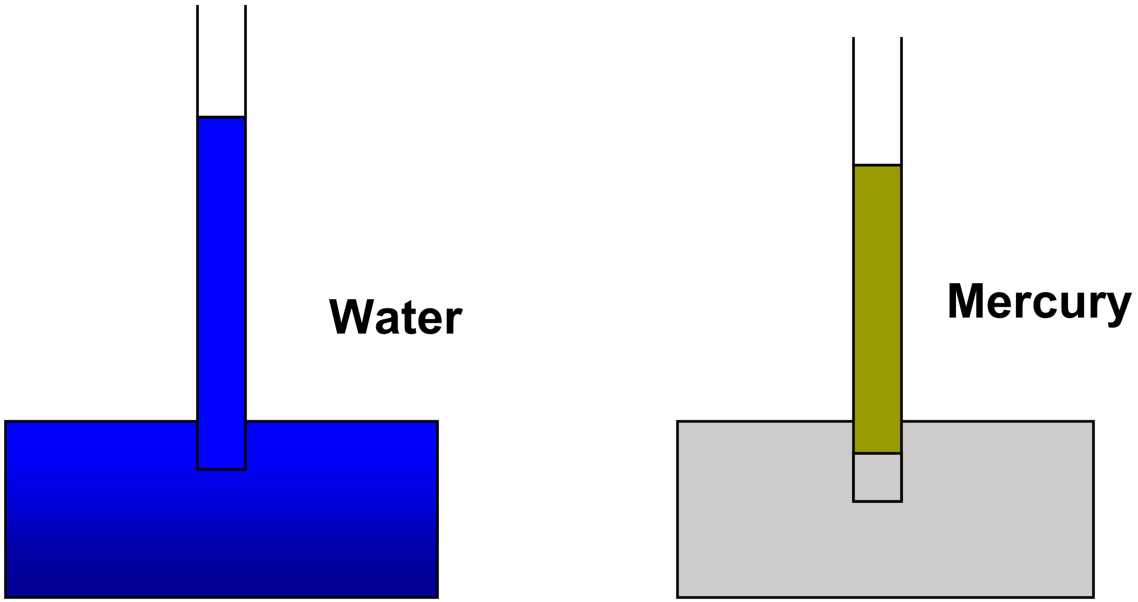
The Liquid State

Capillary Action

- Capillary action is the ability of a liquid to rise (or fall) in a glass tube or other container
- Cohesive forces are the forces that hold liquids together.
- Adhesive forces are the forces between a liquid and another surface.
  - Capillary rise implies that the:
    - Adhesive forces > cohesive forces
  - Capillary fall implies that the:
    - Cohesive forces > adhesive forces

The Liquid State

- Water exhibits a capillary rise.
- Mercury exhibits a capillary fall.



The Liquid State

Evaporation

- Evaporation is the process in which molecules escape from the surface of a liquid and become a gas.
- Evaporation is temperature dependent.

The Liquid State

Vapor Pressure

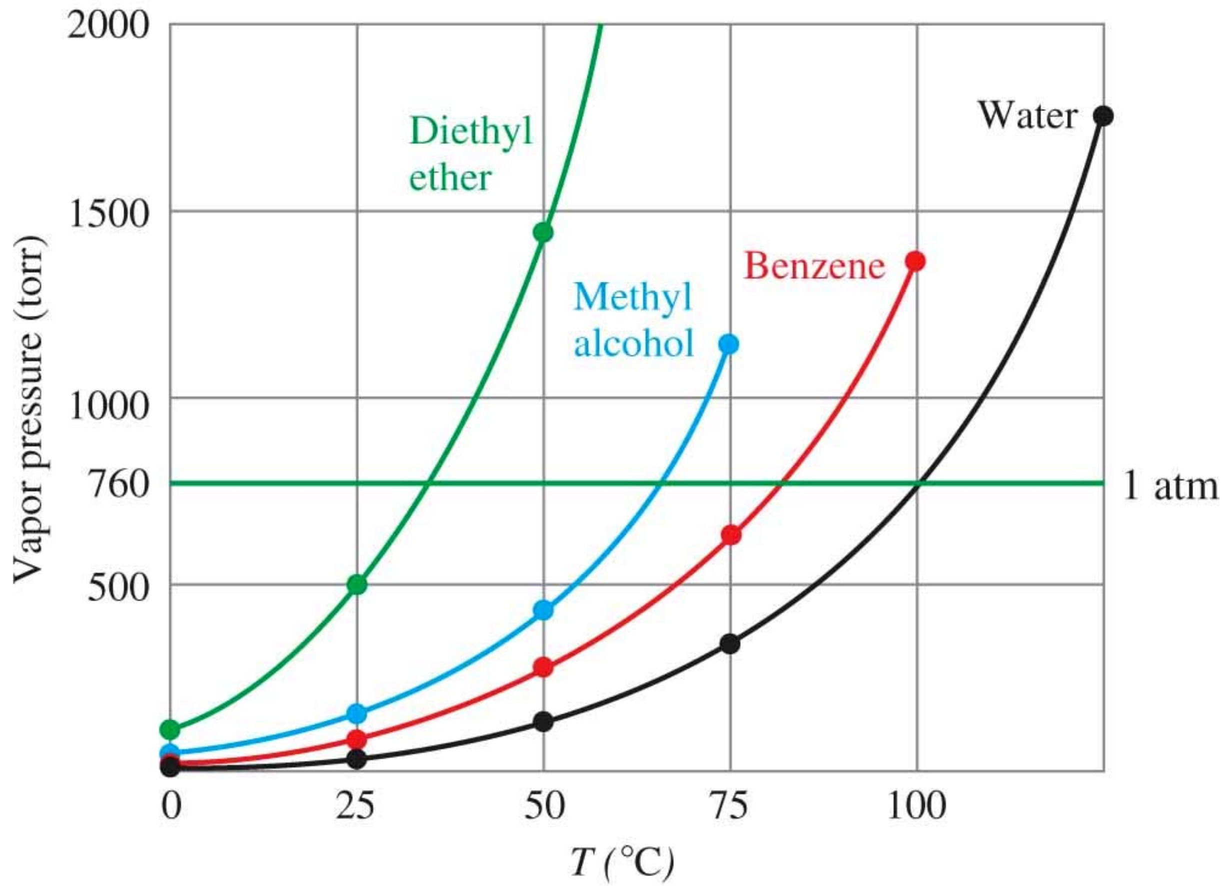
- Vapor pressure is the pressure exerted by a liquid's vapor on its surface at equilibrium.
- Vapor Pressure (torr) and boiling point for three liquids at different temperatures.

	0°C	20°C	30°C	normal boiling point
diethyl ether	185	442	647	36°C
ethanol	12	44	74	78°C
water	5	18	32	100°C

- What are the intermolecular forces in each of these compounds?

The Liquid State

Vapor Pressure as a function of temperature.



The Liquid State

Boiling Points and Distillation

- The **boiling point** is the temperature at which the liquid’s vapor pressure is equal to the applied pressure.
- The **normal boiling point** is the boiling point when the pressure is exactly 1 atm.
- **Distillation** is a method we use to separate mixtures of liquids based on their differences in boiling points.

The Liquid State

- Next, we must address the energy associated with phase changes.
  - For example, solid to liquid or liquid to gas and the reverse.

Molar heat of vaporization or ΔH_{vap}

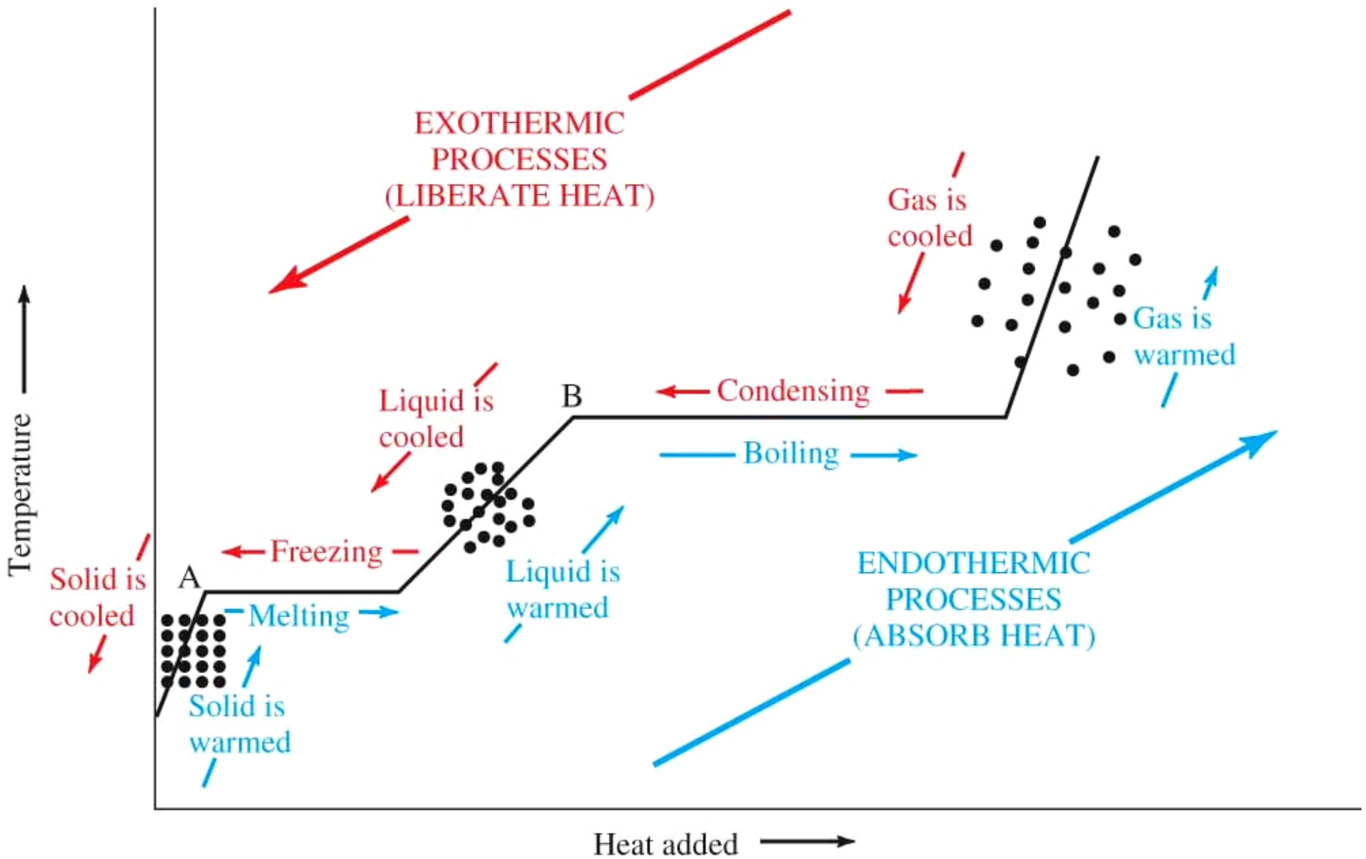
- The ΔH_{vap} is the amount of heat required to change 1.00 mole of a liquid to a gas at ***constant*** temperature.

  ΔH_{vap} has units of J/mol.

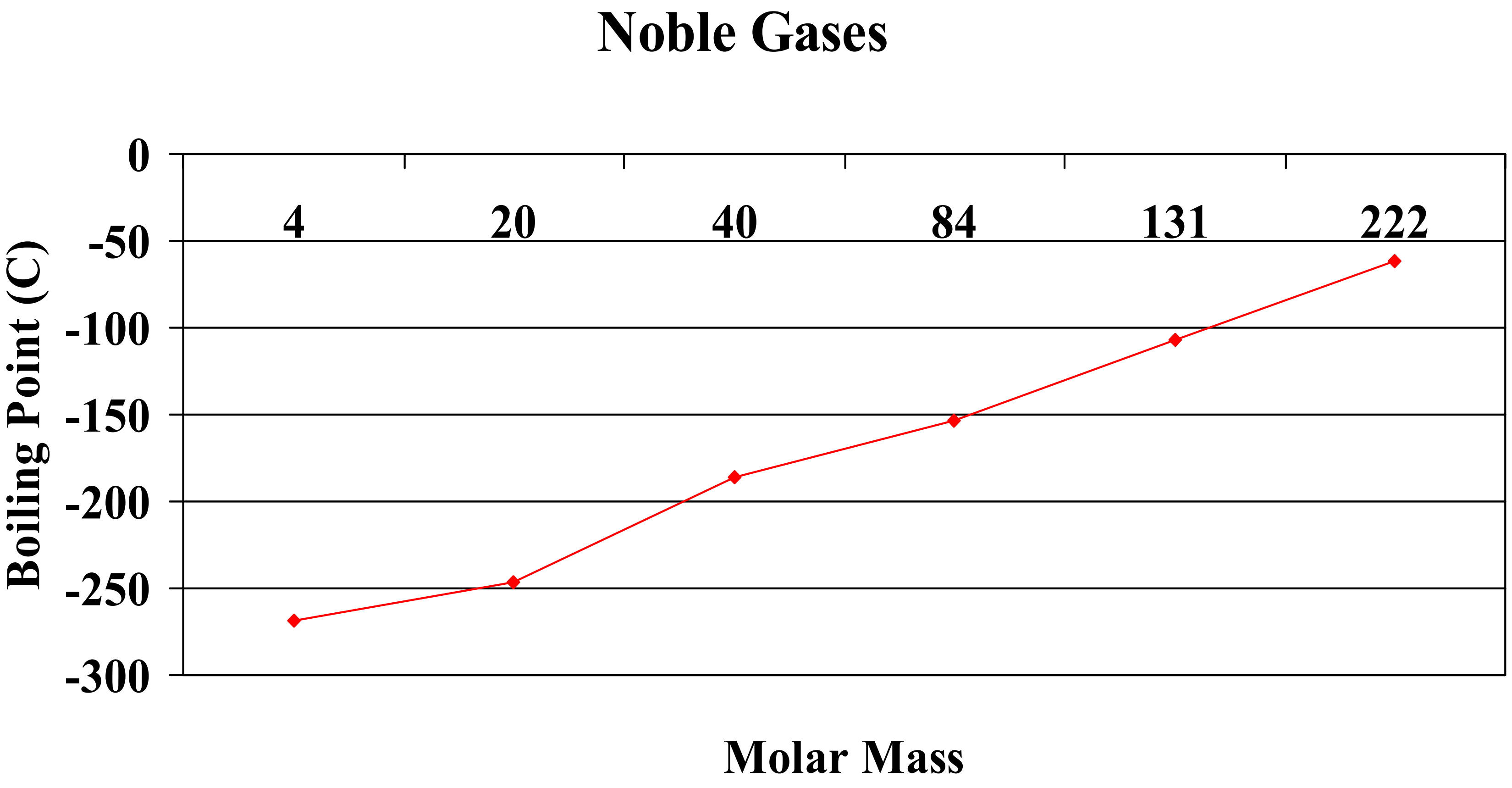
Molar heat of condensation

- The reverse of molar heat of vaporization is the heat of condensation.

The Liquid State



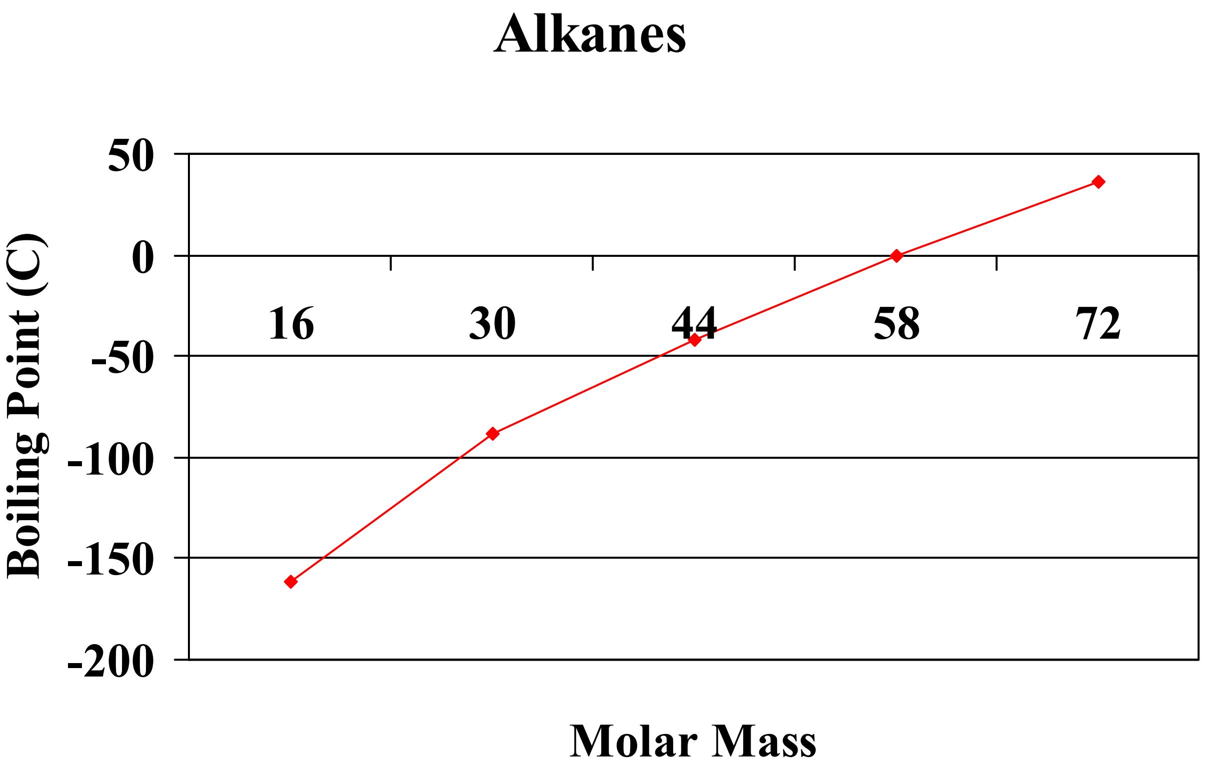
The Liquid State



The Liquid State

Compound	MW(amu)	B.P.(^oC)
CH_4	16	-161
C_2H_6	30	-88
C_3H_8	44	-42
n-C_4H_{10}	58	-0.6
n-C_5H_{12}	72	+36

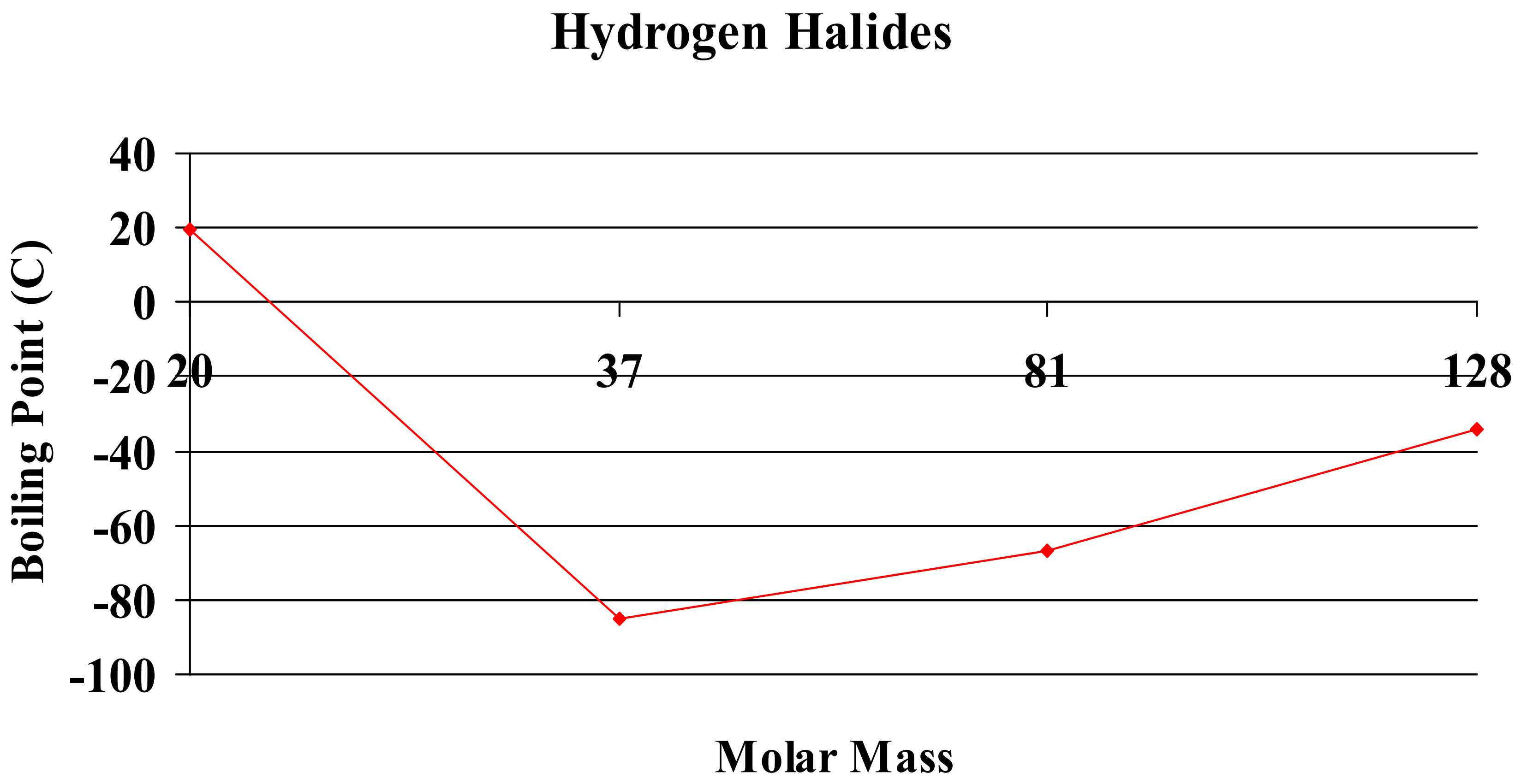
The Liquid State



The Liquid State

Compound	MW(amu)	B.P.(^{o}C)
HF	20	19.5
HCl	37	-85.0
HBr	81	-67.0
HI	128	-34.0

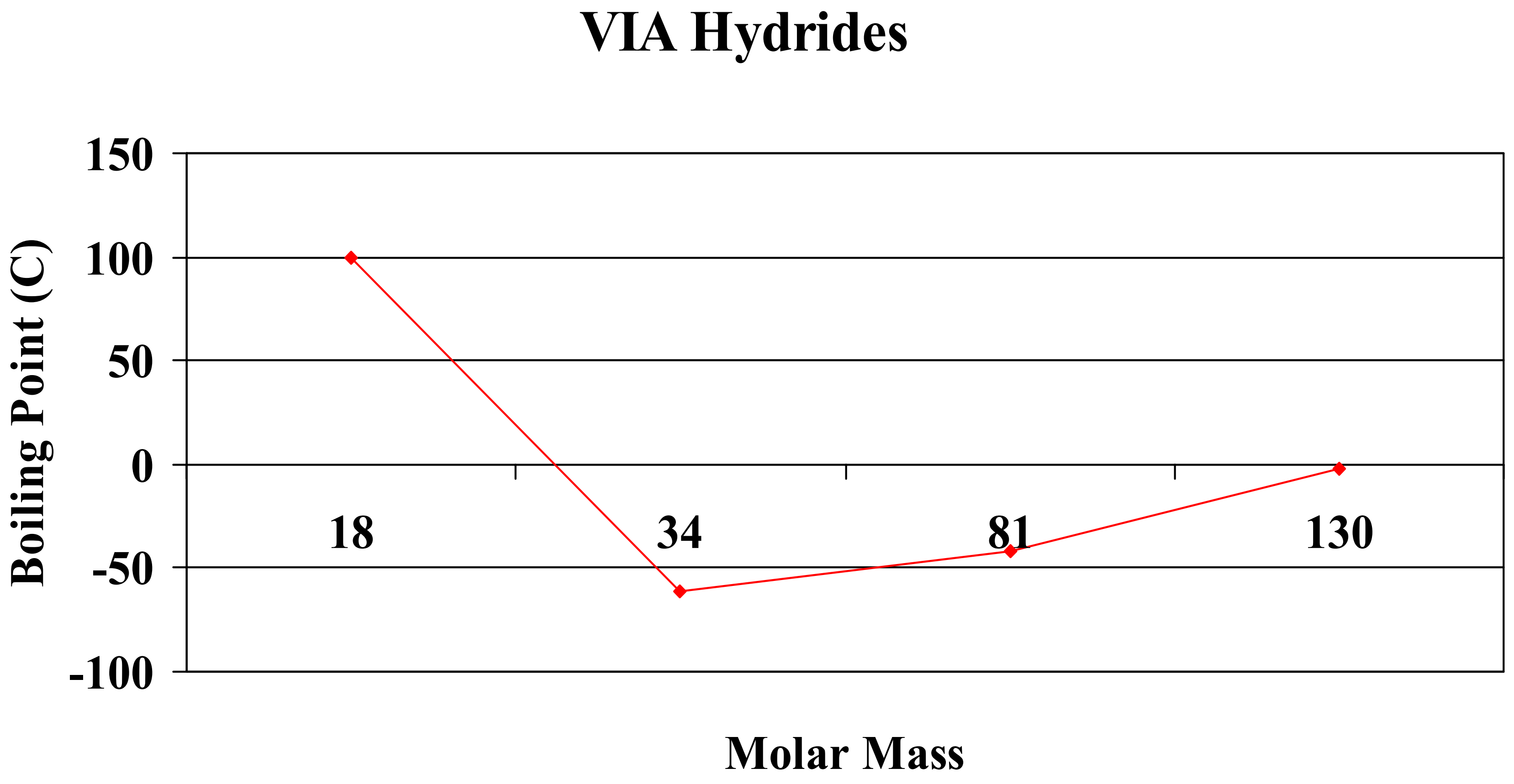
The Liquid State



The Liquid State

Compound	MW(amu)	B.P.(°C)
H_2O	18	100
H_2S	34	-61
H_2Se	81	-42
H_2Te	130	-2

The Liquid State



The Liquid State

- Arrange the following substances in order of increasing boiling points.

$$C_2H_6,\ NH_3,\ Ar,\ NaCl,\ AsH_3$$

$$Ar < C_2H_6 < AsH_3 < NH_3 < NaCl$$

nonpolar nonpolar polar very polar ionic

London London dipole-dipole H-bonding ion-ion

The Solid State

Normal Melting Point

- The **normal melting point** is the temperature at which the solid melts (liquid and solid in equilibrium) at exactly 1.00 atm of pressure.
- The melting point increases as the strength of the intermolecular attractions increase.

Heat Transfer Involving Solids

Heat of Fusion

- **Heat of fusion** is the amount of heat required to melt one gram of a solid at its melting point at constant temperature.

  - **Heat of crystallization** is the reverse of the heat of fusion.

Heat Transfer Involving Solids

Molar heat of fusion or ΔH_{fusion}

- The molar heat of fusion is the amount of heat required to melt a mole of a substance at its melting point.
- The molar heat of crystallization is the reverse of molar heat of fusion

Sublimation and the Vapor Pressure of Solids

Sublimation

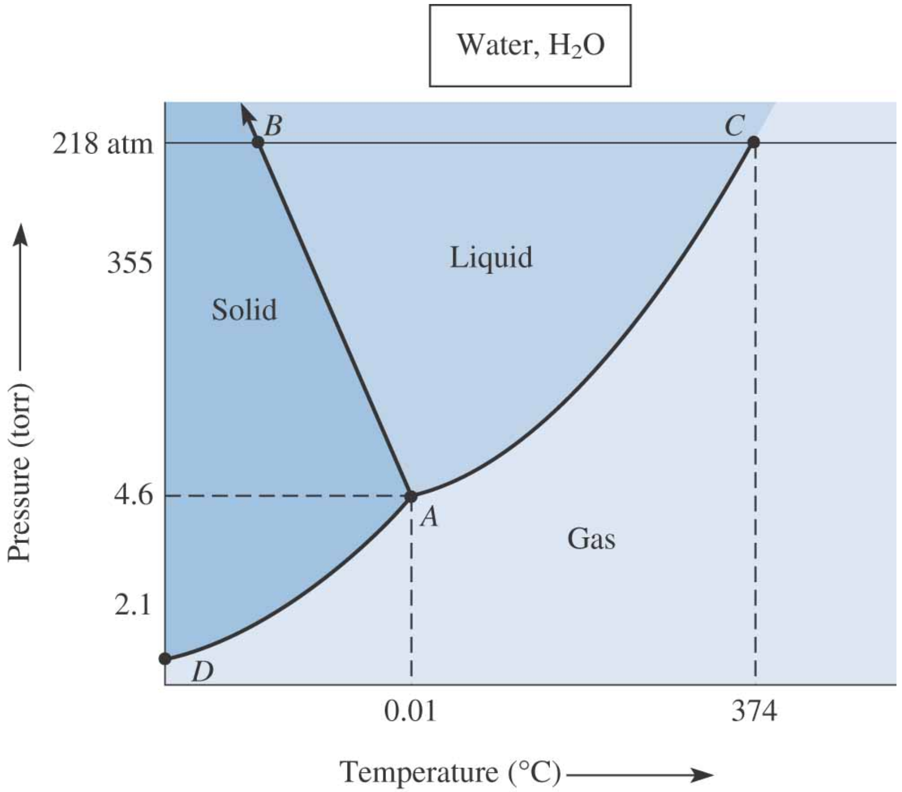
- In the sublimation process the solid transforms directly to the vapor phase without passing through the liquid phase.
- Solid CO_2 or “dry” ice does this well.

$$\text{solid} \underset{\text{condensation}}{\overset{\text{sublimation}}{\rightleftharpoons}} \text{gas}$$

Sublimation of Iodine.

Phase Diagrams (P versus T)

- Phase diagrams are a convenient way to display all of the different phase transitions of a substance.



Phase Diagrams (P versus T)

- Compare water's phase diagram to carbon dioxide's phase diagram.