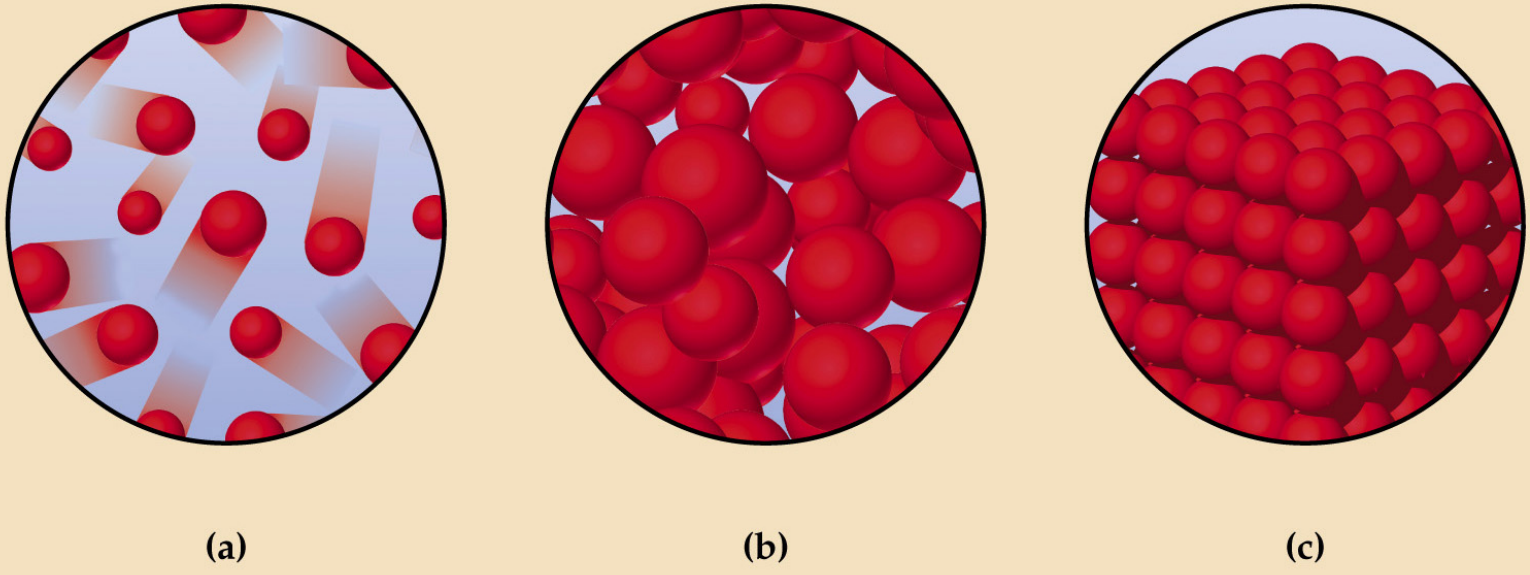
Liquids

Chapter 13



Gases	Liquids	Solids
Variable shape and volume	Variable shape, fixed volume	Fixed shape and volume
May expand or compress	May flow, not compressible	Non-compressible crystalline solids
Low densities	High density	High density
Mix to form homogeneous mixtures	Mix if soluble	Do not mix by diffusion

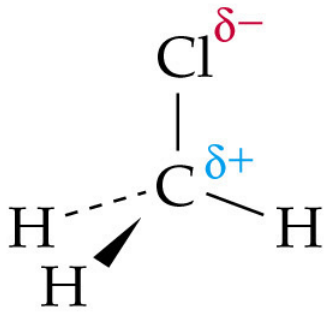
Intermolecular Forces

- Forces holding one molecule to another in a substance.
- van der Waals forces
- Several types – ion-dipole, dipole-dipole, dipole-induced dipole and London dispersion forces
- Hydrogen bonding

Polar Molecules

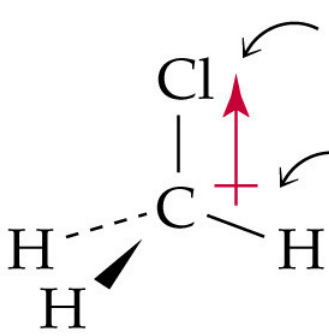
- Dipole - A molecule such as HF which has a positive and a negative end. This dipolar character is often represented by an arrow pointing towards the negative charge.

- Dipole moments – the measure of the net molecular polarity
    - Measured in units of Debyes (D) = Qr (charge x separation)



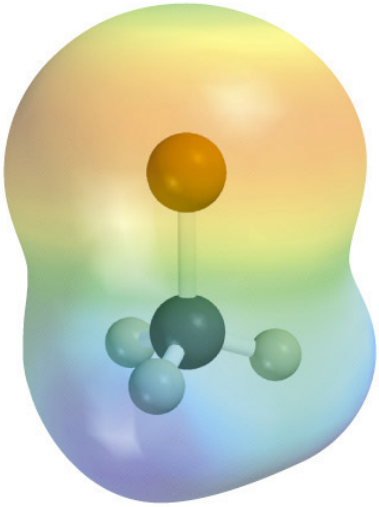
Chloromethane, CH_3Cl

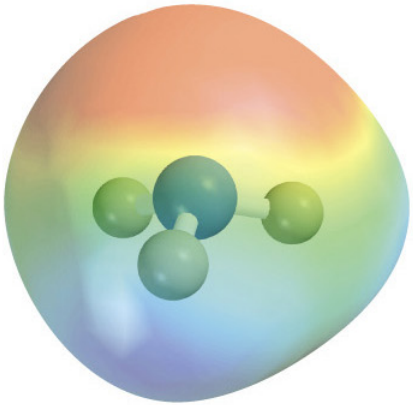
or

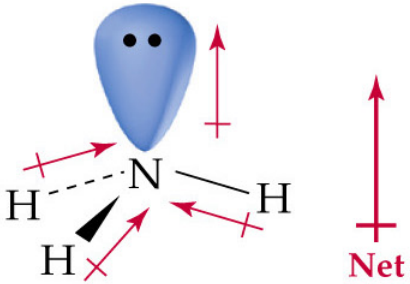


Chlorine is at negative end of bond dipole.

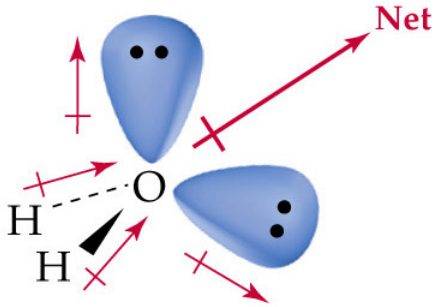
Carbon is at positive end of bond dipole.





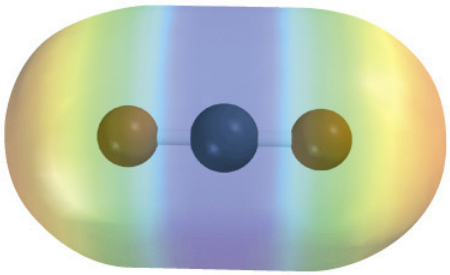


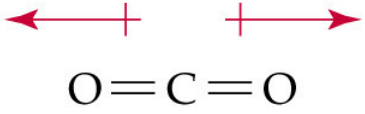
Ammonia (μ = 1.47 D)



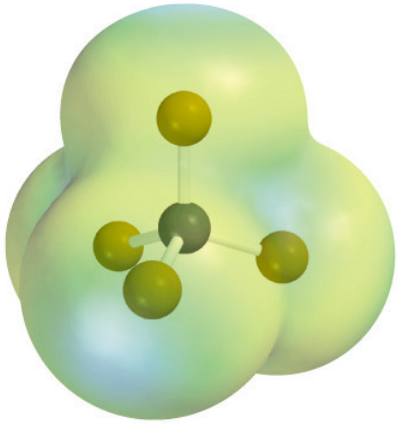
Water (μ = 1.85 D)

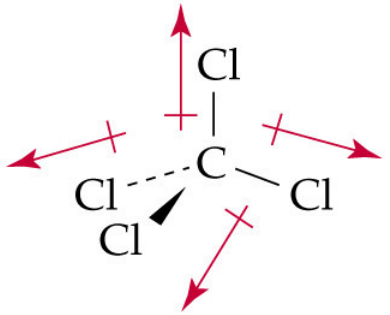
Polar bonds
Non-polar molecules





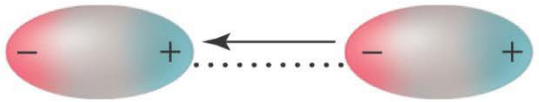
Carbon dioxide (μ = 0)

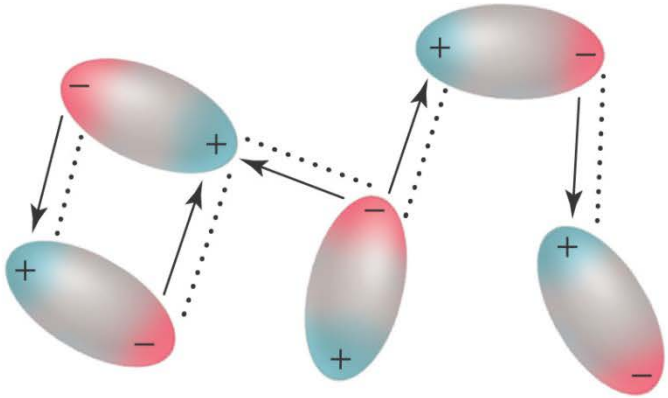


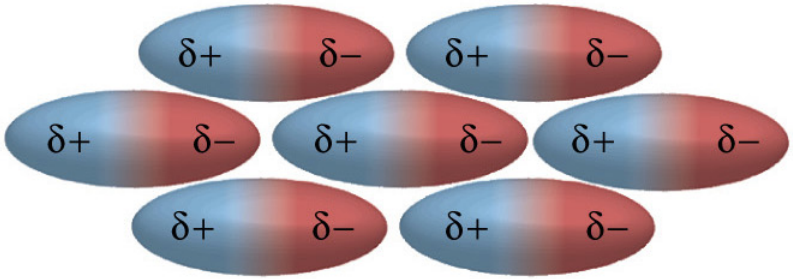


Tetrachloromethane (μ = 0)

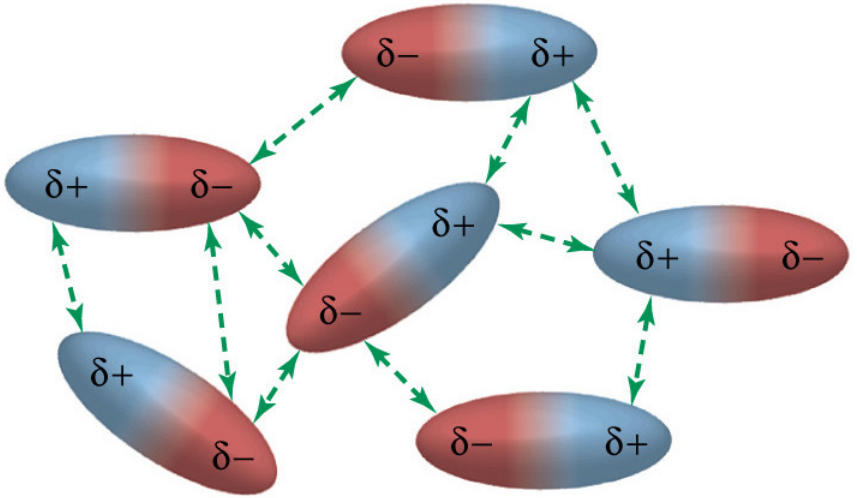
Dipole – Dipole forces
or
Polar - Polar interactions







(a)



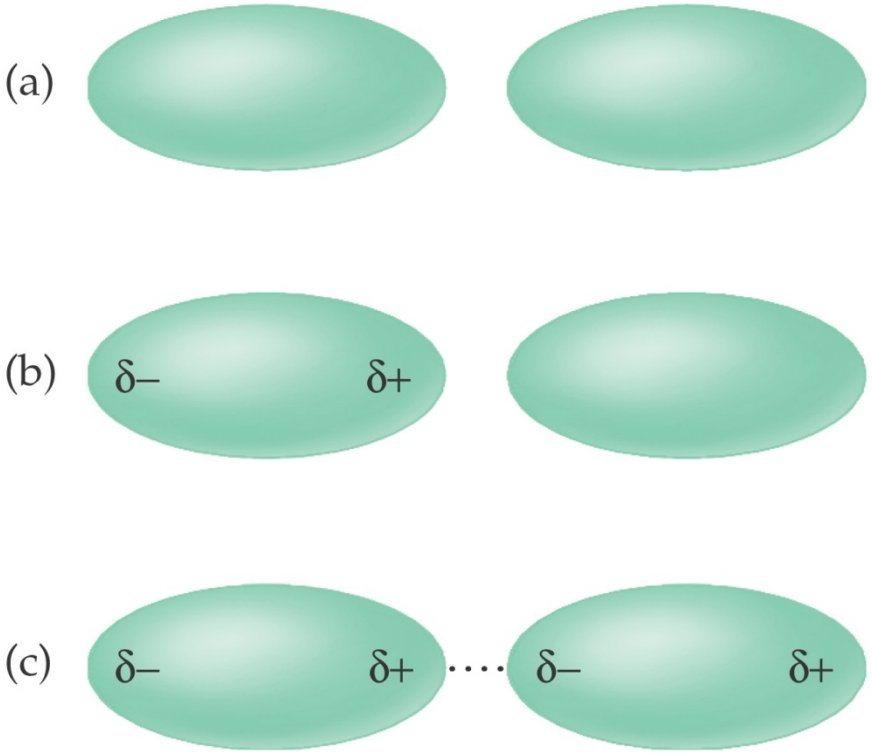
(b)

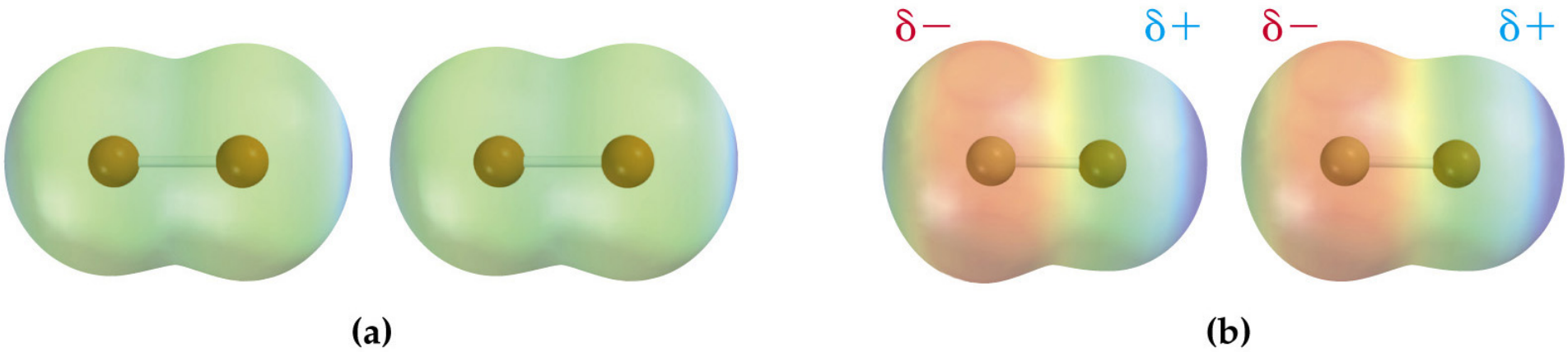
London forces

Induced dipole – induced dipole

or

Nonpolar - Nonpolar interactions

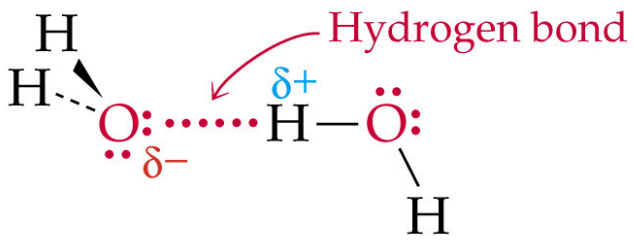


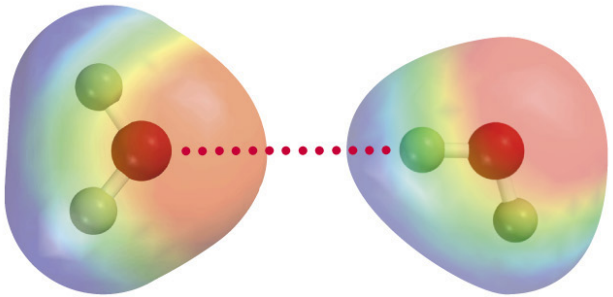


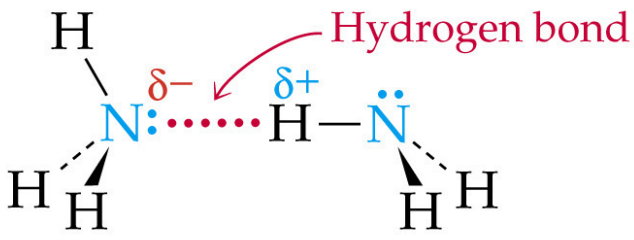
(a) (b)

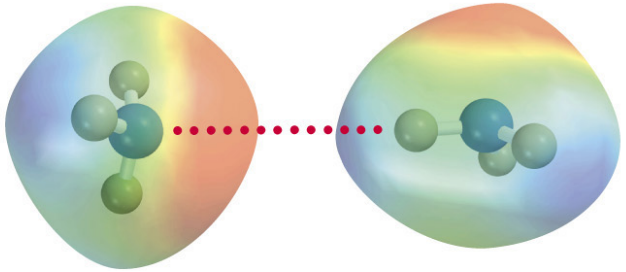
Hydrogen Bonds

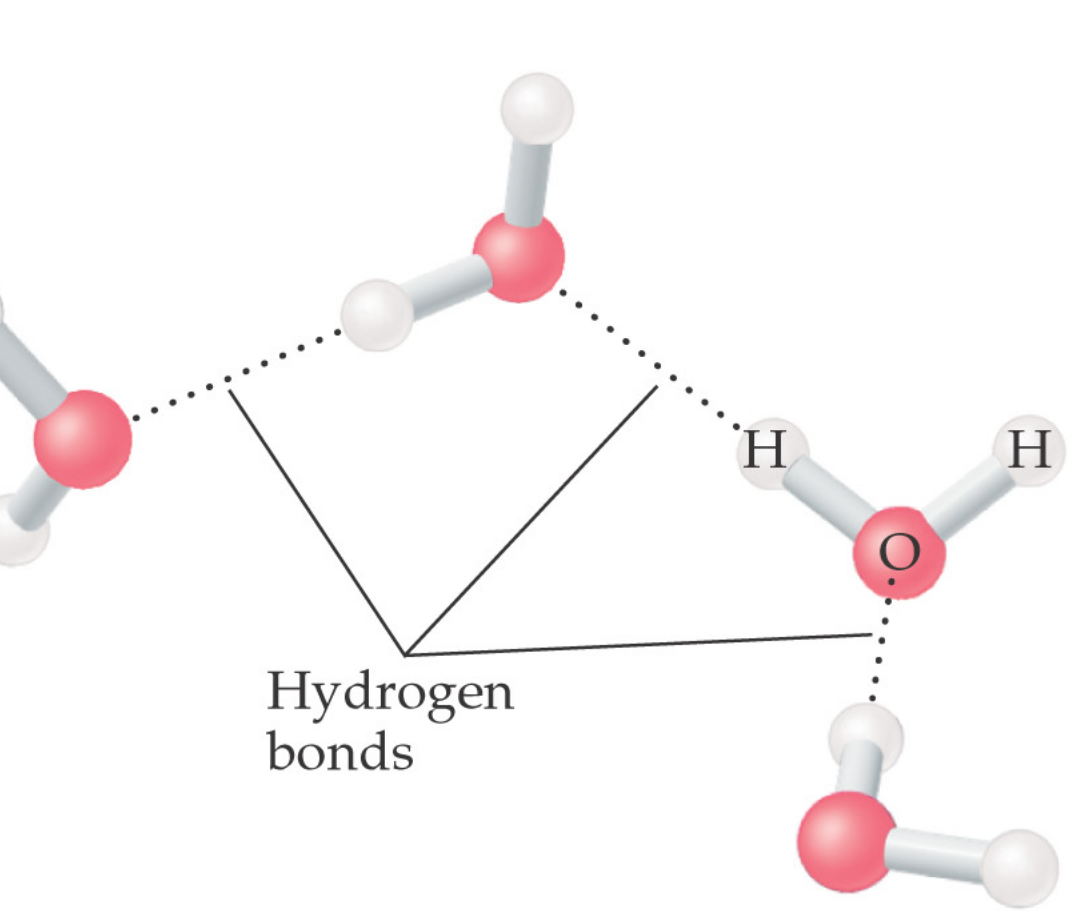
- A special type of polar interaction between a hydrogen atom bonded to an electronegative element and another electronegative element.

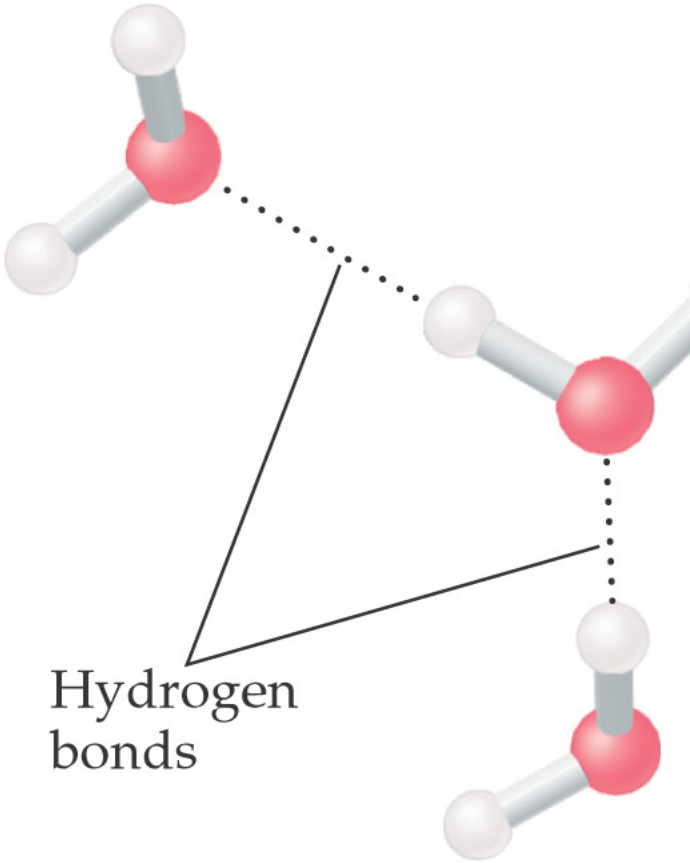


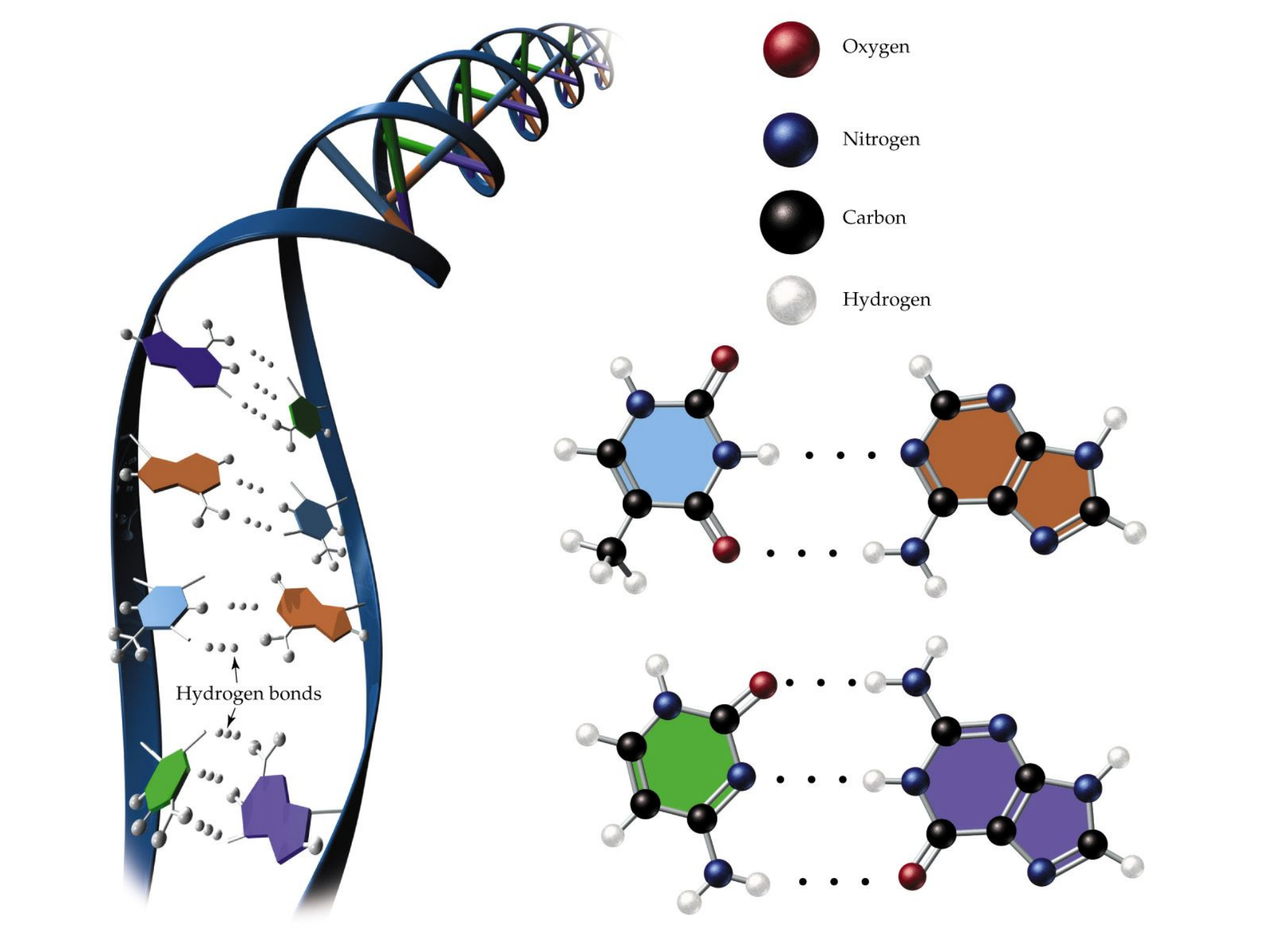


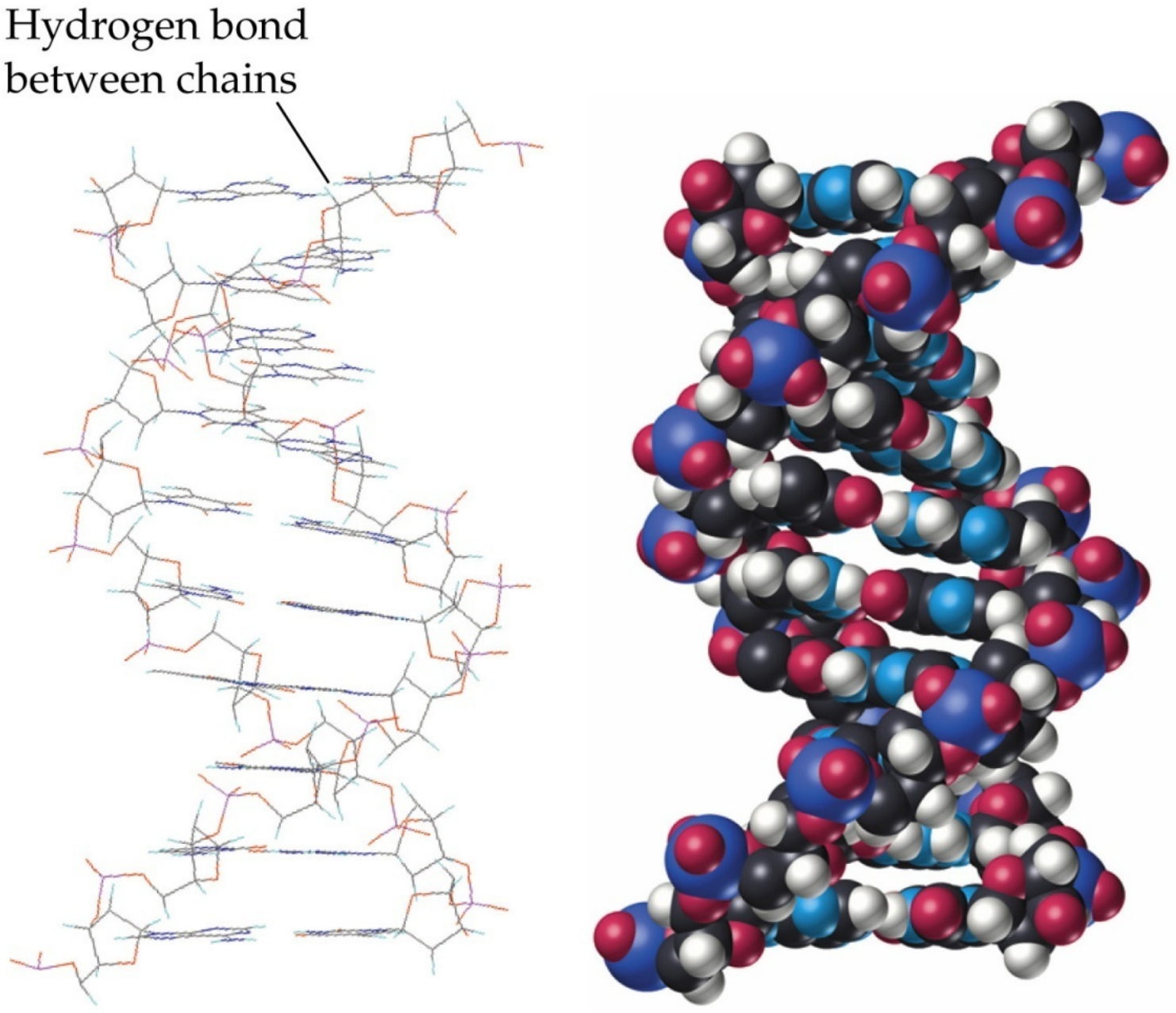


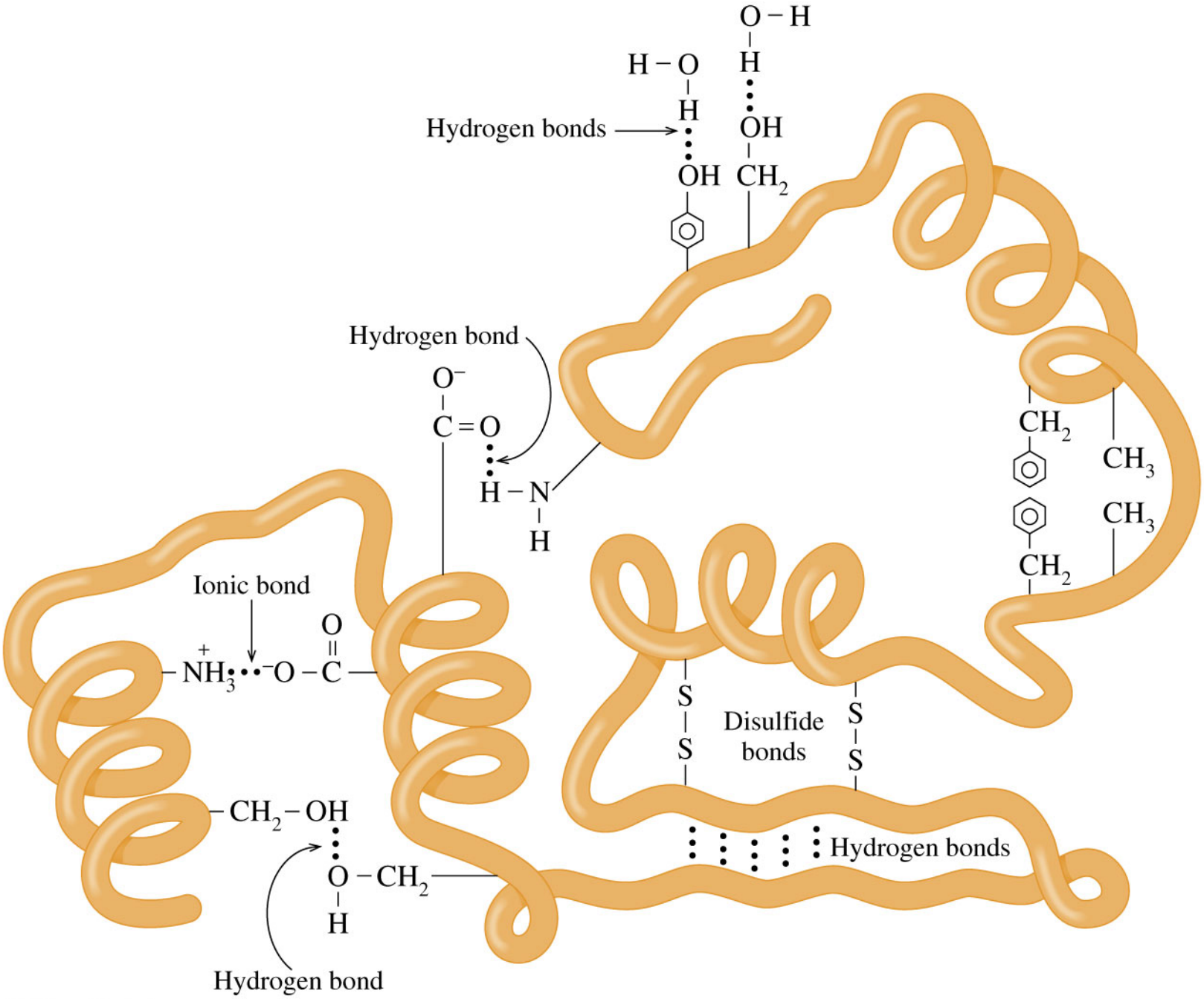


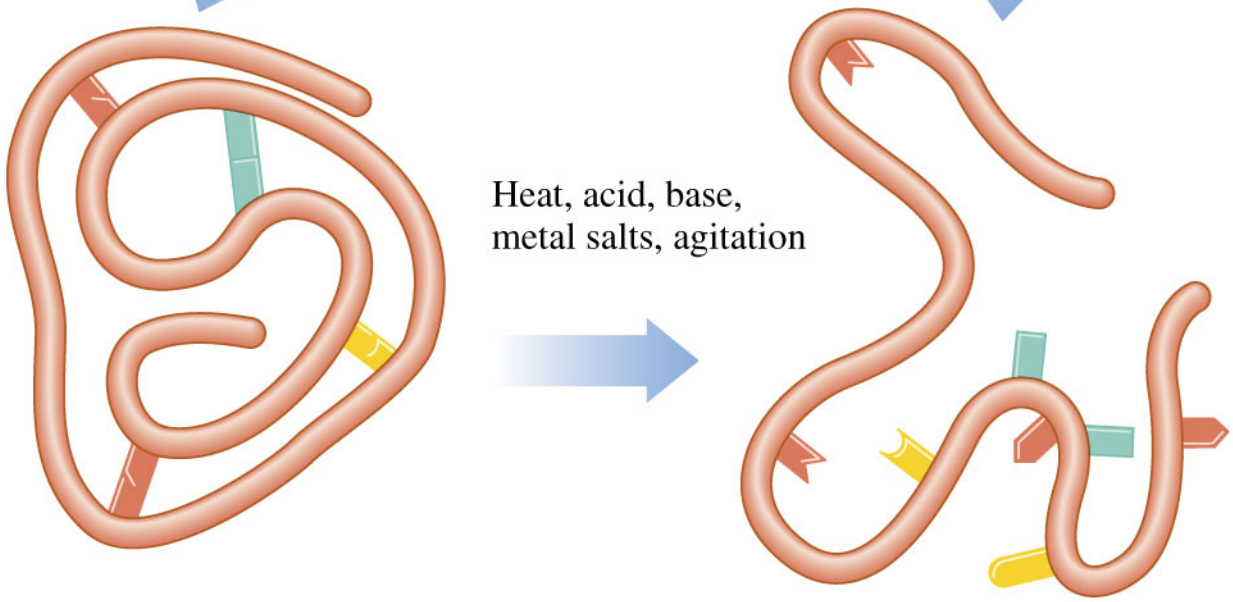





Oxygen
Nitrogen
Carbon
Hydrogen
Hydrogen bonds

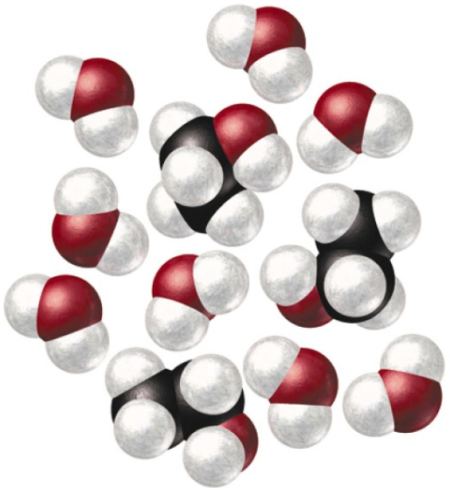

Hydrogen bond
between chains

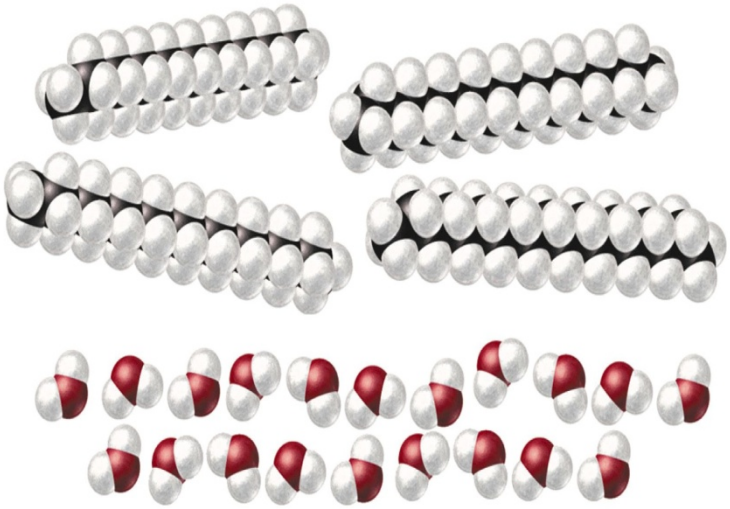




How do intermolecular forces affect molecular properties?

Solubility





Like dissolves Like

Viscosity

- resistance to flow

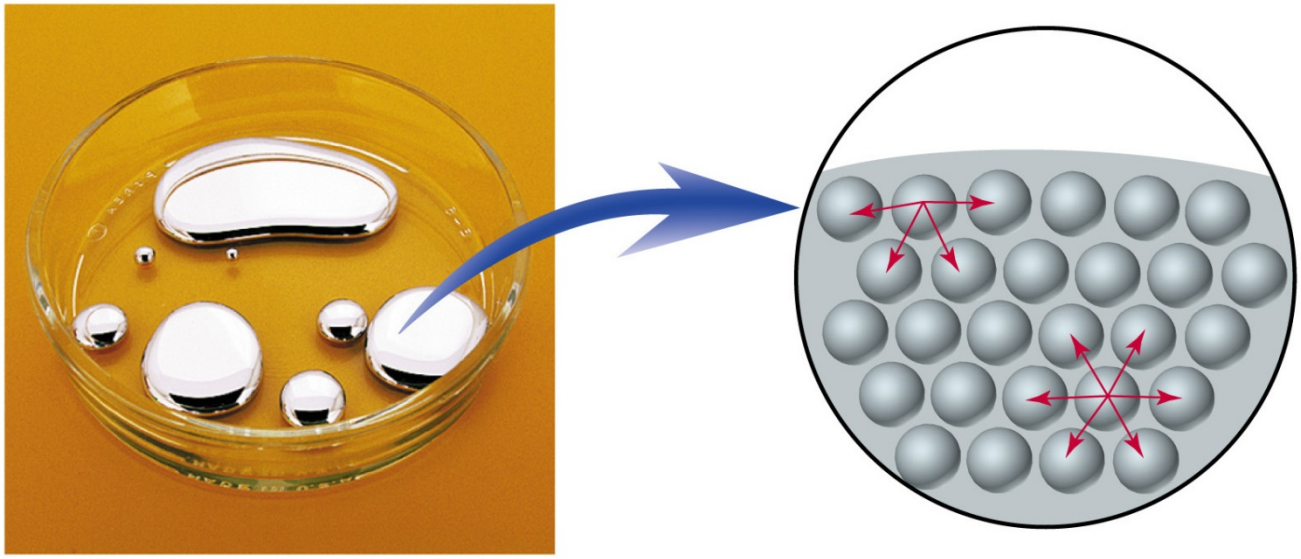
- If a liquid has strong intermolecular interactions then particles will not flow past each other easily and viscosity will be high.

Table 13.2 Viscosity of Selected Liquids

Liquid	Approximate Molar Mass	Intermolecular Attraction	Viscosity at 20°C*
water	18 g/mol	strong	1.00
propionic acid, C_2H_5COOH	74 g/mol	strong	1.10
butyl alcohol, C_4H_9OH	74 g/mol	strong	2.95
propyl chloride, C_3H_7Cl	79 g/mol	weak	0.35
ethyl ether, $C_2H_5OC_2H_5$	74 g/mol	weak	0.23

*Values are expressed in centipoise, a common unit of viscosity.

Surface Tension



- tendency to minimize surface area

- Adhesion – Forces that bind a substance to a surface
- Cohesion – Forces that bind a substance to itself

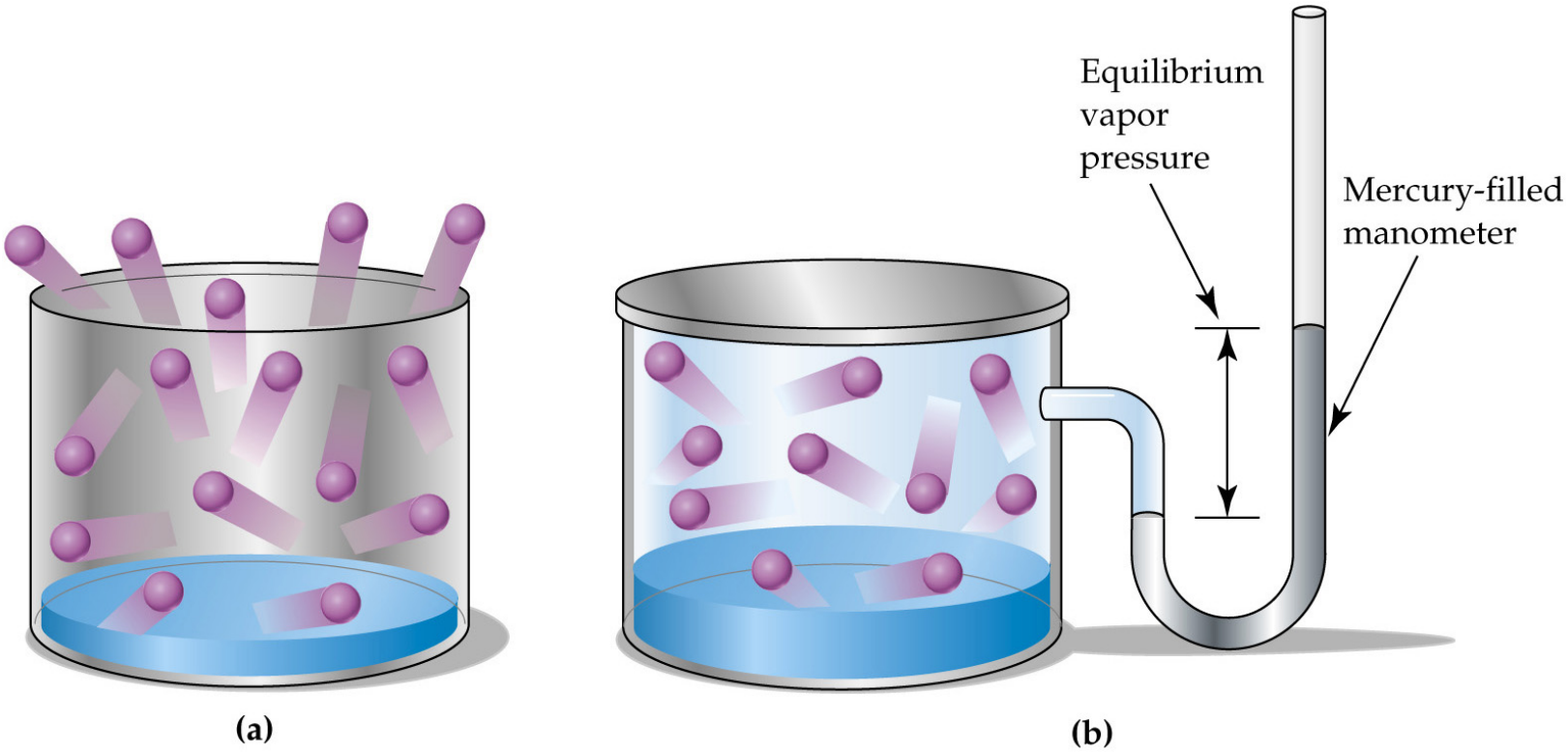
Table 13.3 Surface Tension of Selected Liquids

Liquid	Approximate Molar Mass	Intermolecular Attraction	Surface Tension at 20°C*
water	18 g/mol	strong	70
propionic acid, C_2H_5COOH	74 g/mol	strong	27
butyl alcohol, C_4H_9OH	74 g/mol	strong	25
propyl chloride, C_3H_7Cl	79 g/mol	weak	18
ethyl ether, $C_2H_5OC_2H_5$	74 g/mol	weak	17

*Values are expressed in dynes per square centimeter, a common unit of surface tension.

Vapor Pressure

The pressure exerted by a vapor in equilibrium with its liquid phase.



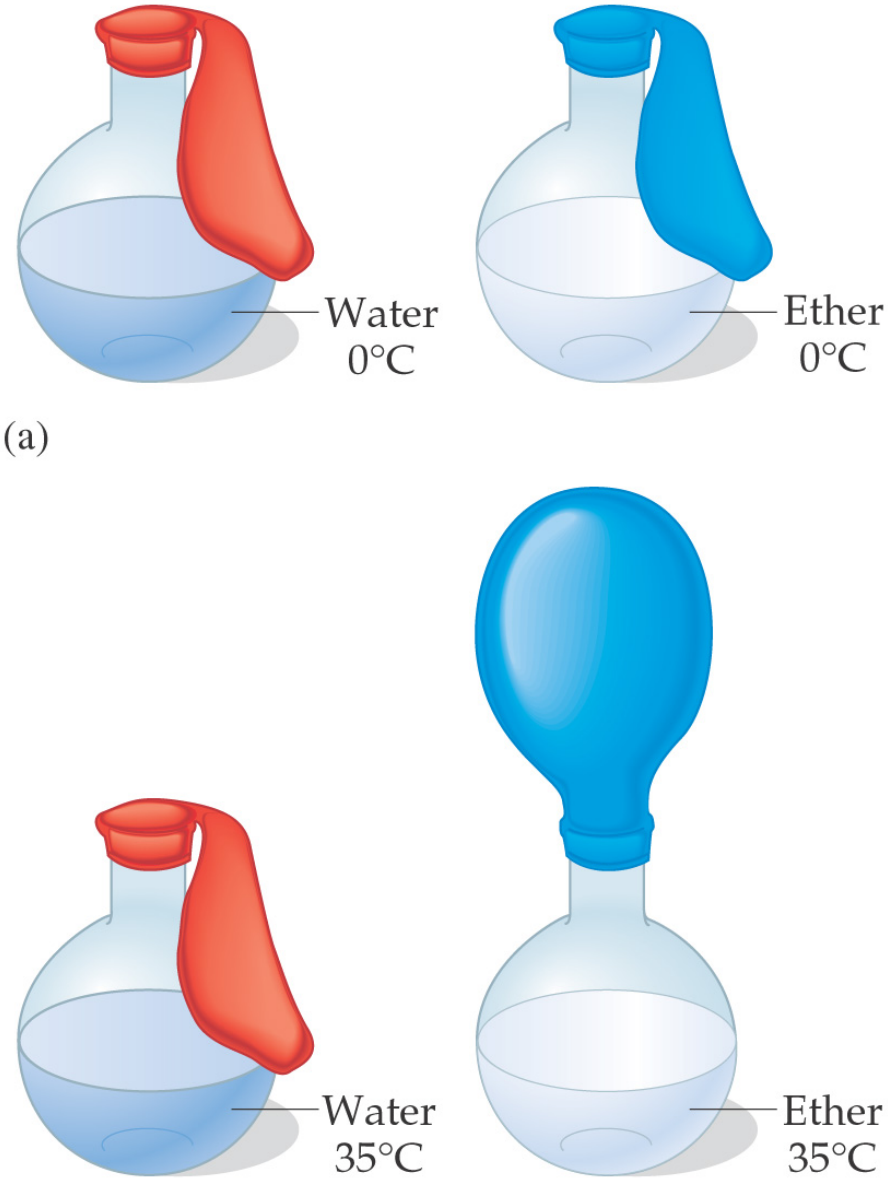
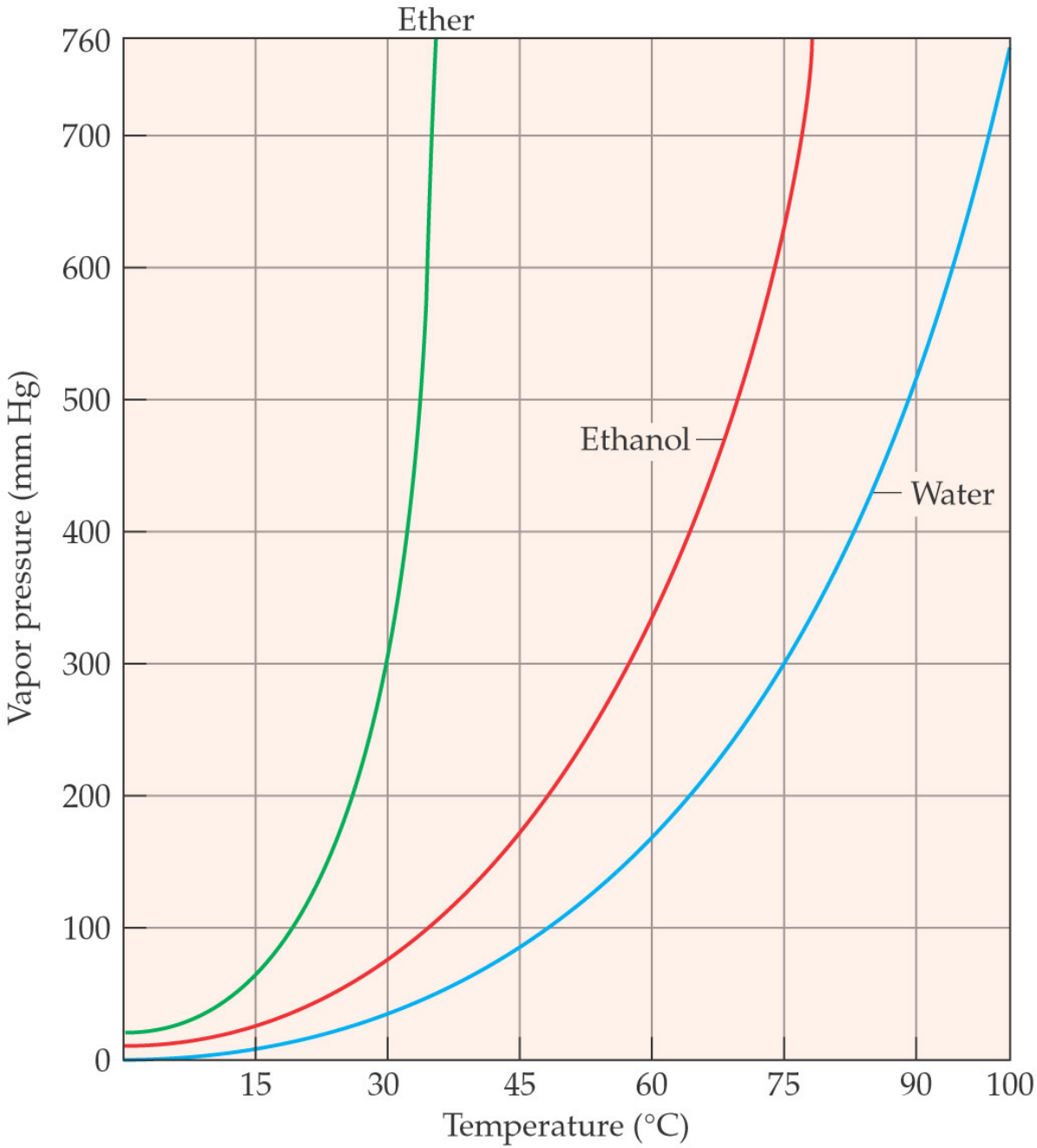
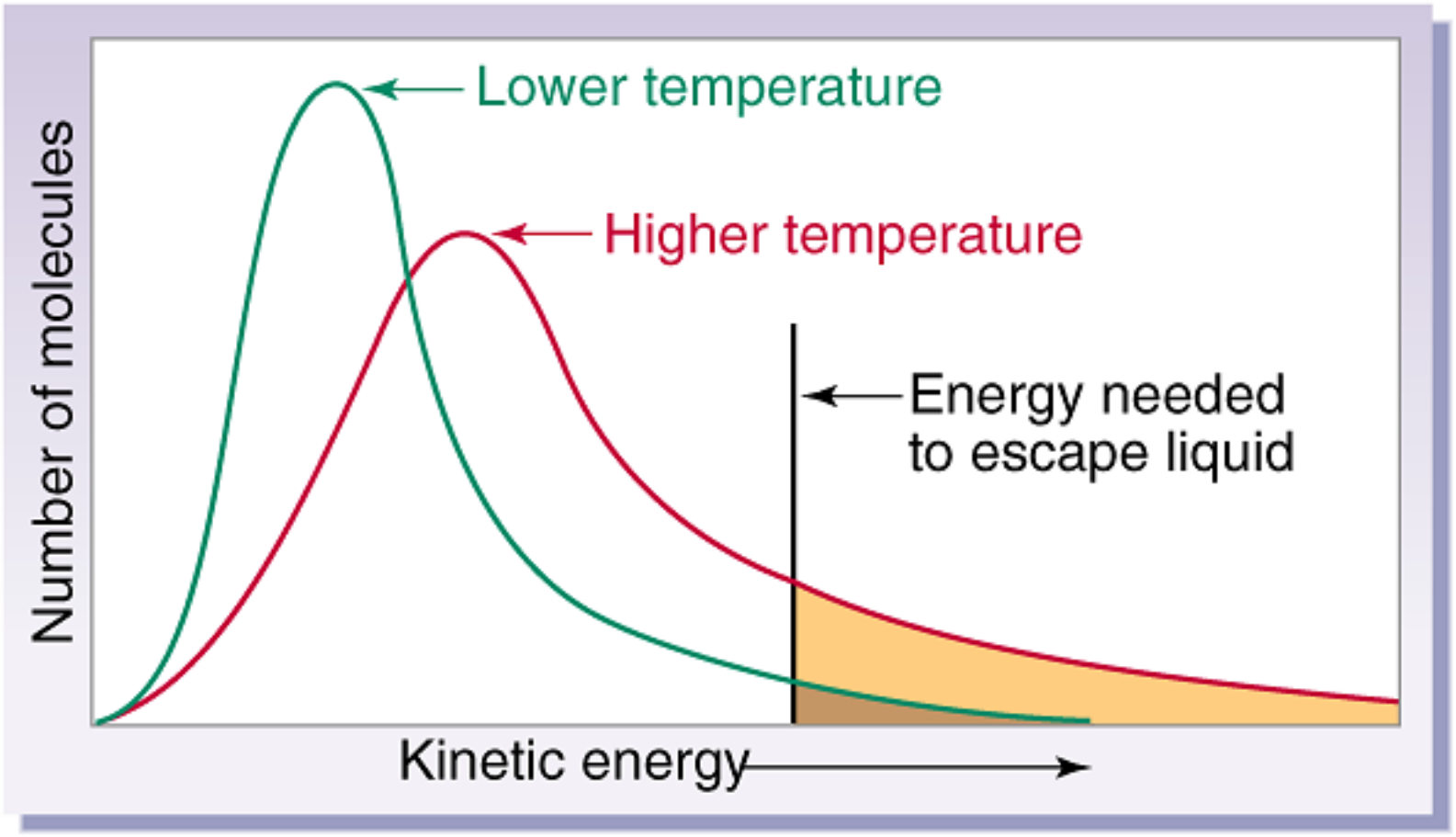


Table 13.1 Vapor Pressure of Selected Liquids

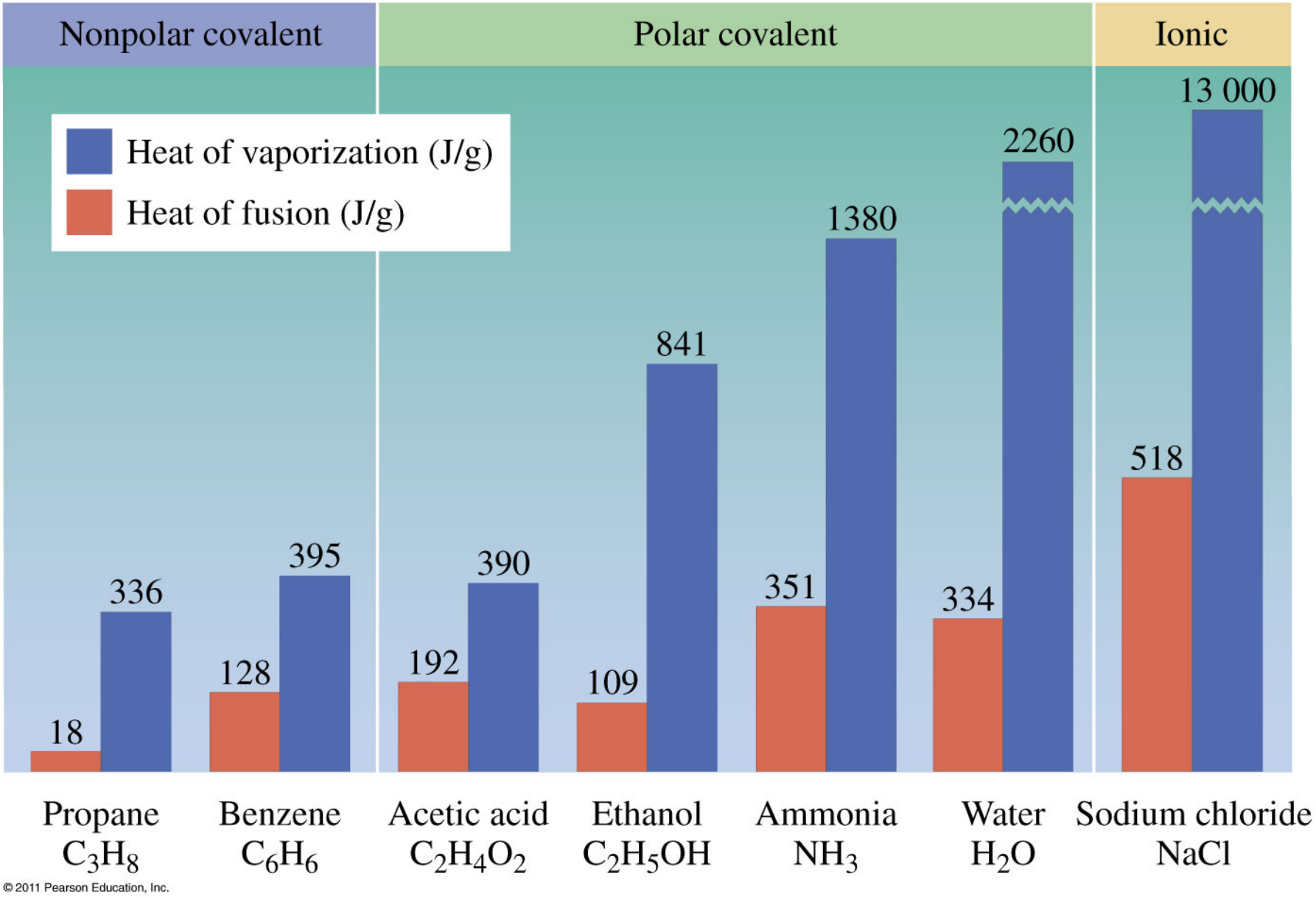
Liquid	Approximate Molar Mass	Intermolecular Attraction	Vapor Pressure at 20°C
water	18 g/mol	strong	18 mm Hg
propionic acid, C_2H_5COOH	74 g/mol	strong	5 mm Hg
butyl alcohol, C_4H_9OH	74 g/mol	strong	6 mm Hg
propyl chloride, C_3H_7Cl	79 g/mol	weak	300 mm Hg
ethyl ether, $C_2H_5OC_2H_5$	74 g/mol	weak	450 mm Hg




Lower temperature
Higher temperature
Energy needed
to escape liquid
Number of molecules
Kinetic energy

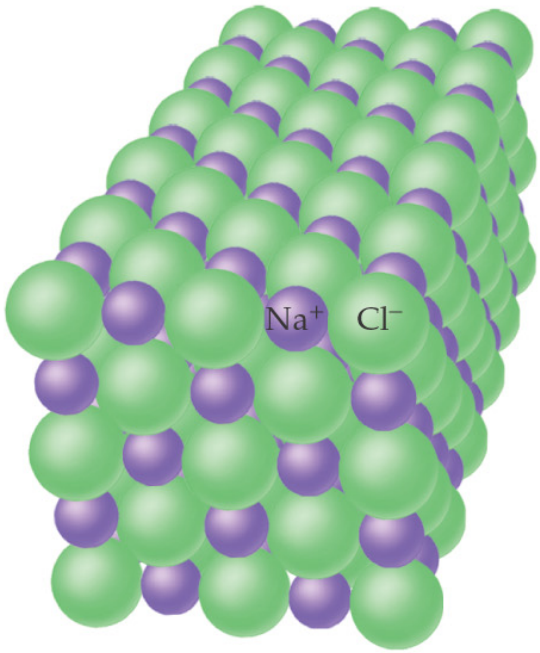
Boiling point

- the temperature at which the vapor pressure of a liquid is equal to the atmospheric pressure.

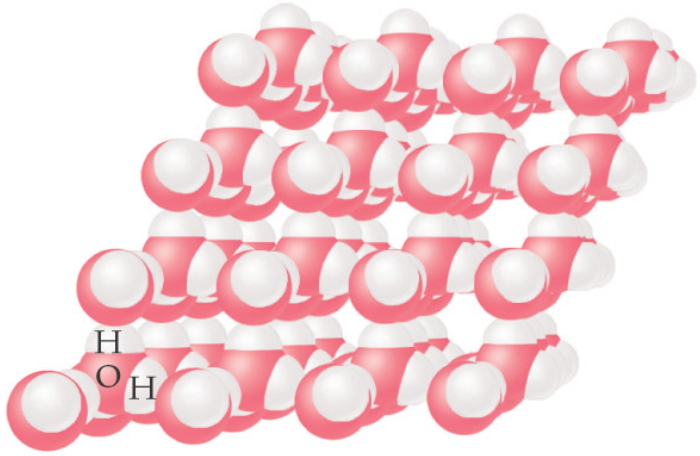


- Crystalline solid – atoms, ions, or molecules lie in an orderly array
  - typically have flat well defined surfaces called faces.

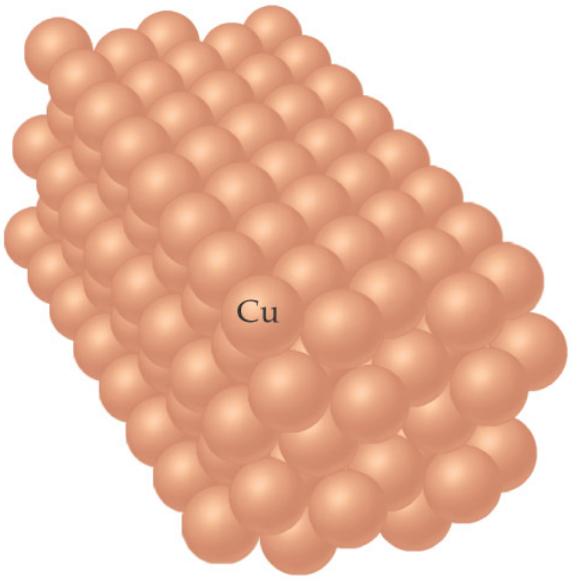
- Amorphous solid – atoms or molecules lie in random jumble.



(a)

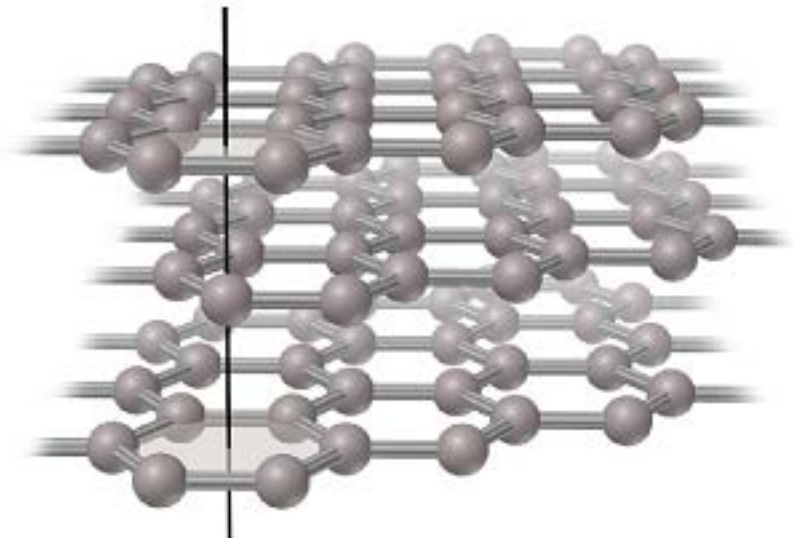


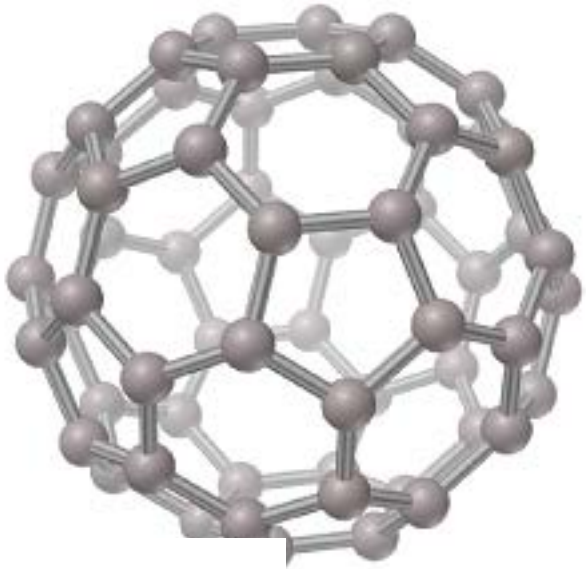
(b)



(c)

Carbon allotropes





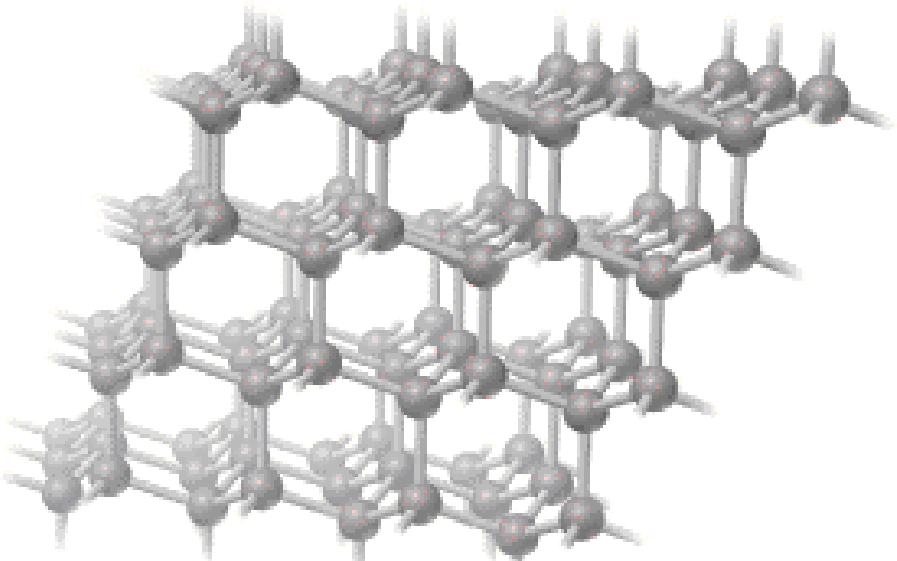
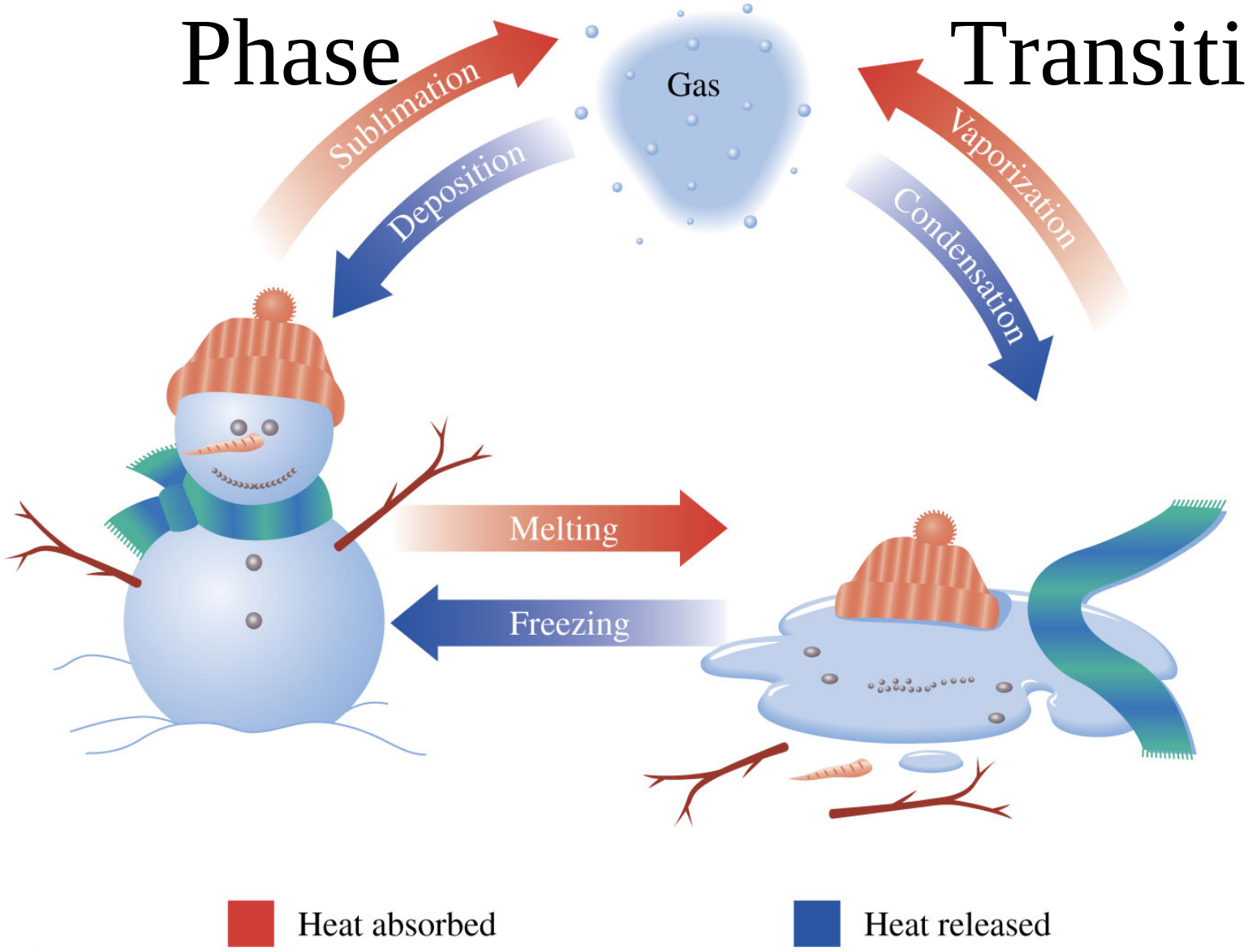


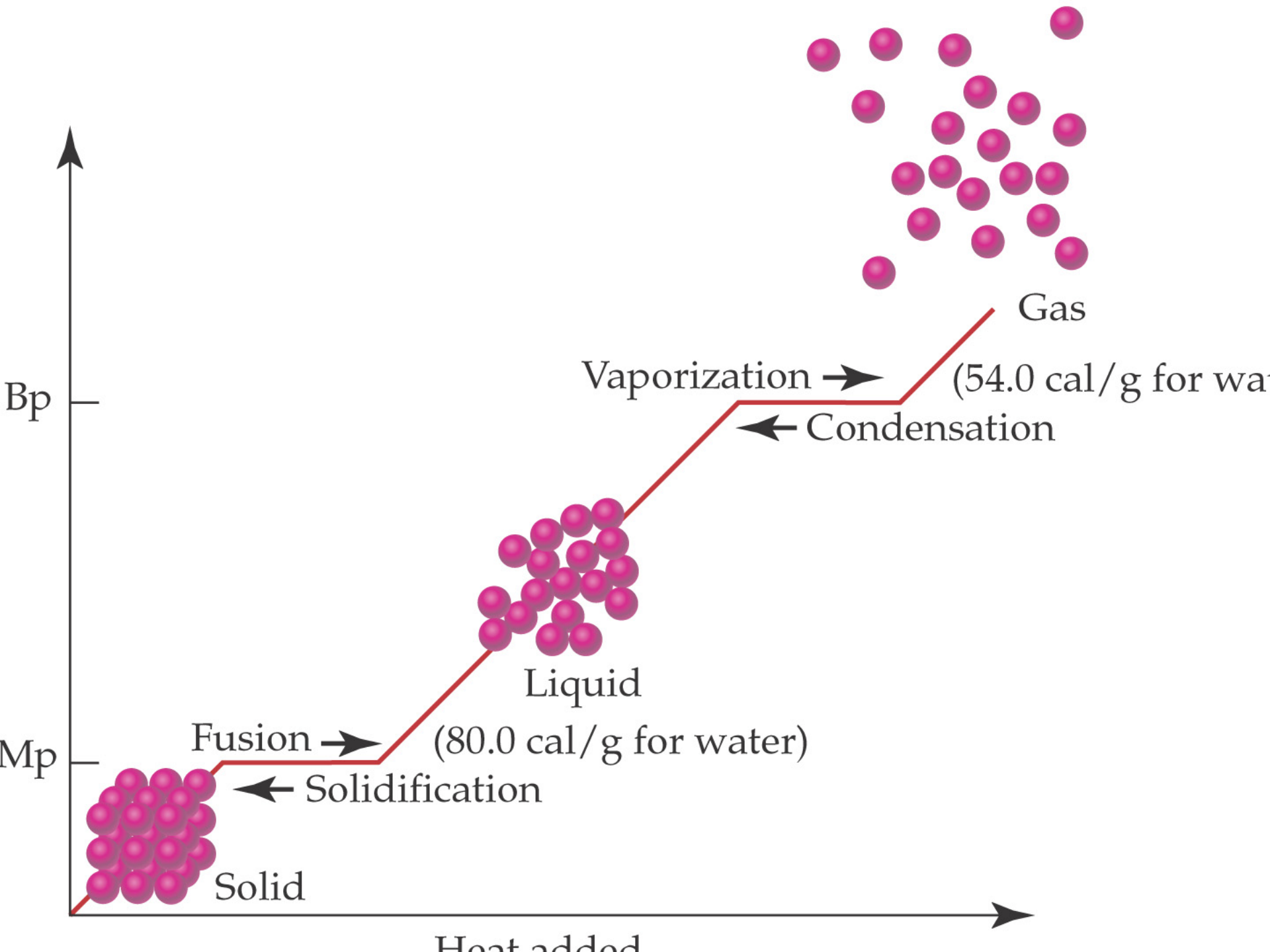
Table 13.4 General Properties of Crystalline Solids

Type of Solid	General Properties	Examples
ionic	high melting point, hard, brittle, at least slightly soluble in water, conductor of electricity when melted or in solution	NaCl, $CaCO_3$, $MgSO_4$
molecular	low melting point, generally insoluble in water, nonconductor of electricity	S_8, $C_{10}H_8$, $C_6H_{12}O_6$
metallic	low to high melting point, malleable, ductile, conductor of electricity, insoluble in most solvents	Fe, Ag, Au

Phase Transitions

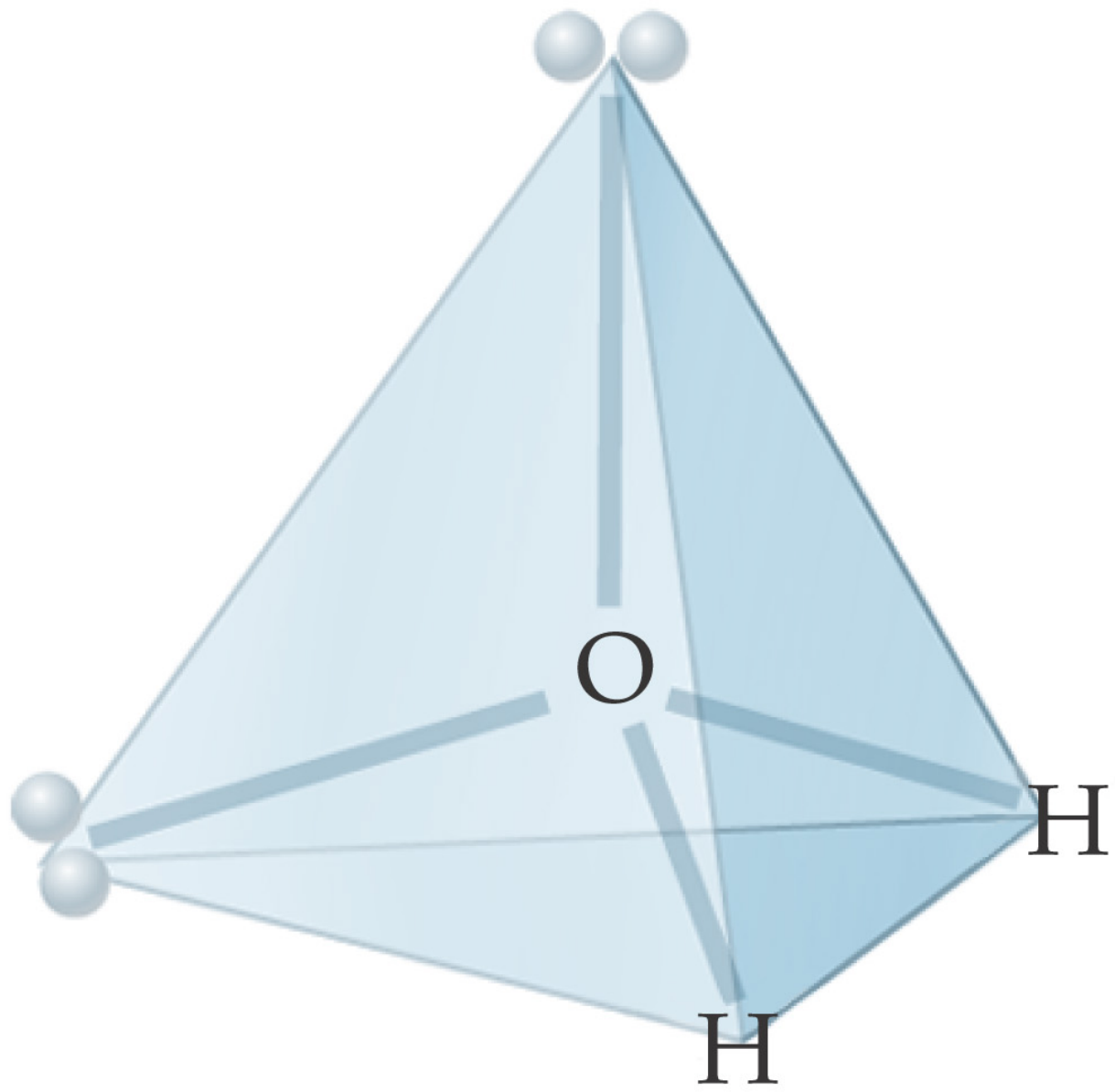


Vaporization	Liquid to gas transition	Condensation	Gas to liquid transition
Melting	Solid to liquid transition	Freezing	liquid to solid transition
Sublimation	Solid to gas transition	Deposition	Gas to solid transition

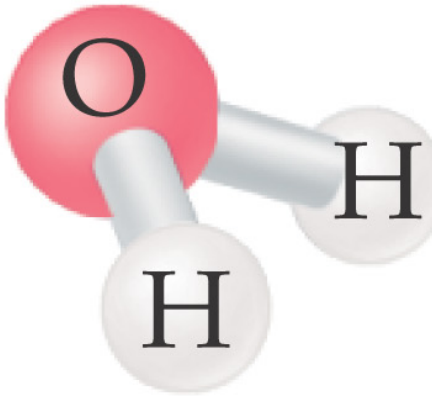

Gas
Vaporization
(54.0 cal/g for wa
Condensation
Bp
Liquid
Fusion
(80.0 cal/g for water)
Mp
Solidification
Solid
Heat added

Water

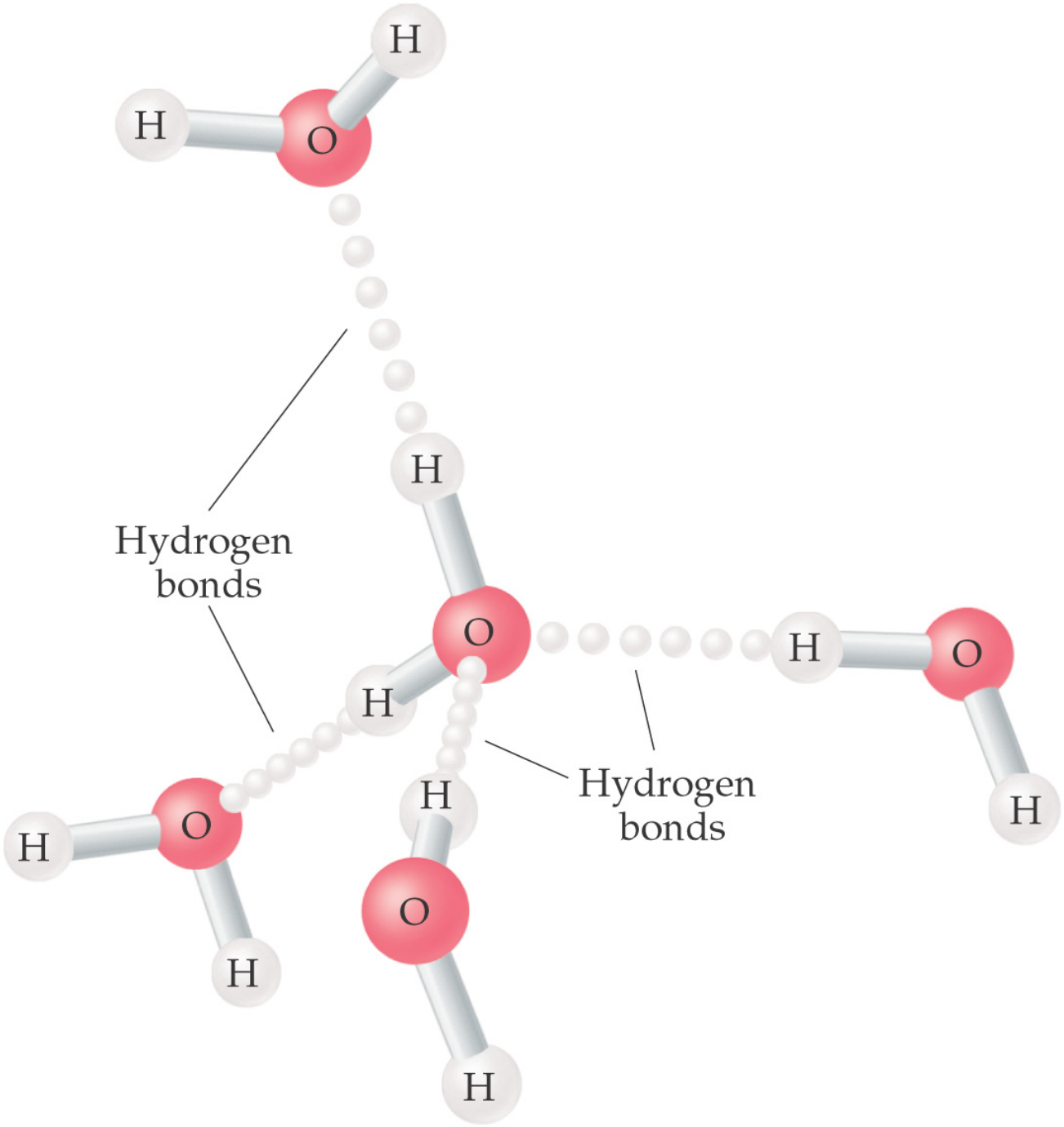
- colorless, odorless, tasteless, liquid at ordinary temperatures
- only inorganic compound occurring naturally as a liquid
- composes ~65% of mass of living organisms
- excellent solvent for many things
- abnormally high boiling and melting point
- ice is less dense than water (it floats)

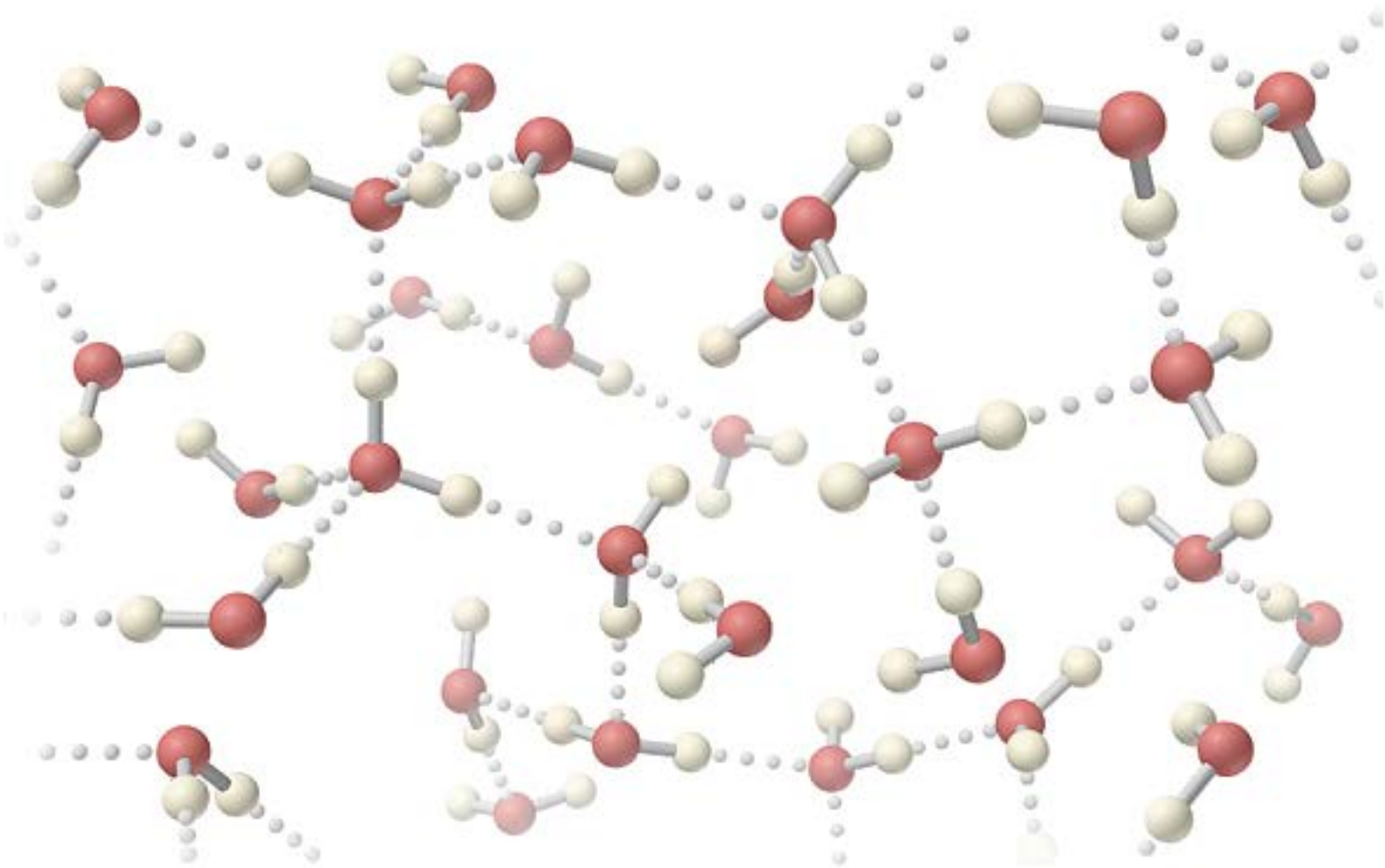


(a)

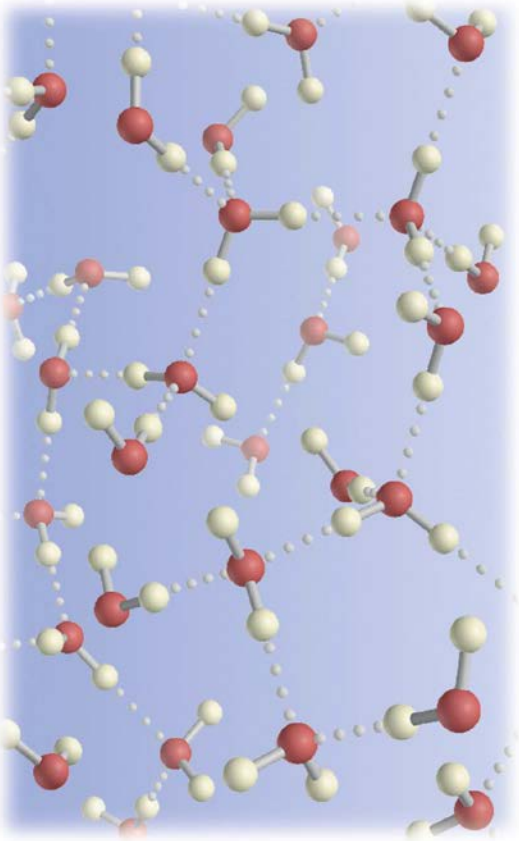


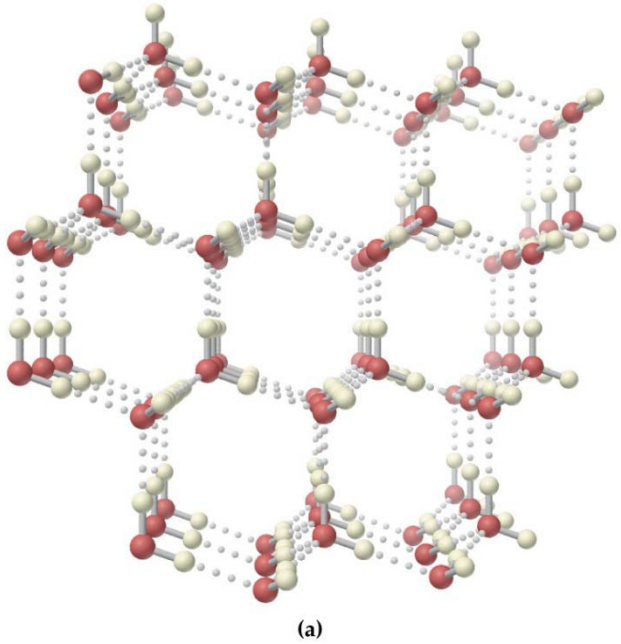
(b)



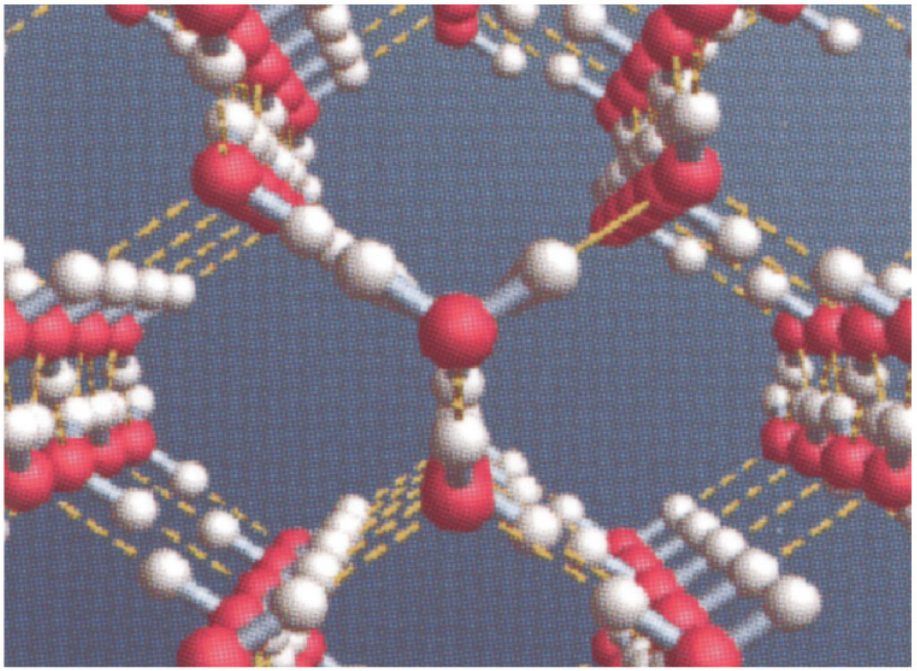


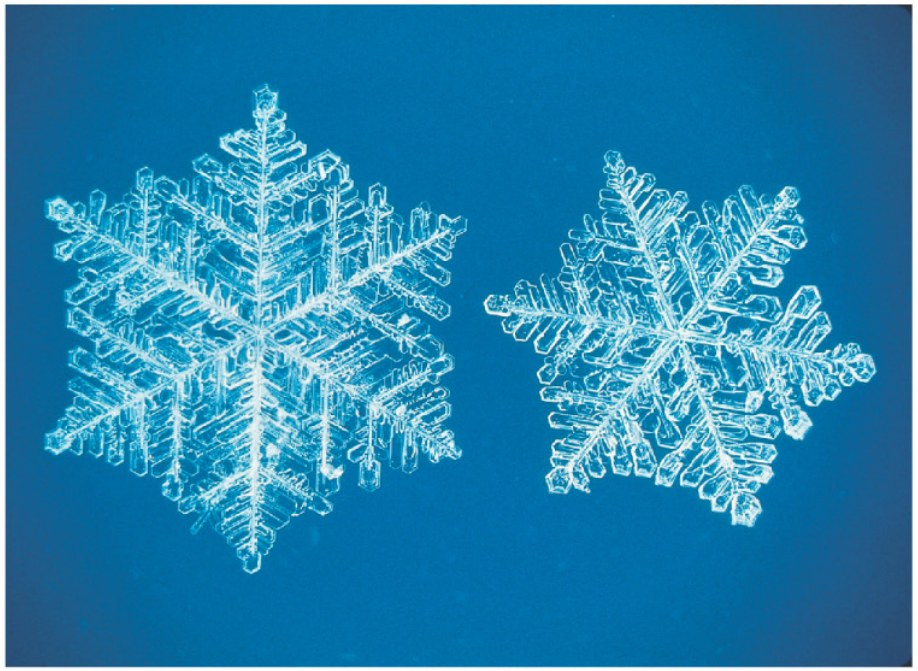
Liquid and solid water



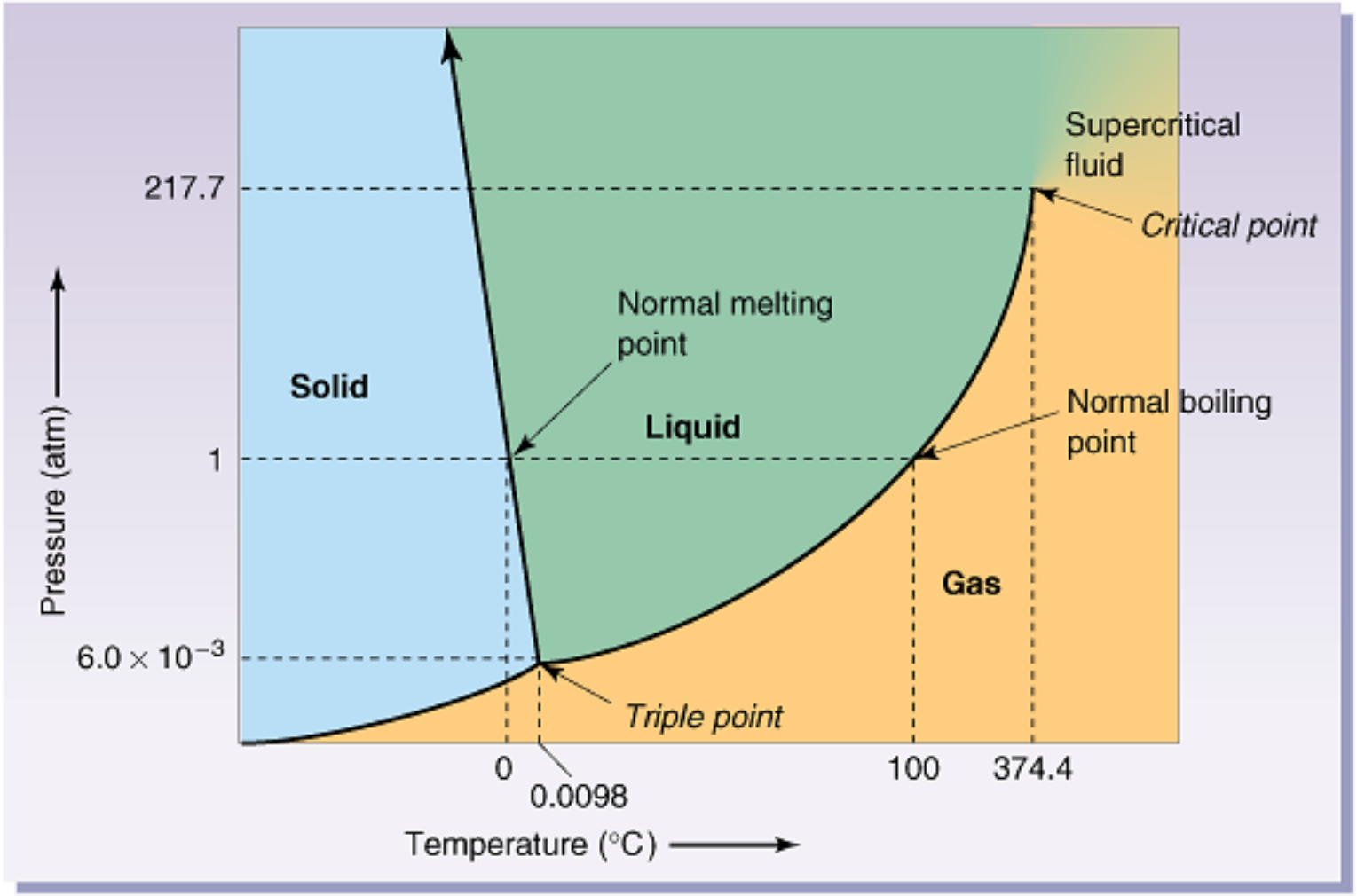


(a)





Phase diagram for H_2O



Water purification

- Hard water -- Contains Ca^{+2}, Mg^{+2}, Fe^{+3} and other minerals.
- Soft water -- Doesn't contain Ca^{+2}, Mg^{+2}, Fe^{+3} ions.
- Softened water -- metal cations in hard water are replaced by Na^{+}.
- Deionized water -- cations are replaced by H^{+} and anions are replaced by OH^{-}