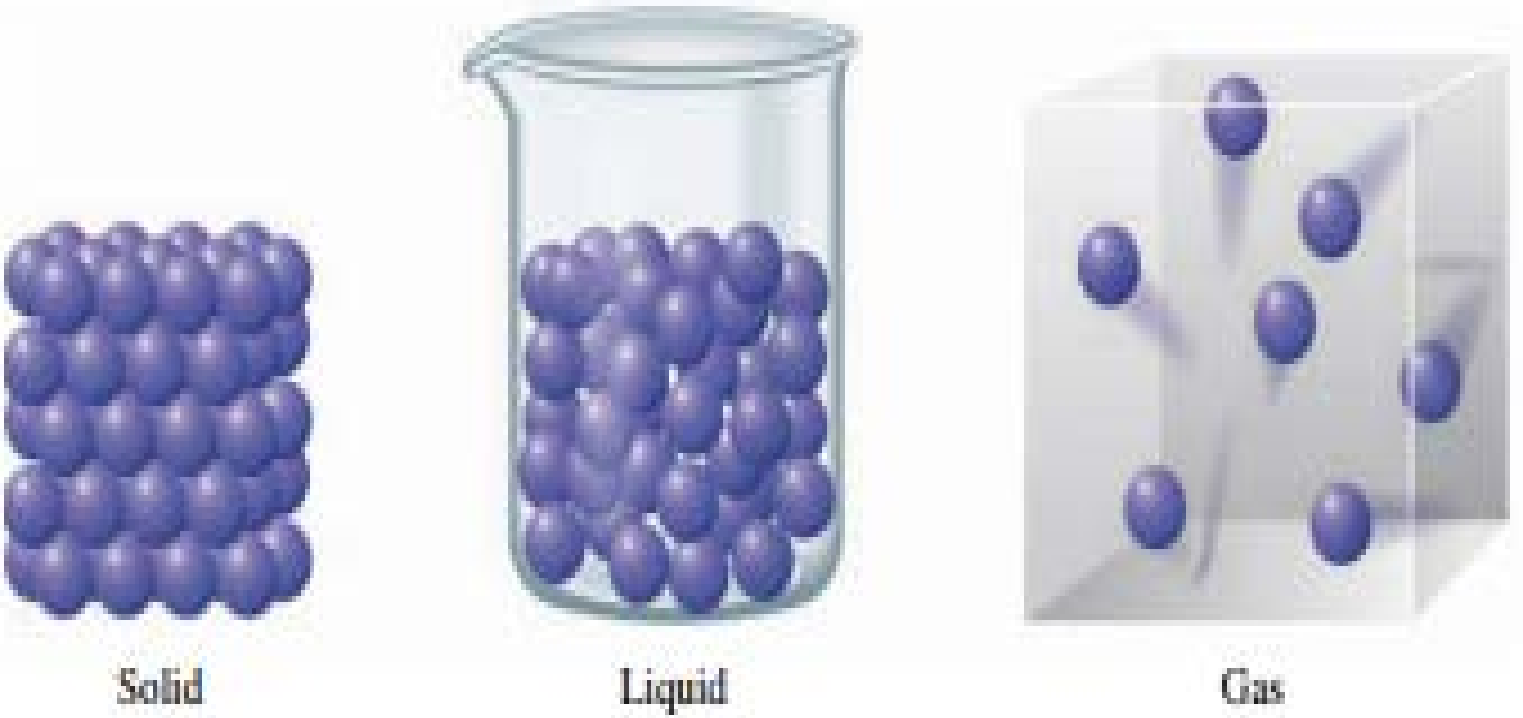
GENERALCHEMISTRY

STATES OF MATTER

Comparison of gases, liquids and solids



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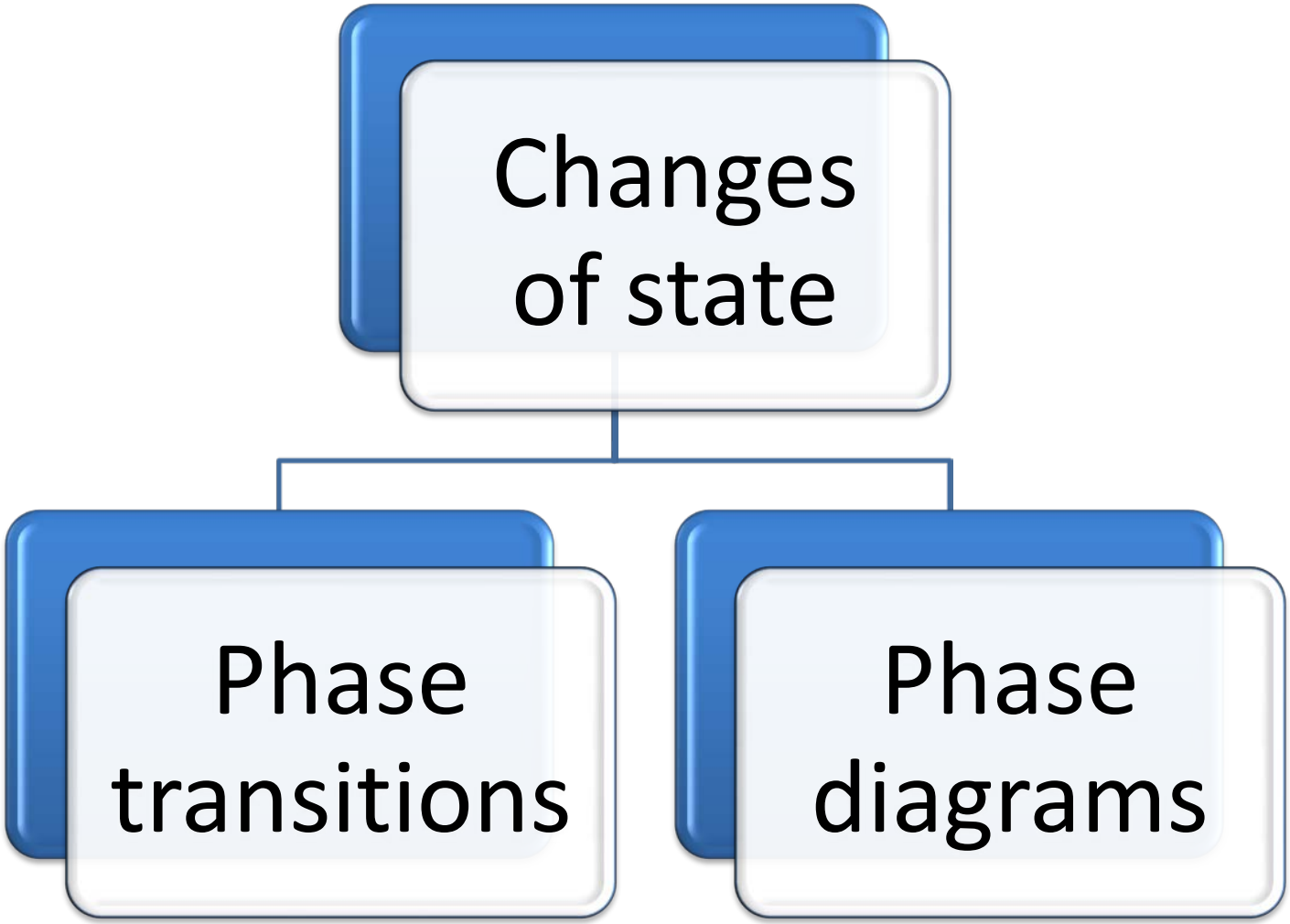
Changes of state
Phase transitions
Phase diagrams

Phase transitions

Melting is *the change of a solid to the liquid state* (melting is also referred to as *fusion*). For example,

$$\underset{\text{ice, snow}}{H_2O(s)} \longrightarrow \underset{\text{liquid water}}{H_2O(l)} \qquad \text{(melting, fusion)}$$

Freezing is *the change of a liquid to the solid state*. The freezing of liquid water to ice is a common example.

$$\underset{\text{liquid water}}{H_2O(l)} \longrightarrow \underset{\text{ice}}{H_2O(s)} \qquad \text{(freezing)}$$

The casting of a metal object involves the melting of the metal, then its freezing in a mold.

Vaporization is *the change of a solid or a liquid to the vapor.* For example,

$$\underset{\text{liquid water}}{H_2O(l)} \longrightarrow \underset{\text{water vapor}}{H_2O(g)} \qquad \text{(vaporization)}$$

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Sublimation of iodine

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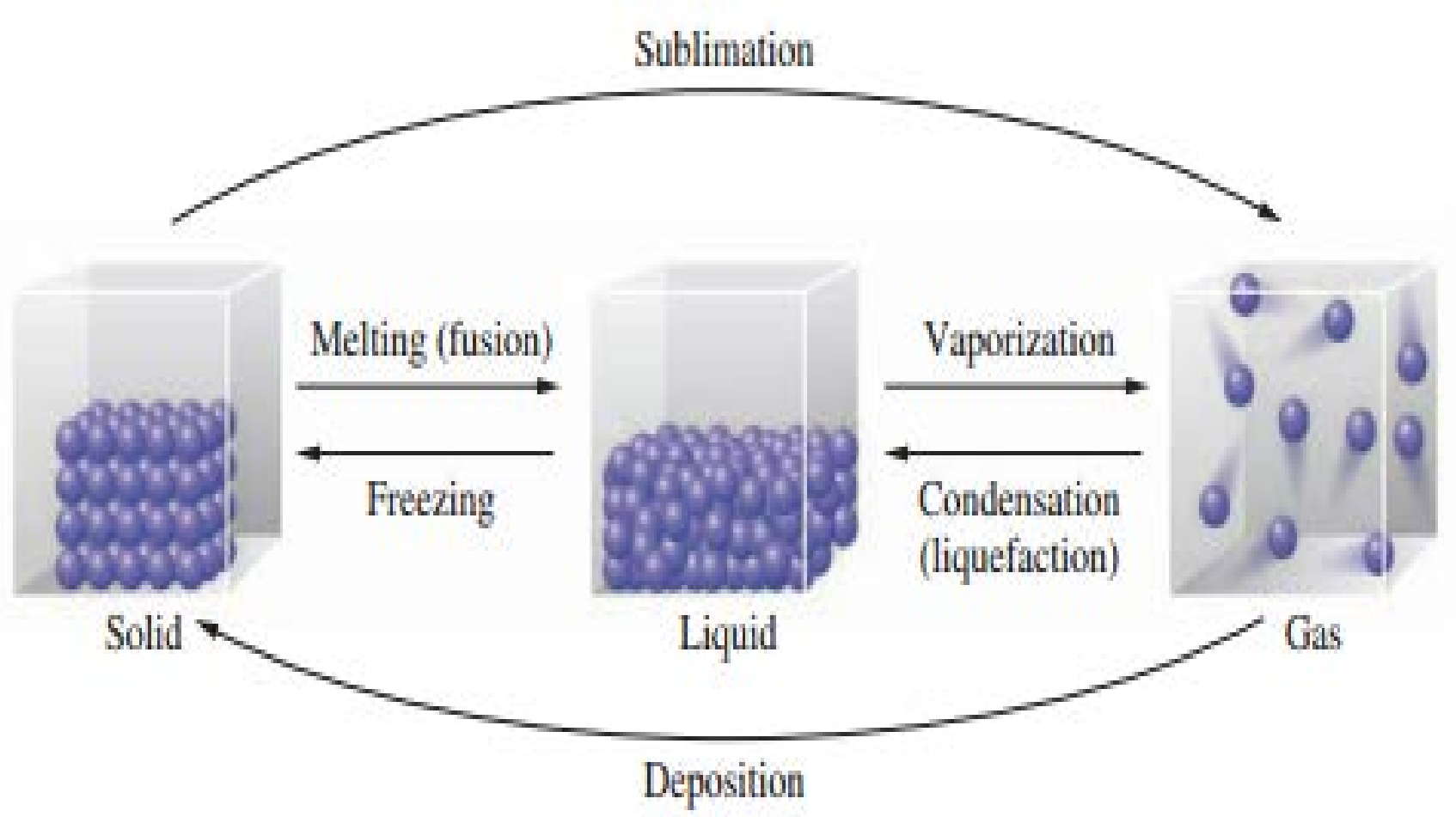
Sublimation and deposition



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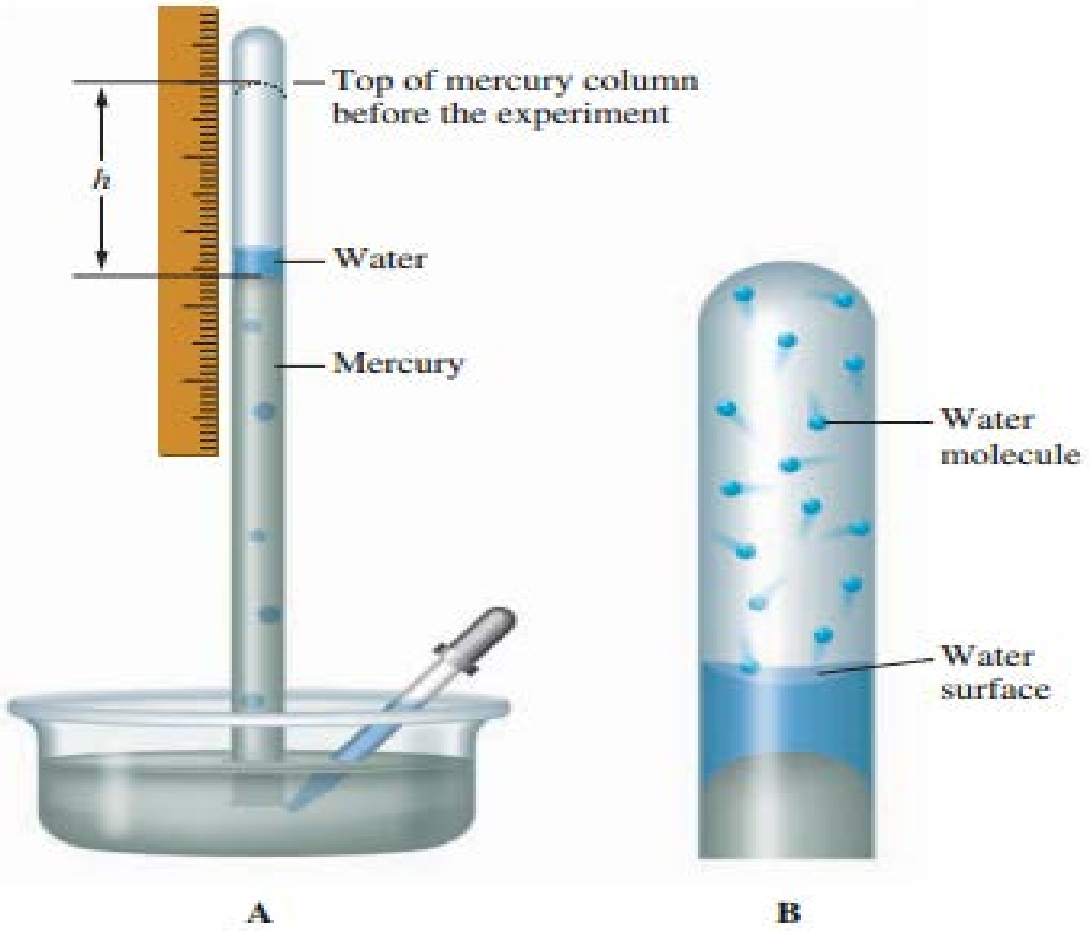
Vapor Pressure

Measurement of the vapor pressure of water



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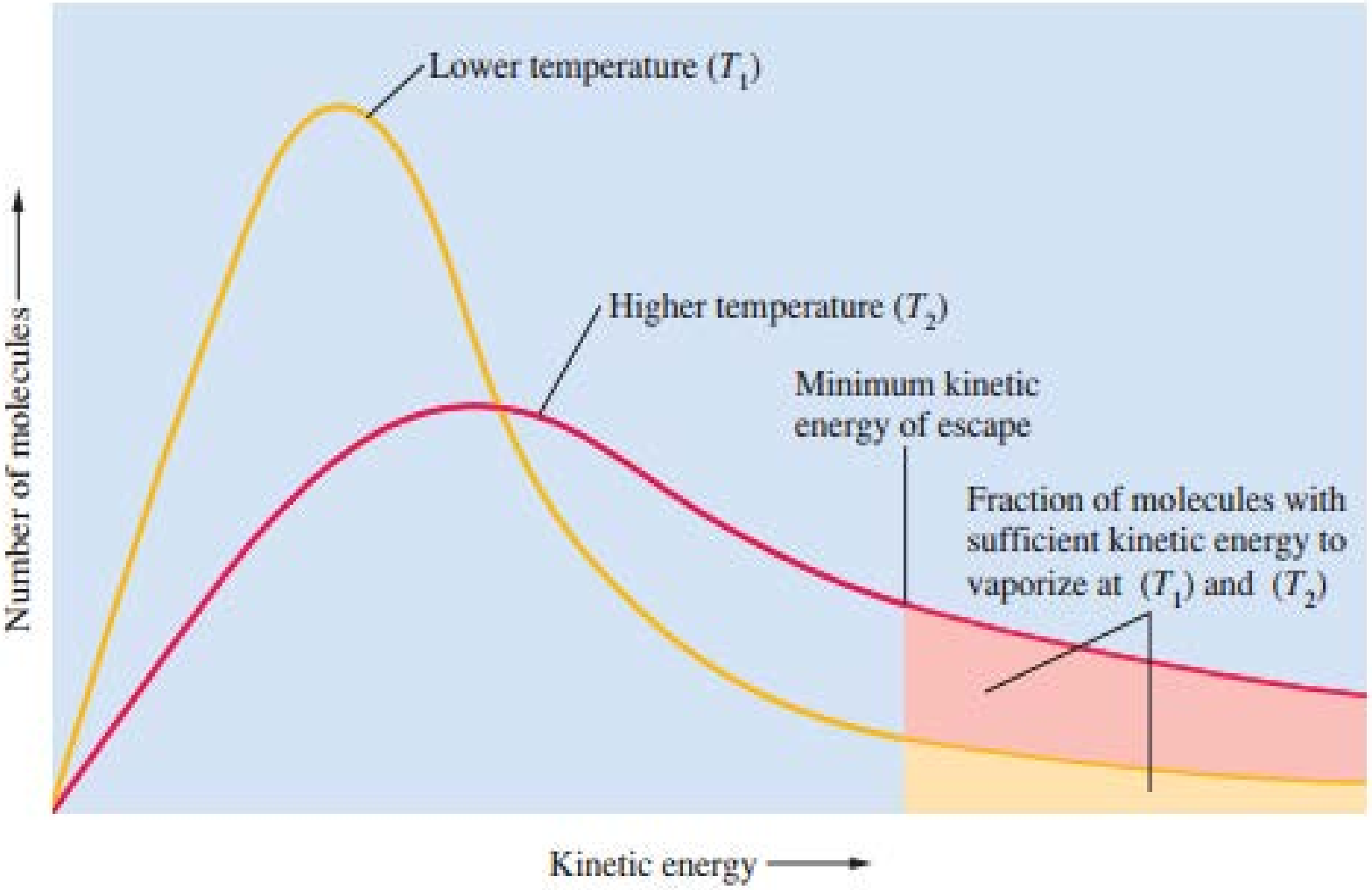
Distribution of kinetic energies of molecules in a liquid



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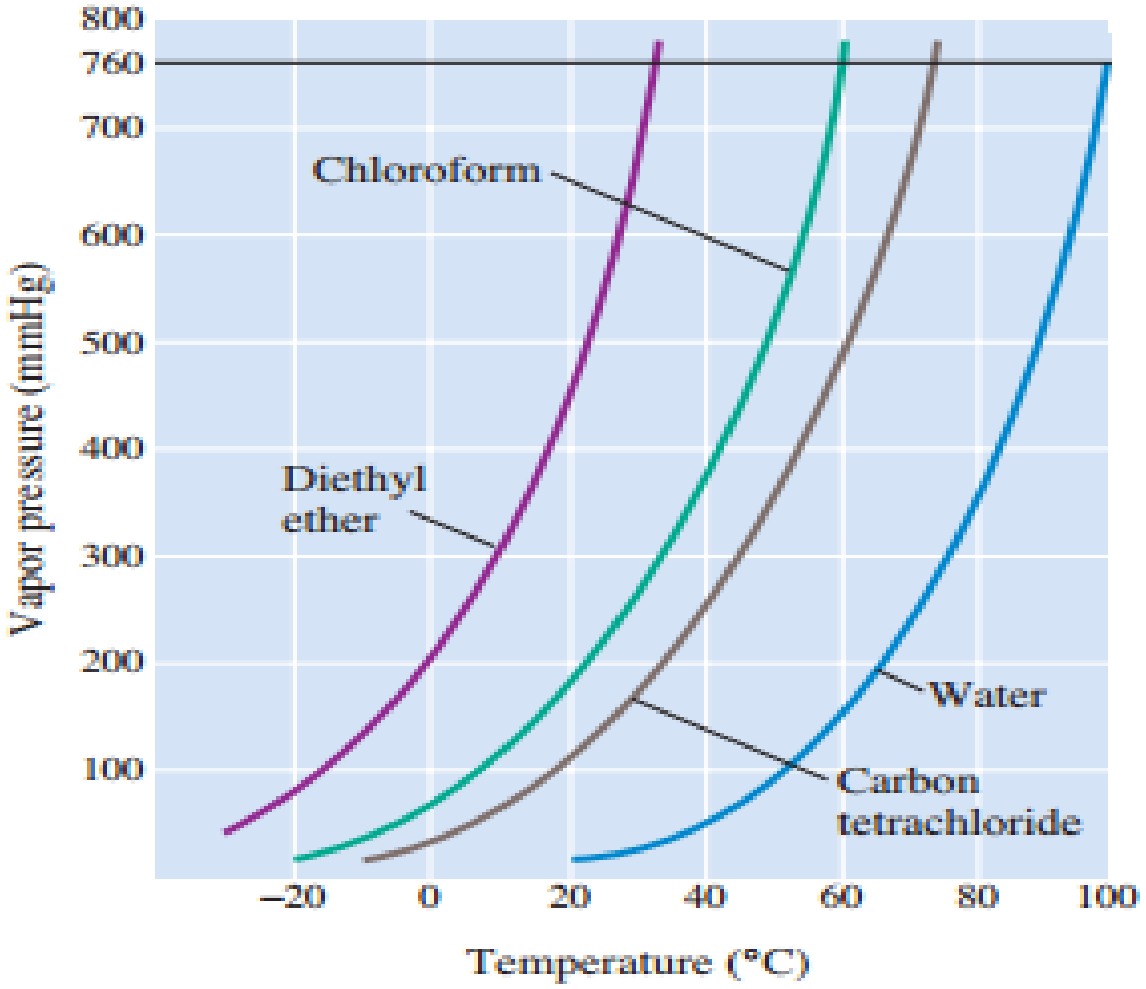
Variation of vapor pressure with temperature



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Melting points and Boiling points of several Substances

Name	Type of Solid*	Melting Point, °C	Boiling Point, °C
Neon, Ne	Molecular	−249	−246
Hydrogen sulfide, H_2S	Molecular	−86	−61
Chloroform, $CHCl_3$	Molecular	−64	62
Water, H_2O	Molecular	0	100
Acetic acid, $HC_2H_3O_2$	Molecular	17	118
Mercury, Hg	Metallic	−39	357
Sodium, Na	Metallic	98	883
Tungsten, W	Metallic	3410	5660
Cesium chloride, CsCl	Ionic	645	1290
Sodium chloride, NaCl	Ionic	801	1413
Magnesium oxide, MgO	Ionic	2800	3600
Quartz, SiO_2	Covalent network	1610	2230
Diamond, C	Covalent network	3550	4827

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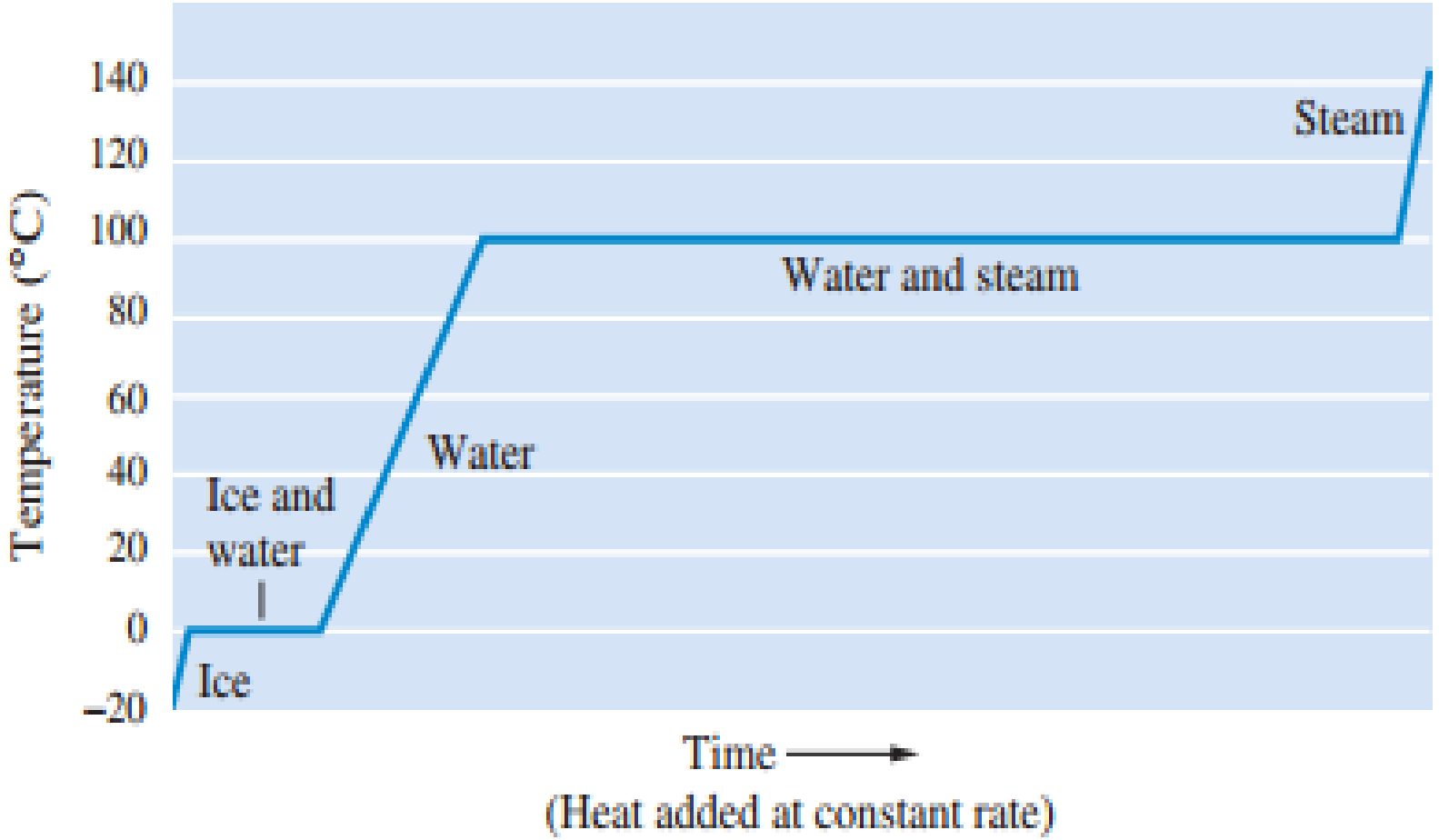
Heat of Phase Transition

Heating curve for water



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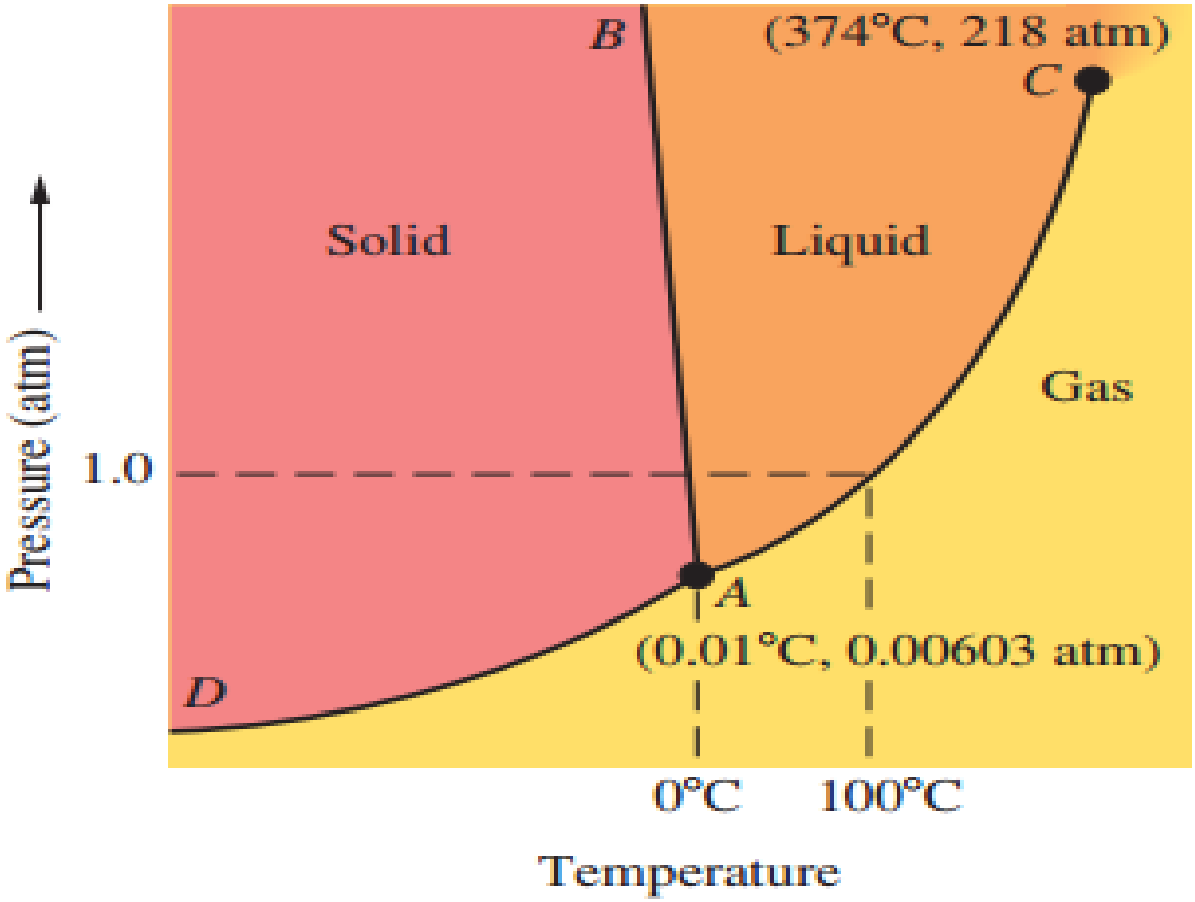
Phase Diagrams

Phase diagram for water (not to scale)



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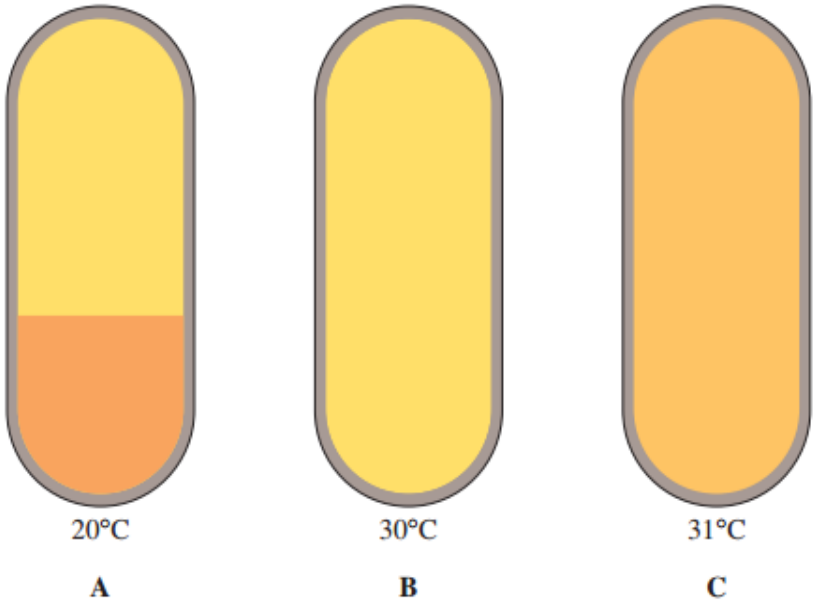
Critical Temperature and Pressure

Observing the critical phenomenon



(A) Carbon dioxide liquid in equilibrium with its vapor at 20°C. *(B)* The same two states in equilibrium at 30°C (just below the critical point); the densities of the liquid and vapor are becoming equal. *(C)* Carbon dioxide at 31°C (the critical temperature); the liquid and vapor now have the same densities—in fact, the distinction between liquid and vapor has disappeared, resulting in what is called a supercritical fluid.

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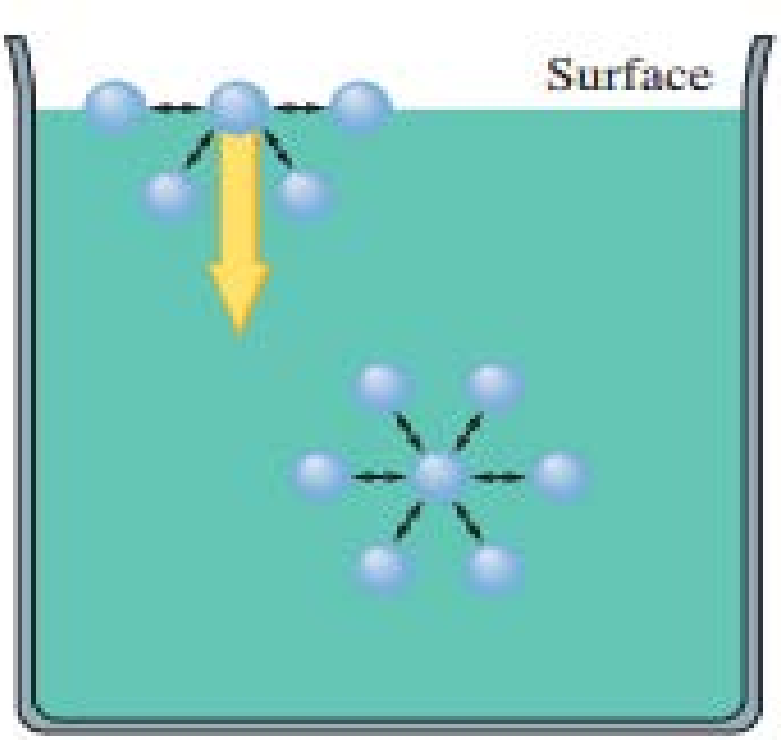
Properties of liquids; Surface tension and viscosity

Explaining surface tension

Note that a molecule at the surface experiences a net force toward the interior of the liquid, whereas a molecule in the interior experiences no net force.



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Properties of some liquids

Substance	Molecular Weight (amu)	Vapor Pressure (mmHg)	Surface Tension (J/m^2)	Viscosity (kg/m·s)
Water, H_2O	18	1.8×10^{1}	7.3×10^{-2}	1.0×10^{-3}
Carbon dioxide, CO_2	44	4.3×10^{4}	1.2×10^{-3}	7.1×10^{-5}
Pentane, C_5H_{12}	72	4.4×10^{2}	1.6×10^{-2}	2.4×10^{-4}
Glycerol, $C_3H_8O_3$	92	1.6×10^{-4}	6.3×10^{-2}	1.5×10^{0}
Chloroform, $CHCl_3$	119	1.7×10^{2}	2.7×10^{-2}	5.8×10^{-4}
Carbon tetrachloride, CCl_4	154	8.7×10^{1}	2.7×10^{-2}	9.7×10^{-4}
Bromoform, $CHBr_3$	253	3.9×10^{0}	4.2×10^{-2}	2.0×10^{-3}

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Comparison of the viscosities of two liquids

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Intermolecular forces; Explaining liquid properties

Types of Intermolecular and Chemical Bonding Interactions

Type of Interaction	Approximate Energy (kJ/mol)
Intermolecular	
Van der Waals (dipole–dipole, London)	0.1 to 10
Hydrogen bonding	10 to 40
Chemical bonding	
Ionic	100 to 1000
Covalent	100 to 1000

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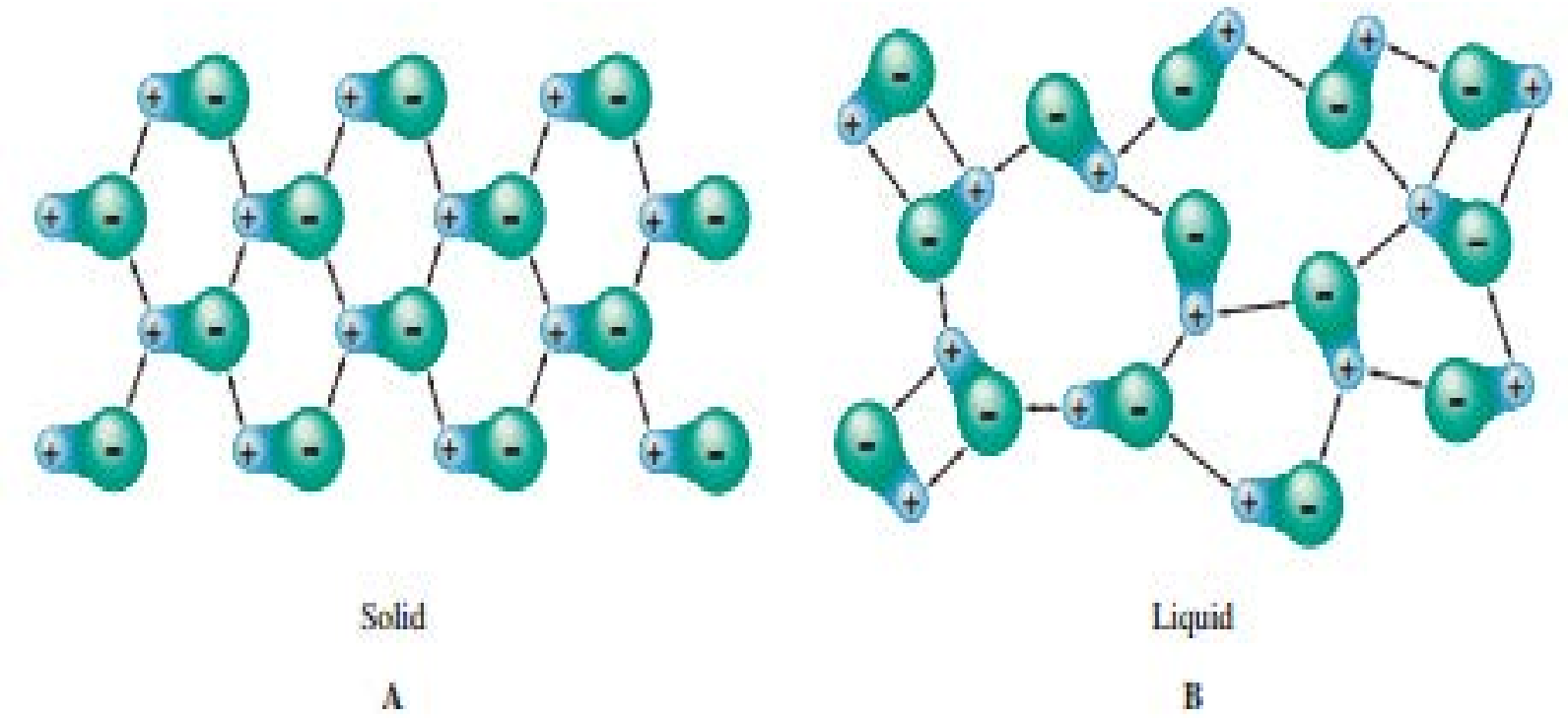
Dipole–Dipole Forces



(A) Molecules tend to line up in the solid so that positive ends point to negative ends.
(B) The normal random motion of molecules in a liquid only partially disrupts this alignment of polar molecules.

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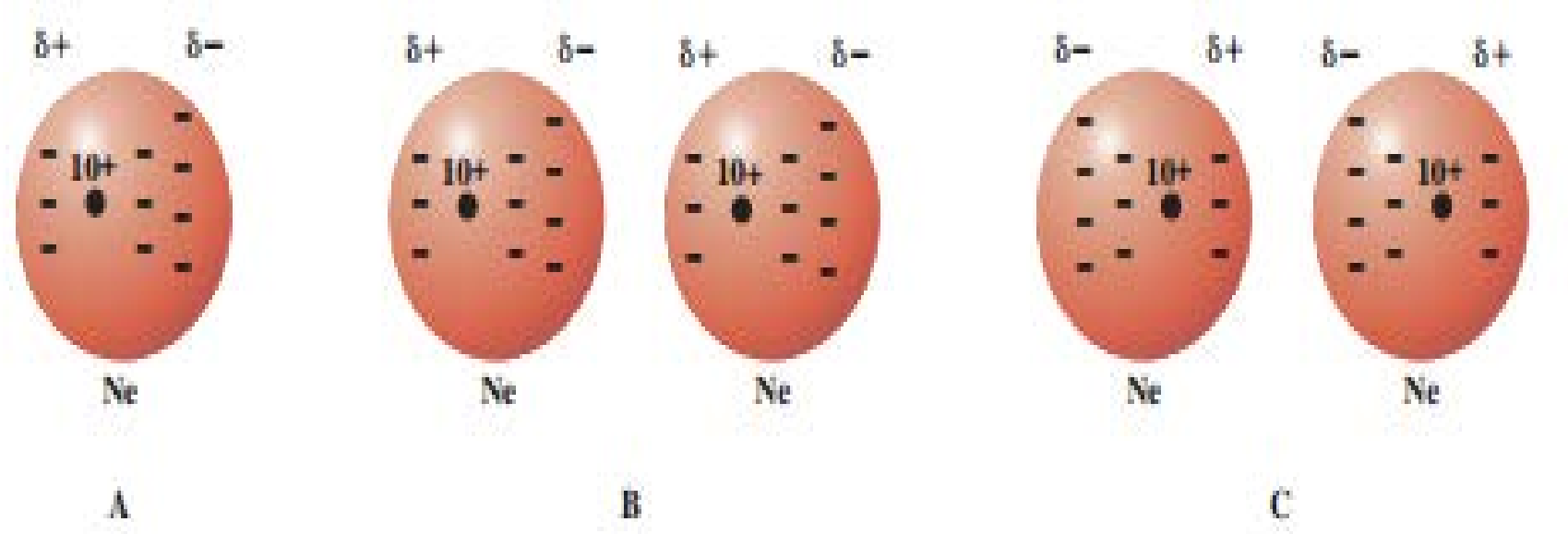
London (Dispersion) Forces



(A) At some instant, there are more electrons on one side of a neon atom than on the other.
(B) If this atom is near another neon atom, the electrons on that atom are repelled. The result is two instantaneous dipoles, which give an attractive force.
(C) Later the electrons on both atoms have moved, but they tend to move together, which gives an attractive force between the atoms.

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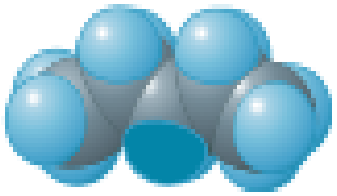

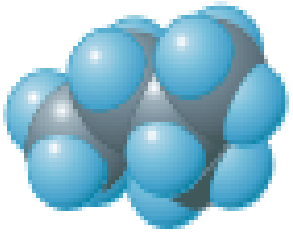

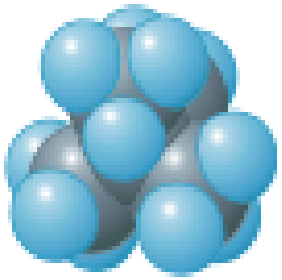

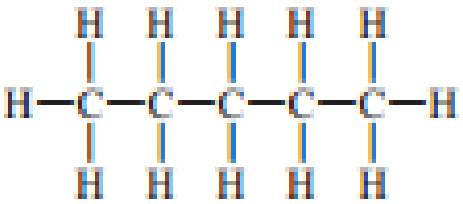

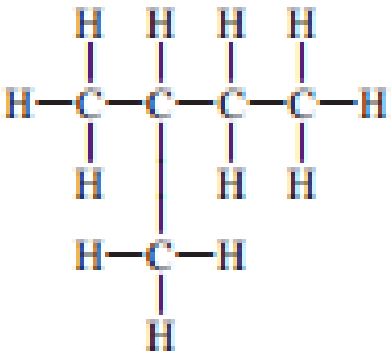

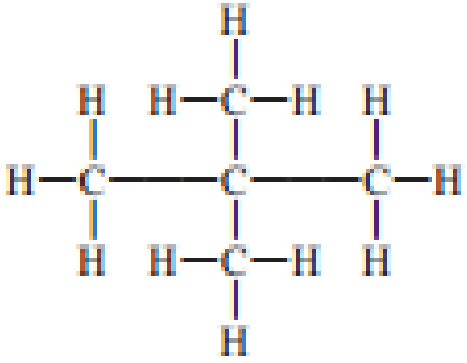

Name:	**pentane**	**2-methylbutane**	**2,2-dimethylpropane**
Boiling Point:	**36°C**	**28°C**	**9.5°C**
ΔH_{vap}:	**25.8 kJ/mol**	**24.7 kJ/mol**	**22.8 kJ/mol**

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Explanation of Intermolecular Forces and the Properties of Liquids

Substance	Molecular Weight (amu)	Vapor Pressure (mmHg)	Surface Tension (J/m^2)	Viscosity (kg/m·s)
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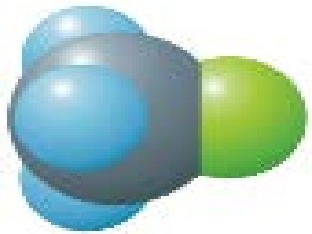
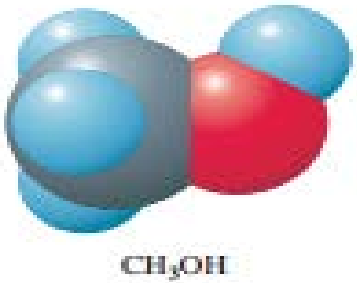
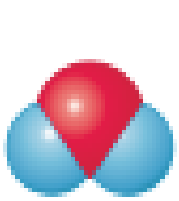
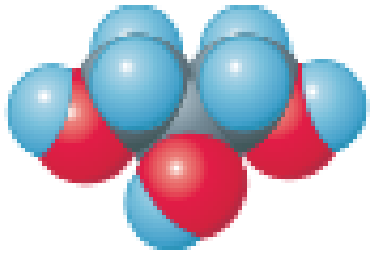
Hydrogen Bonding

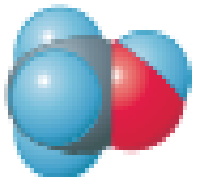


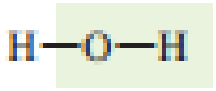


Fluormethane and methanol

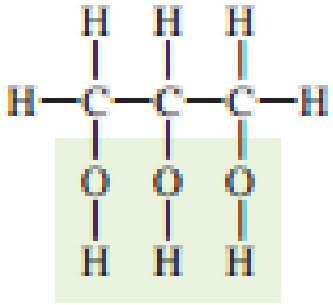




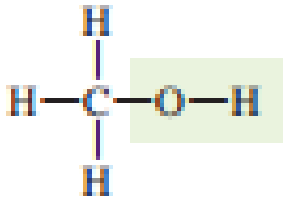




Water



Glycerol



Methanol

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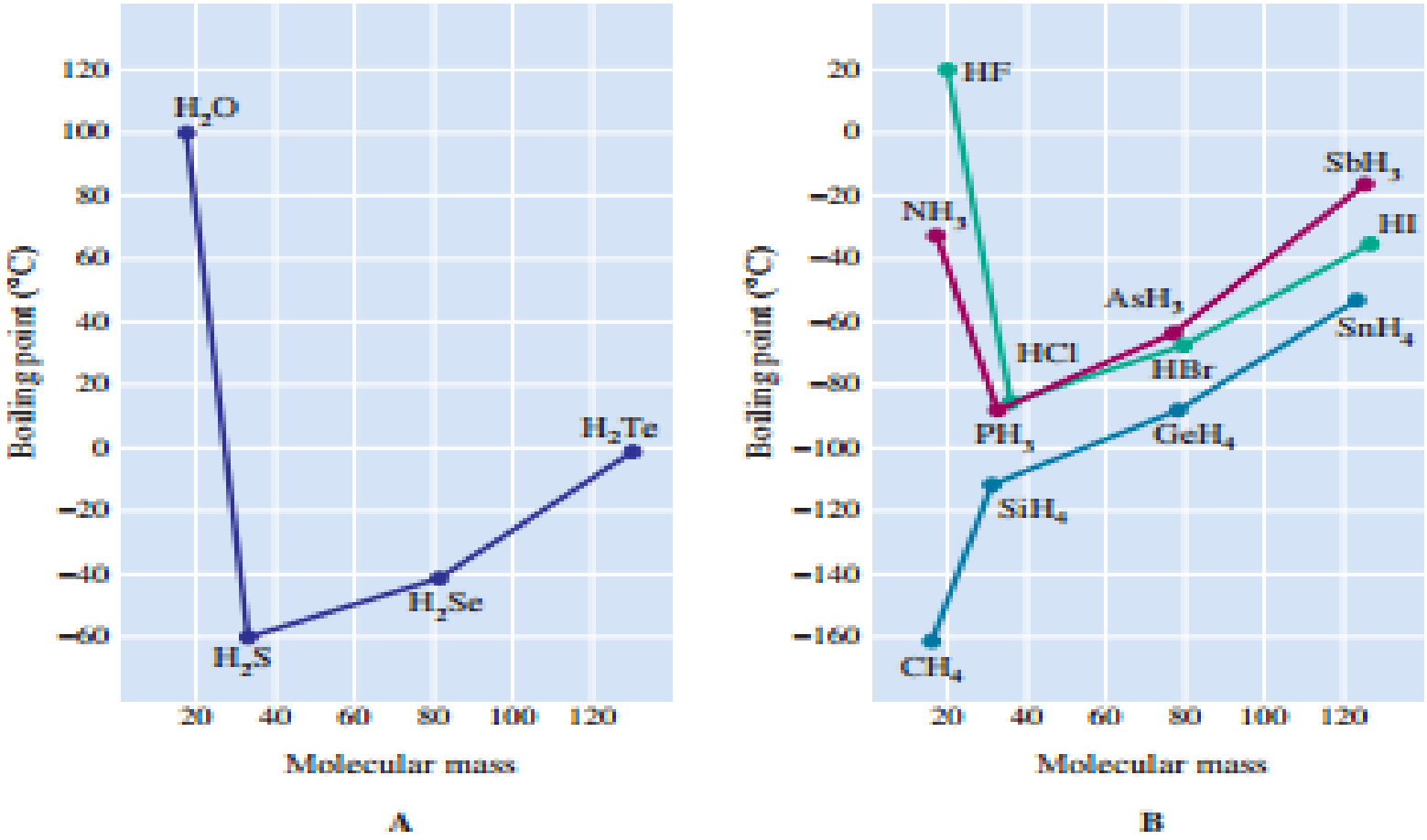
Boiling point versus molecular mass for hydrides



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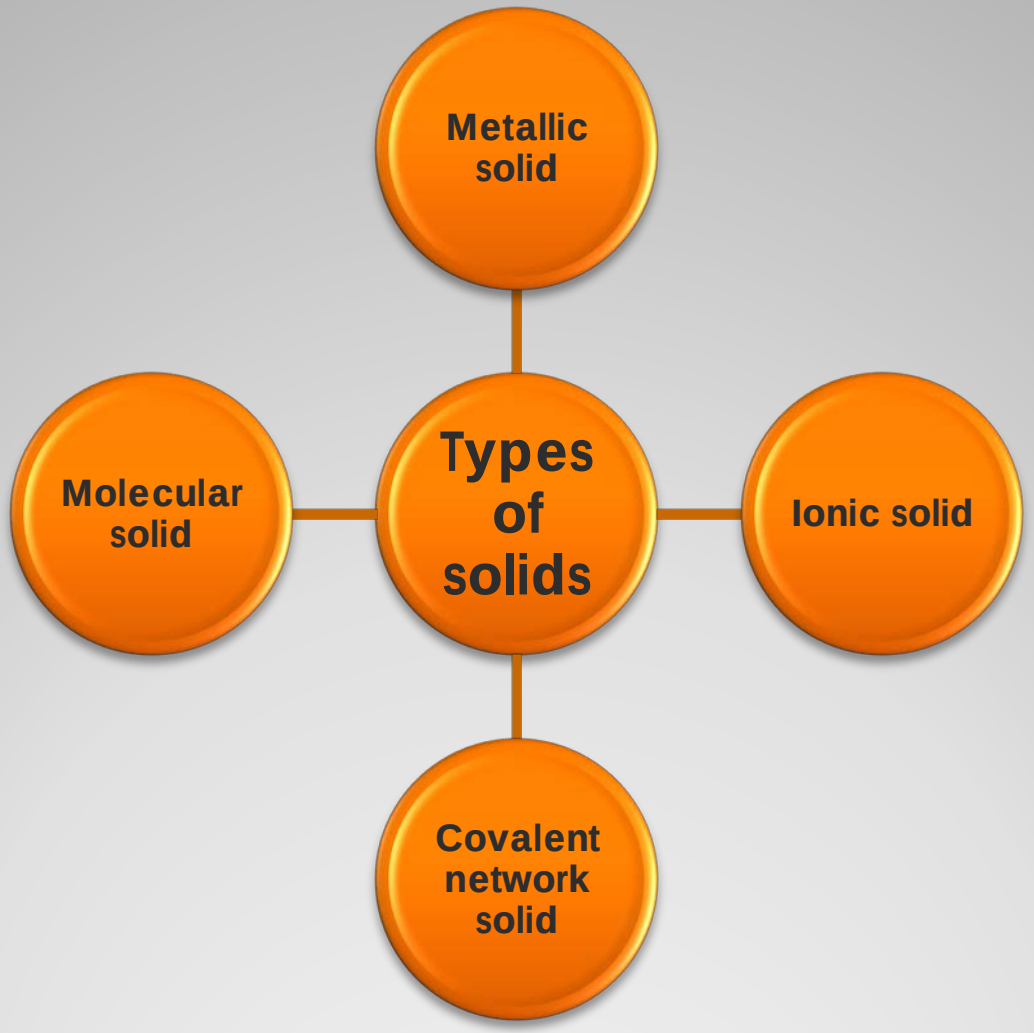
Classification of solids by type of attraction of units



Types of Solids

Type of Solid	Structural Units	Attractive Forces Between Structural Units	Examples
Molecular	Atoms or molecules	Intermolecular forces	Ne, H_2O, CO_2
Metallic	Atoms (positive cores surrounded by electron "sea")	Metallic bonding (extreme delocalized bond)	Fe, Cu, Ag
Ionic	Ions	Ionic bonding	CsCl, NaCl, ZnS
Covalent network	Atoms	Covalent bonding	Diamond, graphite, asbestos

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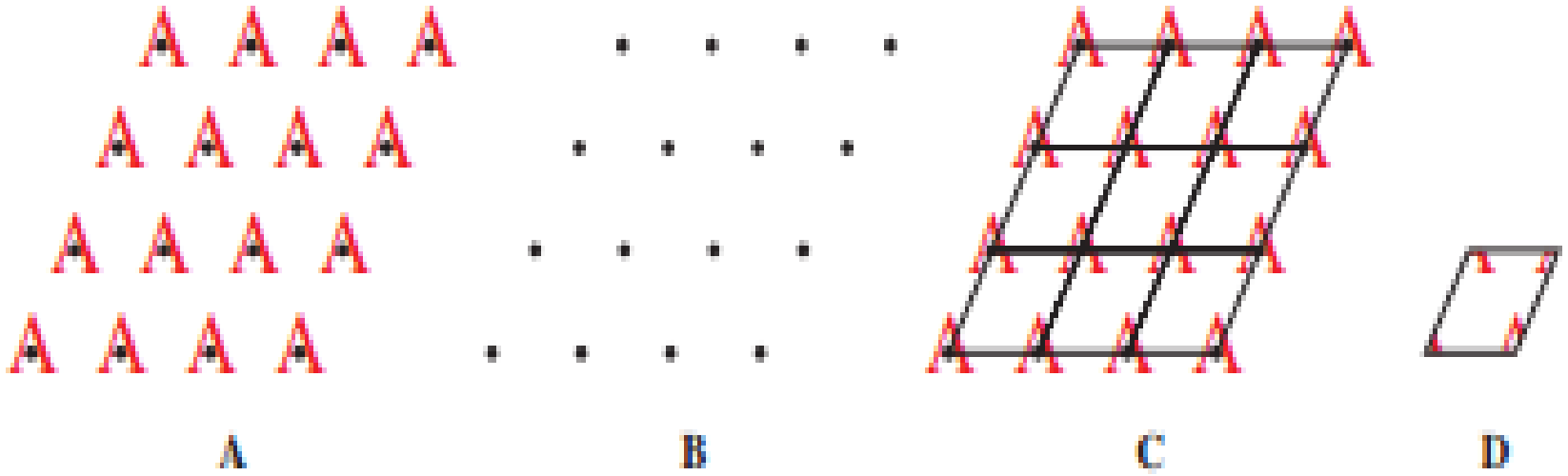
Crystalline solids; Crystal lattices and unit cells



A two-dimensional pattern

(A) A pattern of *A*'s. A point midway on the crossbar of each *A* has been selected for a lattice point.
(B) The pattern of lattice points.
(C) Division of the pattern into unit cells.
(D) A single unit cell

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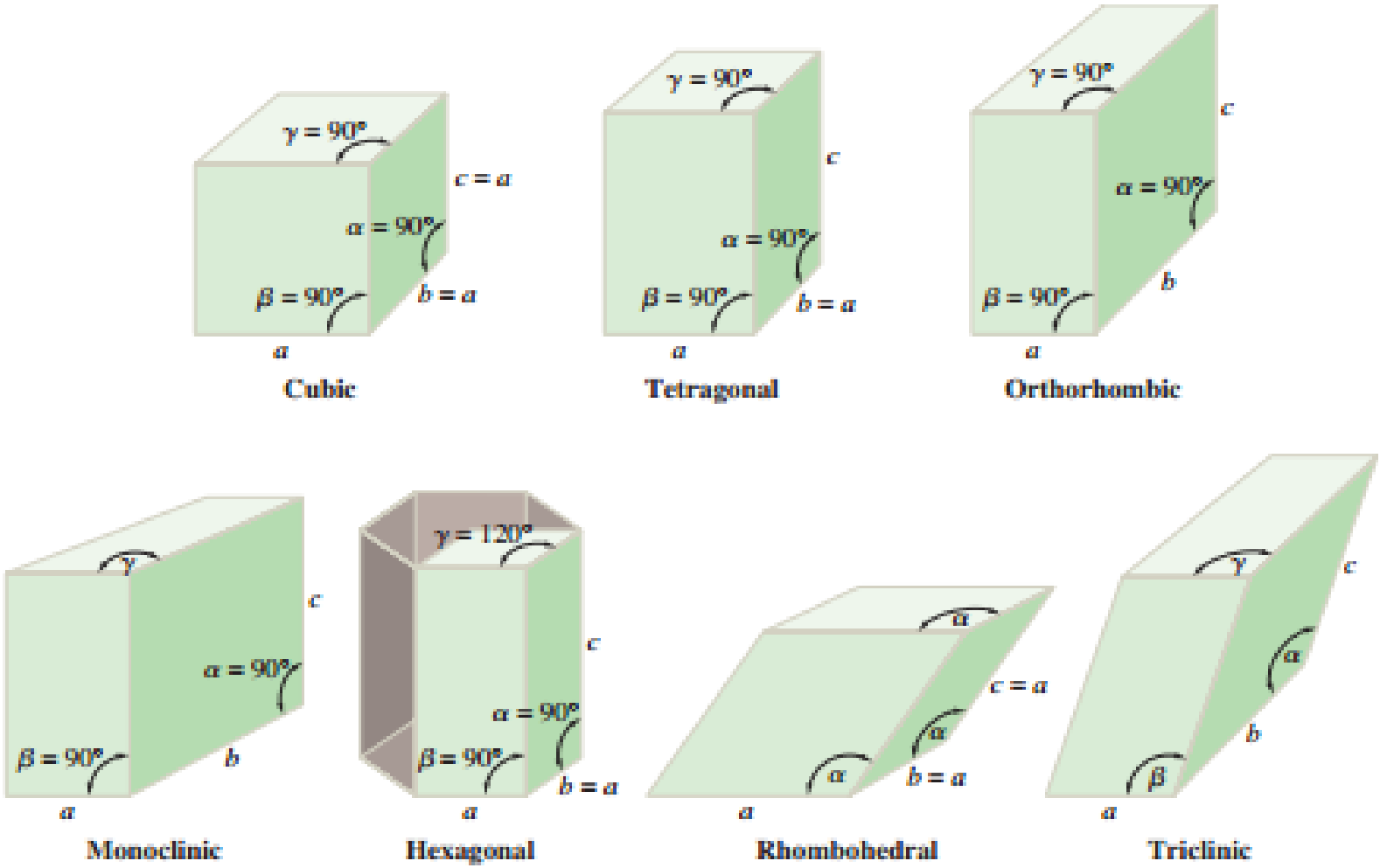
Unit-cell shapes of the different crystal systems



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The Seven Crystal Systems

Crystal System	Edge Length	Angles	Examples
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90°$	NaCl, Cu
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$	TiO_2 (rutile), Sn (white tin)
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	$CaCO_3$ (aragonite), $BaSO_4$
Monoclinic	$a \neq b \neq c$	$\alpha = \beta = 90°, \gamma \neq 90°$	$PbCrO_4$
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90°, \gamma = 120°$	C (graphite), ZnO
Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90°$	$CaCO_3$ (calcite), HgS (cinnabar)
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90°$	$K_2Cr_2O_7$, $CuSO_4 \cdot 5H_2O$

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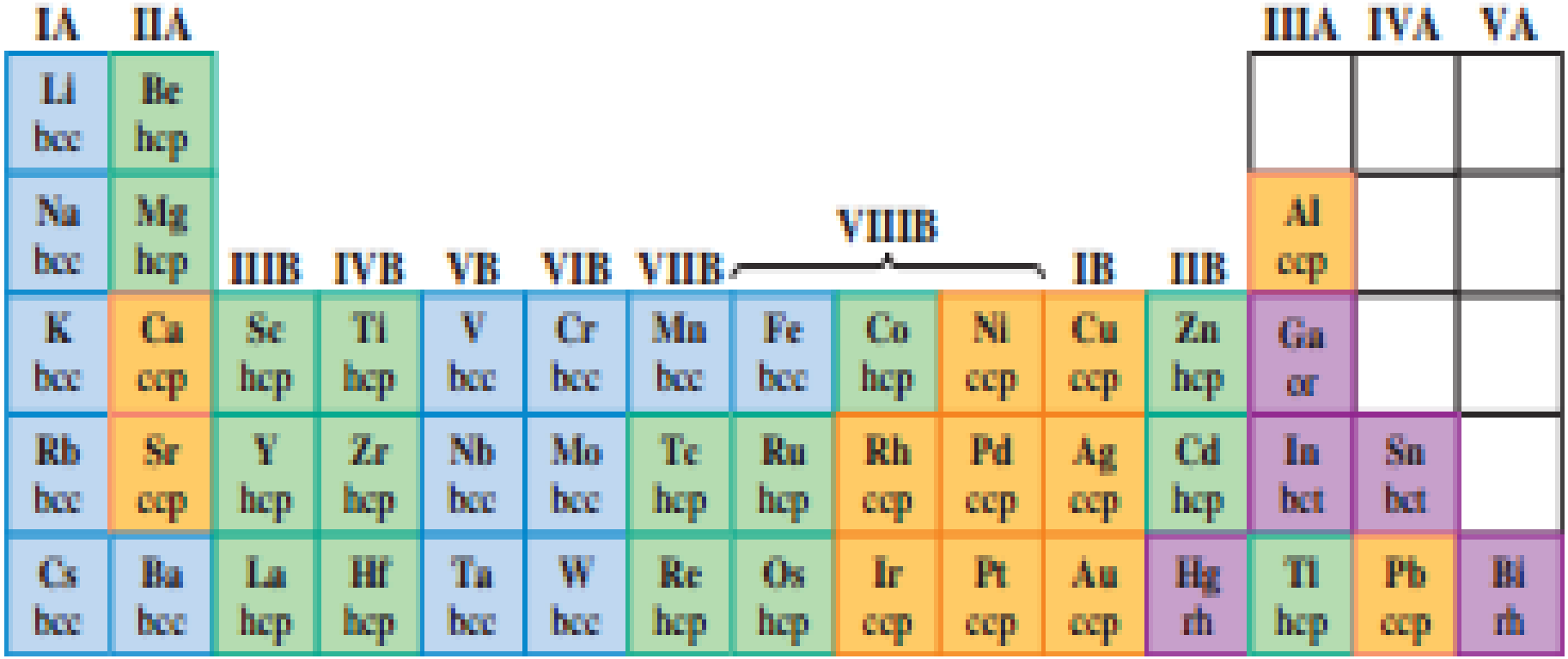
Structures of some crystalline solids

Metallic Solids



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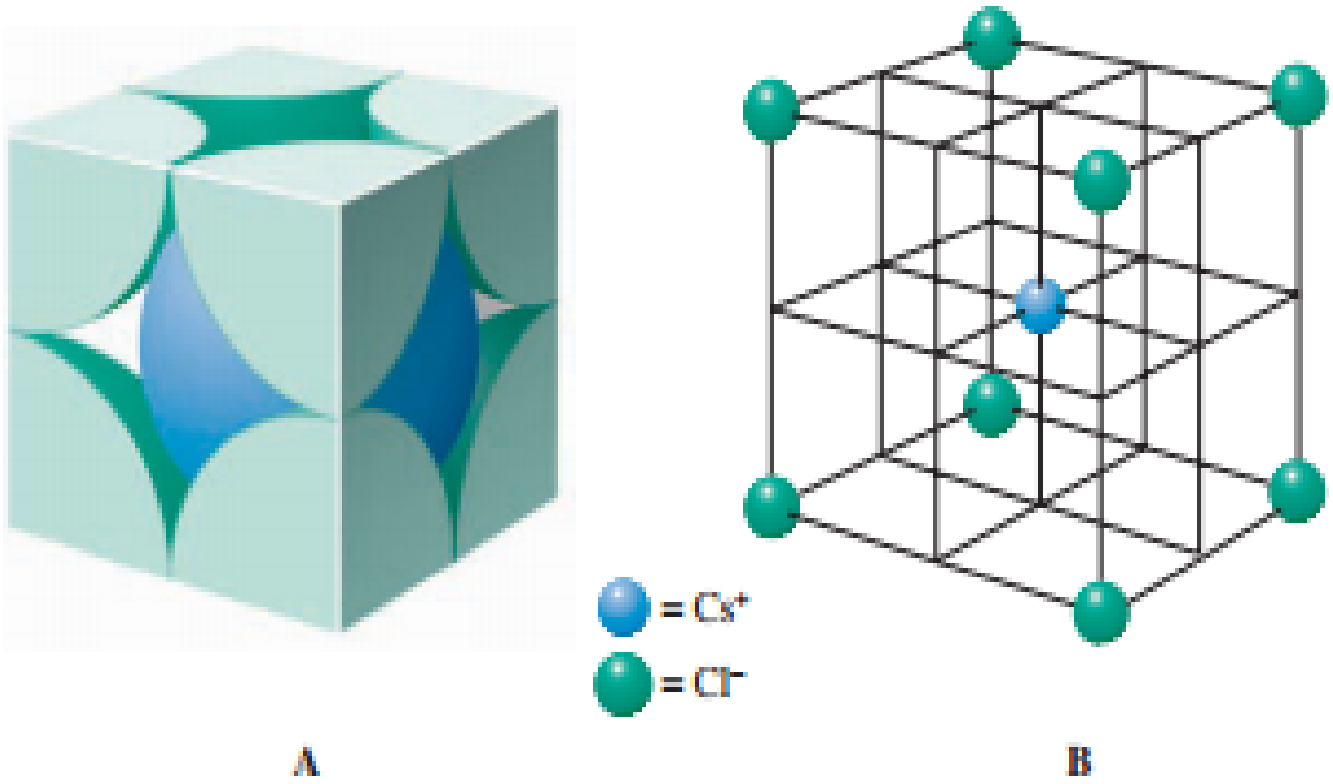
Ionic Solids



Cesium chloride unit cell

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