CHEMISTRY

an atoms-focused approach

Gilbert
Kirss
Foster

Chapter 6

Intermolecular Forces

Attraction between Particles

Chapter Outline

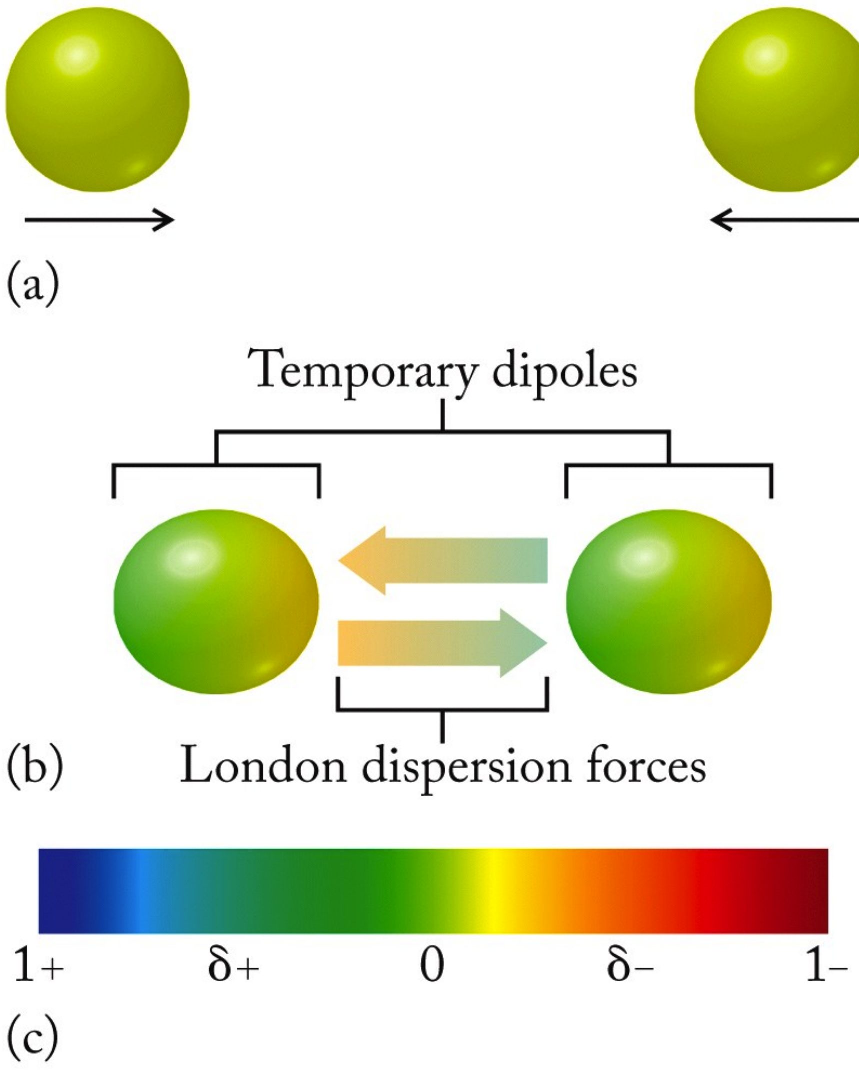
- 6.1 London Dispersion Forces
- 6.2 Interactions Involving Polar Molecules
- 6.3 Trends in Solubility
- 6.4 Phase Diagrams
- 6.5 Properties of Water

Interactions of Nonpolar Molecules

- Dispersion (London) Forces:
  - Intermolecular force between nonpolar molecules caused by the presence of temporary dipoles in the molecules
- Temporary Dipole (Induced Dipole):
  - Separation of charge produced in an atom or molecule by a momentary uneven distribution of electrons
- Polarizability:
  - Relative ease with which the electron cloud in a molecule, ion, or atom can be distorted, inducing a temporary dipole

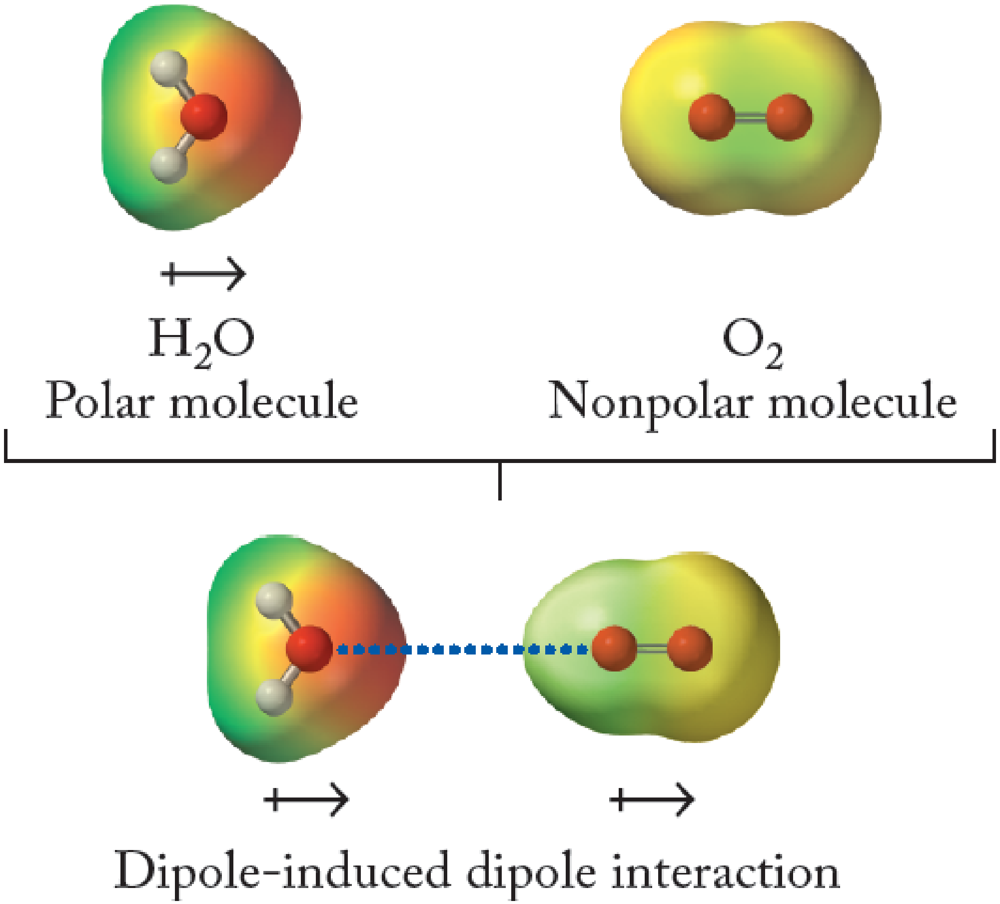
Dispersion Forces

- Dispersion = Momentary shift in e^- density



Induced Dipoles

- Proximity of polar molecule = Dipole – Induced dipole



Strength of Dispersion Force

- Factors Affecting Strength of Dispersion:
  - Size of Atoms/Molecules:
    - Larger atoms/molecules more polarizable than smaller atoms/molecules
    - Dispersion increases with polarizability
  - Shape of Molecules:
    - Increased surface area = Increased interactions between molecules
    - Linear molecules have higher dispersion than branched molecules of similar MW

Importance of Shape

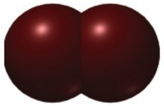
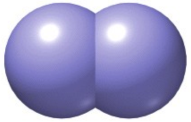
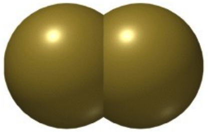
- Constitutional isomers: Same formulas, different connections between atoms in molecule
- Higher surface area molecules, stronger interactions
- Strength of interactions affects physical and chemical properties

Effects of Size on Dispersion

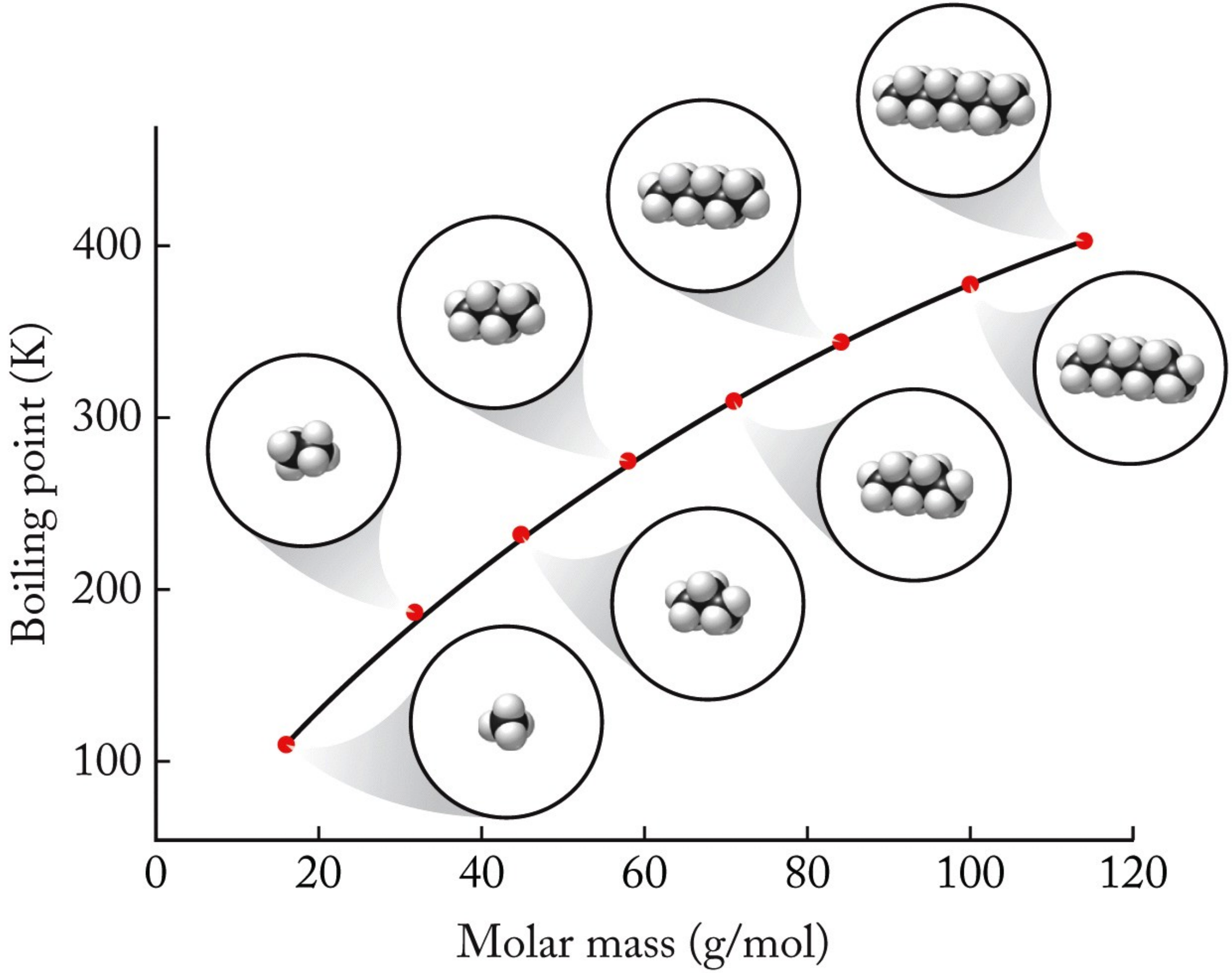
TABLE 6.1 Boiling Points of the Noble Gases

Noble Gas	Atomic View	*Z*	Boiling Point (K)
He		2	4
Ne		10	27
Ar		18	87
Kr		36	120
Xe		54	165
Rn		86	211

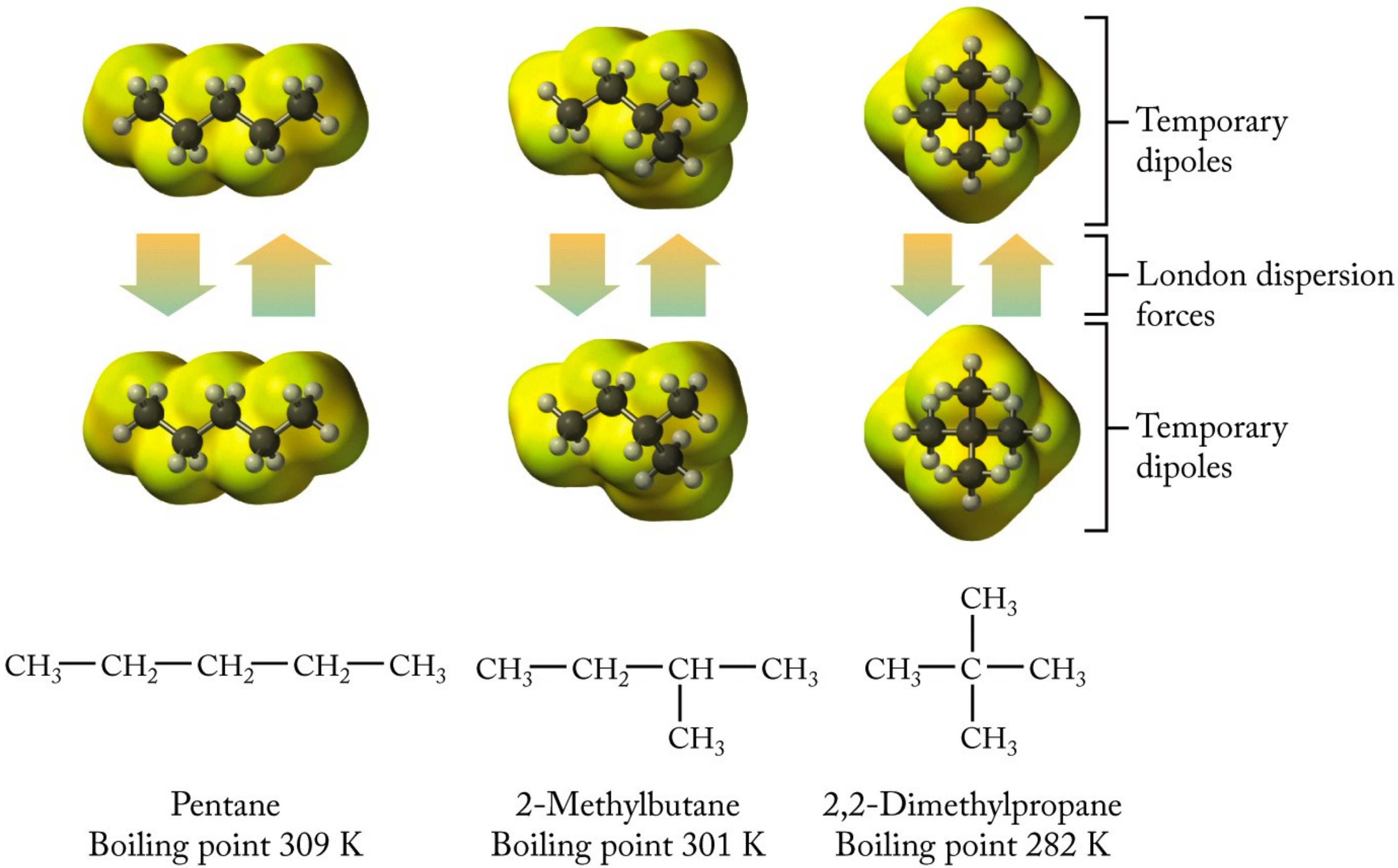
TABLE 6.2 Boiling Points of the Halogens

Halogen	Molecular View	Molar Mass (g/mol)	Boiling Point (K)
F_2		38	85
Cl_2		71	239
Br_2		160	332
I_2		254	457
At_2		420	610

Effects of Size on Dispersion



Effect of Structure on Dispersion



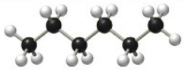
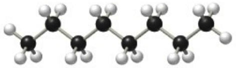
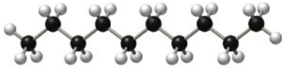
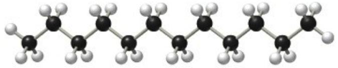
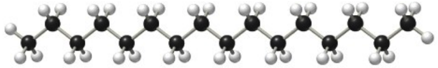
Viscosity

- Viscosity:
  - Measure of resistance to flow of a fluid
- Factors:
  - Molecular shape
  - Molar mass
  - Temperature

Practice: Viscosity

Explain the correlation between molar mass and viscosity for *n*-alkanes.

TABLE 6.3 Viscosities of Some Liquid *n*-Alkanes

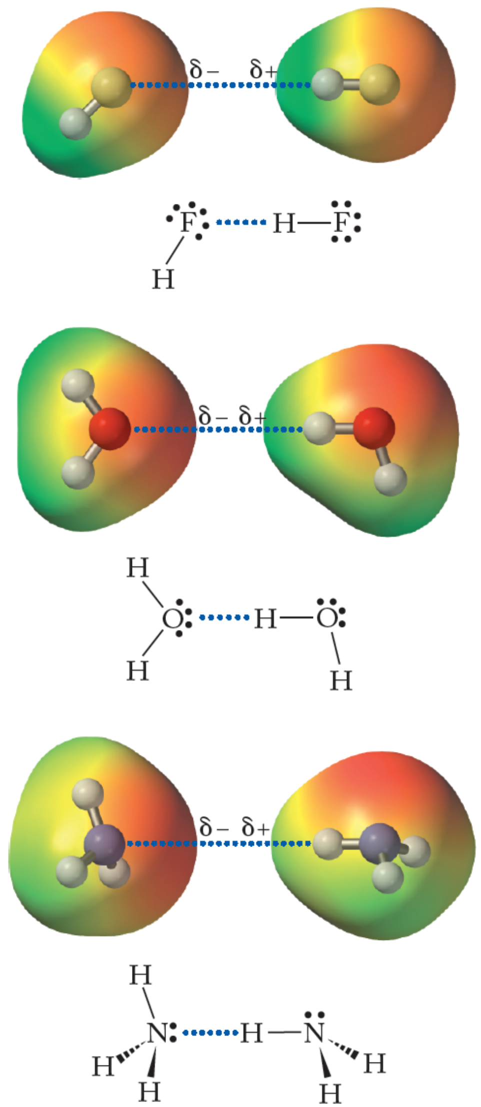
Compound	Molecular Structure	Molar Mass (g/mol)	Viscosity at 20°C (cP)
Hexane		86	0.29
Octane		114	0.54
Decane		142	0.92
Dodecane		170	1.34
Hexadecane		226	3.34

Chapter Outline

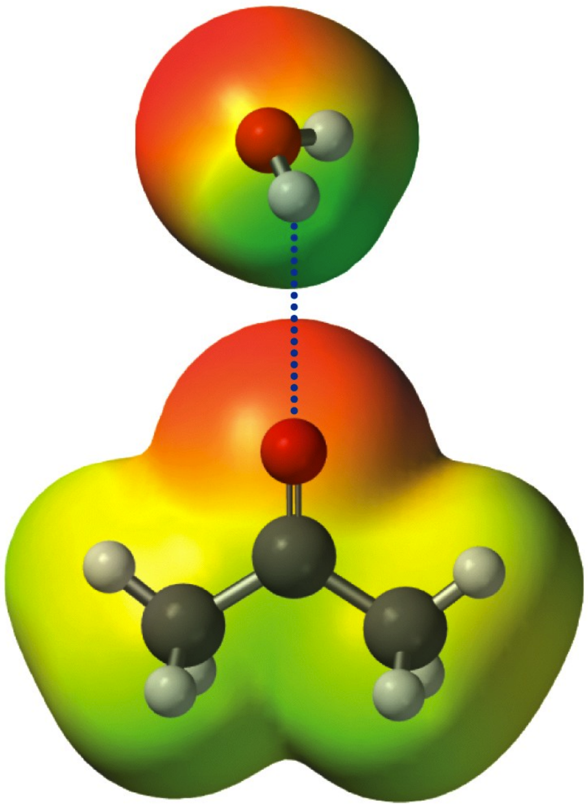
- 6.1 London Dispersion Forces
- 6.2 Interactions Involving Polar Molecules
- 6.3 Trends in Solubility
- 6.4 Phase Diagrams
- 6.5 Properties of Water

Dipole–Dipole Interactions

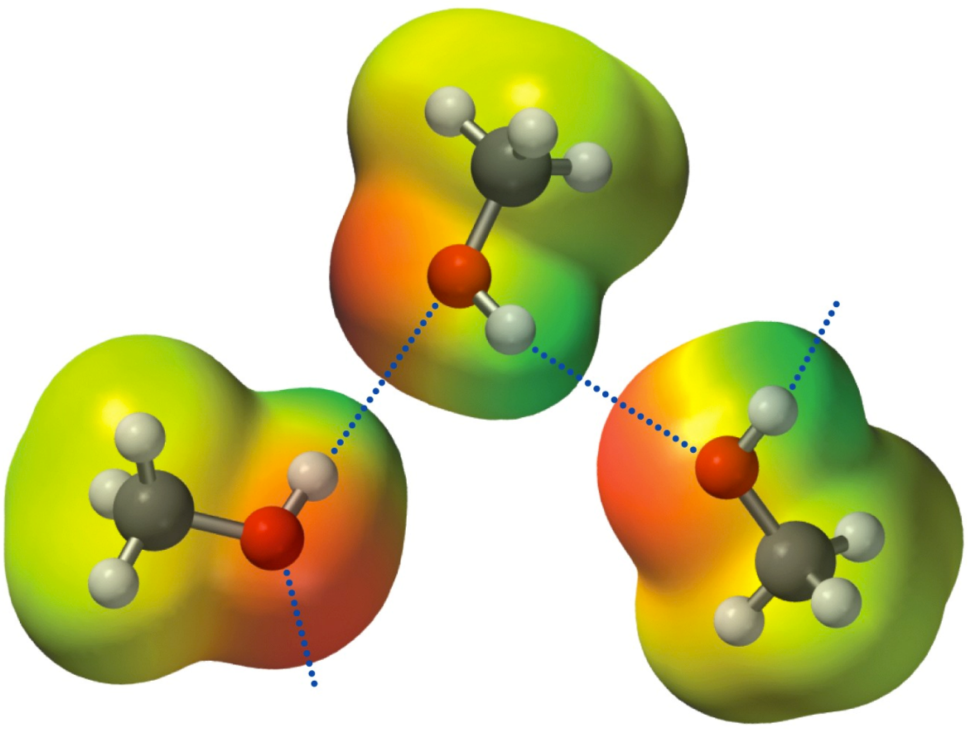
- Dipole–Dipole:
  - Attractive force between polar molecules
- Hydrogen Bond:
  - Strongest dipole–dipole interaction.
  - Occurs between H atom bonded to a small, highly electronegative element (F, O, N), and an atom of oxygen O or N in another molecule.



Examples of H-Bonding



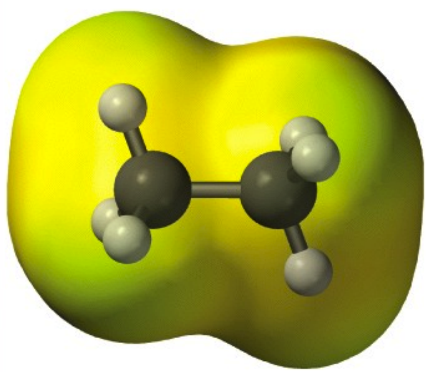
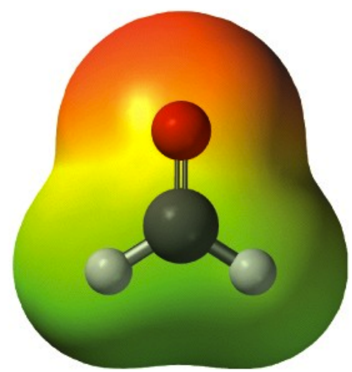
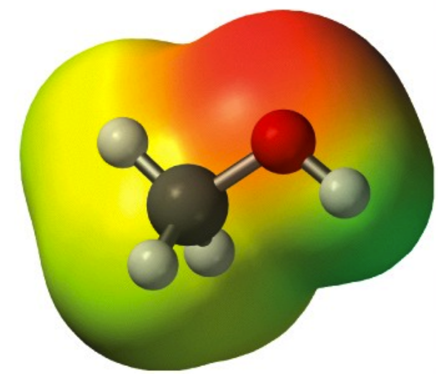
Acetone in Water



Methanol

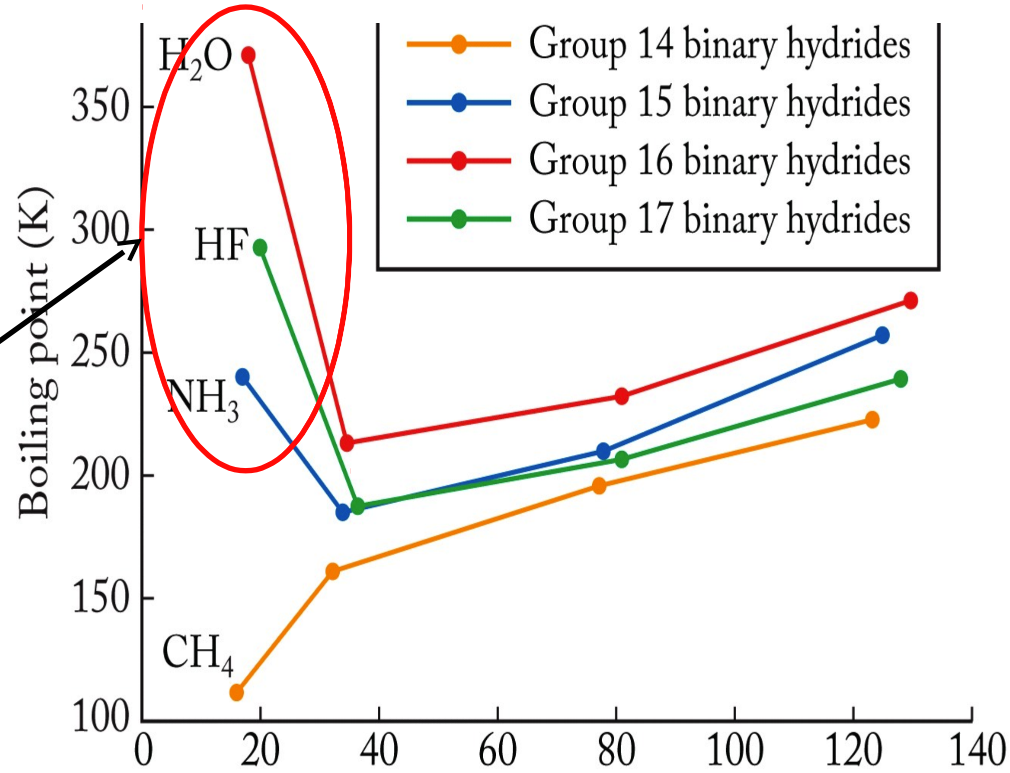
Effect of H-Bonding on Boiling Point

TABLE 6.4 **Some Properties of Ethane, Formaldehyde, and Methanol**

	Ethane	Formaldehyde	Methanol
Formula	CH_3CH_3	CH_2O	CH_3OH
Structure			
$\mathcal{M}$ (g/mol)	30.0	30.0	32.0
Dipole Moment (D)	0.00	2.33	1.69
Boiling Point (K)	184	254	338

Boiling Points of Binary Hydrides

Boiling points related to attractive forces:
– increased boiling point due to H-bonding



Practice: Predicting Boiling Points

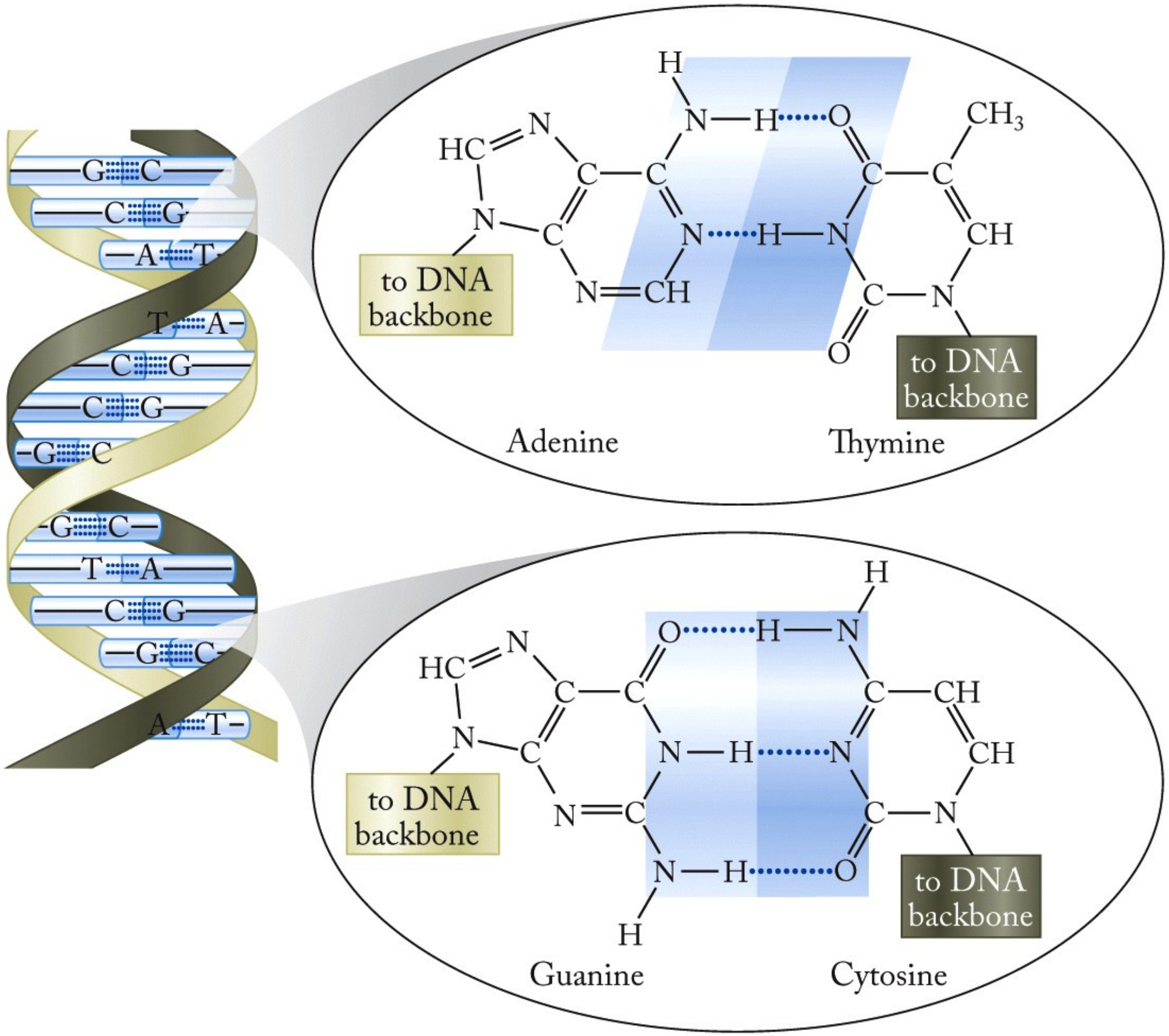
Rank the following compounds in order of increasing boiling point:

CH_3OH, $CH_3CH_2CH_2CH_3$, and $CH_3CH_2OCH_3$

- Collect and Organize:
- Analyze:
- Solve:
- Think about It:

H-Bonding in DNA

H-bonding between complementary sites on double-stranded DNA



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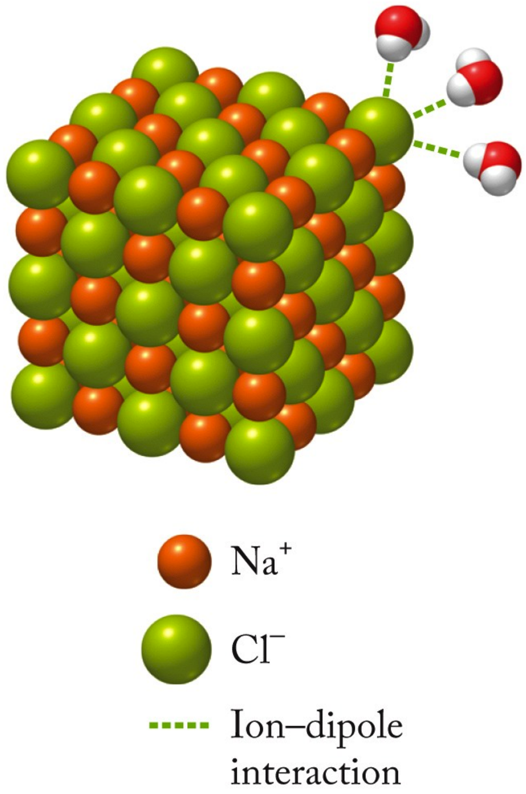
Solubility

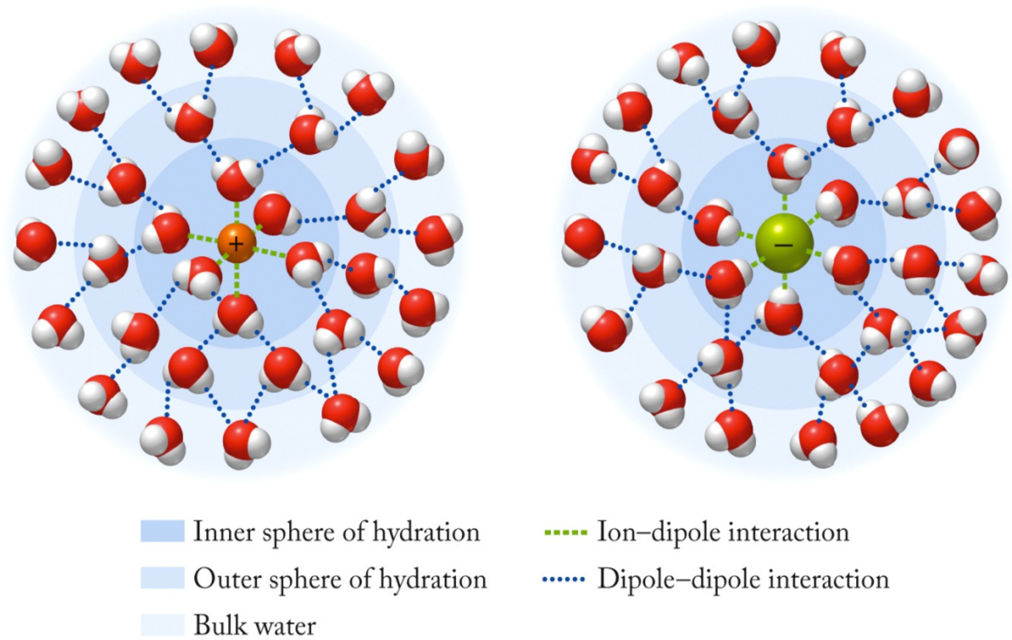
- Solute: Component of solution that is present in smallest number of moles
- Solvent: Component of solution that is present in largest number of moles
- Solubility: Maximum quantity of substance that can dissolve in a given volume of solution
- Miscible: Liquids that are mutually soluble in any proportion

Interactions Involving Polar Molecules

- Ion–Dipole:
  - Attractive force between an ion and a molecule that has a permanent dipole
- Sphere of Hydration:
  - Cluster of water molecules surrounding an ion in aqueous medium
  - *Sphere of solvation* if solvent other than H_2O

Ion–Dipole Interactions





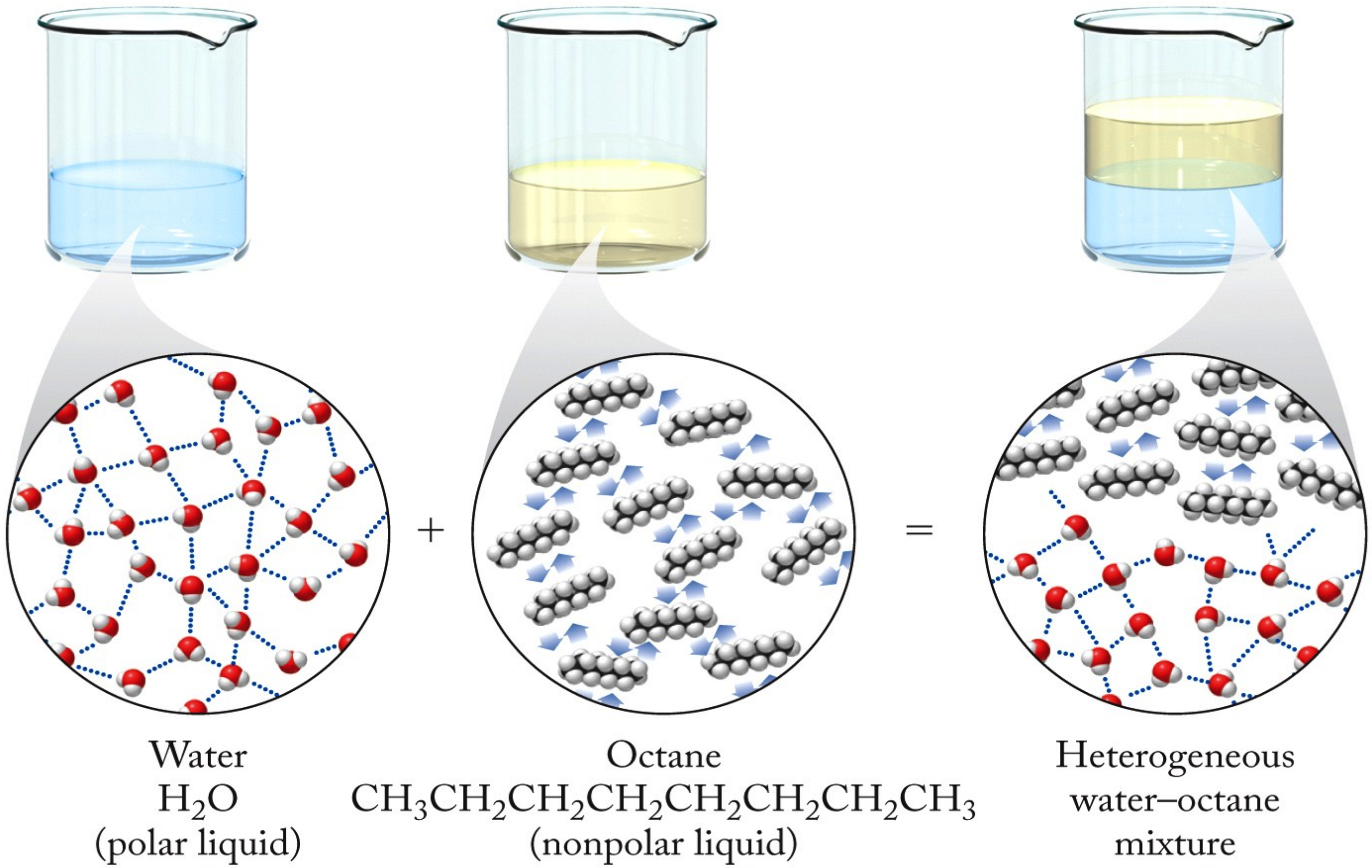
Ion–dipole interactions

Sphere of hydration

Solubility

- Solubility depends on relative strength of solute–solvent interactions compared to solute–solute or solvent–solvent.
- Like Dissolves Like:
  - Ionic/polar solutes will be soluble in polar solvents.
  - Nonpolar solutes will be soluble in nonpolar solvents.

Solubility Examples



Like forces =
Solution!

Dissimilar forces =
No solution!

Combinations of Forces

- More than one intermolecular force may need to be considered when examining solubility.

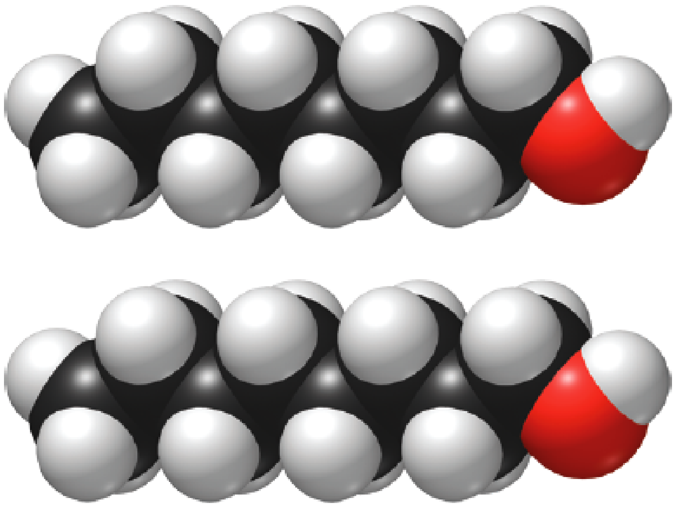
- Solubility decreases as relative energy of H-bonding decreases and dispersion increases.

TABLE 6.5 Solubilities of Some Ketones in Water

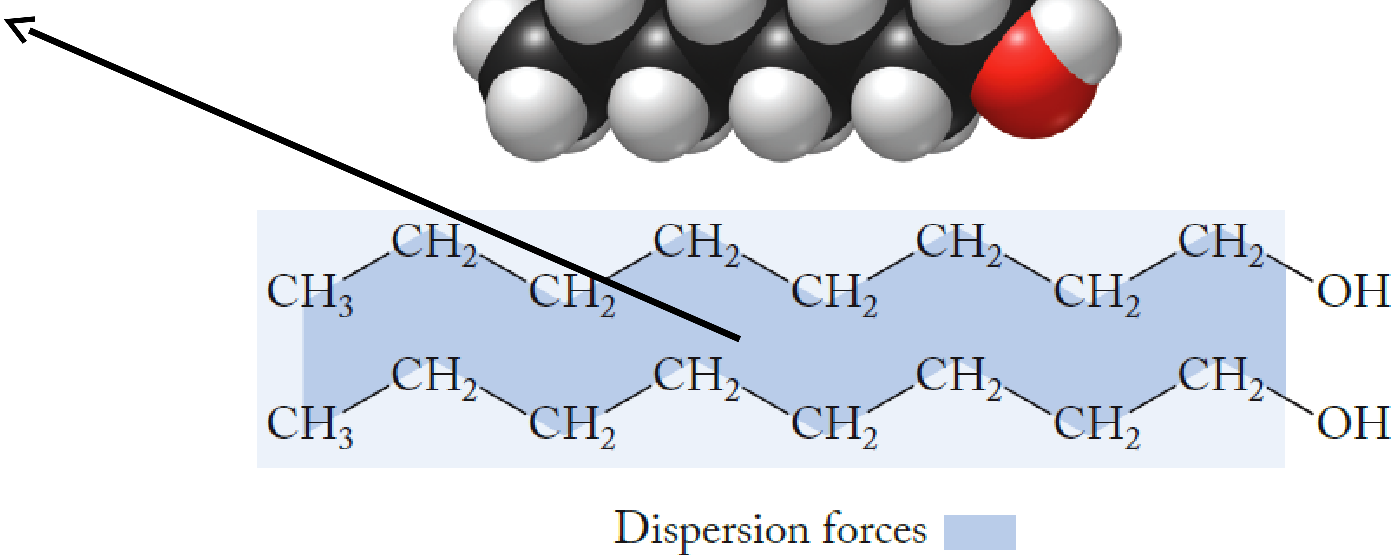
Compound	Condensed Molecular Structure	Solubility in Water (g/100 mL)
2-Propanone	$H_3C-C(=O)-CH_3$	Miscible
2-Butanone	$H_3C-C(=O)-CH_2CH_3$	25.6
2-Pentanone	$H_3C-C(=O)-CH_2CH_2CH_3$	4.3
2-Hexanone	$H_3C-C(=O)-(CH_2)_3CH_3$	1.4
2-Heptanone	$H_3C-C(=O)-(CH_2)_4CH_3$	0.4

Combinations of Forces

Octanol

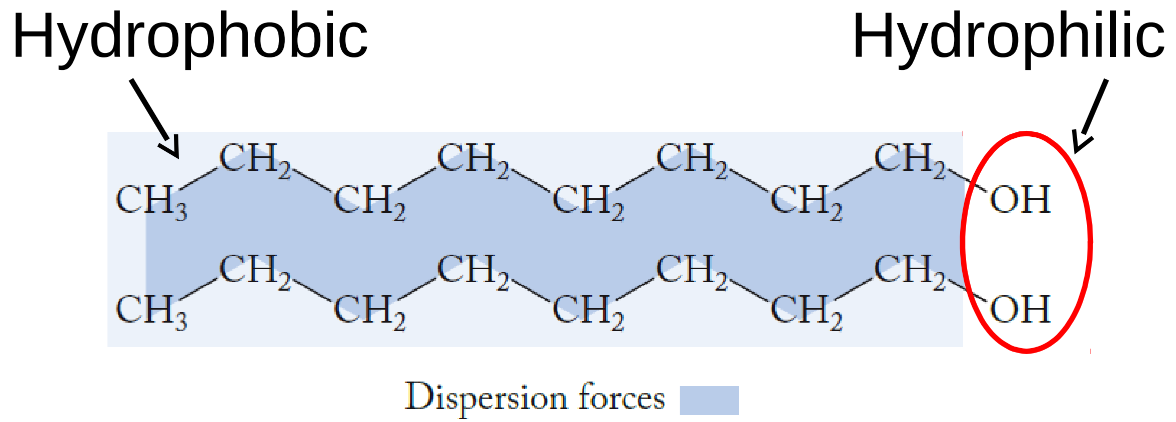


Extensive dispersion forces limit solubility of octanol in water.



Solubility Behavior

- Hydrophobic ("water-fearing")
  - interaction that repels water, diminishes water solubility.
- Hydrophilic ("water-loving")
  - interaction that attracts water, promotes water solubility.



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Factors Affecting Physical States

- Intermolecular forces:
  - Strength of attractive forces compared to kinetic energy of atoms/molecules
- Temperature:
  - Affects kinetic energy of atoms/molecules
- Pressure:
  - Affects distance between atoms/molecules

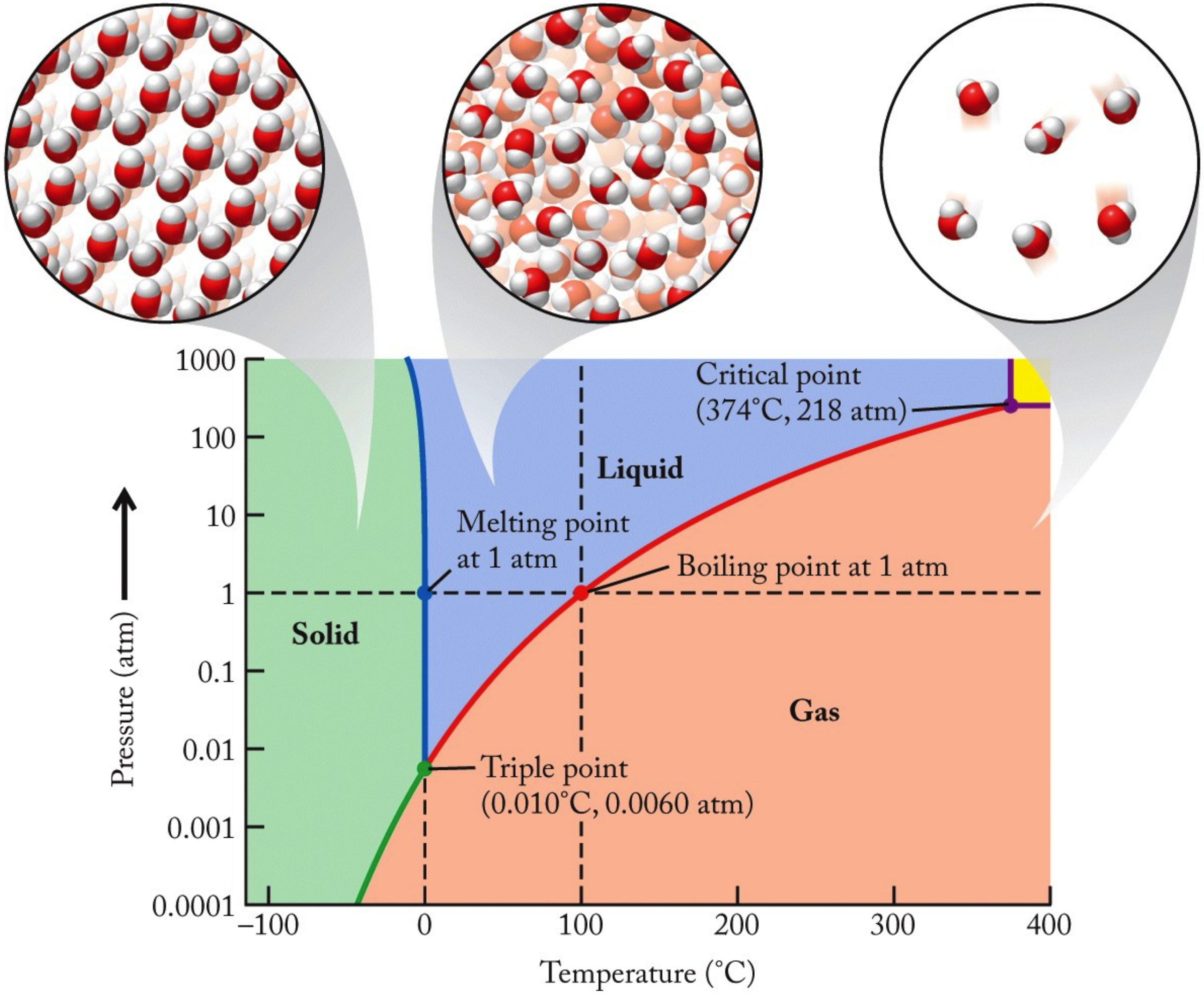
Phase Diagram

- Phase Diagram:
  - A graphical representation of how a substance’s stabilities of the physical states depend on temperature and pressure
  - Lines represent a series of temperature/pressure points where the two states on either side of the line coexist in equilibrium

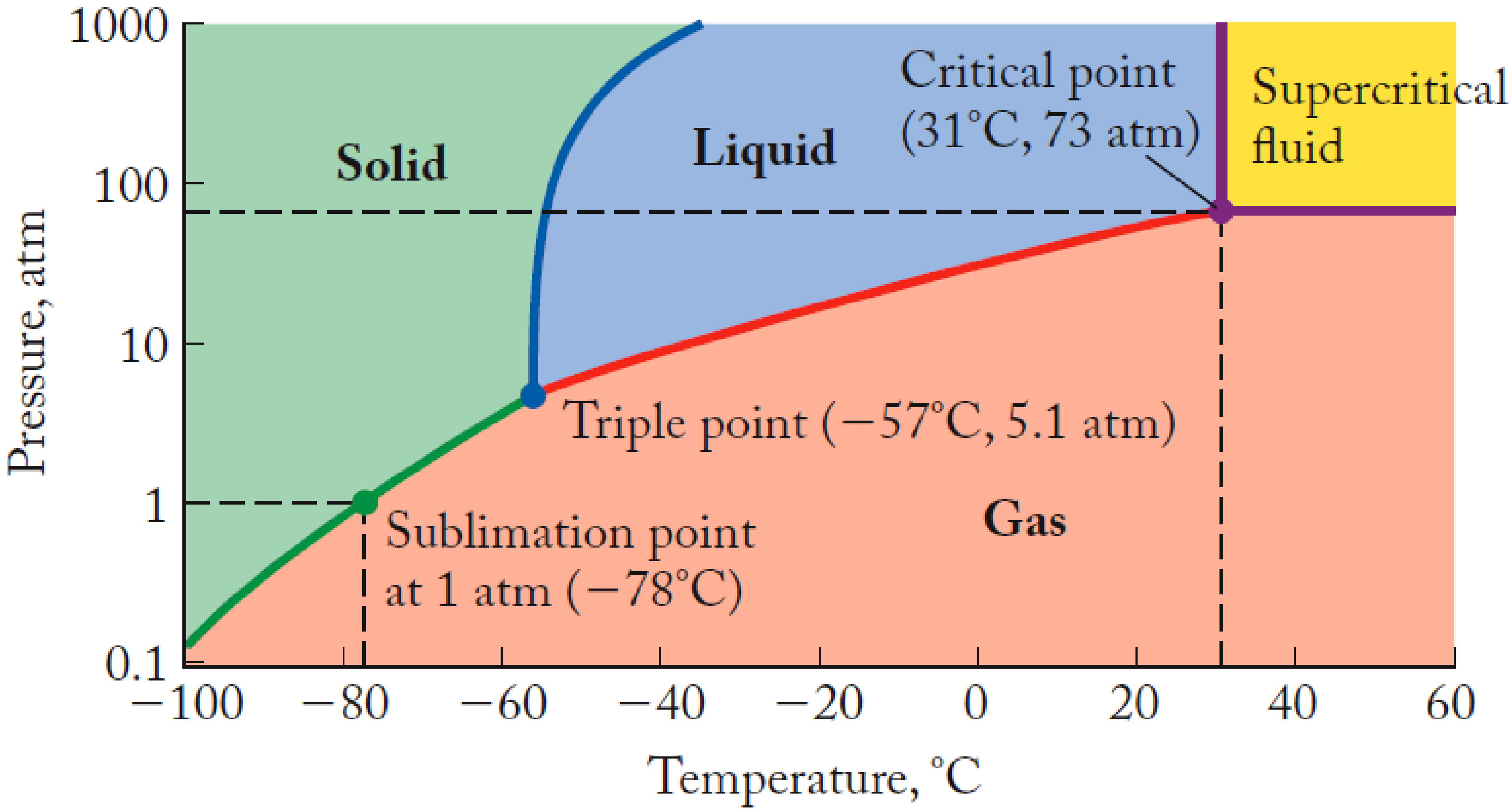
Features of Phase Diagram

- Triple Point:
  - Temperature/pressure where all three phases of a substance coexist
- Critical Point:
  - Specific temperature/pressure at which the liquid and gas phases have the same density
- Supercritical Fluid:
  - A substance above its critical temperature and pressure

Phase Diagram of Water



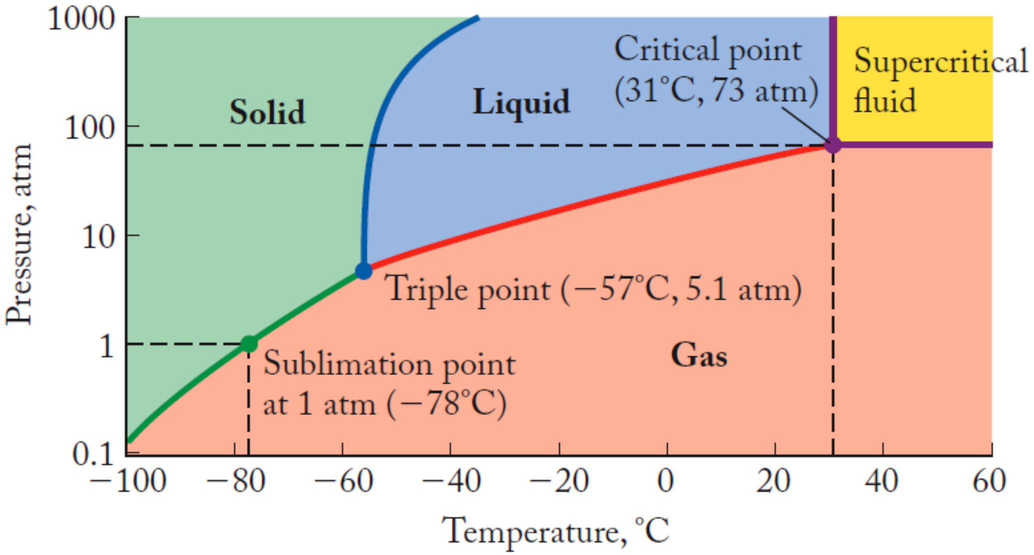
Phase Diagram of CO_2



Practice: Phase Diagrams

Describe the phase changes that occur when the temperature of CO_2 is increased from –100°C to 200°C at a pressure of 25 atm.

- Collect and Organize:
- Analyze:
- Solve:
- Think about It:



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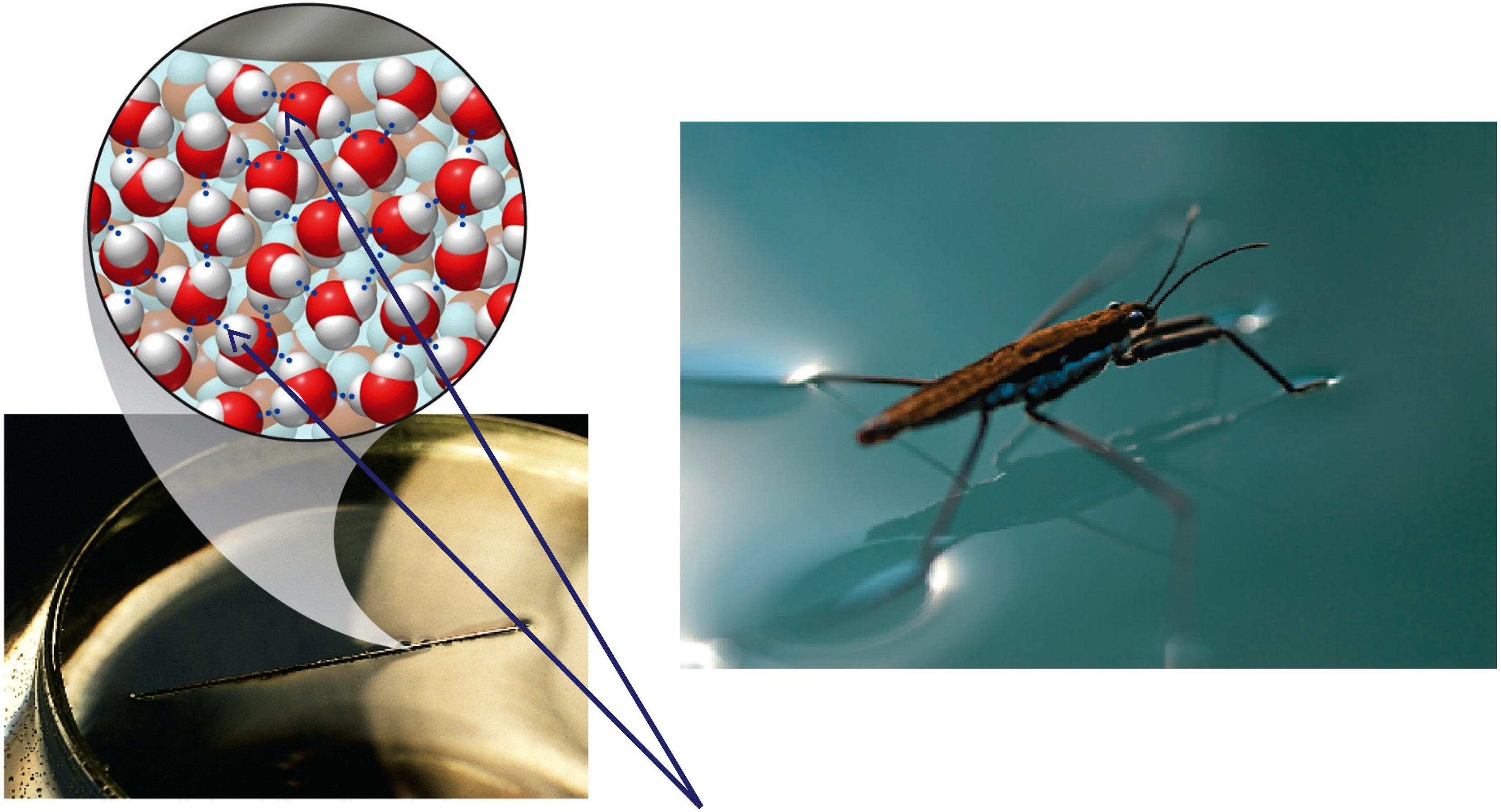
Properties of Water

- Surface Tension:
  - Energy needed to separate the molecules at the surface of a liquid
  - As attractive forces increase, surface tension increases
  - Related example: Meniscus

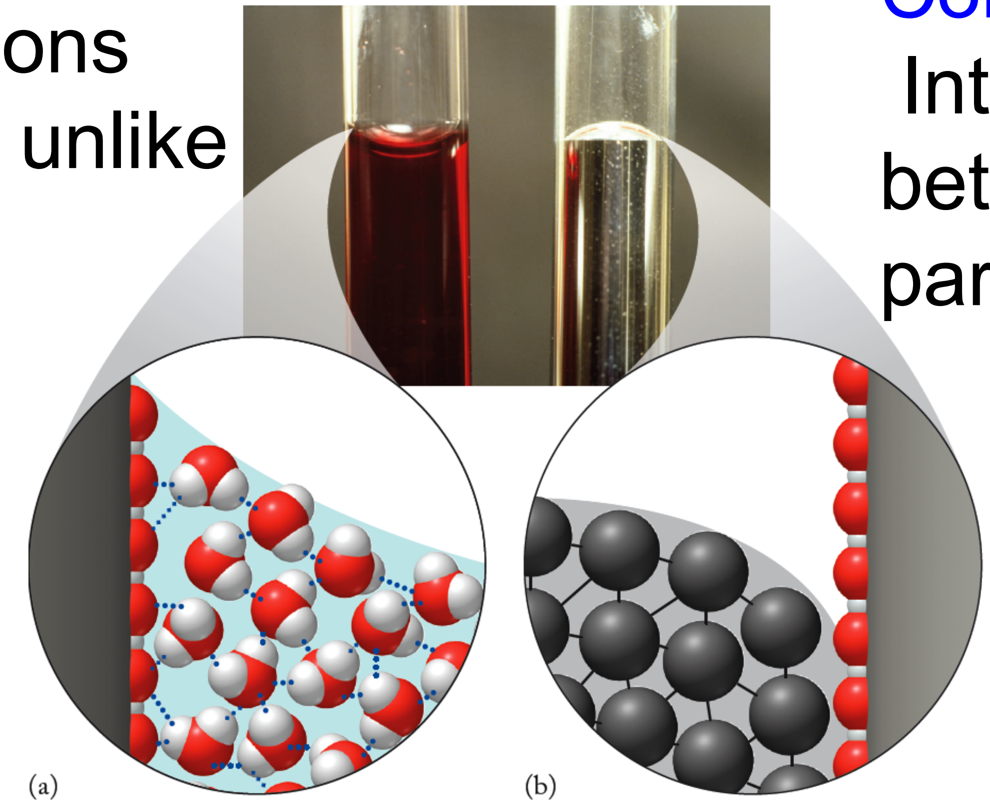
Surface Tension



Intermolecular forces holding molecules together.

Cohesive vs. Adhesive Forces: Meniscus

Adhesive Forces: Interactions between unlike particles



Cohesive Forces: Interactions between like particles

Example

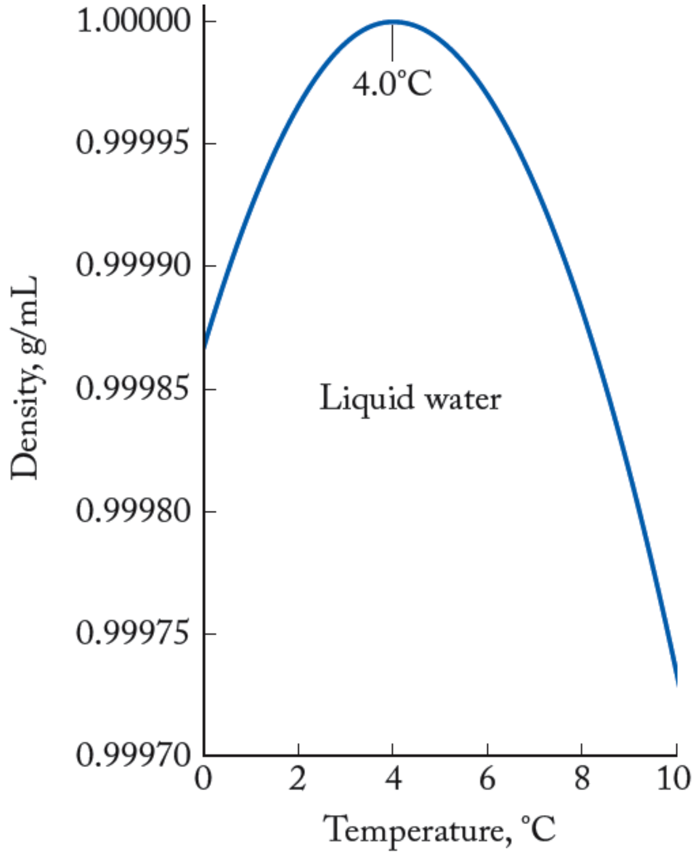
- Meniscus:
  - Curvature of liquid surface due to adhesive and cohesive forces
    - Concave: Adhesive forces ≥ cohesive forces (e.g., water on glass)
    - Convex: Cohesive forces > adhesive forces (e.g., mercury on glass)

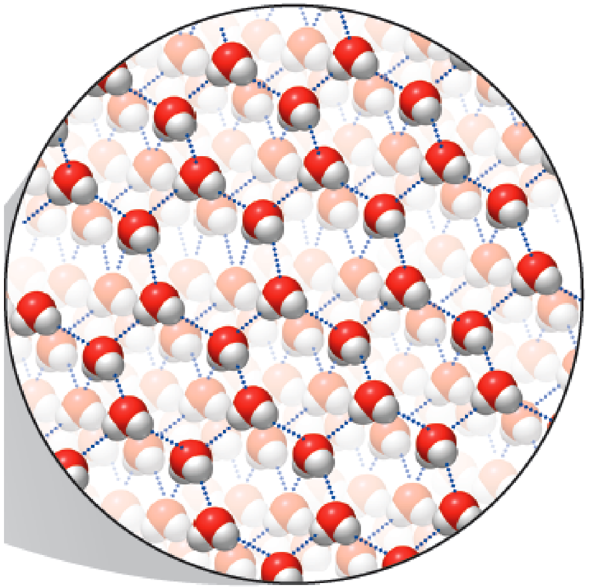
Properties of Water

- Capillary Action:
  - Ability of a liquid to spontaneously flow against gravity and rise up a tube or structure
  - Involves adhesive forces with the tube and cohesive forces within the liquid

Density of Water

- Density of water *decreases* as it freezes





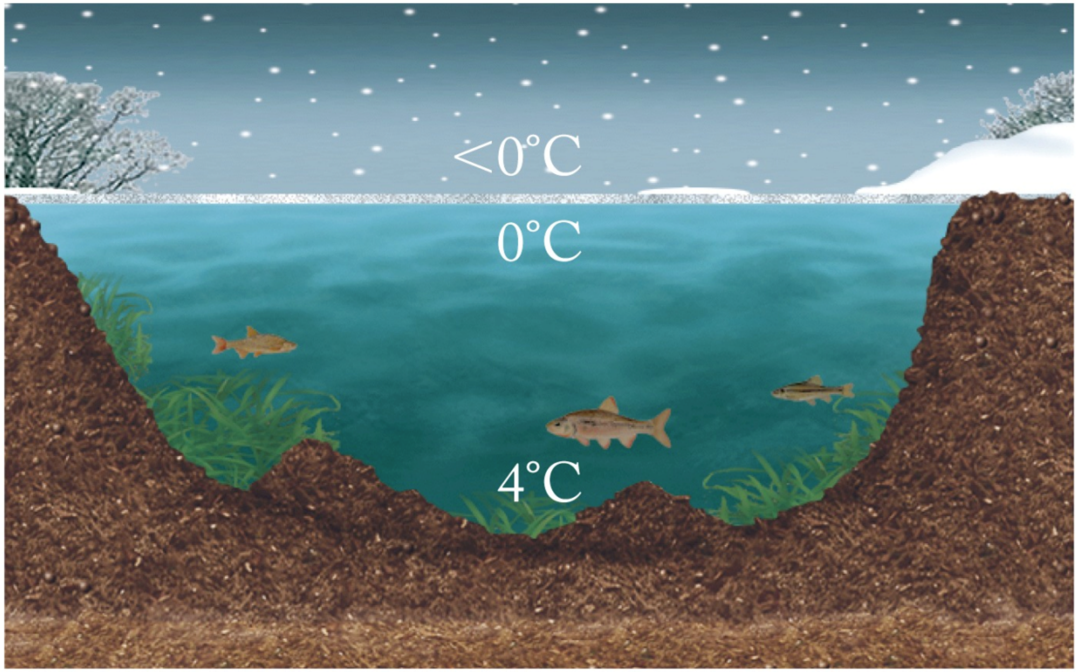
H-bonding results in cage-like structure in solid state; less dense than liquid state

Water and Aquatic Life

- Importance of Density:

Lakes/rivers freeze from top down, allowing fish and aquatic life to survive below.

As surface waters warm or cool, nutrient-rich bottom waters cycle to the surface;
oxygen-rich surface waters cycle to the bottom.



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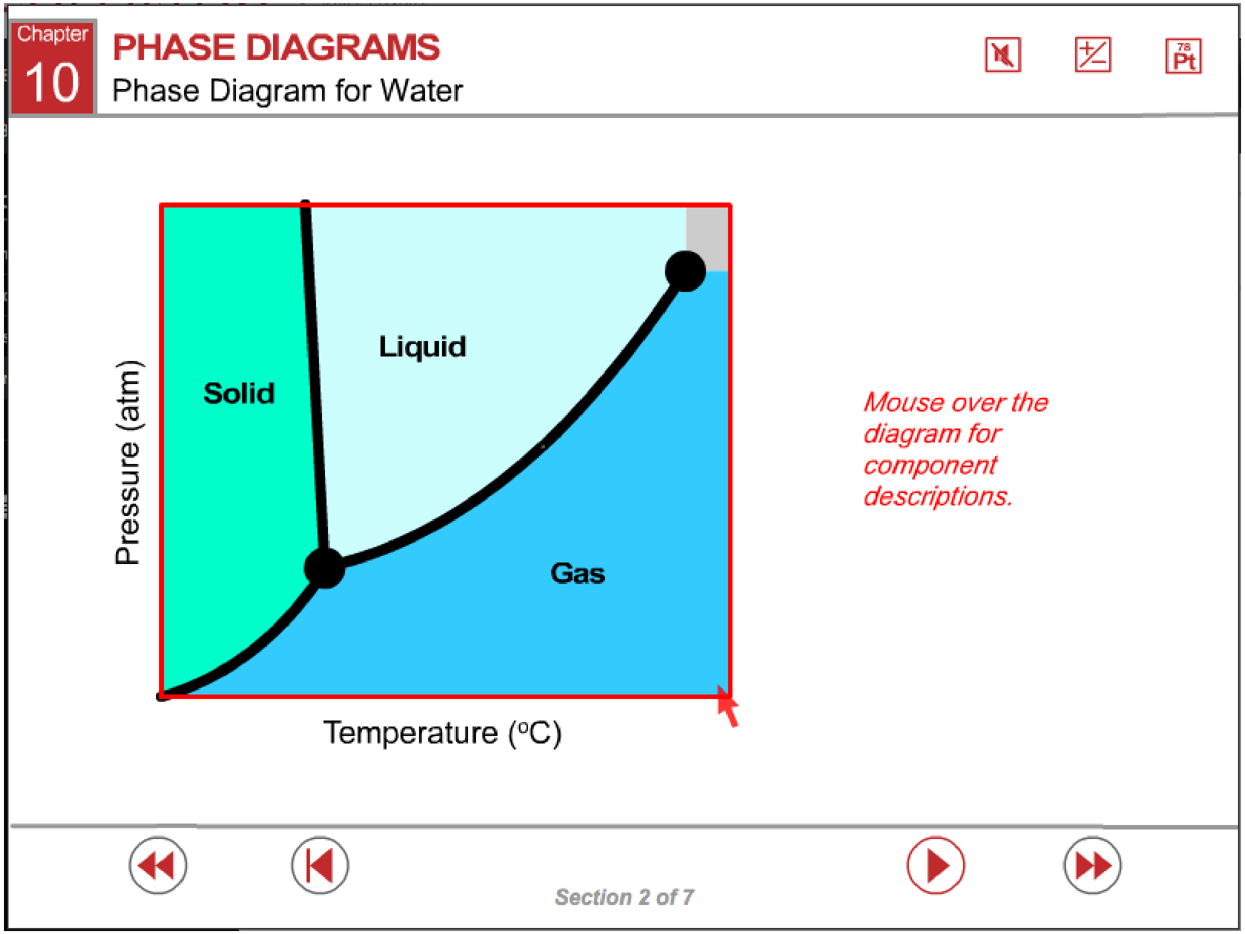

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CHEMISTRY
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