Chapter 14
Liquids: Condensation, Evaporation, and Dynamic Equilibrium

An Introduction to Chemistry
by Mark Bishop
Condensation (Gas to Liquid)

At a high temperature, there are no significant attractions between the particles.

As the temperature is lowered, attractions between particles lead to the formation of very small clusters that remain in the gas phase.

As the temperature is lowered further, the particles move slowly enough to form clusters so large that they drop to the bottom of the container and combine to form a liquid.
Evaporation

This particle is getting a sharp triple kick. The kick propels the particle out of liquid. It is traveling too fast for the attractions to the liquid particles to draw it back, so it is now a gas particle.
Particle Escape

• For a particle to escape from the surface of the liquid, it must meet the following criteria.
  – The particle must be at the liquid’s surface.
  – Its direction of motion must take it beyond the liquid’s surface.
  – Its momentum must be great enough to take it beyond the backward pull of the other particles at the surface.
Rate of Evaporation

• The rate of evaporation is the number of particles moving from liquid to gas per second.

• It is dependent on the following:
  – Surface area of the liquid
  – Strength of attractions between the particles in the liquid
  – Temperature
Relative Rates of Evaporation

Weaker attractions between particles

↓

Lower momentum necessary for particles to escape the liquid

↓

At a constant temperature, a greater percentage of particles that have the momentum necessary to escape

↓

Higher rate of evaporation
Temperature and Rate of Evaporation

- Increased temperature
  - Increased velocity and momentum of the particles
    - Increased percentage of particles that have the minimum momentum to escape
      - Increased rate of evaporation
Dynamic Equilibrium and Rates of Evaporation and Condensation
At equilibrium, the particles leaving the liquid are replaced by particles returning to the liquid.
Relative Equilibrium
Vapor Pressures

Weaker attractions between particles in a liquid → Higher rate of evaporation

Higher rate of condensation needed for equilibrium

Higher equilibrium vapor pressure, $P_{vap}$ ➔ Higher concentration of vapor particles necessary to create the higher rate of condensation
Temperature Effect On Equilibrium Vapor Pressure

Increased temperature $\rightarrow$ Increased rate of evaporation $\downarrow$

Increased rate of condensation needed for equilibrium $\downarrow$

Increased equilibrium vapor pressure, $P_{\text{vap}}$ $\rightarrow$ Increased concentration of vapor particles necessary to bring the rate of condensation to the higher level
Acetone/Water

$P_{vap}$ vs. $T$
Spaces in Liquids

Collisions between particles create tiny bubble-like spaces.
Collisions between vapor particles in the bubble and the liquid particles that form the walls of the bubble create a pressure that can keep the bubble from collapsing.
Bubble Formation

$P_{\text{vap}} < P_{\text{ext}}$
Bubble collapses

$P_{\text{vap}} = P_{\text{ext}}$
Bubble maintains its volume

$P_{\text{vap}} > P_{\text{ext}}$
Bubble expands
Pressure and Boiling Points

Decreased external pressure above liquid water

↓

Decreased vapor pressure necessary to allow bubbles to form

↓

Decreased temperature necessary to reach this lower vapor pressure

↓

Decreased boiling-point temperature
Pressure and Boiling Point for Water

The boiling point of water at the top of Mount Everest with an external pressure of 34 kPa is 72 °C.

The normal boiling point of water is 100 °C.

The boiling point of water with an external pressure of 202 kPa is about 120 °C.
Strengths of Attraction and Boiling Point

- Increased strength of attractions
  - Decreased rate of evaporation
  - Decreased rate of condensation at equilibrium
  - Lower concentration of vapor necessary to reach lower rate of condensation
  - Lower vapor pressure at any given temperature
  - Higher temperature necessary to bring the vapor pressure to the external pressure
  - Increased boiling-point temperature
Normal Boiling Points

The normal boiling point of acetone is 56.5 °C.
The normal boiling point of water is 100 °C.

Graph showing the relationship between vapor pressure ($P_{\text{vap}}$) in kPa and temperature in °C for water and acetone.
Chapter 14

- Electronegativity
  - Classifying bonds as nonpolar covalent, polar covalent, or ionic
- Predicting molecular polarity
  - Metallic bonds
  - Dipole-dipole attractions
  - Hydrogen bonds
  - Covalent bonds
  - Ionic bonds
  - London forces
- Types of attractions between particles
- Draw Lewis structures (Section 12.2)
- Draw geometric sketches from Lewis structures (Section 12.4)
- Classify elements as metallic or nonmetallic (Section 2.3)
- Identify types of compounds from names or formulas (Section 5.3)
Condensation
(Gas to Liquid)

At a high temperature, there are no significant attractions between the particles.

As the temperature is lowered, attractions between particles lead to the formation of very small clusters that remain in the gas phase.

As the temperature is lowered further, the particles move slowly enough to form clusters so large that they drop to the bottom of the container and combine to form a liquid.
Dipole-Dipole Attractions
Dipole-Dipole Attractions in a Liquid

The polar molecules are held together by dipole-dipole attractions, which are broken and re-formed as the molecules travel throughout the liquid.
# Electronegativities

<table>
<thead>
<tr>
<th></th>
<th>1A</th>
<th>2A</th>
<th>3B</th>
<th>4B</th>
<th>5B</th>
<th>6B</th>
<th>7B</th>
<th>8B</th>
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<th>8B</th>
<th>1B</th>
<th>2B</th>
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<td>Ra</td>
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</table>

Electronegativities of various elements:
- 0.98 for Li, 1.57 for Be
- 0.93 for Na, 1.31 for Mg
- 0.82 for K, 1.00 for Ca
- 0.82 for Rb, 0.95 for Sr
- 0.79 for Cs, 0.89 for Ba
- 0.7 for Fr, 0.9 for Ra

Elements are listed in their respective periods and groups in the periodic table.
Electronegativity, a measure of the electron attracting ability of atoms in chemical bonds is used to predict:

- whether a chemical bond is nonpolar covalent, polar covalent, or ionic.
- which atom in a polar covalent bond is partial negative and which is partial positive.
- which atom in an ionic bond forms the cation and which forms the anion.
- which of two covalent bonds are more polar.
<table>
<thead>
<tr>
<th>Bond Type</th>
<th>Description</th>
<th>ΔEN Range</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Covalent bond</strong></td>
<td>(nonmetal-nonmetal always covalent)</td>
<td></td>
<td>Nonpolar covalent bond: ΔEN &lt; 0.4</td>
</tr>
<tr>
<td><strong>Ionic bond</strong></td>
<td>(metal-nonmetal usually ionic)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*ΔEN* refers to the difference in electron negativity.
Which atom in a polar covalent bond is partially negative and which is partially positive?

higher electronegativity ➞ partial negative charge

lower electronegativity ➞ partial positive charge
Which of two bonds is more polar?

The greater the $\Delta EN$ is, the more polar the bond.
Predicting Molecular Polarity

• Three questions will help you predict whether substances are composed of polar or nonpolar molecules.
  – Is the substance molecular?
  – If the substance is molecular, do the molecules contain polar covalent bonds?
  – If the molecules contain polar covalent bonds, are these bonds asymmetrically arranged?
Examples of Polar and Nonpolar Molecules

- **Polar**
  - $H_2O$, $NH_3$
  - Oxyacids
  - Hydrogen halides: HF, HCl, HBr, and HI
  - Alcohols: $CH_3OH$, $C_2H_5OH$

- **Nonpolar**
  - Elements composed of molecules: $H_2$, $N_2$, $O_2$, $F_2$, $Cl_2$, $Br_2$, $I_2$, $P_4$, $S_8$, $Se_8$
  - $CO_2$
  - Hydrocarbons, $C_aH_b$
In HF, the hydrogen bond is between the partial positive H of one HF molecule and the partial negative F of another HF molecule.
In H\textsubscript{2}O, the hydrogen bond is between the partial positive H of one H\textsubscript{2}O molecule and the partial negative O of another H\textsubscript{2}O molecule.
In CH$_3$OH, the hydrogen bond is between the partial positive H of one CH$_3$OH molecule and the partial negative O of another CH$_3$OH molecule.
In $\text{NH}_3$, the hydrogen bond is between the partial positive H of one $\text{NH}_3$ molecule and the partial negative N of another $\text{NH}_3$ molecule.
1. Chance or collisions cause nonpolar molecules to form instantaneous dipoles.

Nonpolar molecule \(\cdots\) Instantaneous dipole

2. Instantaneous dipoles induce dipoles in other nonpolar molecules.

Repulsion between the partial negative charge of the instantaneous dipole and the negative charge of the electrons in the nonpolar molecule pushes the electrons in the nonpolar molecule to the right, forming an induced dipole.

3. Induced dipoles can induce dipoles in other nonpolar molecules, resulting in many molecules with partial charges. London forces are the attractions between the partial positive and partial negative charges in these instantaneous and induced dipoles.
1. Chance or collisions cause polar molecules to become more polar.

2. More highly polar molecules induce increases in polarity in less polar molecules.

   Repulsion between the partial negative charge of the more polar molecule and the negative charge of the electrons in the less polar molecule pushes the electrons in the less polar molecule to the right, leading to an induced increase in polarity.

3. The more polar molecules can induce increases in polarity in other less polar molecules, resulting in many molecules with larger partial charges. London forces are the attractions between the partial positive and partial negative charges in these instantaneously increased dipoles and induced increases in dipoles.
Why Larger Molecules Have Stronger London Forces

Larger Molecules

- More electrons
- Instantaneous dipoles are more likely
- More instantaneous dipoles
- More and stronger attractions between dipoles
- Stronger London forces

Electrons in larger electron clouds
- Electrons farther from nuclei
- Highest energy electrons less attracted to the nuclei
- Easier to distort electron cloud
- Larger charges on both instantaneous dipoles and induced dipoles
Types of Attractions – Carbon

- **Diamond** - Carbons atoms held together by covalent bonds, forming huge 3-dimensional molecules.

- **Graphite** - Carbons atoms held together by covalent bonds, forming huge 2-dimensional molecules held together by London forces.

- **Fullerenes** - Carbons atoms held together by covalent bonds, forming 3-dimensional molecules held together by London forces.
Predicting Types of Attractions

What kind of substance?

Metallic element → Metallic bonds

Diamond → Covalent bonds

Other nonmetallic elements → London forces

Ionic compound → Ionic bonds

Molecular compound

Do the molecules contain O-H, N-H, or H-F bonds?

No → Are any bonds polar?

No → London forces

Yes → Hydrogen bonds

Yes → Symmetrical or asymmetrical arrangement of polar bonds?

Asymmetrical → Dipole-dipole attractions

Symmetrical → London forces
## Types of Particles and Attractions - Elements

<table>
<thead>
<tr>
<th>Type of element</th>
<th>Particles to visualize</th>
<th>Examples</th>
<th>Type of Attraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>metals</td>
<td>cations in a sea of electrons</td>
<td>gold, Au</td>
<td>metallic bonds</td>
</tr>
<tr>
<td>noble gases</td>
<td>atoms</td>
<td>xenon, Xe</td>
<td>London forces</td>
</tr>
<tr>
<td>carbon (diamond)</td>
<td>atoms</td>
<td>C(dia)</td>
<td>covalent bonds</td>
</tr>
<tr>
<td>other nonmetallic elements</td>
<td>molecules</td>
<td>H₂, N₂, O₂, F₂, Cl₂, Br₂, I₂, S₈, Se₈, P₄</td>
<td>London forces</td>
</tr>
</tbody>
</table>
### Types of Particles and Attractions - Compounds

<table>
<thead>
<tr>
<th>Type of compound</th>
<th>Particles to visualize</th>
<th>Examples</th>
<th>Type of Attraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ionic</td>
<td>cations and anions</td>
<td>NaCl</td>
<td>ionic bonds</td>
</tr>
<tr>
<td>nonpolar molecular</td>
<td>molecules</td>
<td>hydrocarbons</td>
<td>London forces</td>
</tr>
<tr>
<td>polar molecular w/out H-F, O-H, or N-H</td>
<td>molecules</td>
<td>HCl</td>
<td>dipole-dipole</td>
</tr>
<tr>
<td>polar molecular with H-F, O-H, or N-H</td>
<td>molecules</td>
<td>HF, H₂O, NH₃, alcohols</td>
<td>hydrogen bonds</td>
</tr>
</tbody>
</table>
Particles and Types of Attractions for the Elements

- **Metals** – cations in a sea of electrons, metallic bonds
- **Noble gases** – atoms, London forces
- **Carbon (diamond)** – atoms, covalent bonds
- **Other nonmetallic elements** – molecules, London forces
Particles and Types of Attractions for the Compounds

- **Ionic** – cations and anions, ionic bonds
- **Molecular**
  - Nonpolar – molecules, London forces
  - Polar without H-F, O-H, or N-H – molecules, dipole-dipole attractions
  - Polar with H-F, O-H, or N-H – molecules, hydrogen bonds