Liquids, Solids and Phase Changes

12.1 Physical States and Phase Changes

• Physical states – gas, liquid and solid
  – Phases – physically distinct, homogeneous parts of a sample of matter (can be gaseous, liquid or solid)
  – Condensed phases – liquid or solid
    • A sample can contain more than one liquid phases (immiscible) or more than one solid phases
  – Phase changes – conversions between the different phases of a substance

• Intramolecular (bonding) forces – exist within each molecule or polyatomic ion (influence the chemical properties)
• Intermolecular (interparticle) forces – exist between the particles (molecules or ions) of a substance (influence the physical properties)

Kinetic-Molecular View of the Three States

• The physical state of a substance is governed by the relative magnitudes of the potential energy of intermolecular attraction and the kinetic energy of molecular motion

Gas – the particles are far apart; the energy of motion dominates the energy of attraction
Liquid – the particles are close together; the energies of attraction and motion are comparable
Solid – the particles are close together; the energy of attraction dominates the energy of motion

<table>
<thead>
<tr>
<th>State</th>
<th>Shape and Volume</th>
<th>Compressibility</th>
<th>Ability to Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Conforms to shape and volume of container</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Liquid</td>
<td>Conforms to shape of container; volume limited by surface</td>
<td>Very low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Solid</td>
<td>Maintains its own shape and volume</td>
<td>Almost none</td>
<td>Almost none</td>
</tr>
</tbody>
</table>

Types of Phase Changes

• Phase changes are caused by changing conditions such as temperature and pressure
  – At high $T$, the $E_k$ of molecular motion increases
  – At high $P$, the molecules get closer together and the $E_p$ of intermolecular attraction increases
• Vaporization – conversion from liquid to gas
• Condensation – conversion from gas to liquid
• Melting (fusion) – conversion from solid to liquid
• Freezing – conversion from liquid to solid
• Sublimation – conversion from solid to gas
• Deposition – conversion from gas to solid
Enthalpies (Heats) of Phase Changes

- Phase changes are accompanied by energy and enthalpy changes
  - Vaporization, melting and sublimation are always endothermic – energy must be absorbed to overcome the intermolecular forces
  - Condensation, freezing and deposition are always exothermic – energy is released as the molecules get closer and attract each other

- Heat of vaporization ($\Delta H_{vap}$) – enthalpy change for the conversion of 1 mol of a substance from liquid to gas

- Heat of fusion ($\Delta H_{fus}$) – enthalpy change for the conversion of 1 mol of a substance from solid to liquid

- Heat of sublimation ($\Delta H_{sub}$) – enthalpy change for the conversion of 1 mol of a substance from solid to gas

- The heats of the reverse processes (condensation, freezing and deposition) have the same magnitudes but opposite signs (For example: $\Delta H_{cond} = -\Delta H_{vap}$)

- For most substances: $0 < \Delta H_{fus} < \Delta H_{vap} < \Delta H_{sub}$

- According to Hess’s law:

  $$\Delta H_{fus} + \Delta H_{vap} = \Delta H_{sub}$$