**17-6. Phase Change: Latent Heat**

Phase change:  \( \text{Solid} \xrightarrow{\text{Fusion}} \text{Liquid} \xrightarrow{\text{Vaporization}} \text{Gas} \)

Temperature: no change
Latent Heats

Solid $\xrightleftharpoons{Absorbs}{\text{Releases}}$ Liquid

Liquid $\xrightleftharpoons{Absorbs}{\text{Releases}}$ Gas

heat of fusion $L_F$

heat of vaporization $L_V$

Latent heat $Q = mL$

$L - \text{kcal/kg or J/kg}$

<p>| TABLE 15-4 |
| HEATS OF FUSION AND VAPORIZATION |</p>
<table>
<thead>
<tr>
<th>SUBSTANCE</th>
<th>NORMAL MELTING POINT</th>
<th>HEAT OF FUSION, $L_f$ (J/kg)</th>
<th>NORMAL BOILING POINT</th>
<th>HEAT OF VAPORIZATION, $L_v$ (J/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>$<em>^</em>$</td>
<td>$*$</td>
<td>4.216</td>
<td>$-268.93$</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>13.84</td>
<td>$-259.31$</td>
<td>58.6 $\times 10^3$</td>
<td>20.26</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>63.18</td>
<td>$-209.97$</td>
<td>25.5 $\times 10^3$</td>
<td>77.34</td>
</tr>
<tr>
<td>Oxygen</td>
<td>54.36</td>
<td>$-218.79$</td>
<td>13.8 $\times 10^3$</td>
<td>90.18</td>
</tr>
<tr>
<td>Ethanol</td>
<td>159</td>
<td>$-114$</td>
<td>104.2 $\times 10^3$</td>
<td>351</td>
</tr>
<tr>
<td>Mercury</td>
<td>234</td>
<td>$-39$</td>
<td>11.8 $\times 10^3$</td>
<td>630</td>
</tr>
<tr>
<td>Water</td>
<td>273.15</td>
<td>0.00</td>
<td>334 $\times 10^3$</td>
<td>373.15</td>
</tr>
<tr>
<td>Sulfur</td>
<td>392</td>
<td>119</td>
<td>38.1 $\times 10^3$</td>
<td>717.75</td>
</tr>
<tr>
<td>Lead</td>
<td>600.5</td>
<td>327.3</td>
<td>24.5 $\times 10^3$</td>
<td>2023</td>
</tr>
<tr>
<td>Antimony</td>
<td>903.65</td>
<td>630.50</td>
<td>168 $\times 10^3$</td>
<td>1713</td>
</tr>
<tr>
<td>Silver</td>
<td>1233.95</td>
<td>960.80</td>
<td>88.3 $\times 10^3$</td>
<td>2466</td>
</tr>
<tr>
<td>Gold</td>
<td>1336.15</td>
<td>1063.00</td>
<td>64.5 $\times 10^3$</td>
<td>2933</td>
</tr>
<tr>
<td>Copper</td>
<td>1356</td>
<td>1083</td>
<td>134 $\times 10^3$</td>
<td>1460</td>
</tr>
</tbody>
</table>

* A pressure in excess of 25 atmospheres is required to make helium solidify. At 1 atmosphere pressure, helium remains a liquid down to absolute zero.
17-7. Mechanisms of Heat Transfer

On a cold day, why is a piece of metal feels much colder to the touch than a piece of wood?

Heat transfer: only when there is a temperature difference
  Conduction: need medium
  Convection: need medium
  Radiation: No medium

Heat may be transferred by more than one way at the same time
Conduction

Molecular collision

\[ H = \frac{dQ}{dt} = k A \frac{T_H - T_C}{L} \]

Or:

\[ H = \frac{dQ}{dt} = A \frac{T_H - T_C}{R} \]

\( k \): thermal conductivity

\( J / s \cdot m \cdot K = W / m \cdot K \)

\( R = L/k \): thermal resistance

Conductors:
- Silver: 406
- Copper: 385
- Aluminum: 205
- Steel: 50

Insulators:
- Fiberglass: 0.04
- Wool: 0.04
- Goose down: 0.025
- Air: 0.024
Convection

Mass movements of molecules from one place to another. Only in fluids: liquids & gases.

Forced convection: circulation by pump/blower
Natural convection: natural density differences
Radiation

Every body emits energy in the form of electromagnetic radiation, no need for a medium.

Stefan-Boltzmann Equation

\[ H = \frac{dQ}{dt} = Ae\sigma T^4 \]

Stefan-Boltzmann constant \( \sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{-K}^4 \)

Emissivity \( e: 0 \) (shiny surfaces) \( \sim 1 \) (black)

Net flow rate of heat radiation

\[ \frac{dQ}{dt} = Ae\sigma(T_1^4 - T_2^4) \]

A good absorber is also a good emitter