Thermodynamics #2

0. Heat and phase transitions
   phases or states of matter (P, T)
   classic solid, liquid, gas
   exotic plasma (e-, nuclei+)
   superconductor, superfluid
   neutron star, quark-gluon plasma (?)

Sketch of phase diagram for water

Critical point
\[ p = 225 \text{ atm} \]
\[ T = 374 ^\circ \text{C} \]

Triple point (0.01°C)

Vaporize/condense
solidify (furn)/melt
sublimation

Phase change involves heat
called "latent" heat \( (L) \)

\[ Q = m \cdot v \cdot L \]
water @ 1 atm

\[ \begin{align*}
L_v &= 2.256 \times 10^5 \text{ J/kg} & \text{vaporization} \\
L_f &= 2.34 \times 10^5 \text{ J/kg} & \text{fusion} \\
Q &= L \cdot \text{mass}
\end{align*} \]

Example: Adding ice to water

\[ \begin{align*}
Q &= m_\text{w} C_\text{w} (T_0 - T_f) = \\
&= m_{\text{iw}} C_{\text{iw}} (-0^\circ \text{C} - T_{\text{ia}}) + m_{\text{ia}} L_f \\
&+ m_{\text{ia}} C_{\text{ia}} (T_f - 0^\circ \text{C})
\end{align*} \]

Conservation of energy
Conduction

Rate of heat transfer \( H = \frac{dQ}{dt} \)

depends on:
- Temperature difference
- Material, area, length
- Ends are held at fixed temperature

\[ H = \rho A \left( \frac{T_h - T_c}{L} \right) = \frac{A}{R} (T_h - T_c) \]

Thermal conductivity, material dependent constant

\[
\begin{align*}
\text{Cu} & \quad 385.0 \\
\text{Brass} & \quad 109.0 \\
\text{Steel} & \quad 50.2 \\
\text{Styrofoam} & \quad 0.01 \\
\text{Air} & \quad 0.024
\end{align*}
\]
Complete equality between emission/absorption

$$H_{\text{net}} = A e \sigma (T_\text{obj}^4 - T_\text{sky}^4)$$

Melting of Greenland ice:

Ice has small $e$, but water has large $e$:

- Sunlight

Once pool of water develops, rate of melting increases

What is the temperature of empty space (the universe)?

$$T = 2.7 \, \text{K} \quad \text{(microwave)}$$

called Cosmic Microwave Background (CMB)
Example:

\[
\begin{array}{c}
T_4 \\
\hline
k_1 & k_2 \\
\hline
L_1 & L_2 \\
T_{12}
\end{array}
\]

At equilibrium, with fixed \( T_4 \), \( T_c \), flow of heat is equal across any perpendicular area.

\[
H = k_1 A \frac{(T_4 - T_{12})}{L_1} = k_2 A \frac{(T_{12} - T_c)}{L_2}
\]

Solve for \( T_{12} \):

\[
\frac{k_1}{L_1} T_4 + \frac{k_2}{L_2} T_c = \left( \frac{k_1}{L_1} + \frac{k_2}{L_2} \right) T_{12}
\]

Solve for \( H \).

Thermal Resistance \( R_i = \frac{L_i}{k_i} \)

Mixes material property \( k \) up length, but useful in practice. Can show,

\[
H = A \frac{(T_{14} - T_L)}{R_1 + R_2}
\]

Thermal resistance add: \( R_{eff} = R_1 + R_2 \)

"imperial unit" "R-value" \( 6^{\prime}\cdot F/\text{in}/8\text{in} \approx 0.176 \text{ K m}^2/\text{W} \)
3. Radiative heat transfer:

EM spectrum \( \lambda \cdot f = c \)

\[ c = 3 \times 10^8 \text{ m/s} \]

<table>
<thead>
<tr>
<th>Range</th>
<th>( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>( \sim 50 \text{ nm} )</td>
</tr>
<tr>
<td>Visible</td>
<td>400 - 700 nm</td>
</tr>
<tr>
<td>Infrared</td>
<td>( \sim 10 \mu\text{m} )</td>
</tr>
<tr>
<td>Microwave</td>
<td>( \sim \text{mm} )</td>
</tr>
<tr>
<td>Radio waves</td>
<td>( \sim \text{m} )</td>
</tr>
</tbody>
</table>

All objects emit radiation according to their temperature.

Spectrum has "black-body" like (universal) shape see p. 1335

\[ I(\lambda) \]

\[ \lambda_m \cdot T = 2.90 \times 10^{-3} \text{ m.K} \quad \text{(Wien law)} \]

28. 38. 30
\[
T = \frac{2.90 \times 10^{-3} \text{ m} \cdot \text{K}}{\text{500 nm}} = \frac{3}{5} \times 10^{4} \text{ K}
\]

\[
= 6000 \text{ K}
\]

approximately the \( T \) of the surface of the sun.

or \( \lambda = \frac{2.90 \times 10^{-3} \text{ m} \cdot \text{K}}{(273 + 37)^{4}} \text{ m} \)

body temperature

infrared

infrared radiation

detection

night vision

ear thermometer
Rate of heat loss due to radiation

\[ \frac{dQ}{dt} = A e \sigma T^4 \]

\( A \) = surface area

\( e \) = emissivity describes type of surface

0 \( \leq e \leq 1 \), \( e = 1 \) "black-body"

perfect absorber/emitter of radiation

0, perfect reflector

Typically, \( e (2) \) but usually can be ignored

\( e \) of silver is very low

Diagram:

\[ T = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \]

Stephen Boltzmann's universal constant of nature.