Temperature and Heat

March 27, 2012

Chapter

17
Reminder of the Zeroth Law of Thermodynamics and the Principle of Thermal Equilibrium

(a) If systems $A$ and $B$ are each in thermal equilibrium with system $C$ ...

(b) … then systems $A$ and $B$ are in thermal equilibrium with each other
The Zeroth Law

- If C is initially in thermal equilibrium with both A and B then A and B are also in thermal equilibrium with each other.

- Further, two systems are in thermal equilibrium if and only if they have the same temperature.
Temperature Scales and Thermometers

(a) Metal 1
(b) Metal 2

When heated, metal 2 expands more than metal 1.

(c) Thermometer scale in °C
Every Day Temperature Scales of Fahrenheit and Celsius

- Fahrenheit Scale

\[ T_F = \frac{9}{5} T_C + 32^\circ \]

Based on water’s freezing and boiling points.
The Kelvin Scale of Absolute Temperature

- The Kelvin Scale is based on the temperature-pressure relationship for gasses. It was observed that this relationship had a common intercept for a variety of gasses when the pressure reached zero. The temperature at which this happened was -273.15°C.
<table>
<thead>
<tr>
<th>Temperature</th>
<th>K</th>
<th>C</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water boils</td>
<td>373</td>
<td>100°</td>
<td>212°</td>
</tr>
<tr>
<td>Water freezes</td>
<td>273</td>
<td>0°</td>
<td>32°</td>
</tr>
<tr>
<td>CO₂ solidifies</td>
<td>195</td>
<td>-78°</td>
<td>-109°</td>
</tr>
<tr>
<td>Oxygen liquifies</td>
<td>90</td>
<td>-183°</td>
<td>-298°</td>
</tr>
<tr>
<td>Absolute zero</td>
<td>0</td>
<td>-273°</td>
<td>-460°</td>
</tr>
</tbody>
</table>
A reminder about the proper use of the Kelvin Scale

**INCORRECT**

\[ T = 273.15 \, ^\circ K \]

**CORRECT**

\[ T = 273.15 \, K \]
Thermal Expansion

\[ \Delta L = \alpha L_0 \Delta T \] (linear thermal expansion)

\[ \Delta V = \beta V_0 \Delta T \] (volume thermal expansion)
Typical expansion coefficients $\alpha$ (note that $\beta = 3\alpha$ for solids)

<table>
<thead>
<tr>
<th>Material</th>
<th>Expansion Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>$2.4 \times 10^{-5}$ K$^{-1}$</td>
</tr>
<tr>
<td>Brass</td>
<td>$2.0 \times 10^{-5}$</td>
</tr>
<tr>
<td>Copper</td>
<td>$1.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>Glass</td>
<td>$0.4 - 0.9 \times 10^{-5}$</td>
</tr>
<tr>
<td>Quartz</td>
<td>$0.04 \times 10^{-5}$</td>
</tr>
<tr>
<td>Steel</td>
<td>$1.2 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
The expansion of water is nearly linear, but in the range of 0-10 degrees C there is a region of non-linearity.
Thermal Stresses in materials

\[
\left( \frac{\Delta L}{L_0} \right)_{\text{thermal}} = \alpha \Delta T
\]

from chapter 11 on Young's Modulus we saw :

\[
\left( \frac{\Delta L}{L_0} \right)_{\text{tension}} = \frac{F}{AY}
\]

\[
\left( \frac{\Delta L}{L_0} \right)_{\text{thermal}} + \left( \frac{\Delta L}{L_0} \right)_{\text{tension}} = 0
\]

then \[
\frac{F}{A} = -YA\alpha \Delta T \quad \text{(thermal stress)}
\]
Heat.. another kind of energy

- Temperature rise in a liquid is directly proportional to the work done on the liquid... from the work of Sir James Joule.
Units of Heat

A calorie is the amount of heat required to raise the temperature of 1 gram of water from 14.5 °C to 15.5° C.

1 calorie = 4.186 J
1 kcal = 4186 J
1 Btu = 252 cal = 1055 J
Specific Heat

\[ Q = mc\Delta T \]

Where \( Q \) is the heat required for a temperature change of \( \Delta T \) of mass \( m \) and \( c \) is its specific heat:

\[ c = \frac{1}{m} \frac{dQ}{dT} \]

the specific heat of water is 4190 J/kg K;

1 cal/g °C; 1 Btu/lb °F.