Learning Goals

• Identify the relation between stresses and changes of length for various parts of a multipart structure undergoing thermal expansion
• Explain what is meant by heat
• For objects of equal mass in thermal contact, to explain why the temperature changes of the two objects need not be the same when heat flows from one to the other
• Deduce the specific heat / heat capacity of a system of known mass from a graph of temperature vs energy added. Explain how this heat capacity is related to the slope of such a graph
• Provide a microscopic reason why certain materials have a larger molar specific heat than other materials
Last time in Physics 157...
Net change in length

\[ \Delta L = \Delta L_T + \Delta L_F \]

\[ \Delta L_T = \alpha L \Delta T \quad \Delta L_F = \frac{1}{Y} L \frac{\Delta F}{A} \]

This applies to each part of a system.
Stressed Rods

A compound bar consisting of a copper rod with a length of 1 m and cross-section area of 2.00 cm$^2$ placed end to end with a steel rod with length 1m and cross-section area 2.00 cm$^2$. The compound rod is placed between two rigid walls. Initially there is no stress in the bars at room temperature 20º C.

Find the force on each wall at 40º C.

$\alpha_{\text{steel}} = 12 \times 10^{-6}$ K$^{-1}$, $\alpha_{\text{copper}} = 17 \times 10^{-6}$ K$^{-1}$,

$Y_{\text{steel}}= 200 \times 10^9$ N m$^{-2}$, $Y_{\text{copper}}= 110 \times 10^9$ N m$^{-2}$
Length change from $\Delta T$ and $\Delta F$ for each part:

$$\Delta L_1 = \alpha_1 L \Delta T - \frac{F}{A} \cdot \frac{L}{Y_1}$$

$$\Delta L_2 = \alpha_2 L \Delta T - \frac{F}{A} \cdot \frac{L}{Y_2}$$
\[
\begin{align*}
\Delta L_1 + \Delta L_2 &= 0 \quad \text{(1)} \\
\Delta L_1 &= \alpha_1 L \Delta T - \frac{F \cdot L}{A \cdot Y_1} \quad \text{(2)} \\
\Delta L_2 &= \alpha_2 L \Delta T - \frac{F \cdot L}{A \cdot Y_2} \quad \text{(3)}
\end{align*}
\]

Solve for \( F \)

\[
F = \frac{(\alpha_1 + \alpha_2) \Delta T}{\left(\frac{1}{Y_1} + \frac{1}{Y_2}\right)} \cdot A = 8.2 \times 10^3 \text{ N}
\]
If you find it annoying to use your calculator...

Type some Sage code below and press Evaluate.

1. \(\alpha_1 = 12 \times 10^{-6}\)
2. \(\alpha_2 = 17 \times 10^{-6}\)
3. \(V_1 = 200 \times 10^9\)
4. \(V_2 = 110 \times 10^9\)
5. \(DT = 1520\)
6. \(A = 2.0 \times 10^{-4}\)
7. \(A \times DT \frac{(\alpha_1 + \alpha_2)}{(1/V_1 + 1/V_2)}\)

Evaluate

Answer: 0.823225806451613
The structure shown has various parts all made of different materials.

1) If the system is heated, what constraints must be satisfied by the four quantities \( \Delta L_1, \Delta L_2, \Delta L_3, \) and \( \Delta L_4? \)

2) After heating, the green, red, and black objects have compressive forces \( F_2, F_3, \) and \( F_4 \) acting on their ends. What is the relation between the magnitude of these forces?

Click A if you are done number 1
Click B if you are done number 1 and 2
Click C if you are stuck
The structure shown has various parts all made of different materials.

1) If the system is heated, what constraints must be satisfied by the four quantities $\Delta L_1$, $\Delta L_2$, $\Delta L_3$, and $\Delta L_4$?

2) After heating, the green, red, and black objects have compressive forces $F_2$, $F_3$, and $F_4$ acting on their ends. What is the relation between the magnitude of these forces?
**Heat:**

\[ Q = \text{heat: amount of energy transferred due to temperature differences} \]
Clicker: two objects with the same mass are put in thermal contact but insulated from their environment. If the initial temperatures are 100°C and 0°C, the final equilibrium temperature will be

A) Somewhere between 0°C and 100°C but not necessarily 50°C
B) 50°C
C) Not necessarily between 0°C and 100°C
Heat required to raise the temperature of a material determined by its **specific heat** $c$:

$$Q = m \cdot c \cdot \Delta T$$

- $Q$: heat added
- $m$: mass
- $c$: specific heat
- $\Delta T$: change in temperature

$c$ in $\frac{J}{kg \cdot K}$: energy required to heat 1 kg of material by 1 K
Heat is added to two kilograms of a liquid, and data for the temperature vs energy transfer is shown.

If we took data for another liquid with the same mass but a larger specific heat, the slope of this graph would be

A) Larger  
B) Smaller  
C) The same  
D) Any of the above are possible.

**EXTRA:** what is the specific heat of the original liquid?
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If we took data for another liquid with the same mass but a larger specific heat, the slope of this graph would be

A) Larger
B) Smaller
C) The same
D) Any of the above are possible.

**EXTRA:** what is the specific heat of the original liquid?

\[ Q = mc \Delta T \]

\[ c = \frac{3000}{7.2} \approx 200 \text{ J/kg K} \]
Heat required to raise the temperature of a material determined by its **specific heat** $c$:

\[ Q = m \cdot c \cdot \Delta T \]

**OR:**

\[ Q = n \cdot C \cdot \Delta T \]

- $m$ is the mass
- $n$ is the number of moles
- $C$ is the molar specific heat = molar heat capacity

$c$ in $\frac{J}{kg \cdot K}$: energy required to heat 1 kg of material by 1 K

$C$ in $\frac{J}{mol \cdot K}$: energy required to heat 1 mole of material by 1 K
### Table 17.3  Approximate Specific Heats and Molar Heat Capacities (Constant Pressure)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific Heat, $c$ (J/kg · K)</th>
<th>Molar Mass, $M$ (kg/mol)</th>
<th>Molar Heat Capacity, $C$ (J/mol · K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>910</td>
<td>0.0270</td>
<td>24.6</td>
</tr>
<tr>
<td>Beryllium</td>
<td>1970</td>
<td>0.00901</td>
<td>17.7</td>
</tr>
<tr>
<td>Copper</td>
<td>390</td>
<td>0.0635</td>
<td>24.8</td>
</tr>
<tr>
<td>Ethanol</td>
<td>2428</td>
<td>0.0461</td>
<td>111.9</td>
</tr>
<tr>
<td>Ethylene glycol</td>
<td>2386</td>
<td>0.0620</td>
<td>148.0</td>
</tr>
<tr>
<td>Ice (near 0°C)</td>
<td>2100</td>
<td>0.0180</td>
<td>37.8</td>
</tr>
<tr>
<td>Iron</td>
<td>470</td>
<td>0.0559</td>
<td>26.3</td>
</tr>
<tr>
<td>Lead</td>
<td>130</td>
<td>0.207</td>
<td>26.9</td>
</tr>
<tr>
<td>Marble (CaCO₃)</td>
<td>879</td>
<td>0.100</td>
<td>87.9</td>
</tr>
<tr>
<td>Mercury</td>
<td>138</td>
<td>0.201</td>
<td>27.7</td>
</tr>
<tr>
<td>Salt (NaCl)</td>
<td>879</td>
<td>0.0585</td>
<td>51.4</td>
</tr>
<tr>
<td>Silver</td>
<td>234</td>
<td>0.108</td>
<td>25.3</td>
</tr>
<tr>
<td>Water (liquid)</td>
<td>4190</td>
<td>0.0180</td>
<td>75.4</td>
</tr>
</tbody>
</table>
Why is heat capacity higher for some materials?

Temperature proportional to average kinetic energy of molecules

For more complicated materials, part of added energy added goes to rotations/vibrations etc..., so it takes more $Q$ to increase the kinetic energy.