Physics 2101
Section 6
November 15th: Ch. 18

Announcement:

- Final Exam: December 6th
- Makeup: December 8th

Lecture Notes:
http://www.phys.lsu.edu/classes/fall2012/phys2101-6/
Quick Review: Temperature

How do we know about temperature?  

**thermometers**

**Linear scale: need 2 points to define**

- **Fahrenheit [° F]**  
  body temp and ~1/3 of body temp  
  ~100 ° F  
  ~33 ° F

- **Celsius [° C]**  
  “freezing point” and “boiling point” of water  
  0 ° C  
  100 ° C

- **Kelvin [K]**  
  Absolute zero and triple point of water  
  0 K  
  273.16 K

**Conversion factors**

- **K → ° C**  
  \[ T_C = T_K - 273.15^\circ \quad (1 \Delta K = 1 \Delta^\circ C) \]

- **° C → ° F**  
  \[ T_F = \frac{9}{5} T_C + 32^\circ \]
Fahrenheit originally established a scale in which the temperature of an ice-water-salt mixture was set at 0 degrees.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point of water&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100</td>
<td>212</td>
</tr>
<tr>
<td>Normal body temperature</td>
<td>37.0</td>
<td>98.6</td>
</tr>
<tr>
<td>Accepted comfort level</td>
<td>20</td>
<td>68</td>
</tr>
<tr>
<td>Freezing point of water&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>Zero of Fahrenheit scale</td>
<td>≈ −18</td>
<td>0</td>
</tr>
<tr>
<td>Scales coincide</td>
<td>−40</td>
<td>−40</td>
</tr>
</tbody>
</table>

<sup>a</sup>Strictly, the boiling point of water on the Celsius scale is 99.975°C, and the freezing point is 0.00°C. Thus, there is slightly less than 100°C between those two points.
Quick Review: Linear Thermal Expansion

Most substances expand when heated and contract when cooled.

\[ \Delta L = \alpha L_0 \Delta T \]

\[ L = L_0 \left(1 + \alpha \Delta T\right) \]
Example: Bimetal Strip

Common device to measure and control temperature

\[ |F| = kx = kL_0 \left( 1 + \alpha \Delta T \right) \]
Thermal expansion and a Pendulum Clock

\[ T = 2\pi \sqrt{\frac{L}{g}} \]

\[ L = L_0 + \Delta L = L_0 + \alpha_{\text{brass}} L_0 \Delta T \]

If the original period was 1 second

\[ L_0 = \left( \frac{1s}{2\pi} \right)^2 g = 24.824 \text{ cm} \]

\[ L = 24.824 \text{ cm} \left( 1 + (19 \times 10^{-6} / \degree C)(-20\degree C) \right) \]

\[ = 24.824 \text{ cm}(0.9996) \]

\[ = 24.814 \text{ cm} \]

It runs slow (less time per tick)

\[ \# \text{ ticks} = 24 \times 60 \times 60 = 86400 \text{ at } 20\degree C \]

\[ \text{at } 0\degree C: \quad \text{time} = 86400 \times 0.9998 = 86383 \text{ s} \]

\[ 1.7 \text{ hr/yr behind at } 0\degree C \]

Problem 2: Pendulum Clock

A pendulum clock made of brass is designed to keep accurate time at 20\degree C. If the clock operates at 0\degree C, does it run fast or slow?

If so, how much?

The new period is:

\[ T = 2\pi \sqrt{\frac{24.814}{9.8}} = 0.9998 \text{ s} \]
18-6 Area Expansion

Expansion in 1-D

\[ \Delta L = \alpha L_0 \Delta T \]
\[ L = L_0 \left(1 + \alpha \Delta T\right) \]

Expansion in 2-D

\[ A = \left[ L_0 \left(1 + \alpha \Delta T\right) \right] \left[ W_0 \left(1 + \alpha \Delta T\right) \right] \]
\[ \Delta A = A_0 \left(1 + \alpha \Delta T\right)^2 - A_0 \]
\[ = A_0 \left(2\alpha \Delta T + (\alpha \Delta T)^2\right) \]
\[ \equiv A_0 \left(2\alpha\right) \Delta T \]
\[ \equiv A_0 \beta \Delta T \]

\[ \beta = 2\alpha \]
Thermal Expansion of Holes

Do holes expand or contract when heated?

Does radius increase or decrease when heated?

The hole gets larger too!
When the temperature of the piece of metal shown below is increased and the metal expands, what happens to the gap between the ends?

1. It becomes narrower
2. It becomes wider
3. It remains unchanged
Volume Expansion

Expansion in 1-D
\[ \Delta L = \alpha L_0 \Delta T \]
\[ L = L_0 \left( 1 + \alpha \Delta T \right) \]

Expansion in 2-D
\[ \Delta A 
\approx A_0 (2\alpha) \Delta T 
\approx A_0 \beta_A \Delta T \]

Expansion in 3-D
\[ V = \left[ L_0 \left( 1 + \alpha \Delta T \right) \right] \left[ W_0 \left( 1 + \alpha \Delta T \right) \right] \left[ H_0 \left( 1 + \alpha \Delta T \right) \right] \]
\[ \Delta V = V_0 \left( 1 + \alpha \Delta T \right)^3 - V_0 \]
\[ = V_0 \left( 3\alpha \Delta T + 3(\alpha \Delta T)^2 + (\alpha \Delta T)^3 \right) \]
\[ \approx V_0 (3\alpha) \Delta T \]
\[ \approx V_0 \beta_V \Delta T \]
\[ \beta_V = 3\alpha \]

--- coefficient of volume expansion

Volume expansion coefficients
solids: \( 1 - 87 \times 10^{-6}/^\circ C \)
liquids: \( 210 - 1100 \times 10^{-6}/^\circ C \)
gasses: \( 3400 \times 10^{-6}/^\circ C \)
Problem 3: Gas tank in the sun
The 70-L steel gas tank of a car is filled to the top with gasoline at 20°C. The car is then left to sit in the sun, and the tank reaches a temperature of 40°C. How much gasoline do you expect to overflow from the tank? [gasoline has a coefficient of volume expansion of 950×10^{-6}/°C ]
How does a thermometer work?

Is it linear expansion?

Mercury \[ \alpha \approx 61 \times 10^{-6} / ^\circ C \]

\[ \Delta L \approx 61 \times 10^{-6} / ^\circ C (20 cm)(20 ^\circ C) \]

\[ \approx 0.2 mm \]

...so it can’t be linear expansion

How about bulk (volume) expansion?

assume that the bulb is 10mmx2mmx2mm=40mm³

\[ \Delta V = (182 \times 10^{-6} \ ^\circ C^{-1})(40 mm^3)(20 ^\circ C) \]

\[ = 0.145 mm^3 \]

So if the column is 0.1mm x 0.1mm then it will go up 14.5 mm

VOLUME EXPANSION
Zeroth Law of Thermodynamics

**Defines THERMAL EQUILIBRIUM**

If two systems are in thermal equilibrium with a third, then they are in thermal equilibrium with each other

\[ T_1 = T_2 = T_3 \]

No Heat flow

In this case:

a) \( A \) is in thermal equilibrium with \( T \)

b) \( B \) is in thermal equilibrium with \( T \)

c) \( A \) & \( B \) are in thermal equilibrium
Temperature and Heat

If two objects are NOT in thermal equilibrium, their temperatures must be different.

To make their temperatures equal (i.e. thermal equilibrium), HEAT MUST FLOW.

HEAT has to do with the transfer of thermal energy.

Symbol for HEAT: \( Q \) - **BE VERY CAREFUL ABOUT THE SIGN**

**“System”** - particular objector or set of objects

**“Environment”** - everything else in the universe

- **Heat is negative** when energy is transferred from the system’s thermal energy to its environment (heat is released or lost)
- **Heat is zero** when no energy is transferred between the system’s thermal energy and its environment (AT THERMAL EQUILIB)
- **Heat is positive** when energy is transferred to the system’s thermal energy from its environment (heat is absorbed)
Heat: Transfer of Thermal Energy

Remember: WORK (W) - energy transferred to system via a force acting on it

James Joule (1818-1889)

-> A given amount of work done is equivalent to a particular amount of heat input

Units:

joule (or J): SI unit

calorie: “the amount of heat that would raise the temperature of 1 g of water from 14.5°C to 15.5°C

Btu: “the amount of heat that would raise the temperature of 1 lb of water from 63°F to 64°F

Mechanical equivalent to Heat:

1 cal = 3.969×10^{-3} Btu = 4.1860 J
1 Cal = 1000 cal = 1 kilocalorie
Absorption of Heat by Solids and Liquids

If heat is put into a solid, the temperature rises. How much?

\[ Q = C \Delta T = C(T_f - T_i) \]

“Change of system energy with change of temperature”

**Heat Capacity**

- depends on the material

**Heat Transfer**

**Specific Heat** (heat capacity \( \propto \) mass)

\[ Q = cm \Delta T = cm(T_f - T_i) \]

Water: \( c_{\text{water}} = 1 \text{ cal/g} \cdot ^\circ \text{C} = 1 \text{ Btu/lb} \cdot ^\circ \text{F} = 4190 \text{ J/kg} \cdot ^\circ \text{C} \)

\(~\text{independent of mass}\)

**Molar Specific Heat** (heat capacity \( \propto \) # of particles)

\[ Q = c_{\text{molar}} n \Delta T \]

1 mol = \(6.02 \times 10^{23}\) elementary units
Heat Capacity (C) versus Specific Heat (c)

C = cm

Heat capacity  specific heat

\[ Q = cm \Delta T = cm(T_f - T_i). \]  

(18-14)

\[ c = \frac{1\text{cal}}{gC^0} = \frac{1\text{BTU}}{lbF^0} = \frac{4190\text{J}}{kgK} \]

Molar Specific Heat

1 mol = 6.02x10^{23} elementary units
--1 mol of Aluminum is = 6.02x10^{23} atoms
--1 mol of CO is = 6.02x10^{23} molecules

Molar Specific Heat

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific Heat</th>
<th>Molar Specific Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cal</td>
<td>J</td>
</tr>
<tr>
<td></td>
<td>g \cdot K</td>
<td>kg \cdot K</td>
</tr>
<tr>
<td><strong>Elemental Solids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>0.0305</td>
<td>128</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.0321</td>
<td>134</td>
</tr>
<tr>
<td>Silver</td>
<td>0.0564</td>
<td>236</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0923</td>
<td>386</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.215</td>
<td>900</td>
</tr>
<tr>
<td><strong>Other Solids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td>0.092</td>
<td>380</td>
</tr>
<tr>
<td>Granite</td>
<td>0.19</td>
<td>790</td>
</tr>
<tr>
<td>Glass</td>
<td>0.20</td>
<td>840</td>
</tr>
<tr>
<td>Ice (−10°C)</td>
<td>0.530</td>
<td>2220</td>
</tr>
<tr>
<td><strong>Liquids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>0.033</td>
<td>140</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>0.58</td>
<td>2430</td>
</tr>
<tr>
<td>Seawater</td>
<td>0.93</td>
<td>3900</td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>4180</td>
</tr>
</tbody>
</table>
Absorption of Heat: Problem #18-42

A 20.0 g copper ring at 0.000 °C has an inner diameter of D=2.54000 cm. An Al sphere at 100.0 °C has a diameter of d= 2.54508 cm. The sphere is placed on top of the ring and the two are allowed to come to thermal equilibrium, with no heat lost to the surroundings. The sphere just passes through the ring at the equilibrium temperature. What is the mass of the sphere???

First find the temperature where D=d

\[ D = D_0 \left(1 + \alpha_{Cu} (T_f - 0)\right) \]
\[ d_f = d_i \left(1 + \alpha_{Al} (T_f - 100)\right) \]
\[ 2.54000 \left(1 + \alpha_{Cu} (T_f - 0)\right) = 2.54508 \left(1 + \alpha_{Al} (T_f - 100)\right) \]

\[ T_f = 50.38^\circ C \]

Heat into ring \( Q = c_{Cu} m_r T_f \)

Heat from Sphere \( |Q| = c_{Al} m_s \left(T_f - T_i\right) \)

\[ m_s = \frac{c_{Cu} m_r T_f}{c_{Al} \left(T_f - T_i\right)} \]
Calorimetry
If 0.20 kg of tea at 95°C is poured into a 0.15 kg glass cup initially at 25 °C, what will be the final temperature $T_f$ of the mixture when equilibrium is reached, assuming no heat flows to the surroundings ($c_{\text{glass}} = 840 \text{ J/kg} \cdot \text{K}$ & $c_{\text{water}} = 4190 \text{ J/kg} \cdot \text{K}$).

Heat lost = heat gained or $\sum Q = 0$
More Example: Hot Jogger

In a half hour a 65-kg jogger can generate $8 \times 10^5$ J of heat. If the heat were not removed by the various means possible, by how much will the body’s temperature rise?

In the relatively cool environmental temperature of 50 F, healthy marathon runners can have body temperatures as high as 103.8 F. Weight lifters often have temperatures of 101 F during workouts in a warm gym. One runner who was still conscious is reported to have developed a temperature of 107.8 F after finishing a marathon, but most people cannot tolerate temperatures that high.

When your temperature rises above 102, your muscle often start to burn, when your temperature is over 104 you will usually become short of breath and when your temperature rises above 105, you will often have signs of brain distress, such as a headache, blurred vision, ringing in your ears, dizziness, nausea and passing out.