Physics 110
Spring 2006
Heat – Their Solutions

NOTE: YOU WILL NEED TO LOOK UP THERMAL AND VOLUME EXPANSION COEFFICIENTS FOR VARIOUS MATERIALS!

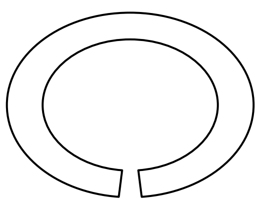
1. A copper telephone wire has essentially no sag between poles 35m apart on a winter day when the temperature is -20^{o}C. How much longer is the wire when the temperature is 35^{o}C on a sunny summer day?

   $$\Delta L = L_{old}\alpha\Delta T = 35m \times 1.7 \times 10^{-5}\left({}^{o}C\right)^{-1} \times \left(35^{o}C - \left(-20^{o}C\right)\right) = 3.27cm$$

2. A square hole measuring 8cm along each side is cut in a sheet of copper. What is the change in area of the hole if the temperature of the sheet is increased by 50K? Is this an increase or decrease in area of the hole?

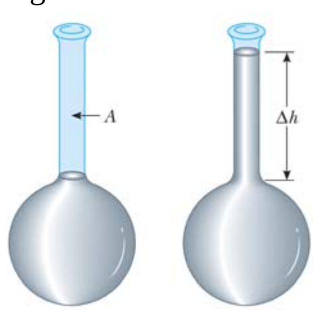
   $$\Delta A = 2\alpha A_{old}\Delta T = 2 \times 17 \times 10^{-6}\left({}^{o}C\right)^{-1} \times 0.0064m^2 \times \left(50^{o}C\right) = 1.09 \times 10^{-5}m^2 = 0.109cm^2$$
   and this is an increase in area since all dimensions expand.

3. A circular steel ring has a gap cut into it. If the ring is heated does the gap increase or decrease? If the gap has a width of 1.600cm when the temperature is 30^{o}C, what is the width of the gap when the temperature is 190^{o}C?

   The gap is approximately a linear dimension so it will increase when heated and $\Delta L = L_{old}\alpha\Delta T = 1.600cm \times 1.1 \times 10^{-5}\left({}^{o}C\right)^{-1} \times \left(160^{o}C\right) = 2.82 \times 10^{-3}cm$. Thus the new length will be 1.600cm + 0.0028cm = 1.603cm.

4. A mercury thermometer is constructed as shown below. The capillary tube has a diameter of 0.0040 cm and the bulb has a diameter of 0.250cm. Neglecting the expansion of the glass, what is the change in height of the mercury column that occurs with a temperature change of 30^{o}C?

$$\Delta V = A\Delta h = \beta V_{old}\Delta T \rightarrow \Delta h = \frac{\beta V_{old}\Delta T}{A} = \frac{\frac{4}{3}\pi(0.125cm)^3 \times 1.82\times10^{-4}\left({}^oC\right)^{-1}\times\left(30^oC\right)}{\pi(0.002cm)^2} = 3.55cm$$

5. A thermal window with an area of $3.0m^2$ and a thickness of 0.600cm. If the temperature difference between the surfaces is 25^oC, what is the rate of thermal energy transfer by conduction through the window?

$$P_{con} = \kappa\frac{A}{L}\Delta T = 0.8\tfrac{W}{m^{2\,o}C}\times\frac{3m^2}{6\times10^{-3}m}\times 25^oC = 10{,}000W = 10kW$$

6. Calculate the "R"-values for windows made of flat glass 1/8" thick and a thermal window made of two single panes each 1/8" thick separated by a ¼" airspace.

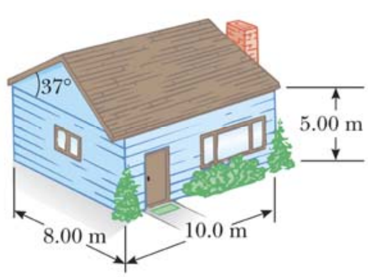
Single Pane: $R_{single} = \dfrac{L_{glass}}{\kappa_{glass}} = \dfrac{\frac{1}{8}" \times \frac{0.0254m}{1in}}{0.8\frac{W}{m^oC}} = 0.0040m^oC$

Double Pane: $R_{thermal} = \dfrac{2L_{glass}}{\kappa_{glass}} + \dfrac{L_{air}}{\kappa_{air}} = 2\times0.0040m^oC + \dfrac{\frac{1}{4}" \times \frac{0.0254m}{1in}}{0.0234\frac{W}{m^oC}} = 0.279m^oC$

7. The tungsten filament of a certain 100.0W light bulb radiates 2.0W of light. (The other 98.0W is carried away by conduction and convection.) The filament has a surface area of $0.250mm^2$ and an emissivity of 0.95. What is the temperature of the filament? (The melting point of tungsten is 3683K.)

$$P_{Rad} = \sigma\varepsilon AT^4 \rightarrow 2.0W = 5.67\times10^{-8}\tfrac{W}{m^2K^4}\times0.950\times0.25\times10^{-6}m^2T^4 \rightarrow T = 3490K$$

8. The average thermal conductivity of the walls (including windows and doors) and the roof of a typical house is $0.480\ W/m^{2o}C$ and the average thickness is 21.0cm. The house is heated with natural gas having a heat of combustion (the energy produced per cubic meter of gas burned) of $9300\ kcal/m^3$, where 1cal = 4.186J. How many cubic meters of gas must be burned each day to maintain an inside temperature of 25^oC if the outside temperature is 0^oC? (Neglect heat loss through the ground and the fact that the house absorbs and emits radiation.)



The total cross sectional area is given as

$$A_{Total} = A_{end\ walls} + A_{ends\ of\ attic} + A_{side\ walls} + A_{roof}$$

$$= 2(8m \times 5m) + 2\left(2 \times \frac{1}{2} \times 4m \times 4m \tan 37\right) + 2(10m \times 5m) + 2\left(10m \times \frac{4m}{\cos 37}\right).$$

$$= 304m^2$$

Thus the heat loss due to conduction is

$$P_{con} = \kappa \frac{A}{L} \Delta T = 4.8 \times 10^{-4} \tfrac{kW}{m^2\,{}^oC} \times \frac{304m^2}{0.21m} \times 25^oC = 17{,}400W = 17.4kW = 4.15 \frac{kcal}{s}.$$

The heat loss per day (~86400s per day) is $3.59 \text{x} 10^5$ kcal/day. Therefore the gas needed to replace this loss is found by dividing $3.59 \text{x} 10^5$ kcal/day by 9300 kcal/m^3, which is 38.6m^3/day.