WileyPLUS Assignment 4

Chapters 8, 9, 10

Due: Friday, November 27 at 11 pm

WileyPLUS Assignment 5

Will be available on Friday

This Week

Tutorial & Test 4

Next Week

Experiment 5: Thermal conductivity of an insulator

The Final Exam Schedule is Final!

Friday, December 18, 1:30 - 4:30 pm

Frank Kennedy Brown & Gold Gyms

The whole course

30 multiple choice questions

Formula sheet provided

Seating (this info is on Aurora)

Brown Gym: A - S

Gold Gym: T - Z

Temperature and Heat

Temperature: $T\,(^{o}C) = T\,(K) - 273.15$

Thermal expansion:

Linear expansion: $\Delta L = \alpha L_0 \Delta T$

Volume expansion: $\Delta V = \beta V_0 \Delta T$

$\beta \approx 3\alpha$

Specific heat:

Heat required to warm mass m by ΔT: $Q = mc\,\Delta T$

c = specific heat

Heat flows from high temperature to low

12.44/39

If the price of electrical energy is 0.186 dollars per kilowatt-hour, what is the cost of using electrical energy to heat the water in a swimming pool (12.3 m x 10.7 m x 1.87 m) from 10.3 to 27.7 °C?

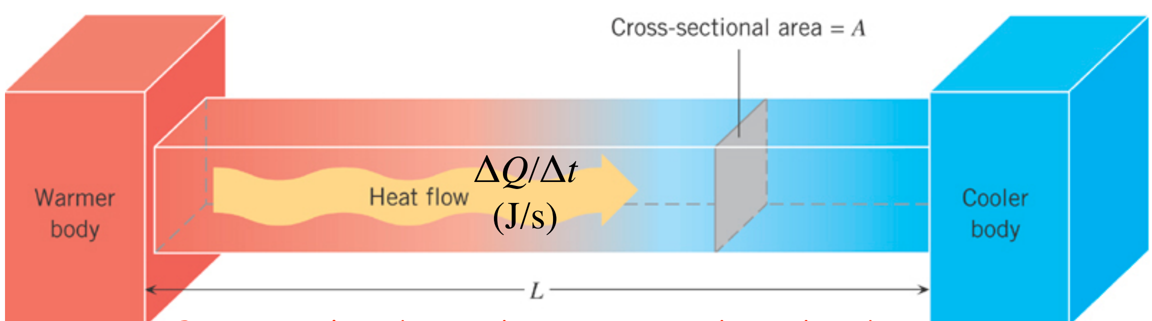
A Detour into Thermal Conduction, Chapter 13

for

Experiment 5
Thermal Conductivity of an Insulator

(examinable on final exam)

Conduction of Heat



T_1 Bar is insulated so no heat escapes through sides T_2

Heat flows along the bar at a rate that is proportional to:

- temperature difference between ends, $T_1 - T_2$
- area of cross section of the bar, A

(J/s, that is, W)

and is inversely proportional to:

- length of bar, L

$$\boxed{\frac{\Delta Q}{\Delta t} = \frac{kA(T_1 - T_2)}{L}}$$

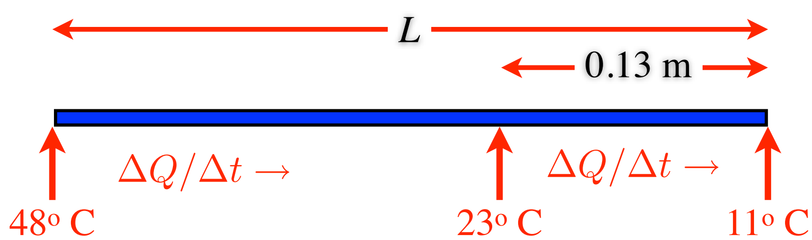
k = thermal conductivity

Table 13.1 Thermal Conductivities[a] of Selected Materials

Substance	Thermal Conductivity, k [J/(s·m·C°)]
Metals	
Aluminum	240
Brass	110
Copper	390
Iron	79
Lead	35
Silver	420
Steel (stainless)	14
Gases	
Air	0.0256
Hydrogen (H_2)	0.180
Nitrogen (N_2)	0.0258
Oxygen (O_2)	0.0265
Other Materials	
Asbestos	0.090
Body fat	0.20
Concrete	1.1
Diamond	2450
Glass	0.80
Goose down	0.025
Ice (0 °C)	2.2
Styrofoam	0.010
Water	0.60
Wood (oak)	0.15
Wool	0.040

[a] Except as noted, the values pertain to temperatures near 20 °C.

$$k = \frac{\Delta Q/\Delta t \times L}{A \times (T_1 - T_2)} \quad \text{W/(m.C}^{\text{o}}\text{)}$$



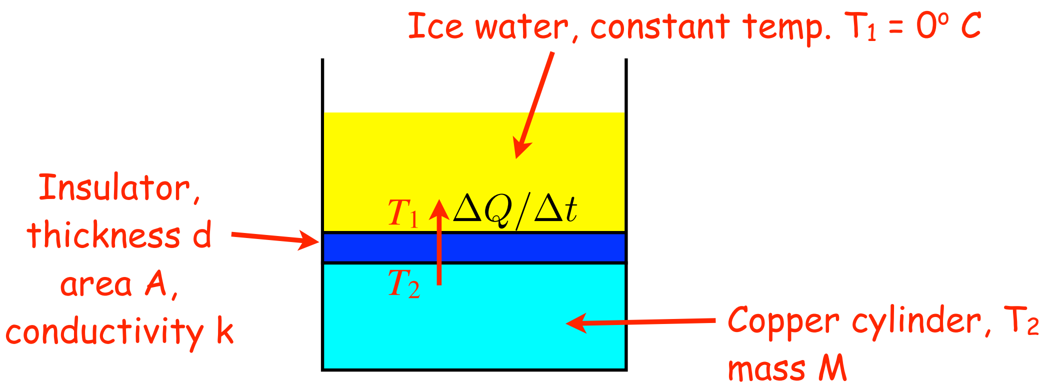
13.16/12: If the bar is of uniform cross-section and no heat is lost through the sides, what is the length of the bar?

As no heat is lost from the sides, the rate of heat flow is constant along the bar.

$$\frac{\Delta Q}{\Delta t} \propto \frac{\Delta T}{L} \qquad \text{A is constant}$$

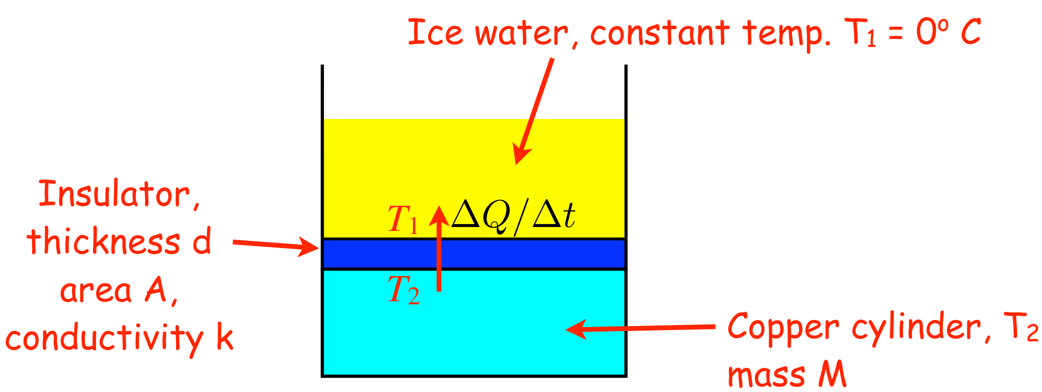
$$\text{So, } \frac{48 - 11}{L} = \frac{23 - 11}{0.13} \quad \rightarrow L = 0.4 \text{ m}$$

Experiment 5: Measure thermal conductivity of an insulator



Heat flows from the copper cylinder, through the insulator to the ice water, which is kept at T_1 = 0° C by the ice.

The copper cools down at a rate proportional to the heat flow, which depends on the thermal conductivity of the insulator.



The rate of heat flow through the insulator is: $\dfrac{\Delta Q}{\Delta t} = \dfrac{kA(T_2 - T_1)}{d}$

This heat comes from the copper, which is insulated from its surroundings

The rate of heat flow out of the copper is: $\dfrac{\Delta Q}{\Delta t} = -\dfrac{Mc\Delta T_2}{\Delta t}$

c = specific heat capacity of copper = 387 J/(kg.C°), table 12.2

$$\text{So, } \frac{\Delta Q}{\Delta t} = \frac{kA(T_2 - T_1)}{d} = -\frac{Mc\Delta T_2}{\Delta t}$$

$$\frac{\Delta Q}{\Delta t} = \boxed{\frac{kA(T_2 - T_1)}{d} = -\frac{Mc\Delta T_2}{\Delta t}}$$

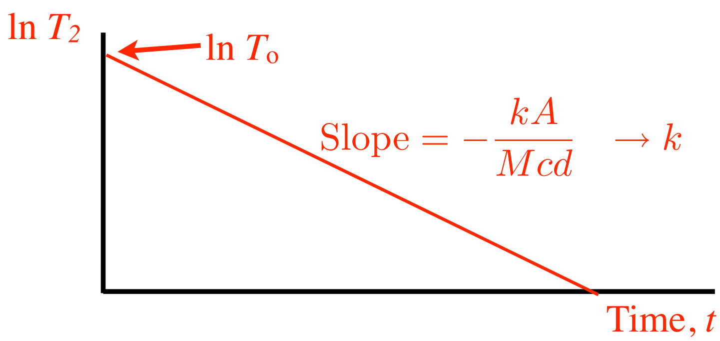
With T_1 fixed at 0° C, $\frac{\Delta T_2}{T_2} = -\frac{kA}{Mcd}\Delta t$

The solution is (rabbit out of hat integral calculus):

$$\ln T_2 = -\frac{kAt}{Mcd} + \ln T_0$$

(ln = natural log, "ln" or "$\log_e$" on calculator)

T_0 = temperature of copper when t = 0



13.3/27: A person's body is covered with 1.6 m^2 of wool clothing that is 2 mm thick. The temperature of the outside surface of the wool is 11°C and the skin temperature is 36°C. How much heat per second does the person lose by conduction?

Wool: k = 0.04 J/(s.m.C°)

The rate of heat conduction is: $\frac{\Delta Q}{\Delta t} = \frac{kA(T_1 - T_2)}{L}$

$$\frac{\Delta Q}{\Delta t} = \frac{0.04 \times 1.6 \times (36 - 11)}{0.002} = 800 \text{ J/s}$$

Metabolic rate when resting is 80 – 100 W

(Supplied by consuming 15 litres/hour of oxygen, each litre supplying 20,000 J of energy)

13.1/3: The amount of heat per second conducted from the blood capillaries beneath the skin to the surface is 240 J/s. The energy is transferred a distance of 2 mm through a body whose surface area is 1.6 m^2. Assuming that the thermal conductivity is that of body fat, determine the temperature difference between the capillaries and the surface of the skin.

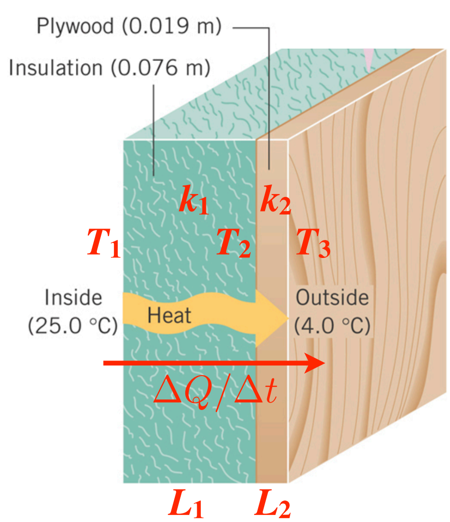
Substance	Thermal Conductivity, k [J/(s·m·C°)]
Body fat	0.20

Rate of heat conduction: $\frac{\Delta Q}{\Delta t} = \frac{kA(T_1 - T_2)}{L}$

$$240\ \mathrm{J/s} = \frac{0.2 \times 1.6(T_1 - T_2)}{0.002}$$

$$T_1 - T_2 = 1.5^\circ\mathrm{C}$$

Layered Insulation



The heat flow through the two layers is:

$$\frac{\Delta Q}{\Delta t} = \boxed{\frac{k_1 A(T_1 - T_2)}{L_1} = \frac{k_2 A(T_2 - T_3)}{L_2}}$$

$$T_2\left[\frac{k_1}{L_1} + \frac{k_2}{L_2}\right] = \frac{k_1 T_1}{L_1} + \frac{k_2 T_3}{L_2}$$

Insulation: $k_1 = 0.03$ J/s/m/C^o, $L_1 = 0.076$ m
Plywood: $k_2 = 0.08$ J/s/m/C^o, $L_2 = 0.019$ m

$$T_2\left[\frac{0.03}{0.076} + \frac{0.08}{0.019}\right] = \frac{0.03 \times 25}{0.076} + \frac{0.08 \times 4}{0.019}$$

$$\rightarrow\ T_2 = 5.8^\circ\ \mathrm{C}$$

$$\text{Heat flow} = \frac{k_2(T_2 - T_3)}{L_2} = 76\ \mathrm{W/m^2}\quad (890\ \mathrm{W/m^2}\ \text{without insulation})$$

(with $T_2 = 25^o$C)

Household insulation R-value

(for reference only!)

$$R\text{-value} \;=\; \frac{\text{Thickness of insulation in inches}}{\text{Thermal conductivity, } k} = \frac{L}{k}$$

$$\text{with } k = \frac{(\text{BTU per hour}) \times (\text{thickness, inches})}{(\text{area, square feet}) \times (^\circ\text{F})}$$

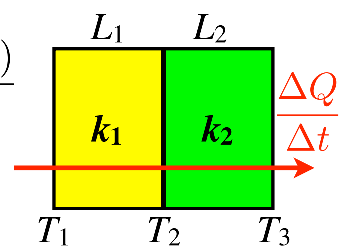
$$\left[k = \frac{\Delta Q/\Delta t \times L}{A \times (T_1 - T_2)}\right]$$

1 BTU (British Thermal Unit) = 1055 J

$$\text{Heat loss, W/m}^2 = 5.7 \times \frac{(T_1 - T_2) \text{ in } ^\circ\text{C}}{R\text{-value}}$$

Metric equivalent: *RSI*-value

Layered Insulation – R-value



$$\text{Heat flow: } \frac{\Delta Q}{\Delta t} = \frac{k_1 A(T_1 - T_2)}{L_1} = \frac{k_2 A(T_2 - T_3)}{L_2}$$

In terms of R-values ($R = L/k$):

$$\boxed{\text{Heat flow} = \frac{A(T_1 - T_2)}{R_1}} = \frac{A(T_2 - T_3)}{R_2}$$

$$\text{and, } T_2\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \frac{T_1}{R_1} + \frac{T_3}{R_2} \rightarrow \boxed{T_2 = \frac{R_2 T_1 + R_1 T_3}{R_1 + R_2}}$$

$$\text{Then, heat flow } = \frac{A}{\cancel{R_1}}\left[\frac{T_1(\cancel{R_1} + \cancel{R_2}) - (\cancel{R_2} T_1 + \cancel{R_1} T_3)}{R_1 + R_2}\right]$$

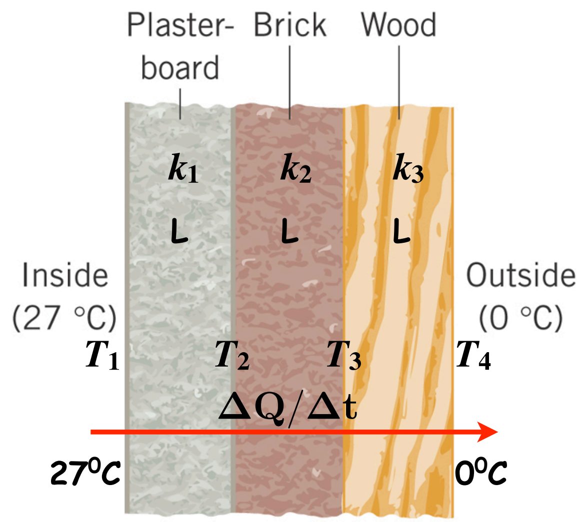
$$\rightarrow \frac{\Delta Q}{\Delta t} = \frac{A}{R_1 + R_2}(T_1 - T_3) \qquad R\text{-values add!}$$

Compare electrical resistances in series

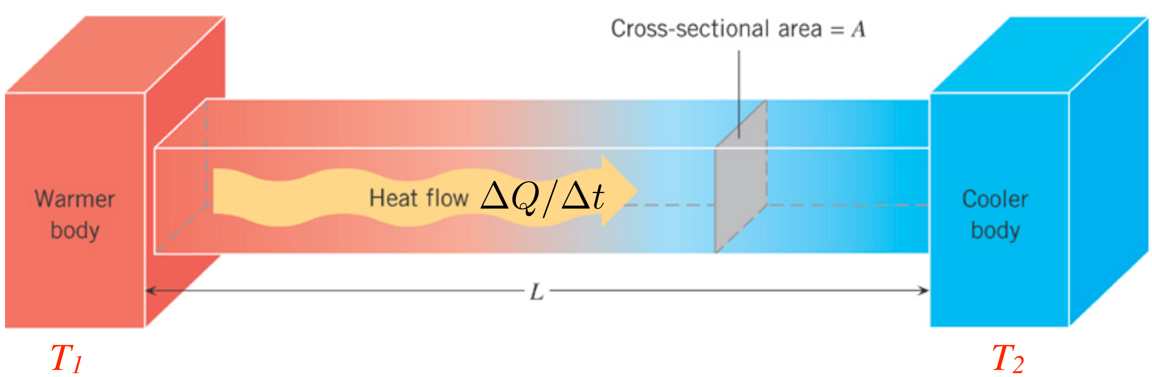
13.13/34: The three building materials have the same thickness, L, and cross-sectional area, A. Find the temperatures at the interfaces.

$k_1 = 0.3$ J/(s.m.C°), Plasterboard
$k_2 = 0.6$ J/(s.m.C°), Brick
$k_3 = 0.1$ J/)s.m.C°), Wood

$$\text{Heat flow} = \frac{A(T_1 - T_4)}{R_1 + R_2 + R_3}$$



Summary



$$\text{Heat flow} = \frac{kA(T_1 - T_2)}{L}$$

k = thermal conductivity, J/(s.m.C°), or W/(m.C°)

R-value = L/k (*RSI*-value when expressed in SI units)

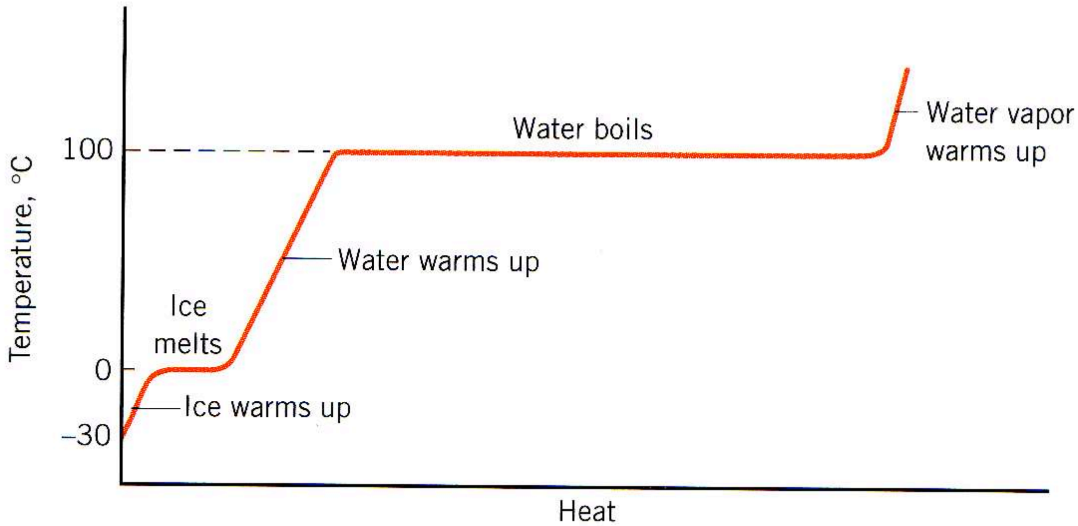
R- and *RSI*-values add

Latent Heat: Change of Phase

The three phases of matter: gas, liquid, solid.

Heat is absorbed, or released, when melting/freezing or boiling/condensation occurs, and temperature remains constant during the change.

Latent heat: the energy absorbed or released during a phase change.



Latent Heat

Heat absorbed/released, $Q = mL$, L = latent heat.

Melting/freezing:

Latent heat of fusion L_f = heat absorbed per kilogram on melting and released on freezing.

Boiling/condensing:

Latent heat of vaporization L_v = heat absorbed per kilogram on boiling and released on condensing.

Water: latent heat of fusion = 33.5×10^4 J/kg
latent heat of vaporization = 22.6×10^5 J/kg

Table 12.3 Latent Heats[a] of Fusion and Vaporization

Substance	Melting Point (°C)	Latent Heat of Fusion, L_f (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization, L_v (J/kg)
Ammonia	−77.8	33.2×10^4	−33.4	13.7×10^5
Benzene	5.5	12.6×10^4	80.1	3.94×10^5
Copper	1083	20.7×10^4	2566	47.3×10^5
Ethyl alcohol	−114.4	10.8×10^4	78.3	8.55×10^5
Gold	1063	6.28×10^4	2808	17.2×10^5
Lead	327.3	2.32×10^4	1750	8.59×10^5
Mercury	−38.9	1.14×10^4	356.6	2.96×10^5
Nitrogen	−210.0	2.57×10^4	−195.8	2.00×10^5
Oxygen	−218.8	1.39×10^4	−183.0	2.13×10^5
Water	0.0	33.5×10^4	100.0	22.6×10^5

[a]The values pertain to 1 atm pressure.

An order of magnitude more energy is needed to vaporize as to melt – melting is more a rearrangement of the molecules without a large change of density, vaporization a change to a state in which molecules are much farther apart and the density much lower.

12.86/78: To cool the body of a 75 kg jogger (average specific heat = 3500 J/(kg.C°)), by 1.5°C, how many kilograms of water in the form of sweat have to be evaporated?

The vaporization of 1 kg of water requires $2.42{\times}10^6$ J of energy.

12.88/80: A 0.2 kg piece of aluminum has a temperature of -155°C and is added to 1.5 kg of water at 3°C. At equilibrium, the temperature is 0°C. Find the mass of ice that has become frozen.

Specific heat of aluminum = 900 J/(kg.C°)

Heat flows: 0.2 kg of aluminum warms from -155°C to 0°C
1.5 kg of water cools from 3°C to 0°C
mass m of water freezes at 0°C
(1.5 – m) kg does not freeze