HW 2: Heat Transfer Fundamentals
EPSS 171 Winter 2019

Advanced Computing for Geoscience Types
9 Total Course Points

This HW will be almost all pencil and paper work. Do it neatly enough for it to be gradeable. Email in a PDF of your work. NO PHYSICAL HARD-COPY. Thanks.

DUE: Thursday, January 24th, 8:00 pm

(<u>with 10% off the final score for every hour it is turned in after 8pm</u>)

Halliday & Resnick, Fundamental of Physics 3rd Edition, Chapter 20, Section 20-3 #32, 33, 34; Section 20-7 #47, 49, 52, 56, 58. —And a problem of mine to do **first**.

32P. A *flow calorimeter* is used to measure the specific heat of a liquid. Heat is added at a known rate to a stream of the liquid as it passes through the calorimeter at a known rate. Then a measurement of the resulting temperature difference between the inflow and the outflow points of the liquid stream enables us to compute the specific heat of the liquid. A liquid of density 0.85 g/cm^3 flows through a calorimeter at the rate of 8.0 cm^3/s. Heat is added by means of a 250-W electric heating coil, and a temperature difference of 15°C is established in steady-state conditions between the inflow and the outflow points. Find the specific heat of the liquid.

Hint: Here you would use

$$\frac{dE}{dt} = \frac{d(mc\Delta T)}{dt}$$

33P. By means of a heating coil, energy is transferred at a constant rate to a substance in a thermally-insulated container. The temperature of the substance is measured as a function of time. (*a*) Show how we can deduce from this information the way in which the heat capacity of the body depends on the temperature. (*b*) Suppose that in a certain temperature range it is found that the temperature T is proportional to t^3, where t is the time. How does the heat capacity depend on T in this range?

34P. Two metal blocks are insulated from their surroundings. The first block, which has a mass $m_1 = 3.16$ kg and is at a temperature of $T_1 = 17°C$, has a specific heat four times that of the second block. This second block is at a temperature $T_2 = 47°C$, and its coefficient of linear expansion is $15 \times 10^{-6}/°C$. When the two blocks are brought together and allowed to come to thermal equilibrium, the area of one face of the second block is found to have decreased by 0.030%. Find the mass of the second block.

47E. Consider the slab shown in Fig. 8. Suppose that $L = 25$ cm, $A = 90$ cm^2, and the material is copper. If $T_H = 125°C$, $T_C = 10°C$, and a steady state is reached, find the rate of heat transfer.

Fouriers Law

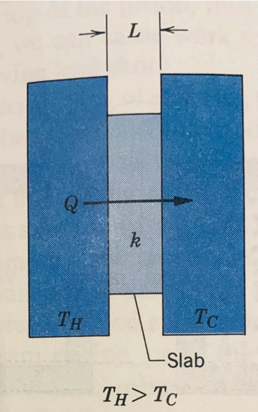

Figure 8 Thermal conduction. Heat flows from a reservo at temperature T_H to a cooler reservoir at temperature T_C through a conducting slab of thickness L and thermal conductivity k.

49E. Show that the temperature T_x at the interface of a compound slab (see Section 7 and Fig. 8) is given by

$$T_x = \frac{R_1 T_H + R_2 T_C}{R_1 + R_2}.$$

Here R_1 and R_2 are the thermal resistances defined in The **FIRST** Problem that I have listed last, back on page 5; the compound slab is shown in Figure 10 below.

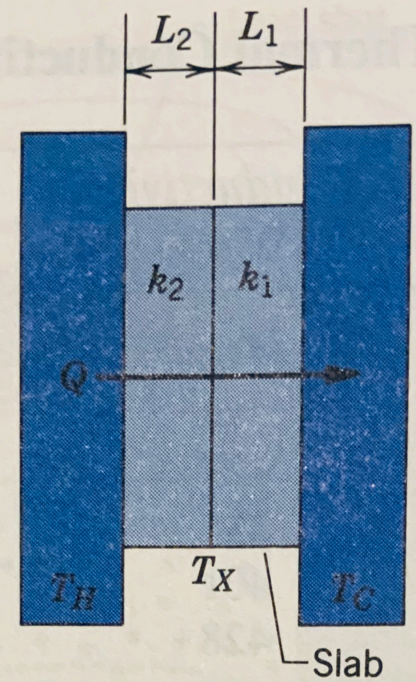

Figure 10 Heat flows through a composite slab made up of materials with different thicknesses and different thermal conductivities.

52P. Two identical rectangular rods of metal are welded end to end as shown in Fig. 23*a*, and 10 cal of heat flows through the rods in 2.0 min. How long would it take for 10 cal to flow through the rods if they are welded as shown in Fig. 23*b*?

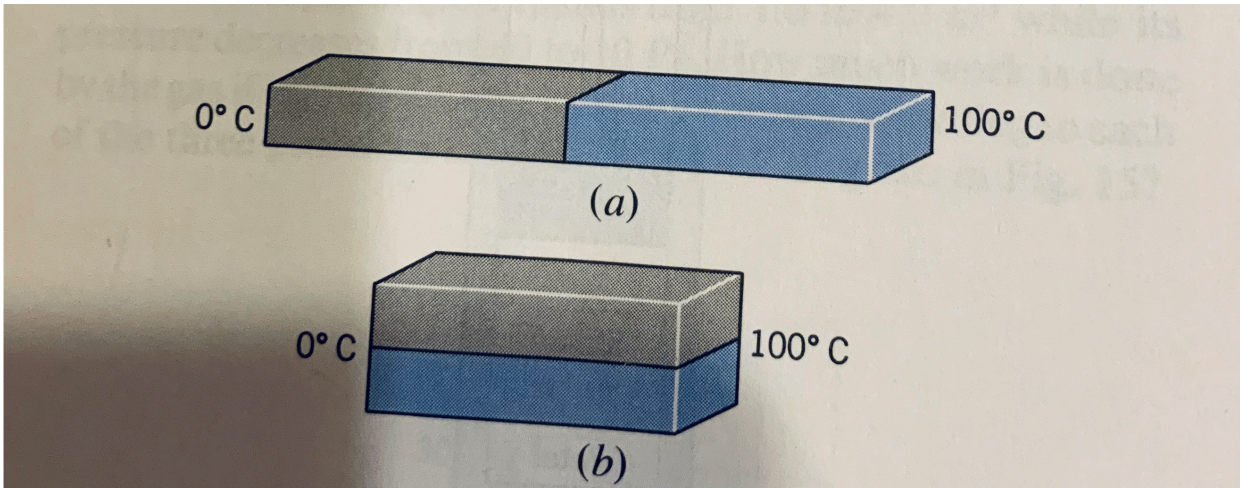

Figure 23 Exercise 50 and Problem 52.

56P. (*a*) What is the rate of heat loss in watts per square meter through a glass window 3.0 mm thick if the outside temperature is $-20°F$ and the inside temperature is $+72°F$? (*b*) A storm window is installed having the same thickness of glass but with an air gap of 7.5 cm between the two windows. What will be the corresponding rate of heat loss presuming that conduction is the only important heat-loss mechanism?

58P. Ice has formed on a shallow pond and a steady state has been reached with the air above the ice at $-5°C$ and the bottom of the pond at 4°C. If the total depth of ice + water is 1.4 m, how thick is the ice? (Assume that the thermal conductivities of ice and water are 0.40 and 0.12 cal/m · °C · s, respectively.)

Halliday and Resnick Odd-numbered Answers: 33b. C ~ T^(-2/3); 47. 1660 W.

THE FIRST PROBLEM: Thermal Conductors in Series.
a) Given the composite slab shown in Figure 10 (above). Make use of Fourier's Law of Thermal Conduction to show that the heat flux, q, can be expressed as

$$q = \frac{T_H - T_C}{\sum_{i=1,2}(L_i/k_i)} = \frac{\Delta T}{\sum_i R_i}$$

and that this can be further re-organized into the expression

$$\Delta T = q\left(\Sigma_i R_i\right)$$

where R_i = (L_i/k_i) is the thermal resistance of the i-th slab component.

b) Explain how the above equation is analogous in form to Ohm's law for electrical resistors in series:

$$\Delta V = I\left(\mathrm{R}_1 + \mathrm{R}_2 + \ldots\right)$$

where here the non-italic R's denote the electrical resistors in the circuit. (It may be helpful to note that the heat flux, q, is called the heat current or the heat current density in some circles.)

c) Describe (qualitatively/physically) why Ohm's Law and Fourier's Law have similar mathematical forms.