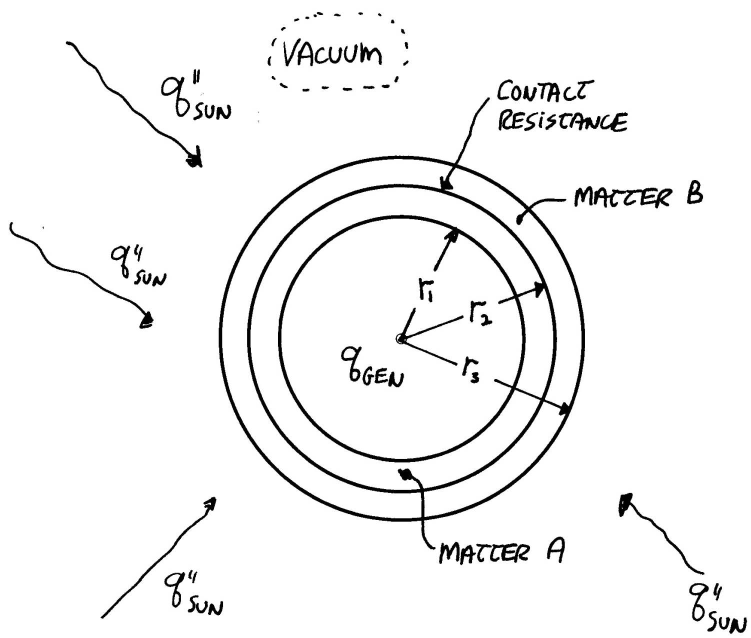
2019 Heat Transfer Midterm Exam

Friday April 26th 2019
16:30 — 18:30

NO NOTES OR BOOKS; USE HEAT TRANSFER TABLES THAT WERE DISTRIBUTED; OUTLINE CLEARLY YOUR ASSUMPTIONS; ANSWER ALL 4 QUESTIONS; ALL QUESTIONS HAVE EQUAL VALUE.

Question #1

Consider a micro satellite in the shape of a hollow sphere orbiting around the earth in space as follows:



Electrical circuits located within the satellite generate power with the amount q_{gen} (in Watts). The temperature within either matter A or matter B can not exceed 600 K for safety reasons. The incoming radiation heat flux from the sun varies between being 0 and being $q''_{\text{sun}} = 1200\ \text{W/m}^2$. The radiation heat flux from the sun may reflect on adjacent solar panels and may thus englobe the micro satellite from all directions. The thermal conductivities are of $k_{\text{A}} = 0.5\ \text{W/mK}$ and of $k_{\text{B}} = 0.2\ \text{W/mK}$, while the contact conductance between matter A and matter B is of $h_{\text{c}} = 24.68\ \text{W/m}^2\text{K}$. Knowing that the outer surface of the micro-satellite is a black body, and that the dimensions are of $r_1 = 8$ cm, $r_2 = 9$ cm, $r_3 = 10$ cm, do the following:

(a) Indicate where the maximum temperature will occur (i.e. the precise location within either matter A or matter B).

(b) Find the maximum allowable q_{gen} that maintains the temperature within both matter A and matter B to less than 600 K.

(c) Find the temperature on the outer surface of the satellite when the maximum temperature within either matter A or B is of 600 K.

Question #2

Quenching is a heat treatment process in which a metal is first heated to a high temperature and rapidly cooled in a liquid bath. The rapid cooling changes the properties of the metal and makes it more stiff and more brittle. We here consider the quenching of an infinitely-long and infinitely-wide plate of steel with a thickness D, which is first heated to a temperature of 1000°C and then immersed in a bath of water for an amount of time Δt. The convective heat transfer coefficient within the bath can be taken as $h = 2500\ \mathrm{W/m^{2\circ}C}$ and the water temperature far from the steel plate can be taken as 30° C. For the quenching to be successful, the steel plate should be removed out of the water when its minimum temperature reaches 100°C. Further, for the quenching not to introduce excessive stresses, the steel plate shouldn't be too thick so that the rate of change of temperature within the steel doesn't vary by more than 25% (that is, the change in temperature of the steel at one location shouldn't exceed the change in temperature of the steel at another location by more than 25%). Put in another way, we wish that the steel plate thickness D is low enough so that the following constraint is satisfied within the steel through the cooling process:

$$\frac{(T_{x,t=0} - T_{x,t=\Delta t})_{\min}}{(T_{x,t=0} - T_{x,t=\Delta t})_{\max}} \geq 0.75$$

Given the latter, determine:

(a) The surface temperature of the steel plate after the cooling process is completed.

(b) The temperature at the center of the steel plate after the cooling process is completed for a steel plate with the maximum possible thickness $D_{\max}$ that prevents excessive stresses from forming.

(c) The maximum allowable thickness $D_{\max}$ of the steel plate that would prevent excessive stresses from forming.

(d) The amount of time Δt in seconds that the steel plate with the thickness $D_{\max}$ needs to be immersed in the bath of water.

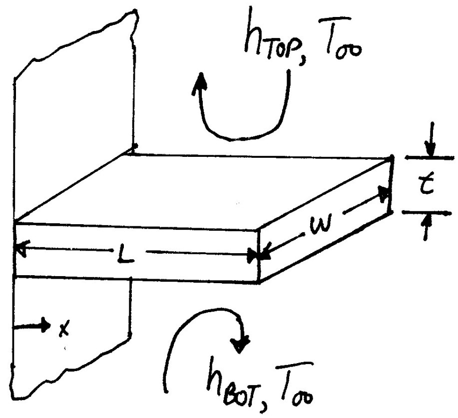
You can use the following steel properties:

$$\rho = 7800\ \mathrm{kg/m^3}, \quad c = 465\ \mathrm{J/kg^\circ C}, \quad k = 50\ \mathrm{W/m^\circ C}$$

Hint: You don't need to know the value of $D_{\max}$ to determine the temperature at the center in part (b).

Question #3

Consider the following rectangular fin cooled by air:



The length, width, and thickness of the fin correspond to $L = 0.25585$ m, $W = 4$ m, $t = 1$ mm. The thermal conductivity of the fin is of 200 W/m°C, while the convective heat transfer coefficient acting on the top surface of the fin is of $h_{\text{top}} = 10$ W/m^2°C and the one acting on the bottom surface is of $h_{\text{bot}} = 20$ W/m^2°C. The temperature of the air far away from the fin is of $T_\infty = 20$°C. Find the ratio between the heat lost to the environment by the second half of the fin (i.e. $x > L/2$) over the heat lost by the entire fin. That is find

$$\frac{q_{\text{lost over } \frac{L}{2}<x<L}}{q_{\text{lost over } 0<x<L}} = ?$$

Outline clearly all assumptions.

Question #4

Consider an electricity cable composed of a copper core surrounded by a plastic insulator. The copper core has a 3 cm radius while the plastic insulator has an inner radius of 3 cm and an outer radius of 5 cm. The thermal conductivity of the copper and of the plastic are of 386 W/m°C and 0.5 W/m°C, respectively. The electrical resistance of the copper is of 16.8 nΩ·m. The electricity cable is surrounded by air at a temperature of 20°C and it is known that the convective heat transfer coefficient due to the air motion is of 5 W/m^2°C. On a sunny day, the incoming radiation heat flux from the sun is of 700 W/m^2 and the emissivity of the plastic is of 0.8. Knowing that the plastic melts at 130°C find the maximum current that the cable can sustain without melting. Further, for this value of the maximum current, determine the temperature of the plastic where it touches the copper and where it touches the air. Hints: the convective heat transfer coefficient does **not** include radiation and it can not be assumed here that the radiation heat transfer is negligible.