Student Code Number:__________________

Ph.D. Qualifying Exam

Heat Transfer

Spring 2009

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Directions: Open Book (only one book allowed) and closed notes

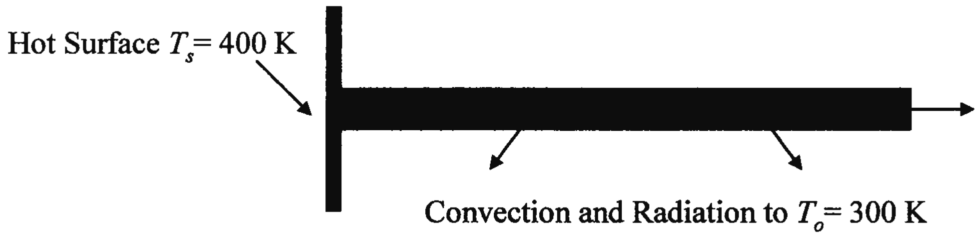
Answer all four questions

All questions have equal weight

Time: 3.0 hours

- Take any required property from your book, approximate values if necessary
- If you make any assumptions to reach a solution, state it clearly

Problem 1: A long circular fin (assume infinitely long) with diameter $D = 1$ cm protrudes from a hot surface at $T_s = 400$ K. The fin as thermal conductivity $k = 20$ W m^{-1} K^{-1}. The fin is cooled by radiation and convection to the environment at $T_o = 300$ K.



a) Carefully derive the differential equation relating the temperature and its derivatives to the coordinate x and other parameters. Start from a control volume along a differential segment Δx, and use the energy conservation to balance heat flow terms due to conduction, convection, and radiation.

The constitutive laws for radiation and convection are-

Convection: $q'' = h_{conv}(T-T_o)$

For numerically determining h_{conv} in parts b and c, you should use the value $h_{conv} = 7$ W m^2 K^{-1}

Radiation: $q'' = \sigma\,\varepsilon\,(T^4 - T_o^4) \sim h_{rad}(T-T_o)$; $h_{rad} = 4\,\sigma\,\varepsilon\,T_o^3$

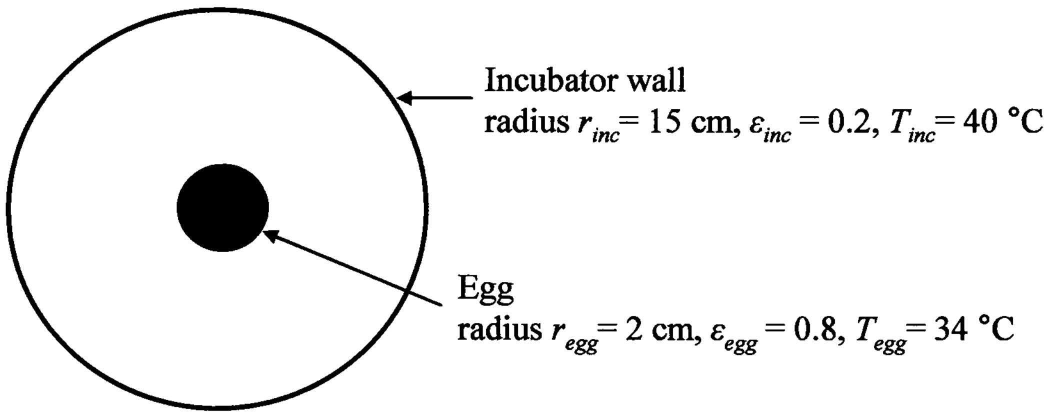
Stefan Boltzman Constant: $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

The emissivity of the fin is ε=0.8

b) Solve the differential equation obtained in part a) for the temperature variation in the x direction within the fin (symbols only). Solve (symbols first, numbers second) for the position x at which the temperature is 320K.

c) The healing length (L_H) is the length over which temperature recovers to within 1/e (constant e ~ 2.718) of T_o. Find out the L_H of this fin?

Problem 2: You are designing an incubator for chicken eggs. The incubator and the egg can be modeled as concentric spheres.

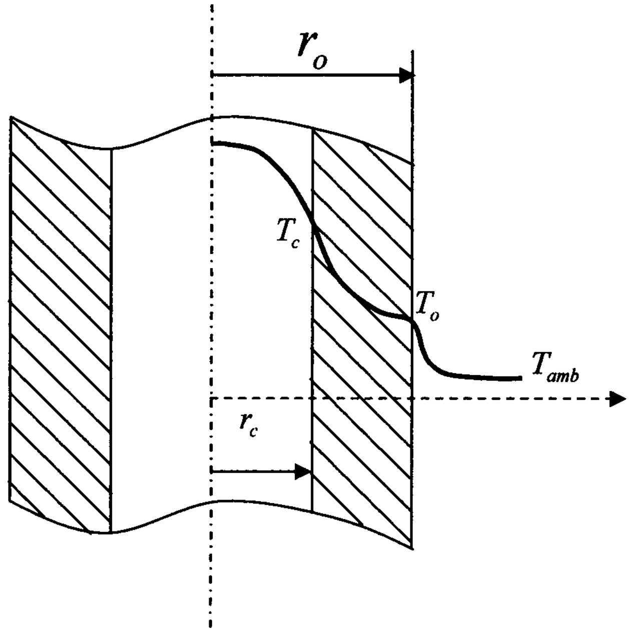


a) What is the approximate viewfactor from the shell to the egg?

b) What is the net rate of radiative heat transfer to the egg from the shell? Is the rate of heat transfer more sensitive to changes of the emissivity of the egg, or to changes of the emissivity of the shell? Why?

Stefan Boltzman Constant: $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

Problem 3: An electric wire with radius $r_c = 1.0\ mm$ is made of copper with its electrical conductivity equal to $5.1 \times 10^7\ (\Omega \cdot m)^{-1}$ and thermal conductivity equal to $380\, W/(mK)$. It is insulated with plastic. The outer radius r_o is equal to $2mm$ and the plastic thermal conductivity is equal to $0.350\, W/(mK)$. The ambient air temperature T_{amb} is at 25.0°C and the heat transfer coefficient from the outer insulated surface to the surrounding air is $8.500\, W/(m^2 K)$.



Determine the maximum current in amperes that can flow at steady-state in the wire without any portion of the insulation getting heated above its maximum allowable temperature of 90.0°C.

Hint: Resistance of an electric wire is $R = \frac{1}{k_e}\frac{l}{A}(\Omega)$, where l is the wire length; A is the area of the wire; and k_e is its electrical conductivity.

Problem 4: Current is passed through a cylindrical laboratory heater, which has a 3 cm diameter, generating heat at the rate of 20 MW/m^3. The heater is exposed to a convection environment at 20°C where the convection heat transfer coefficient is $0.5\,\mathrm{k}W/(m^2K)$. Determine the heater surface temperature. Ignore radiation heat transfer.