

2.58J MIDTERM EXAM No.2

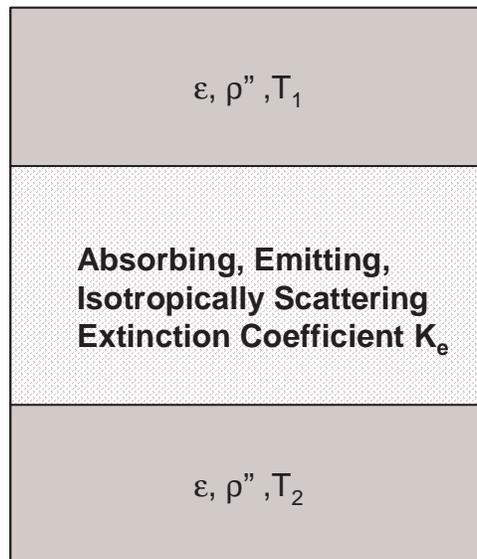
Due May 18, 2006, 11:00 am

Instruction:

This is a take home exam. You should complete the problems independently. The only person you may consult is the TA. The last question is a bonus.

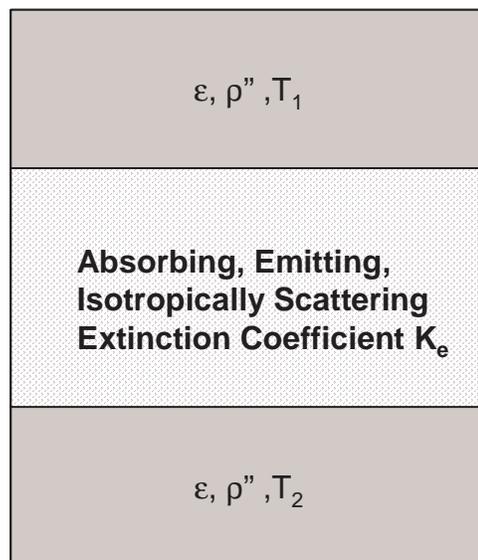
Question 1. Consider radiative heat transfer between two parallel plates (infinite wide and deep) maintained at two temperatures T_1 and T_2 , as shown in the following figure. The medium in between the plates is gray, isotropically scattering, absorbing, and emitting with an extinction coefficient K_e . The emission of both plates is diffuse-gray with an emissivity ϵ . The reflection of both surfaces is gray but specular with a bidirectional reflectivity ρ'' that is independent of angle. The medium is in radiative equilibrium, i.e., neglect molecular heat conduction.

- Derive a relation between ρ'' and ϵ .
- Derive an integral equation that determines the temperature distribution in the medium. You do not need to solve this equation, but the integral equation should be expressed in terms of the local blackbody emissivity power (and hence the local medium temperature) and other given boundary conditions.
- Assuming that the distribution of the local blackbody emissivity power is known, derive an expression for the heat flux between the two parallel plates.



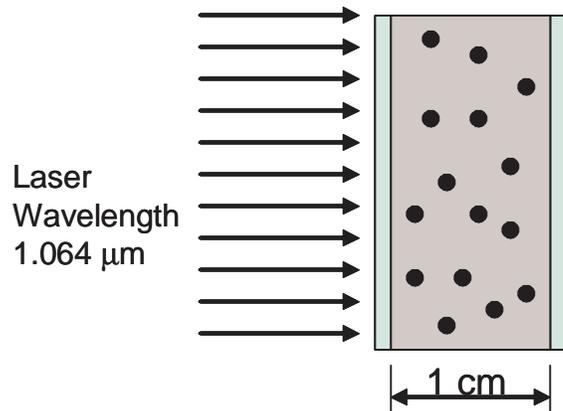
Question 2 (this is similar to problem 1 but seeks an approximate solution): Consider radiative heat transfer between two parallel plates (infinitely wide and deep) maintained at two different temperatures T_1 and T_2 , as shown in the following figure. The medium in between the plates is gray, isotropically scattering, absorbing, and emitting with an extinction coefficient K_e . The emission of both plates is diffuse-gray with an emissivity ϵ . The reflection of the surface is gray but specular a bidirectional reflectivity ρ'' independent of angle. The medium is in radiative equilibrium, i.e., neglect molecular heat conduction.

- (a) Apply the idea of diffusion approximation, derive appropriate temperature jump boundary conditions for the given properties of the surfaces.
- (b) Combine the diffusion approximation and the boundary conditions you obtained above, derive an analytical solution for the temperature distribution inside the medium and the heat flux between the plates.



Question 3 Consider a colloidal solution consisting of nanoparticles of diameter $d=10$ nm, suspended in water. A laser beam with a power density of 10^6 W/m² and a wavelength $\lambda=1.064$ μ m is directed through the water. The volume fraction of the particles is 0.1%. The water is sandwiched between two transparent parallel plates that have a refractive index equal to that of water. You can neglect the reflection between water and glass plates.

- Determine the rate of energy deposition (per unit area of incidence) into the colloidal system due to the absorption of the laser beam.
- If the nanoparticle diameter is 5 nm while the volume fraction remains 0.1%, what is the rate of energy deposition?



Particle diameter 10 nm
 Optical constant (3,0.01)
 Water and hold optical constants: (1.3,0)

Question 4 (Bonus). A very long narrow channel along the x -direction is formed by two parallel plates (infinitely deep perpendicular to the paper) separated by a distance D apart, as shown in the following figure. The channel is filled with a gray, isotropically scattering, absorbing and emitting medium. The effective extinction coefficient of the medium is K_e . A radiation heat flow Q [in Watt] is established in the x -direction due to the internal temperature gradient along the x -direction. There is no net heat flux in other directions. Both plates are black surfaces with a surface temperature that is equal to the local temperature of the medium. We know that $K_e D$ is of the order of one, and thus you cannot neglect the boundary effects in the y -direction. However, the channel is long and you can neglect the boundary effect along the x -direction. Neglect heat conduction in the medium. Derive an expression for the local heat flux inside the channel in terms of the local temperature and its local gradient.

