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ME 109 **Final Exam** 5/14/13

Problem 1 (10 pts)

A black circular disk 0.20 m in diameter and well insulated on one side is electrically heated to a uniform temperature. The electrical energy input is 1000W. The surroundings are at temperature T_{sur}=500K. Find the fraction of the emitted radiative energy that lies in the spectral region from 2 to 6 microns.

The Stefan-Boltzmann constant, $\sigma=5.67\times10^{-8}\ W/m^2K^4$

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Table 12.2 Blackbody Radiation Functions

λT (μm · K)	$F_{(0 \to \lambda)}$	$I_{\lambda,b}(\lambda, T)/\sigma T^5$ (μm · K · sr)$^{-1}$	$\frac{I_{\lambda,b}(\lambda, T)}{I_{\lambda,b}(\lambda_{max}, T)}$
200	0.000000	0.375034×10^{-27}	0.000000
400	0.000000	0.490335×10^{-13}	0.000000
600	0.000000	0.104046×10^{-8}	0.000014
800	0.000016	0.991126×10^{-7}	0.001372
1,000	0.000321	0.118505×10^{-5}	0.016406
1,200	0.002134	0.523927×10^{-5}	0.072534
1,400	0.007790	0.134411×10^{-4}	0.186082
1,600	0.019718	0.249130	0.344904
1,800	0.039341	0.375568	0.519949
2,000	0.066728	0.493432	0.683123
2,200	0.100888	0.589649×10^{-4}	0.816329
2,400	0.140256	0.658866	0.912155
2,600	0.183120	0.701292	0.970891
2,800	0.227897	0.720239	0.997123
2,898	0.250108	0.722318×10^{-4}	1.000000

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λT ($\mu m \cdot K$)	$F_{(0 \to \lambda)}$	$I_{\lambda,b}(\lambda, T)/\sigma T^5$ $(\mu m \cdot K \cdot sr)^{-1}$	$\frac{I_{\lambda,b}(\lambda, T)}{I_{\lambda,b}(\lambda_{max}, T)}$
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373
3,400	0.361735	0.681544	0.943551
3,600	0.403607	0.650396	0.900429
3,800	0.443382	0.615225×10^{-4}	0.851737
4,000	0.480877	0.578064	0.800291
4,200	0.516014	0.540394	0.748139
4,400	0.548796	0.503253	0.696720
4,600	0.579280	0.467343	0.647004
4,800	0.607559	0.433109	0.599610
5,000	0.633747	0.400813	0.554898
5,200	0.658970	0.370580×10^{-4}	0.513043
5,400	0.680360	0.342445	0.474092
5,600	0.701046	0.316376	0.438002
5,800	0.720158	0.292301	0.404671
6,000	0.737818	0.270121	0.373965
6,200	0.754140	0.249723×10^{-4}	0.345724
6,400	0.769234	0.230985	0.319783
6,600	0.783199	0.213786	0.295973
6,800	0.796129	0.198008	0.274128
7,000	0.808109	0.183534	0.254090
7,200	0.819217	0.170256×10^{-4}	0.235708
7,400	0.829527	0.158073	0.218842
7,600	0.839102	0.146891	0.203360
7,800	0.848005	0.136621	0.189143
8,000	0.856288	0.127185	0.176079
8,500	0.874608	0.106772×10^{-4}	0.147819
9,000	0.890029	0.901463×10^{-5}	0.124801
9,500	0.903085	0.765338	0.105956
10,000	0.914199	0.653279×10^{-5}	0.090442
10,500	0.923710	0.560522	0.077600
11,000	0.931890	0.483321	0.066913
11,500	0.939959	0.418725	0.057970
12,000	0.945098	0.364394×10^{-5}	0.050448
13,000	0.955139	0.279457	0.038689
14,000	0.962898	0.217641	0.030131
15,000	0.969981	0.171866×10^{-5}	0.023794
16,000	0.973814	0.137429	0.019026
18,000	0.980860	0.908240×10^{-6}	0.012574
20,000	0.985602	0.623310	0.008629
25,000	0.992215	0.276474	0.003828
30,000	0.995340	0.140469×10^{-6}	0.001945
40,000	0.997967	0.473891×10^{-7}	0.000656
50,000	0.998953	0.201605	0.000279
75,000	0.999713	0.418597×10^{-8}	0.000058
100,000	0.999905	0.135752	0.000019

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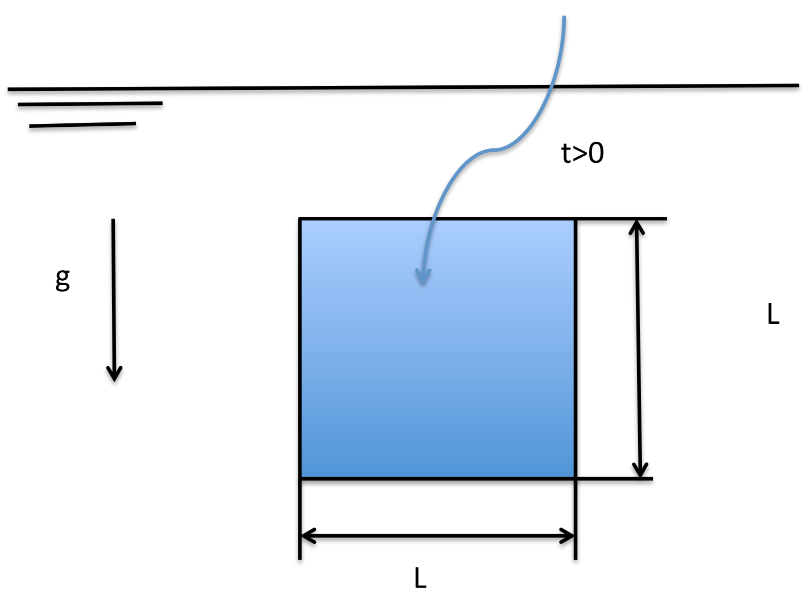
Problem 2 (15 pts)

A square copper plate of thickness d=1 mm and side length L=5 cm is initially at the temperature T_i=360K. The plate is suddenly dipped vertically and with the lower side horizontal in a large pool of water at temperature T_∞=280K.

> (a) assuming the plate temperature is uniform at 340K, find the average heat transfer coefficient.
> (b) using this heat transfer coefficient find the time it takes for the plate temperature to drop to 320K.

Copper properties: thermal conductivity k = 401 W/mK, specific heat c_p=385 J/kgK, density ρ=8933 Kg/m^3.
Water properties: density ρ=980 kg/m^3, specific heat c_p=4.188 kJ/kgK, dynamic viscosity $\mu=420\times10^{-6} Ns/m^2$, thermal conductivity k=0.66W/mK, Prandtl number Pr=2.66, thermal expansion coefficient $\beta=506\times10^{-6}\ K^{-1}$.



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Problem 3 (20pts)

Consider a tube of length L=40 m, inner diameter D_i=5 cm, outer diameter D_o=10cm, made of material of thermal conductivity k=10 W/mK. Water with bulk mean velocity u_m=10 m/s enters the pipe with temperature T_{mi}=350K. The outer surface of the pipe is exposed to cross flow of air of temperature T_∞=300K and free stream velocity, V=20 m/s. Find:

(a) the heat transfer coefficient for the internal flow, h_{int} (5 pts)
(b) the heat transfer coefficient for the external flow, h_{out} (5 pts)
(c) the water outlet temperature T_{mo} (7pts)
(d) the heat transfer from the water to air, q (3pts).

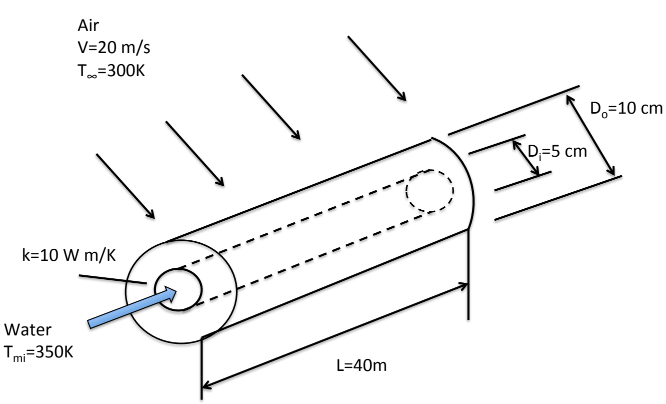
Water properties: density ρ=988 kg/m^3, specific heat c_p=4.18 kJ/kgK, dynamic viscosity $\mu=528\times10^{-6}$Ns/m^2, thermal conductivity k=0.645W/mK, Prandtl number Pr=3.42.

Air properties: density ρ=1.1614 kg/m^3, specific heat c_p=1.007 kJ/kgK, dynamic viscosity $\mu=184.6\times10^{-6}$ Ns/m^2, kinematic viscosity $\nu=15.89\times10^{-6}$ m^2/s, thermal conductivity k=26.3×10^{-3} W/mK, Prandtl number Pr=0.707.

$$\overline{Nu}_D \equiv \frac{\bar{h}D}{k} = C\,Re_D^m\,Pr^{1/3} \qquad (7.52)$$

TABLE 7.2 Constants of Equation 7.52 for the circular cylinder in cross flow [11, 12]

Re_D	C	m
0.4–4	0.989	0.330
4–40	0.911	0.385
40–4000	0.683	0.466
4000–40,000	0.193	0.618
40,000–400,000	0.027	0.805



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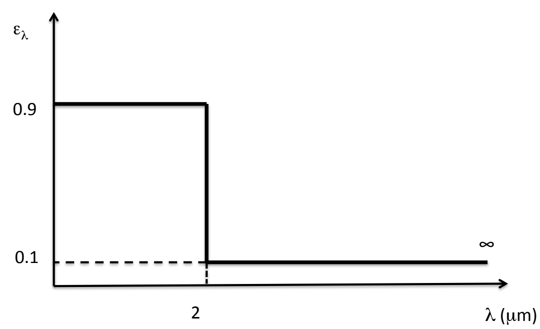
Problem 4 (10 pts)

A thin plate is in earth orbit around the sun and tilted with respect to the impinging solar radiation. The spectral emissivity of the diffuse coated surface that is exposed to the oblique solar light can be approximated as shown in the figure below. The back surface of the plate is completely insulated. The solar flux at normal incidence is 1353 W/m^2. Find the angle of incidence of the solar radiation with respect to the normal to the plate surface when the equilibrium temperature of the plate is 500K.
The Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ W/m^2K^4



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Problem 5 (15 pts)

Consider a three diffuse and gray surface enclosure as shown in the figure below. The heater disk surface (1) has diameter D=1.5 m, emissivity ε_1=0.8 and temperature T_1=1000K. The bottom surface is the interior of a hemispherical surface of diameter D=1.5 m, emissivity ε_2=0.5 and temperature T_2=500K. Surface (3) is insulated. Find:

(a) the heat flow supplied to the heater (10 pts)

(b) the temperature of the refractory surface (5 pts)

The Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4

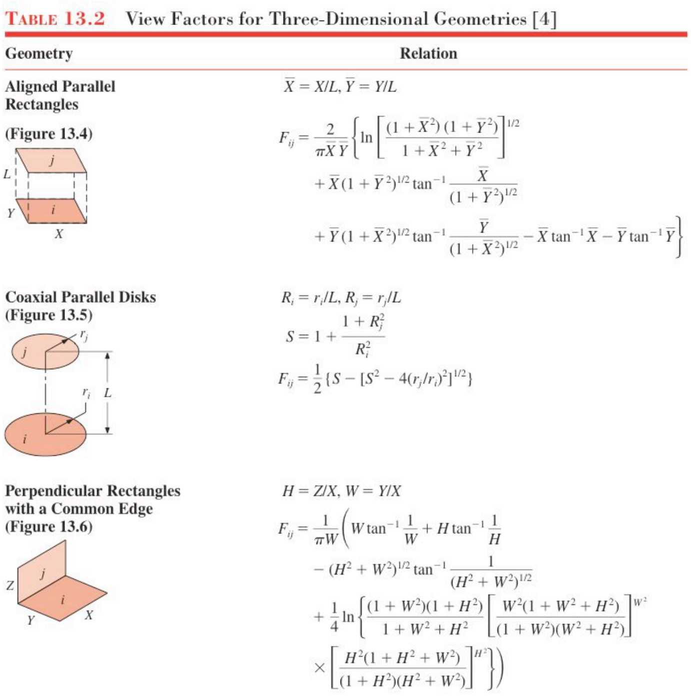
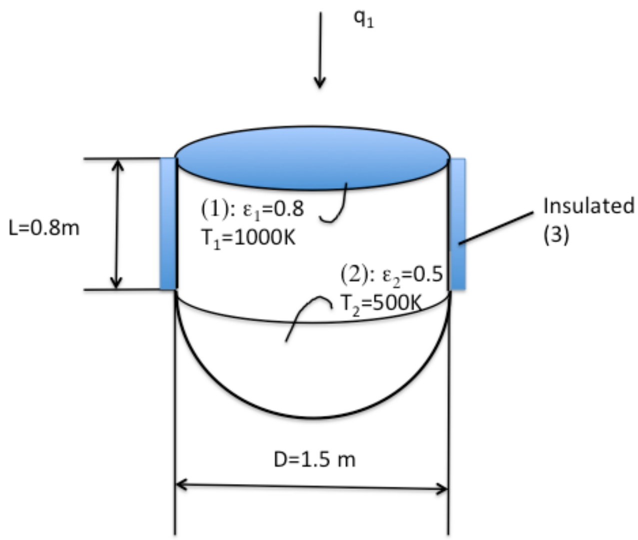


TABLE 13.2 View Factors for Three-Dimensional Geometries [4]

Geometry	Relation
Aligned Parallel Rectangles (Figure 13.4)	$\bar{X} = X/L,\ \bar{Y} = Y/L$ $F_{ij} = \frac{2}{\pi \bar{X}\bar{Y}} \left\{ \ln\left[\frac{(1+\bar{X}^2)(1+\bar{Y}^2)}{1+\bar{X}^2+\bar{Y}^2}\right]^{1/2} + \bar{X}(1+\bar{Y}^2)^{1/2}\tan^{-1}\frac{\bar{X}}{(1+\bar{Y}^2)^{1/2}} + \bar{Y}(1+\bar{X}^2)^{1/2}\tan^{-1}\frac{\bar{Y}}{(1+\bar{X}^2)^{1/2}} - \bar{X}\tan^{-1}\bar{X} - \bar{Y}\tan^{-1}\bar{Y} \right\}$
Coaxial Parallel Disks (Figure 13.5)	$R_i = r_i/L,\ R_j = r_j/L$ $S = 1 + \frac{1+R_j^2}{R_i^2}$ $F_{ij} = \frac{1}{2}\{S - [S^2 - 4(r_j/r_i)^2]^{1/2}\}$
Perpendicular Rectangles with a Common Edge (Figure 13.6)	$H = Z/X,\ W = Y/X$ $F_{ij} = \frac{1}{\pi W}\left(W\tan^{-1}\frac{1}{W} + H\tan^{-1}\frac{1}{H} - (H^2+W^2)^{1/2}\tan^{-1}\frac{1}{(H^2+W^2)^{1/2}} + \frac{1}{4}\ln\left\{\frac{(1+W^2)(1+H^2)}{1+W^2+H^2}\left[\frac{W^2(1+W^2+H^2)}{(1+W^2)(W^2+H^2)}\right]^{W^2} \times \left[\frac{H^2(1+H^2+W^2)}{(1+H^2)(H^2+W^2)}\right]^{H^2}\right\}\right)$



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