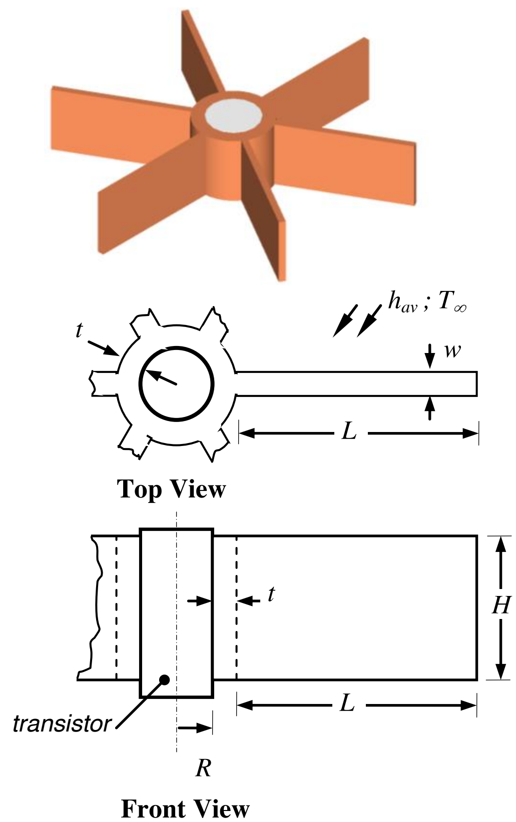
Department of Mechanical Engineering
MECH 375: Heat Transfer-1 Final Examination [Friday April 24, 2009]

Notes: This is an **only** open textbook exam. **Only summary sheets provided by the instructor are allowed;** Exam period: 2:30 hrs.

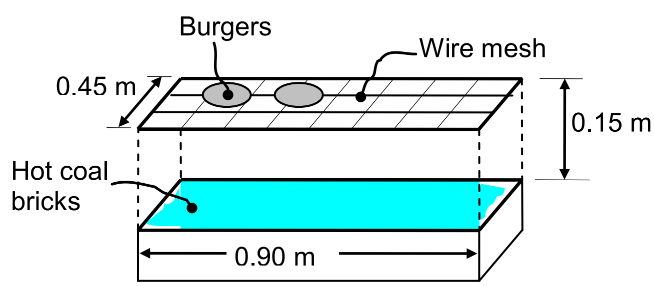
Problem 1: Heat transfer from a cylindrical transistor is enhanced by inserting it in a copper sleeve (k_{cu} = 390 W/m-°C) having 6 integrally machined longitudinal fins on its surface (please see figure). The transistor radius is $R = 4\ \text{mm}$; the sleeve height is $H = 10\ \text{mm}$; the sleeve base thickness is $t = 2\ \text{mm}$; and the fins are of length $L = 20\ \text{mm}$ and thickness $w = 1\ \text{mm}$. The sleeve is press fitted to the transistor, and the thermal contact resistance at the sleeve-transistor interface is characterized by $h_{\substack{contact \\ sleeve-trans}} = 10^3\ \text{W/m}^2\text{-°C}$. Air at T_∞ = 22°C is blown over the fins providing an approximately uniform convection coefficient of $h_{av} = 30\ \text{W/m}^2\text{-°C}$. Assume steady-state one-dimensional radial heat transfer and negligible radiation heat transfer.



a) Sketch the equivalent thermal circuit for heat transfer from the transistor surface to the air. Label clearly each thermal resistance.

b) If the temperature at the transistor surface is $T_{trans.}$ = 80°C (constant), what is the rate of heat transfer from the sleeve?

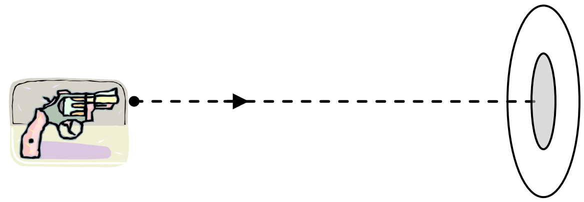
Problem 2: Consider a rectangular coal bricks barbeque grill as presented in the figure. The hot coal bricks are at 650°C, while the wire mesh made of very thin wire is *entirely* covered with burgers initially at 5°C. Neglect convection heat transfer.



a) Treating both the burgers and the coal bricks as black bodies determine the *initial* net rate of radiation heat transfer exchange between the coal bricks and the burgers bottom faces.

b) Also, determine the initial rate of total radiation heat to the bottom faces of the burgers if the side opening of the grill is covered by polished aluminum foil with an emissivity approximated as $\varepsilon_{al} \approx 0$.

Problem 3: Consider a *spherical* bullet of 4.0 mm diameter made of lead fired from a revolver in air and at a speed of 250 m/s. It takes 0.56 second for the bullet to reach the target. The air temperature is constant at 27°C. Assume bullet speed is constant, and radiation heat transfer is negligible. If the initial temperature of the bullet is 200°C,



a) Estimate the average convection heat transfer coefficient

b) Find the final temperature of the bullet right before the impact

c) During the travel time what is the amount of heat lost from the bullet to the air?

The thermo-physical properties of lead are assumed constant at: ρ = 11000 kg/m^3; c_p = 2000 J/kg-°C; k = 35 W/m-°C.

Problem 4: In a clean oil-to-water heat exchanger, the oil enters at 100°C with a heat capacity rate of $C_{oil} =$ 3350 W/K. Water is available at 10°C and 0.6 kg/s. The overall heat transfer coefficient is U =500 W/m^2-°C and the surface area for heat transfer is A = 10 m^2. In this heat exchanger, it is assumed that the solid wall separating the oil and water is very thin. Consider steady-state conditions.

a) Determine the *exit temperatures* and the *rate of heat transfer* in counter flow arrangement.

b) If the ratio of the convection heat transfer coefficients of oil to water is 0.8, calculate the wall temperature at one of the ends of the counter flow heat exchanger where the hot oil enters.

Note: Approximate water properties by saturated liquid data.

Good Luck

Thermophysical properties of Atmospheric Air

T (K)	ρ (kg/m^3)	c_p (kJ/kg · K)	$\mu \cdot 10^7$ (N · s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^6$ (m^2/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709
850	0.4097	1.110	384.3	93.80	59.6	131	0.716
900	0.3868	1.121	398.1	102.9	62.0	143	0.720
950	0.3666	1.131	411.3	112.2	64.3	155	0.723
1000	0.3482	1.141	424.4	121.9	66.7	168	0.726
1100	0.3166	1.159	449.0	141.8	71.5	195	0.728

Thermophysical properties of Saturated Water

Temperature, T (K)	Pressure, P (bars)[b]	Specific Volume (m³/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m²) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K⁻¹)
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5	6.62	0.849	72.7	227.5
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6	5.83	0.857	71.7	276.1
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1	5.20	0.865	70.9	320.6
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4	4.62	0.873	70.0	361.9
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7	4.16	0.883	69.2	400.4
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0	3.77	0.894	68.3	436.7
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3	3.42	0.901	67.5	471.2
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7	3.15	0.908	66.6	504.0
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0	2.88	0.916	65.8	535.5
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3	2.66	0.925	64.9	566.0
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	668	22.6	2.45	0.933	64.1	595.4
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0	2.29	0.942	63.2	624.2
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3	2.14	0.951	62.3	652.3
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7	2.02	0.960	61.4	697.9
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1	1.91	0.969	60.5	707.1
370	0.9040	1.041	1.861	2265	4.214	2.017	289	11.89	679	24.5	1.80	0.978	59.5	728.7
373.15	1.0133	1.044	1.679	2257	4.217	2.029	279	12.02	680	24.8	1.76	0.984	58.9	750.1
375	1.0815	1.045	1.574	2252	4.220	2.036	274	12.09	681	24.9	1.70	0.987	58.6	761
380	1.2869	1.049	1.337	2239	4.226	2.057	260	12.29	683	25.4	1.61	0.999	57.6	788
385	1.5233	1.053	1.142	2225	4.232	2.080	248	12.49	685	25.8	1.53	1.004	56.6	814