UNIVERSITY OF COLORADO - BOULDER

ASEN 3113 THERMODYNAMICS AND HEAT TRANSFER

ASEN 3113: Crib Sheet Exam 3

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Contents

I. Heat Transfer - From Exam 2

A. Conduction

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles.

$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \tag{1}$$

where k = thermal conductivity [W/m*K]

Thermal Diffusivity:

$$\alpha = \frac{\text{Heat conduction}}{\text{Heat storage}} = \frac{k}{\rho c_p} \quad \left(\text{m}^2/\text{s}\right) \tag{2}$$

B. Convection

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. THIS INCLUDES AIR.

$$\dot{Q}_{\text{conv}} = hA_s\left(T_s - T_\infty\right) \tag{3}$$

where h is the convection heat transfer coefficient [W/m^2*K]

C. Radiation

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s\left(T_s^4 - T_{\text{surr }r}^4\right) \tag{4}$$

For a blackbody the ε is 1.

Combined heat transfer:

$$\begin{aligned} \dot{Q}_{\text{total}} &= \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = h_{\text{conv}} A_s\left(T_s - T_{\text{surr}}\right) + \varepsilon\sigma A_s\left(T_s^4 - T_{\text{surr}}^4\right) \\ \dot{Q}_{\text{total}} &= h_{\text{combined}} A_s\left(T_s - T_\infty\right) \quad (\text{W}) \\ h_{\text{combined}} &= h_{\text{conv}} + h_{\text{rad}} = h_{\text{conv}} + \varepsilon\sigma\left(T_s + T_{\text{surr}}\right)\left(T_s^2 + T_{\text{surr}}^2\right) \end{aligned} \tag{5}$$

D. Thermal Resistance

Conduction:

$$\begin{aligned} \dot{Q}_{\text{cond, wall}} &= \tfrac{T_1 - T_2}{R_{\text{wall}}} \\ R_{\text{wall}} &= \tfrac{L}{kA} \quad (\text{ K/W}) \end{aligned} \tag{6}$$

Convection:

$$\dot{Q}_{\text{conv}} = \frac{T_s - T_\infty}{R_{\text{conv}}} \tag{7}$$

$$R_{\text{conv}} = \frac{1}{hA_s} \quad (\text{ K/W}) \tag{8}$$

Radiation:

$$\begin{aligned} \dot{Q}_{\text{rad}} &= \varepsilon\sigma A_s\left(T_s^4 - T_{\text{surr}}^4\right) = h_{\text{rad}} A_s\left(T_s - T_{\text{surr}}\right) = \tfrac{T_s - T_{\text{surr}}}{R_{\text{rad}}} \\ R_{\text{rad}} &= \tfrac{1}{h_{\text{rad}} A_s}(\text{ K/W}) \end{aligned} \tag{9}$$

II. Steady Heat Conduction

Conduction:

$$
\begin{aligned}
\dot{Q}_{\text{cond, wall}} &= \tfrac{T_1 - T_2}{R_{\text{wall}}} \\
R_{\text{wall}} &= \tfrac{L}{kA} \quad (\mathrm{K/W})
\end{aligned}
\tag{10}
$$

Convection:

$$
\dot{Q}_{\text{conv}} = \frac{T_s - T_\infty}{R_{\text{conv}}} \tag{11}
$$

$$
R_{\text{conv}} = \frac{1}{hA_s} \quad (\mathrm{K/W}) \tag{12}
$$

Radiation:

$$
\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s\left(T_s^4 - T_{\text{surr}}^4\right) = h_{\text{rad}}\, A_s\,(T_s - T_{\text{surr}}) = \frac{T_s - T_{\text{surr}}}{R_{\text{rad}}} \tag{13}
$$

$$
R_{\text{rad}} = \frac{1}{h_{\text{rad}} A_s} (\mathrm{K/W}) \tag{14}
$$

Radiation Heat transfer coefficient:

$$
h_{\text{rad}} = \frac{\dot{Q}_{\text{rad}}}{A_s\,(T_s - T_{\text{surr}})} = \varepsilon\sigma\left(T_s^2 + T_{\text{surr}}^2\right)(T_s + T_{\text{surr}}) \quad \left(\mathrm{W/m^2 \cdot K}\right) \tag{15}
$$

Useful example:

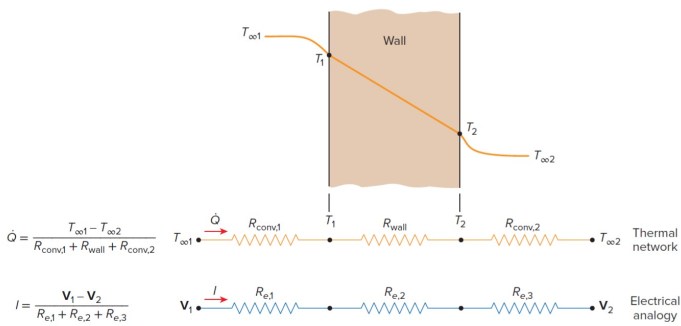

FIGURE 17–6
The thermal resistance network for heat transfer through a plane wall subjected to convection on both sides, and the electrical analogy.

Fig. 1 Steady State Heat Transfer Through a Wall

More Thermal Resistance Things, in a thermal circuit equivalent the rate of heat conduction, convection, and radiation are all equal.

$$
\left(\begin{array}{c}\text{Rate of} \\ \text{heat convection} \\ \text{into the wall}\end{array}\right) = \left(\begin{array}{c}\text{Rate of} \\ \text{heat conduction} \\ \text{through the wall}\end{array}\right) = \left(\begin{array}{c}\text{Rate of heat} \\ \text{convection} \\ \text{from the wall}\end{array}\right) \tag{16}
$$

$$
\dot{Q} = h_1 A\,(T_{\infty 1} - T_1) = kA\tfrac{T_1 - T_2}{L} = h_2 A\,(T_2 - T_{\infty 2})
$$

The above equation can also be arranged as:

$$
\begin{aligned}
\dot{Q} &= \frac{T_{\infty 1} - T_1}{1/h_1 A} = \frac{T_1 - T_2}{L/kA} = \frac{T_2 - T_{\infty 2}}{1/h_2 A} \\
&= \frac{T_{\infty 1} - T_1}{R_{\text{conv},1}} = \frac{T_1 - T_2}{R_{\text{wall}}} = \frac{T_2 - T_{\infty 2}}{R_{\text{conv},2}}
\end{aligned}
\tag{17}
$$

$$
\begin{aligned}
\dot{Q} &= \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}} \\
R_{\text{total}} &= R_{\text{conv},1} + R_{\text{wall}} + R_{\text{conv},2} = \frac{1}{h_1 A} + \frac{L}{kA} + \frac{1}{h_2 A}
\end{aligned}
\tag{18}
$$

A. Contact Resistance

Thermal Contact Resistance(R_c) is the resistance to heat transfer offered by an interface.

$$h_c = \frac{\dot{Q}/A}{\Delta T_{\text{interface}}} \left(\mathrm{W/m^2 \cdot K}\right) \tag{19}$$

$$R_c = \frac{1}{h_c} = \frac{\Delta T_{\text{interface}}}{\dot{Q}/A} \quad \left(\mathrm{m^2 \cdot K/W}\right) \tag{20}$$

Example for copper and insulation:

$$R_{c,\text{ insulation}} = \frac{L}{k} = \frac{0.01\ \mathrm{m}}{0.04\ \mathrm{W/m \cdot K}} = 0.25\ \mathrm{m^2 \cdot K/W} \tag{21}$$

$$R_{c,\text{ copper}} = \frac{L}{k} = \frac{0.01\ \mathrm{m}}{386\ \mathrm{W/m \cdot K}} = 0.000026\ \mathrm{m^2 \cdot K/W} \tag{22}$$

B. Heat Conduction in Cylinders and Spheres

Cylinder:

$$\begin{gathered} \dot{Q}_{\text{cond, cyl}} = \tfrac{T_1 - T_2}{R_{\text{cyl}}} \quad (\mathrm{W}) \\ R_{\text{cyl}} = \tfrac{\ln(r_2/r_1)}{2\pi L k} = \tfrac{\ln(\text{ Outer radius/Inner radius })}{2\pi \times \text{ Length } \times \text{ Thermal conductivity}} \end{gathered} \tag{23}$$

$$\begin{aligned} \dot{Q} &= \tfrac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}} \\ R_{\text{total}} &= R_{\text{conv},1} + R_{\text{cyl}} + R_{\text{conv},2} \\ &= \tfrac{1}{(2\pi r_1 L) h_1} + \tfrac{\ln(r_2/r_1)}{2\pi L k} + \tfrac{1}{(2\pi r_2 L) h_2} \end{aligned} \tag{24}$$

Sphere:

$$\dot{Q}_{\text{cond, }sph} = \frac{T_1 - T_2}{R_{\text{sph}}} \tag{25}$$

$$R_{\text{sph}} = \frac{r_2 - r_1}{4\pi r_1 r_2 k} = \frac{\text{Outer radius } - \text{ Inner radius}}{4\pi(\text{ Outer radius }) \text{ (Inner radius)(Thermal conductivity)}} \tag{26}$$

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}} \tag{27}$$

$$\begin{aligned} R_{\text{total}} &= R_{\text{conv},1} + R_{\text{sph}} + R_{\text{conv},2} \\ &= \frac{1}{\left(4\pi r_1^2\right) h_1} + \frac{r_2 - r_1}{4\pi r_1 r_2 k} + \frac{1}{\left(4\pi r_2^2\right) h_2} \end{aligned} \tag{28}$$

Critical Radius of Insulation for a cylindrical body:

$$r_{\text{cr, cylinder}} = \frac{k}{h} \tag{29}$$

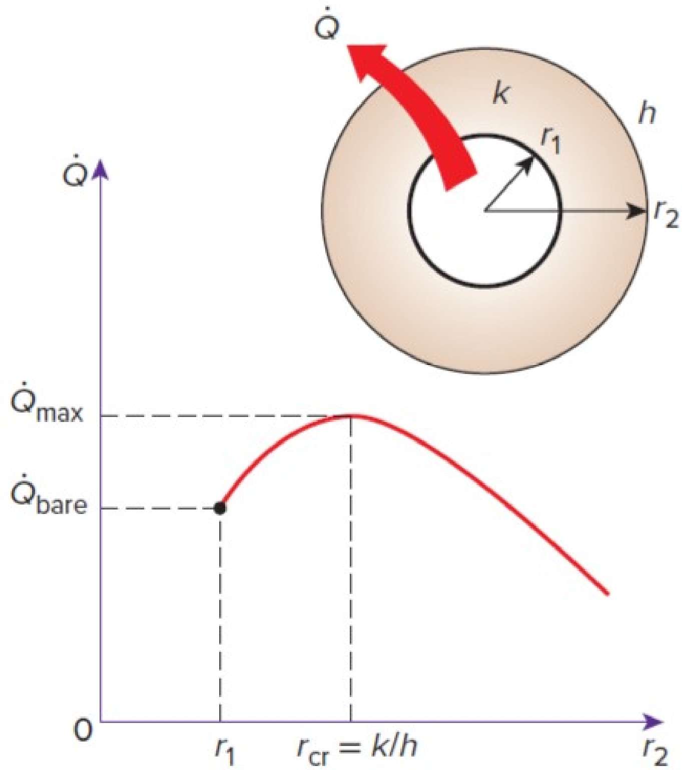

FIGURE 17–31
The variation of heat transfer rate with the outer radius of the insulation r_2 when $r_1 < r_{cr}$.

Fig. 2 Illustration of Critical Radius

For a sphere:

$$r_{\text{cr, sphere}} = \frac{2k}{h} \tag{30}$$

III. Transient Heat Conduction

A. Lumped System Analysis

Can use lumped system analysis when the Biot Number is LESS THAN or EQUAL TO 0.1:

$$\text{Bi} = \frac{hL_c}{k} \tag{31}$$

$$L_c = \frac{V}{A_s} \tag{32}$$

Here the Biot number is defied as:

$$\begin{aligned} \text{Bi} &= \frac{h}{k/L_c}\frac{\Delta T}{\Delta T} = \frac{\text{Convection at the surface of the body}}{\text{Conduction within the body}} \\ \text{Bi} &= \frac{L_c/k}{1/h} = \frac{\text{Conduction resistance within the body}}{\text{Convection resistance at the surface of the body}} \end{aligned} \tag{33}$$

$$
\begin{aligned}
\frac{T(t)-T_\infty}{T_i-T_\infty} &= e^{-bt} \\
b &= \frac{hA_s}{\rho V c_p}
\end{aligned}
\tag{34}
$$

B. Transient Heat Conduction in Plane Walls, Cylinders and Spheres

1. Dimensionless Parameters

Dimensionless Temperature:

$$\theta(X,\tau) = \frac{T(x,t)-T_\infty}{T_i-T_\infty} \tag{35}$$

Dimensionless distance from the center:

$$X = \frac{x}{L} \tag{36}$$

Dimensionless heat transfer coefficient(Biot Number):

$$\mathrm{Bi} = \frac{hL}{k} \tag{37}$$

Dimensionless Time(Fourier Number):

$$\tau = \frac{\alpha t}{L^2} = \mathrm{Fo} \tag{38}$$

$$\theta = \frac{T(t)-T_\infty}{T_i-T_\infty} = e^{-bt} = e^{-\frac{hAt}{\rho V c_r}} = e^{-\mathrm{BiFo}} \tag{39}$$

2. Analytical and Graphical Solutions

For solving these problems, determine the biot number then use tables and interpolation to determine the needed lambda and A values for the equations.

One term approximations for non-center of wall: Plane wall:

$$\theta_{\text{wall}} = \frac{T(x,t)-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2\tau}\cos\left(\lambda_1 x/L\right), \tau > 0.2 \tag{40}$$

Cylinder:

$$\theta_{\text{cyl}} = \frac{T(r,t)-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2\tau} J_0\left(\lambda_1 r/r_o\right), \tau > 0.2 \tag{41}$$

Sphere:

$$\theta_{\text{sph}} = \frac{T(r,t)-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2\tau}\frac{\sin\left(\lambda_1 r/r_o\right)}{\lambda_1 r/r_o}, \tau > 0.2 \tag{42}$$

Center of wall solutions: Plane Wall:

$$\theta_{0,\text{ wall}} = \frac{T_0-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2\tau} \tag{43}$$

Cylinder:

$$\theta_{0,\text{ cyl}} = \frac{T_0-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2\tau} \tag{44}$$

Sphere:

$$\theta_{0,\text{sph}} = \frac{T_0-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2\tau} \tag{45}$$

IV. Radiation Heat Transfer

Electromagnetic waves are characterized by their frequency ν or wavelength λ where c is the speed of light($c_0 = 2.9979 * 10^8$):

$$\lambda = \frac{c}{\nu} \tag{46}$$

Each photon of frequency ν is considered to have an energy of:

$$e = h\nu = \frac{hc}{\lambda} \tag{47}$$

where h = $6.626069 * 10^{-34}$.

$$\dot{Q}_{\text{emit}} = \sigma A_s T_s^4 \tag{48}$$

$$\dot{Q}_{\text{incident}} = \sigma A_s T_{\text{surr}}^4 \tag{49}$$

A. Blackbody Radiation

Blackbody is a perfect emitter and absorber of radiation. The blackbody emmissive power:

$$E_b(T) = \sigma T^4 \quad \left(\mathrm{W/m^2}\right) \tag{50}$$

here $\sigma = 5.670 * 10^{-8}$ which is the steffan-boltzmann constant.

spectral emissive power:

$$E_{b\lambda}(\lambda, T) = \frac{C_1}{\lambda^5 \left[\exp\left(C_2/\lambda T\right) - 1\right]} \quad \left(\mathrm{W/m^2 \cdot \mu m}\right) \tag{51}$$

$$\begin{aligned} C_1 &= 2\pi h c_0^2 = 3.74177 \times 10^8\ \mathrm{W \cdot \mu m^4/m^2} \\ C_2 &= hc_0/k = 1.43878 \times 10^4 \mu\mathrm{m \cdot K} \end{aligned} \tag{52}$$

Dimensionless Blackbody Radiation Function:

$$f_\lambda(T) = \frac{\int_0^\lambda E_{b\lambda}(\lambda, T) d\lambda}{\sigma T^4} \tag{53}$$

this value can be obtained from tables once values for lambda and temperature are found

$$f_{\lambda_1 - \lambda_2}(T) = \frac{\int_0^{\lambda_2} E_{b\lambda}(\lambda, T) d\lambda - \int_0^{\lambda_1} E_{b\lambda}(\lambda, T) d\lambda}{\sigma T^4} = f_{\lambda_2}(T) - f_{\lambda_1}(T) \tag{54}$$

B. Radiative Properties

Emissivity - the ratio of the radiation emitted by the surface at a given temperature to the radiation emitted by a blackbody at the same temperature.

spectral hemispherical emissivity;

$$\varepsilon_\lambda(\lambda, T) = \frac{E_\lambda(\lambda, T)}{E_{b\lambda}(\lambda, T)} \tag{55}$$

total hemispherical emissivity:

$$\varepsilon(T) = \frac{E(T)}{E_b(T)} \tag{56}$$

OR

$$\varepsilon(T) = \frac{E(T)}{E_b(T)} = \frac{\int_0^\infty \varepsilon_\lambda(\lambda, T) E_{b\lambda}(\lambda, T) d\lambda}{\sigma T^4} \tag{57}$$

The average emissivity can be determined by taking the average of 3 different wavelengths:

$$\varepsilon_\lambda = \begin{cases} \varepsilon_1 = \text{ constant}, & 0 \le \lambda < \lambda_1 \\ \varepsilon_2 = \text{ constant}, & \lambda_1 \le \lambda < \lambda_2 \\ \varepsilon_3 = \text{ constant}, & \lambda_2 \le \lambda < \infty \end{cases} \tag{58}$$

$$\begin{aligned} \varepsilon_1(T) &= \frac{\varepsilon_1 \int_0^{\lambda_1} E_{b\lambda} d\lambda}{E_b} + \frac{\varepsilon_2 \int_{\lambda_1}^{\lambda_2} E_{b\lambda} d\lambda}{E_b} + \frac{\varepsilon_3 \int_{\lambda_2}^{\infty} E_{b\lambda} d\lambda}{E_b} \\ &= \varepsilon_1 f_{0-\lambda_1}(T) + \varepsilon_2 f_{\lambda_1-\lambda_2}(T) + \varepsilon_3 f_{\lambda_2-\infty}(T) \end{aligned} \tag{59}$$

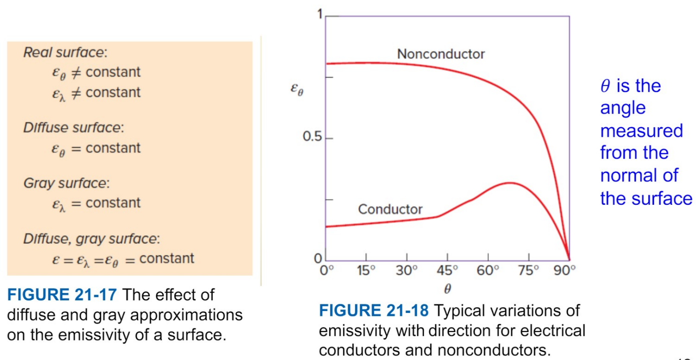

FIGURE 21-17 The effect of diffuse and gray approximations on the emissivity of a surface.

FIGURE 21-18 Typical variations of emissivity with direction for electrical conductors and nonconductors.

Fig. 3 emissivity relationships

Absorbtivity:

$$\alpha = \frac{\text{Absorbed radiation}}{\text{Incident radiation}} = \frac{G_{\text{abs}}}{G}, \quad 0 \le \alpha \le 1 \tag{60}$$

Reflectivity:

$$\rho = \frac{\text{Reflected radiation}}{\text{Incident radiation}} = \frac{G_{\text{ref}}}{G}, \quad 0 \le \rho \le 1 \tag{61}$$

Transmissivity:

$$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}} = \frac{G_{\text{tr}}}{G}, \quad 0 \le \tau \le 1 \tag{62}$$

Where G is the irradiation: Radiation Flux incident on a surface

$$\begin{aligned} &G_{\text{abs}} + G_{\text{ref}} + G_{\text{tr}} = G \\ &\alpha + \rho + \tau = 1 \end{aligned} \tag{63}$$

Here if it is an opaque surface then the transmissivty, τ, goes to 0.

Spectral hemispherical equations:

$$\begin{aligned} \alpha_\lambda(\lambda) &= \frac{G_{\lambda,\text{abs}}(\lambda)}{\text{G}_\lambda(\lambda)} \\ \rho_\lambda(\lambda) &= \frac{G_{\lambda,\text{ref}}(\lambda)}{\text{G}_\lambda(\lambda)} \\ \tau_\lambda(\lambda) &= \frac{G_{\lambda,\text{tr}}(\lambda)}{\text{G}_\lambda(\lambda)} \end{aligned} \tag{64}$$

OR

$$\alpha = \frac{\int_0^\infty \alpha_\lambda G_\lambda d\lambda}{\int_0^\infty G_\lambda d\lambda}, \quad \rho = \frac{\int_0^\infty \rho_\lambda G_\lambda d\lambda}{\int_0^\infty G_\lambda d\lambda}, \quad \tau = \frac{\int_0^\infty \tau_\lambda G_\lambda d\lambda}{\int_0^\infty G_\lambda d\lambda} \tag{65}$$

Diffuse: Radiation is reflected equally in all directions.

C. Kirchhoff’s Law

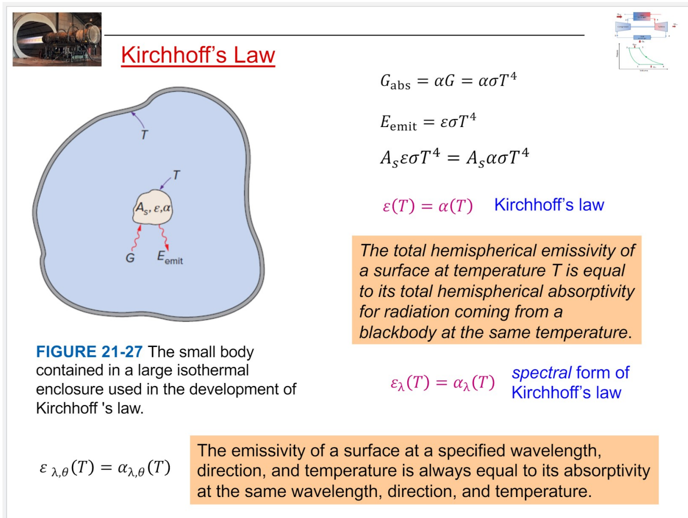

Fig. 4 Kirchhoff’s Law info

D. Wein’s Displacement Law

$$(\lambda T)_{\text{max power}} = 2897.8 \mu\text{m} \cdot \text{K} \tag{66}$$

E. Tables

TABLE 21–1

The wavelength ranges of different colors

Color	Wavelength band
Violet	0.40–0.44 μm
Blue	0.44–0.49 μm
Green	0.49–0.54 μm
Yellow	0.54–0.60 μm
Orange	0.60–0.67 μm
Red	0.63–0.76 μm

Fig. 5 wavelength ranges

TABLE 18–2

Coefficients used in the one-term approximate solution of transient one-dimensional heat conduction in plane walls, cylinders, and spheres (Bi = hL/k for a plane wall of thickness $2L$, and Bi = hr_o/k for a cylinder or sphere of radius r_o)

	Plane Wall		Cylinder		Sphere	
Bi	λ_1	A_1	λ_1	A_1	λ_1	A_1
0.01	0.0998	1.0017	0.1412	1.0025	0.1730	1.0030
0.02	0.1410	1.0033	0.1995	1.0050	0.2445	1.0060
0.04	0.1987	1.0066	0.2814	1.0099	0.3450	1.0120
0.06	0.2425	1.0098	0.3438	1.0148	0.4217	1.0179
0.08	0.2791	1.0130	0.3960	1.0197	0.4860	1.0239
0.1	0.3111	1.0161	0.4417	1.0246	0.5423	1.0298
0.2	0.4328	1.0311	0.6170	1.0483	0.7593	1.0592
0.3	0.5218	1.0450	0.7465	1.0712	0.9208	1.0880
0.4	0.5932	1.0580	0.8516	1.0931	1.0528	1.1164
0.5	0.6533	1.0701	0.9408	1.1143	1.1656	1.1441
0.6	0.7051	1.0814	1.0184	1.1345	1.2644	1.1713
0.7	0.7506	1.0918	1.0873	1.1539	1.3525	1.1978
0.8	0.7910	1.1016	1.1490	1.1724	1.4320	1.2236
0.9	0.8274	1.1107	1.2048	1.1902	1.5044	1.2488
1.0	0.8603	1.1191	1.2558	1.2071	1.5708	1.2732
2.0	1.0769	1.1785	1.5995	1.3384	2.0288	1.4793
3.0	1.1925	1.2102	1.7887	1.4191	2.2889	1.6227
4.0	1.2646	1.2287	1.9081	1.4698	2.4556	1.7202
5.0	1.3138	1.2403	1.9898	1.5029	2.5704	1.7870
6.0	1.3496	1.2479	2.0490	1.5253	2.6537	1.8338
7.0	1.3766	1.2532	2.0937	1.5411	2.7165	1.8673
8.0	1.3978	1.2570	2.1286	1.5526	2.7654	1.8920
9.0	1.4149	1.2598	2.1566	1.5611	2.8044	1.9106
10.0	1.4289	1.2620	2.1795	1.5677	2.8363	1.9249
20.0	1.4961	1.2699	2.2880	1.5919	2.9857	1.9781
30.0	1.5202	1.2717	2.3261	1.5973	3.0372	1.9898
40.0	1.5325	1.2723	2.3455	1.5993	3.0632	1.9942
50.0	1.5400	1.2727	2.3572	1.6002	3.0788	1.9962
100.0	1.5552	1.2731	2.3809	1.6015	3.1102	1.9990
∞	1.5708	1.2732	2.4048	1.6021	3.1416	2.0000

TABLE 18–3

The zeroth- and first-order Bessel functions of the first kind

η	$J_0(\eta)$	$J_1(\eta)$
0.0	1.0000	0.0000
0.1	0.9975	0.0499
0.2	0.9900	0.0995
0.3	0.9776	0.1483
0.4	0.9604	0.1960
0.5	0.9385	0.2423
0.6	0.9120	0.2867
0.7	0.8812	0.3290
0.8	0.8463	0.3688
0.9	0.8075	0.4059
1.0	0.7652	0.4400
1.1	0.7196	0.4709
1.2	0.6711	0.4983
1.3	0.6201	0.5220
1.4	0.5669	0.5419
1.5	0.5118	0.5579
1.6	0.4554	0.5699
1.7	0.3980	0.5778
1.8	0.3400	0.5815
1.9	0.2818	0.5812
2.0	0.2239	0.5767
2.1	0.1666	0.5683
2.2	0.1104	0.5560
2.3	0.0555	0.5399
2.4	0.0025	0.5202
2.6	−0.0968	0.4708
2.8	−0.1850	0.4097
3.0	−0.2601	0.3391
3.2	−0.3202	0.2613

Fig. 6 Table for λ and A based off of Bi

TABLE 21–2

Blackbody radiation functions f_λ

λT, μm·K	f_λ	λT, μm·K	f_λ
200	0.000000	6200	0.754140
400	0.000000	6400	0.769234
600	0.000000	6600	0.783199
800	0.000016	6800	0.796129
1000	0.000321	7000	0.808109
1200	0.002134	7200	0.819217
1400	0.007790	7400	0.829527
1600	0.019718	7600	0.839102
1800	0.039341	7800	0.848005
2000	0.066728	8000	0.856288
2200	0.100888	8500	0.874608
2400	0.140256	9000	0.890029
2600	0.183120	9500	0.903085
2800	0.227897	10,000	0.914199
3000	0.273232	10,500	0.923710
3200	0.318102	11,000	0.931890
3400	0.361735	11,500	0.939959
3600	0.403607	12,000	0.945098
3800	0.443382	13,000	0.955139
4000	0.480877	14,000	0.962898
4200	0.516014	15,000	0.969981
4400	0.548796	16,000	0.973814
4600	0.579280	18,000	0.980860
4800	0.607559	20,000	0.985602
5000	0.633747	25,000	0.992215
5200	0.658970	30,000	0.995340
5400	0.680360	40,000	0.997967
5600	0.701046	50,000	0.998953
5800	0.720158	75,000	0.999713
6000	0.737818	100,000	0.999905

Fig. 7 λ*f table