RADIATION HEAT TRANSFER

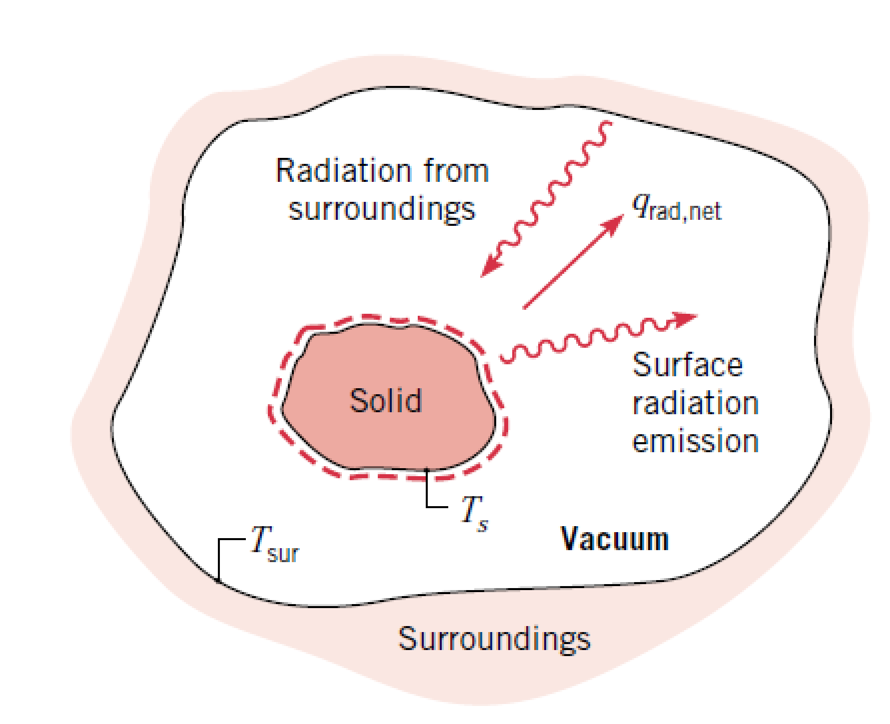
LAB 10

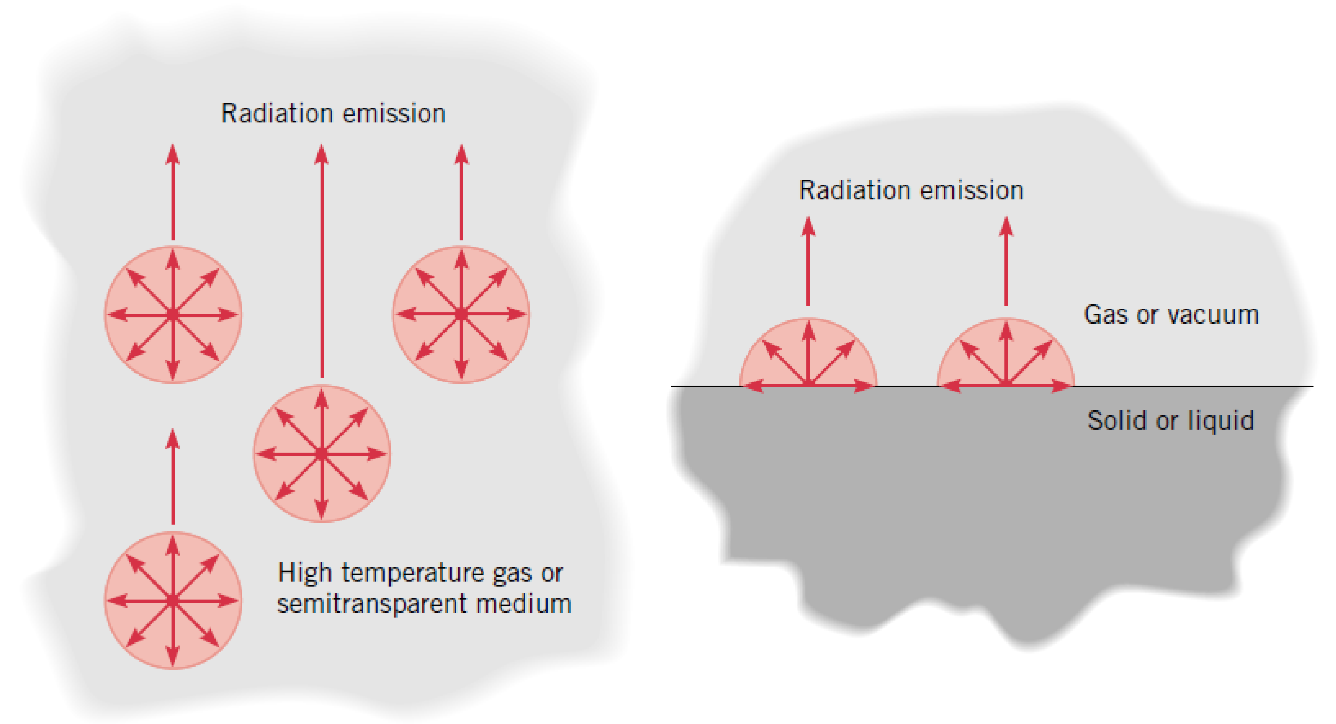
RADIATION HEAT TRANSFER

- Electromagnetic Waves Radiation
- Radiative Heat Flux
- Radiation Intensity
- Black Body Radiation
- Stefan-Boltzmann Law
- Solar Heat Flux
- Lab 10 Goal: To verify that the total radiation emitted by a heat source is proportional to the fourth power of its absolute temperature (Stefan-Boltzmann Law) and the effect emissivity has on measured emission

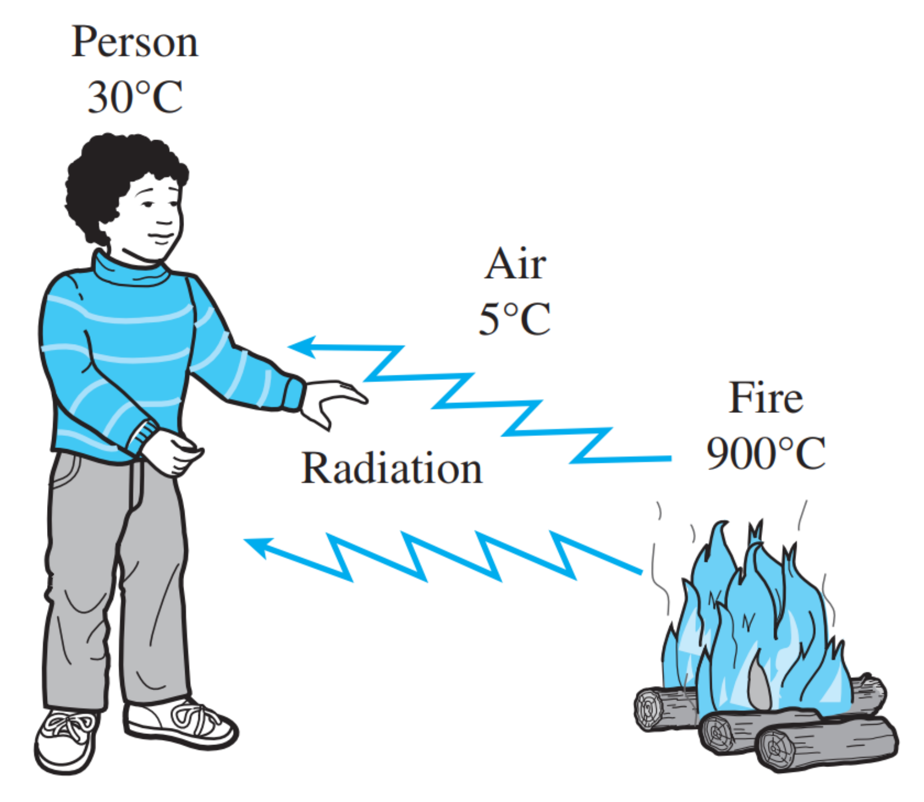
ELECTROMAGNETIC WAVES

- Radiation refers to the emission of electromagnetic waves from the surface of an object





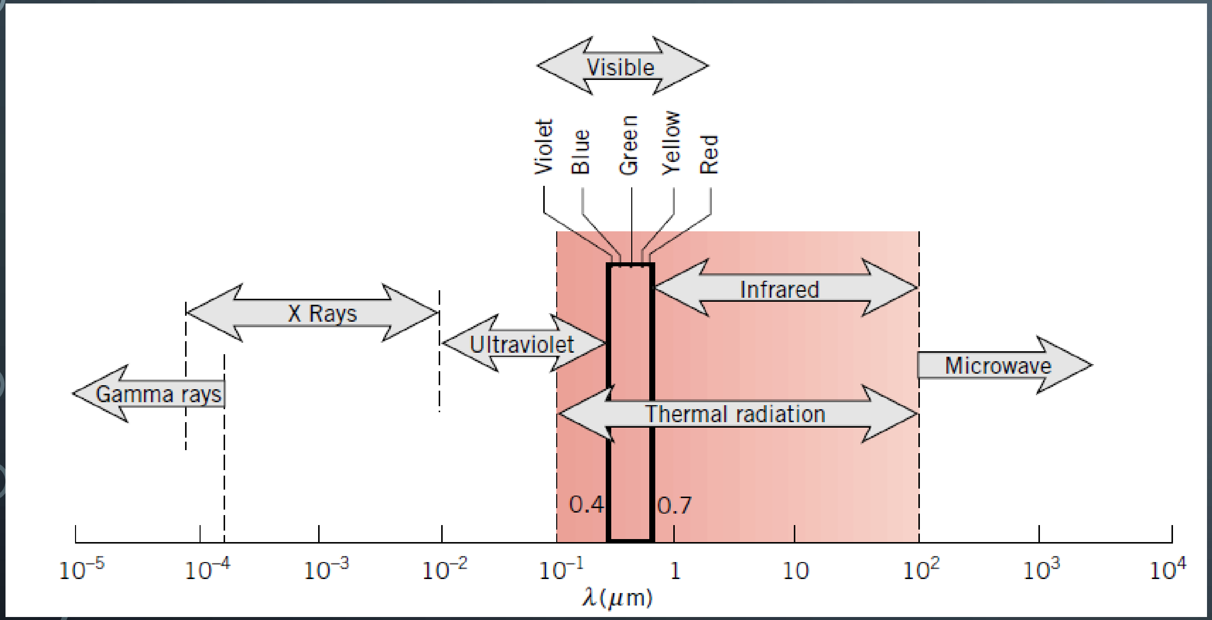
ELECTROMAGNETIC WAVES

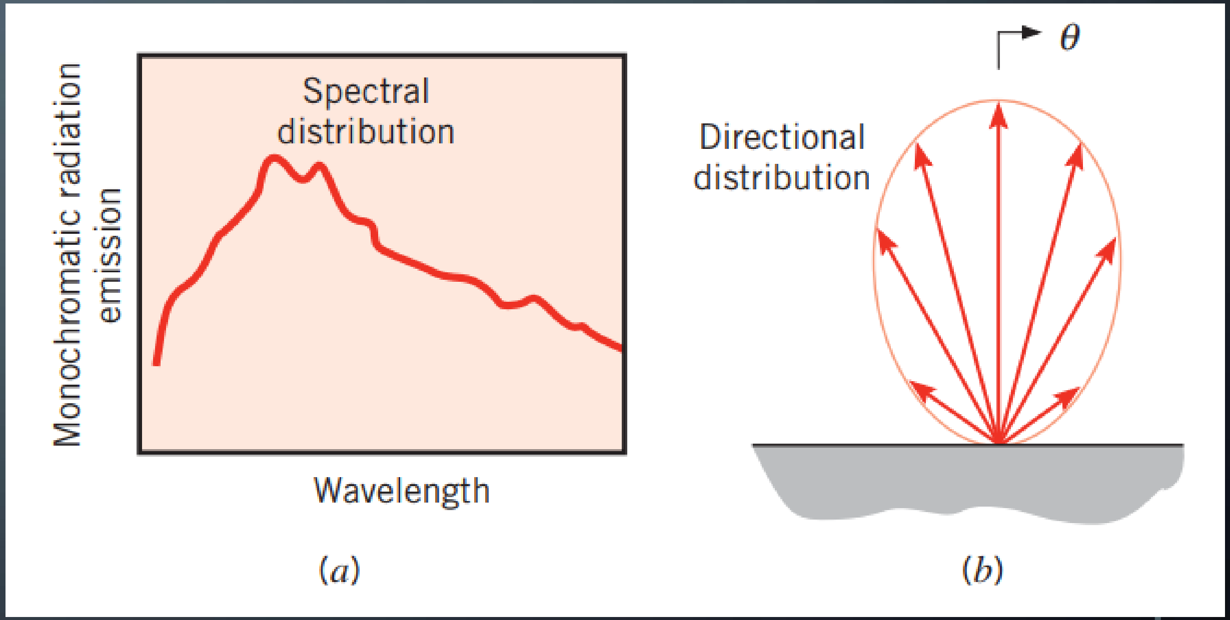


- Each photon of frequency v is considered to have energy of

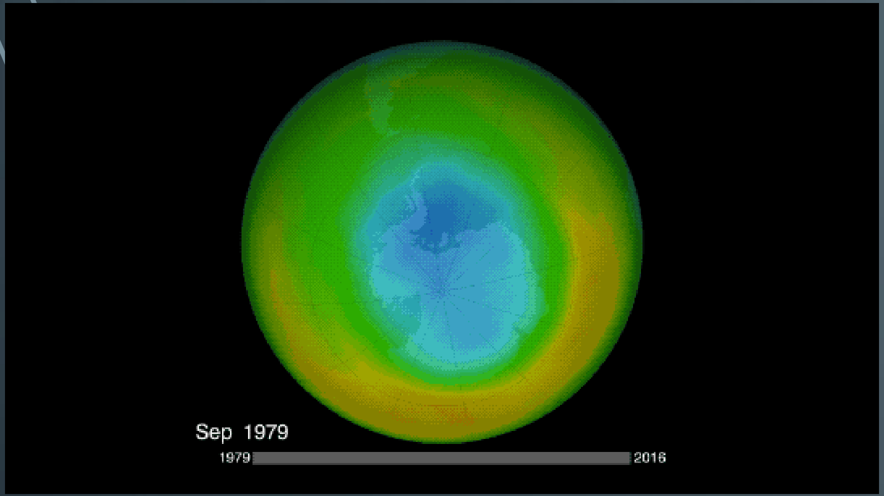
$$e = h\nu = \frac{hc}{\lambda}$$

ELECTROMAGNETIC WAVES





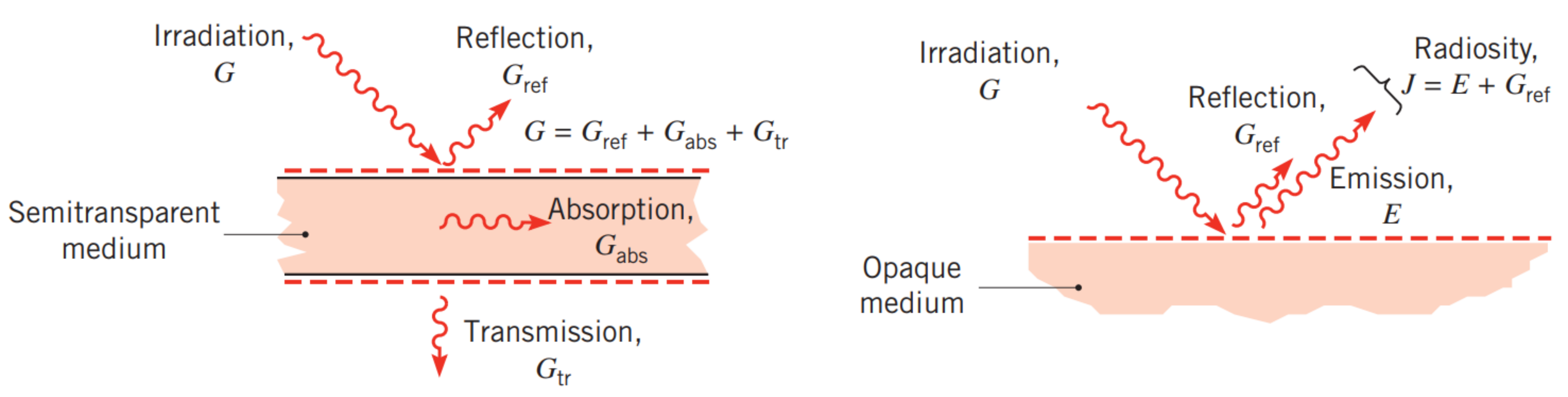
ELECTROMAGNETIC WAVES



RADIATIVE HEAT FLUX

TABLE 12.1 Radiative fluxes (over all wavelengths and in all directions)

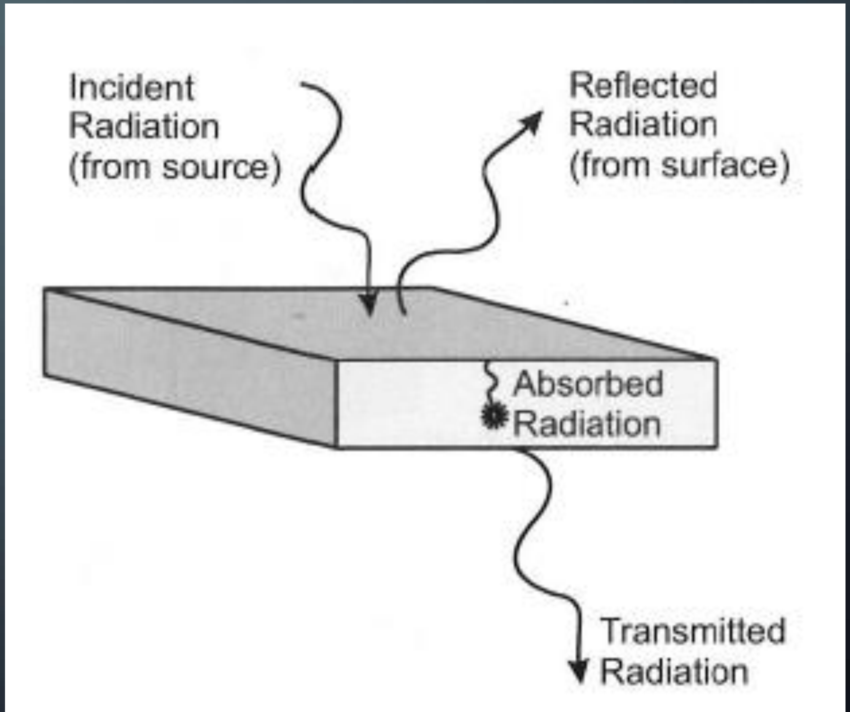
Flux (W/m²)	Description	Comment
Emissive power, E	Rate at which radiation is emitted from a surface per unit area	$E = \varepsilon \sigma T_s^4$
Irradiation, G	Rate at which radiation is incident upon a surface per unit area	Irradiation can be reflected, absorbed, or transmitted
Radiosity, J	Rate at which radiation leaves a surface per unit area	For an opaque surface $J = E + \rho G$
Net radiative flux, $q''_{rad} = J - G$	Net rate of radiation leaving a surface per unit area	For an opaque surface $q''_{rad} = \varepsilon \sigma T_s^4 - \alpha G$



RADIATIVE HEAT FLUX

- Reflectivity – The fraction reflected (ρ)
- Absorptivity – The fraction absorbed (α)
- Transmissivity – The fraction transmitted (τ)

$$\rho + \alpha + \tau = 1$$

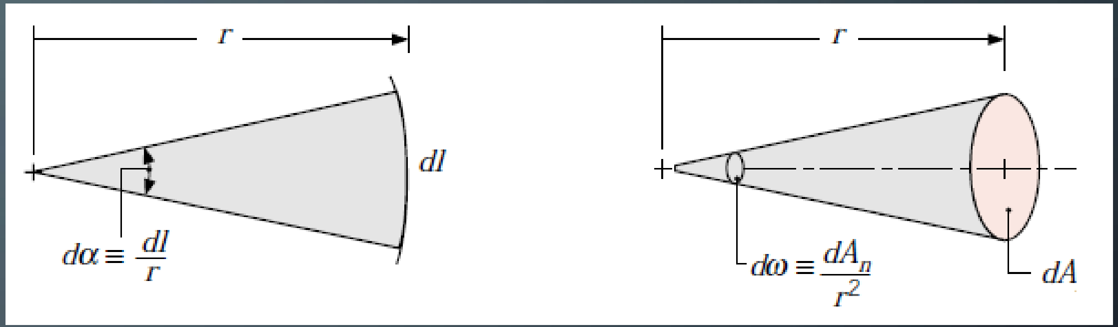


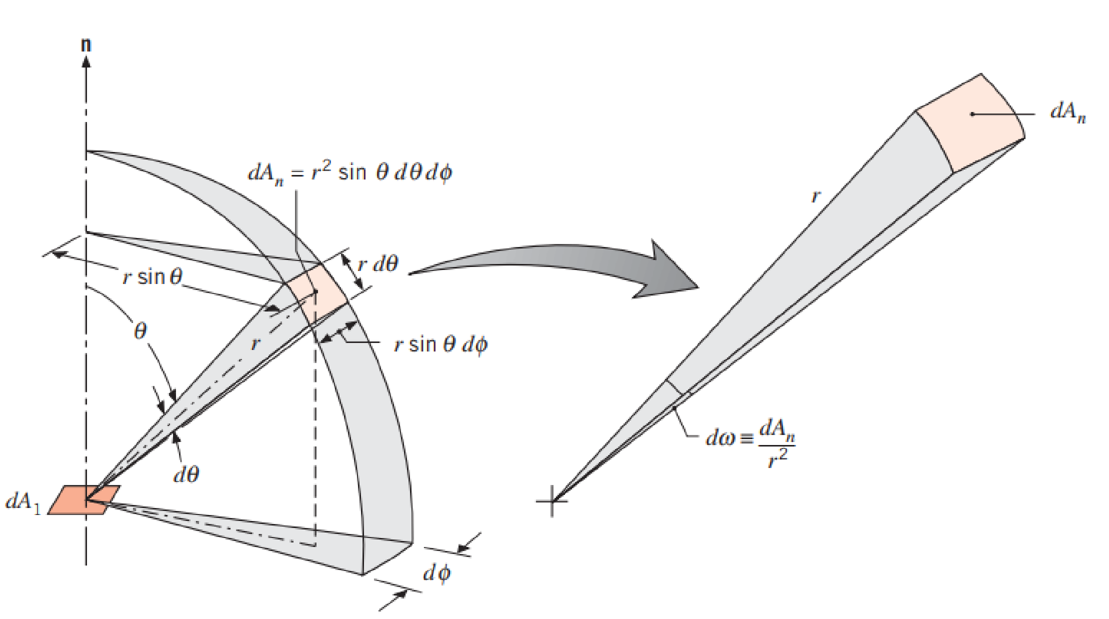
RADIATION INTENSITY

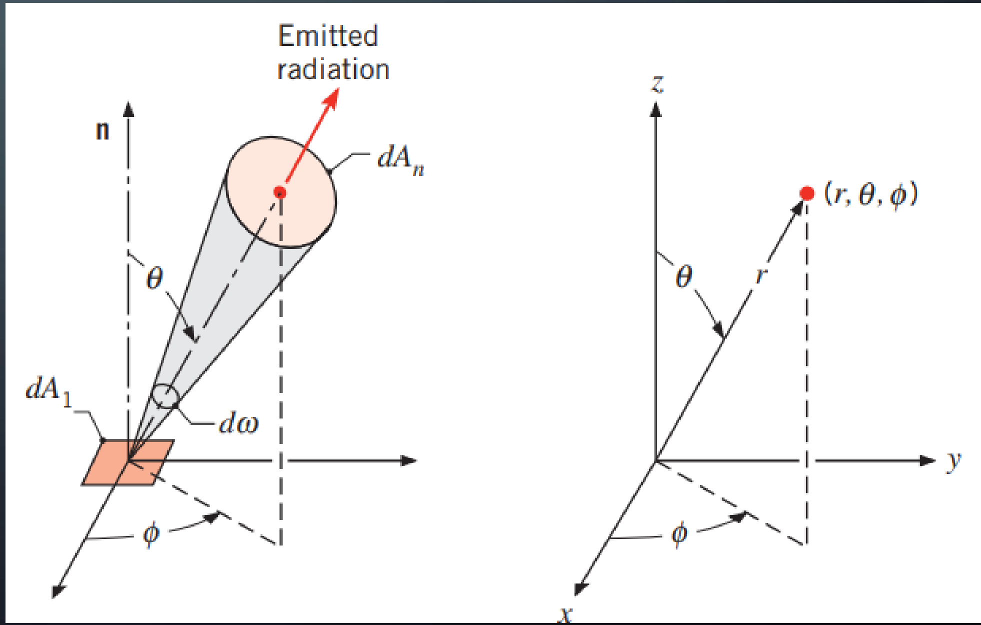
- Solid angle

$$d\omega = \frac{dA_n}{r^2}$$

$$dA_n = r^2 \sin\theta d\theta d\phi$$







RADIATION INTENSITY

- Emission

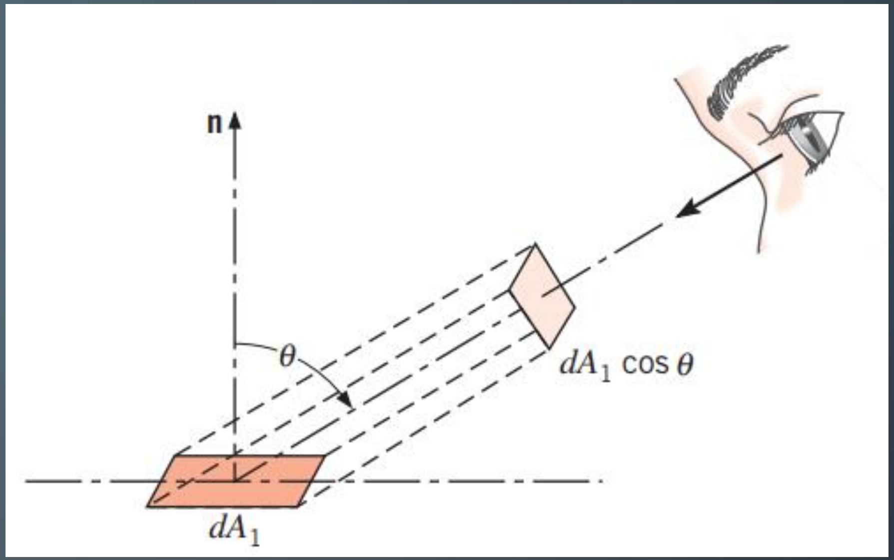
$$E = \pi I_e$$

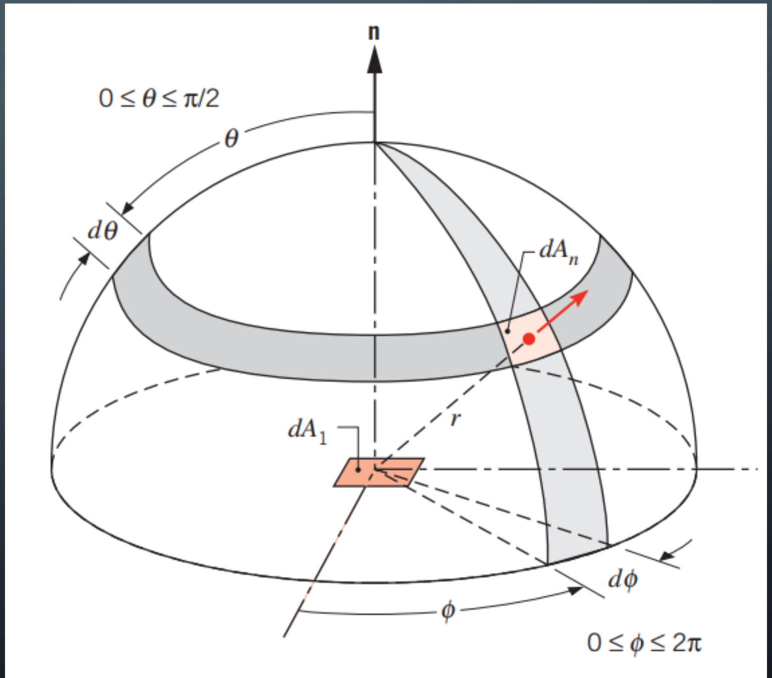
- Irradiation

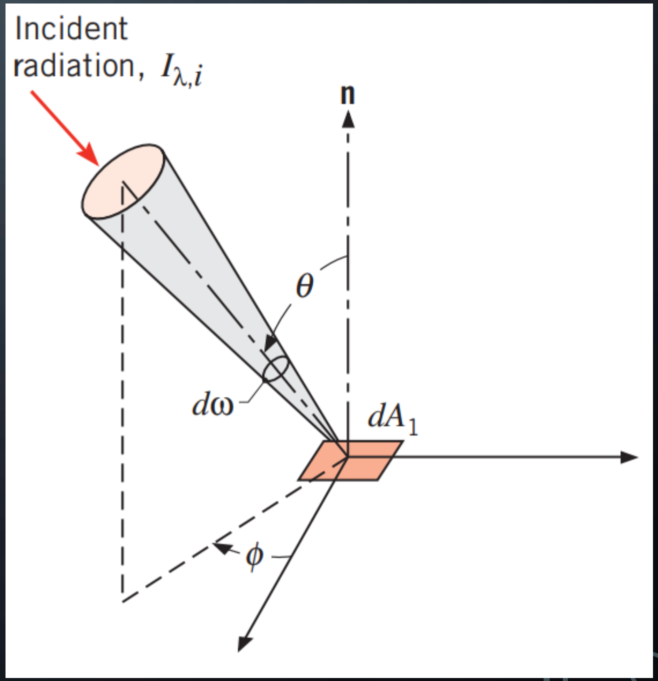
$$E = \pi I_i$$

- Radiosity

$$J = \pi I_{e+r}$$

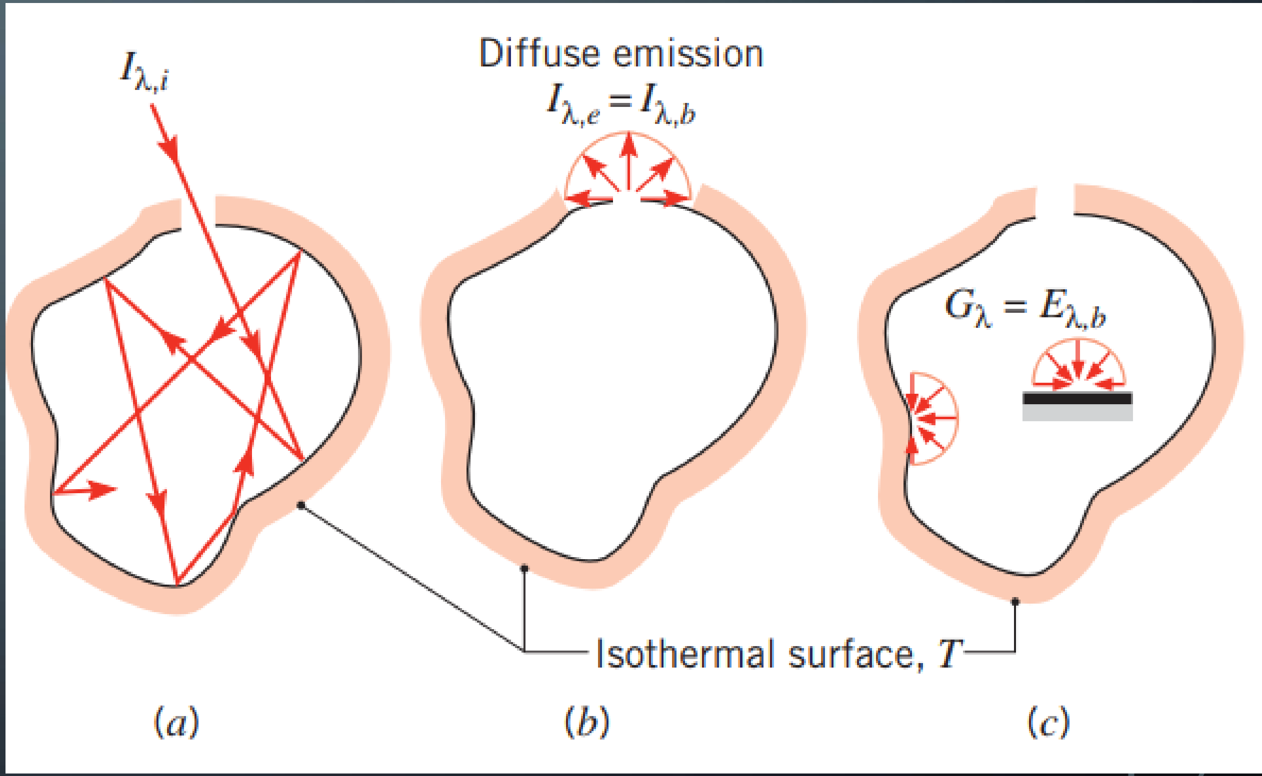






BLACK BODY RADIATION

- A blackbody absorbs all incident radiation, regardless of wavelength and direction.
- For a prescribed temperature and wavelength, no surface can emit more energy than a blackbody.
- Although the radiation emitted by a blackbody is a function of wavelength and temperature, it is independent of direction. That is, the blackbody is a diffuse emitter.



BLACK BODY RADIATION

- Plank distribution

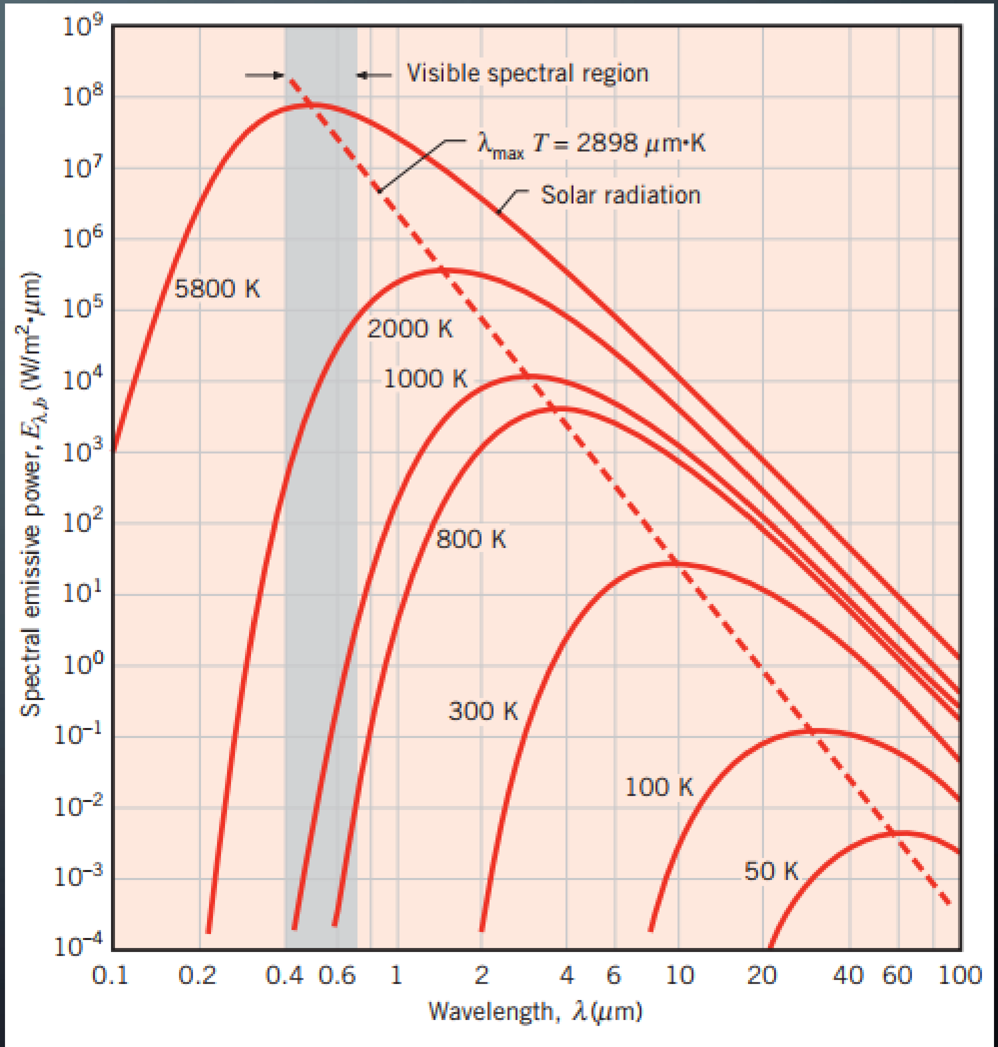
$$E_{\lambda,b}(\lambda,T) = \pi I_{\lambda,b}(\lambda,T) = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]}$$

$$C_1 = 2\pi h c_o^2 = 3.742 \times 10^8\, W \cdot \frac{\mu m^4}{m^2}$$

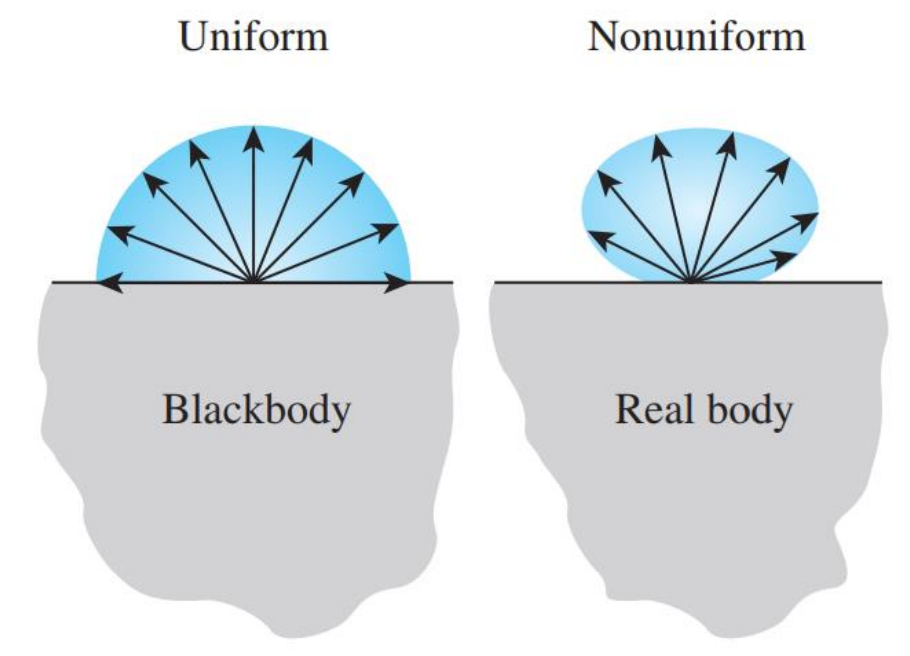
$$C_2 = \frac{h c_o}{k_B} = 1.439 \times 10^4 \mu m \cdot K$$

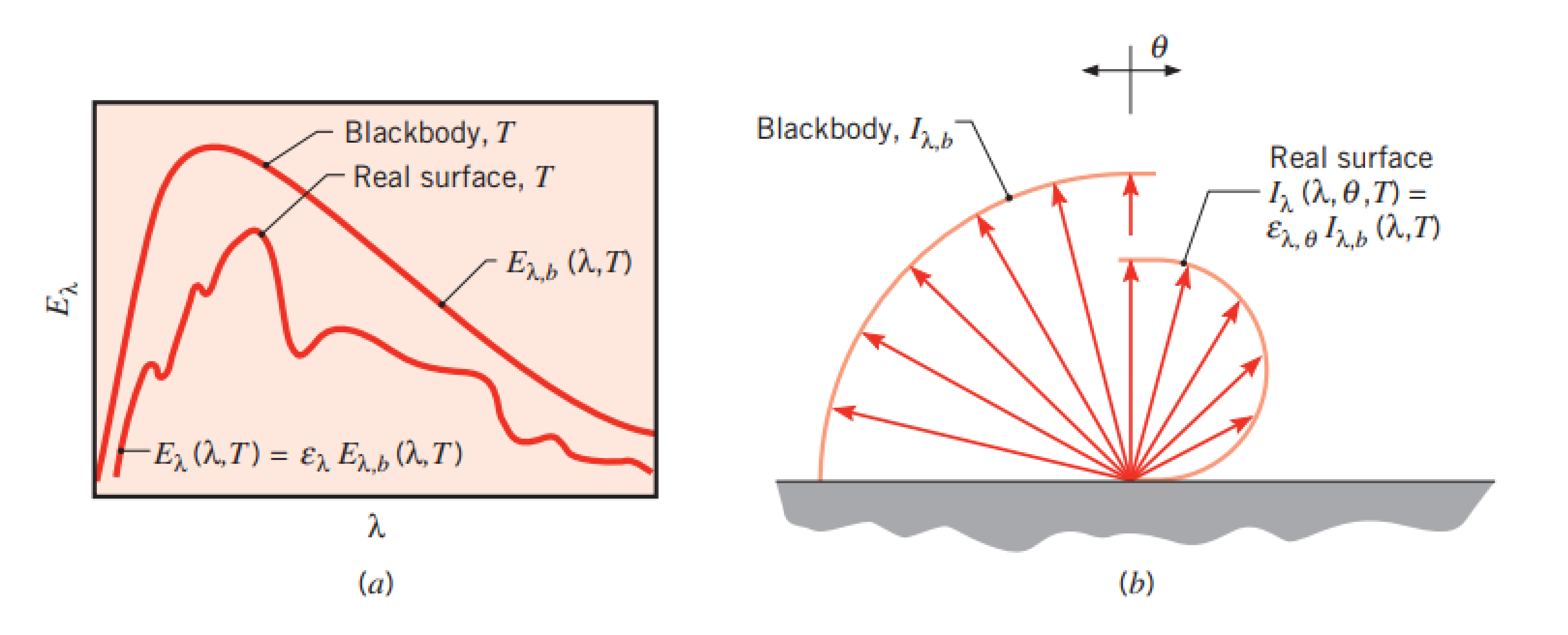
- Wien's displacement law

$$\lambda_{max} T = 2898 \mu m \cdot K$$



BLACK BODY RADIATION





STEFAN BOLTZMANN LAW

- Black Body Irradiation

$$E_b = \sigma T^4$$

$$I_b = E_b/\pi$$

- Ambient Effects

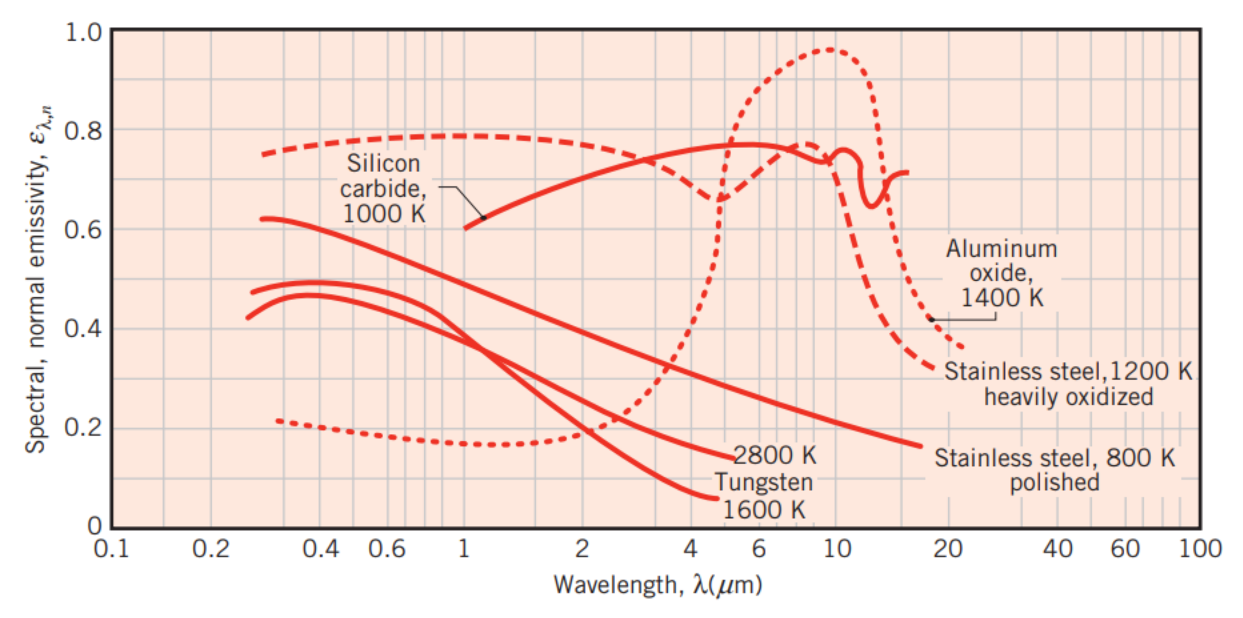
$$E_T = E_{HS} + E_{amb}$$

$$E_{amb} = \sigma T_{amb}^4$$

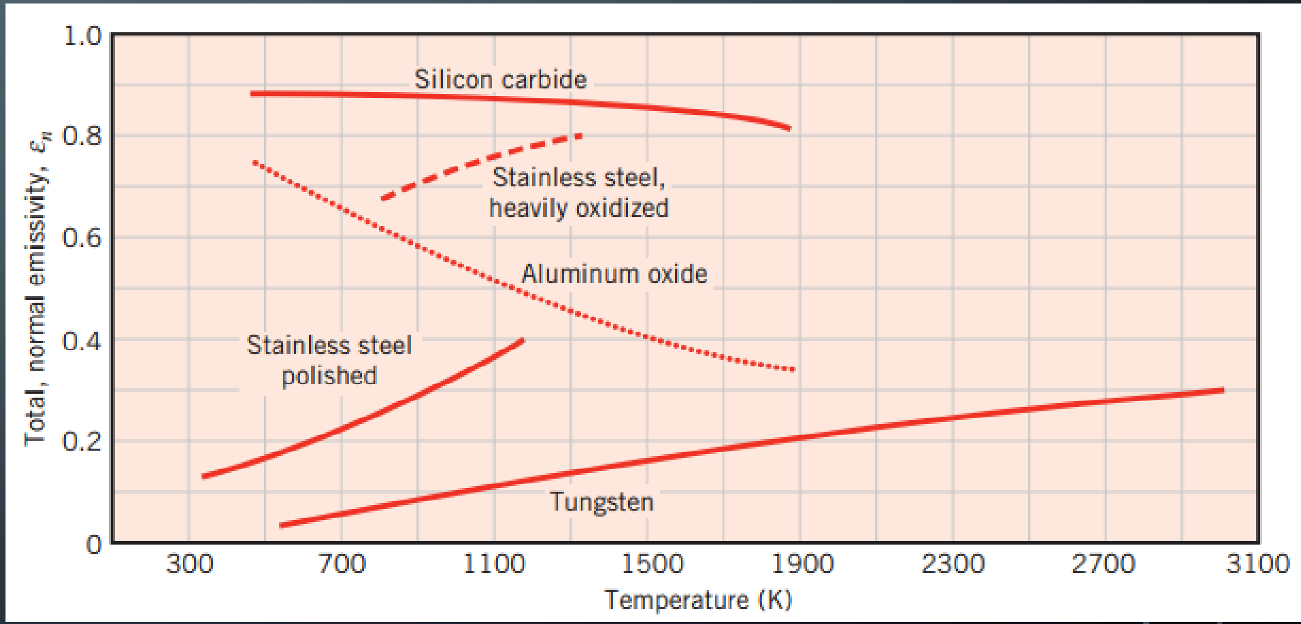
- Real Irradiation

$$E = \varepsilon(\lambda, T)\sigma T^4$$

EMISSIVITY



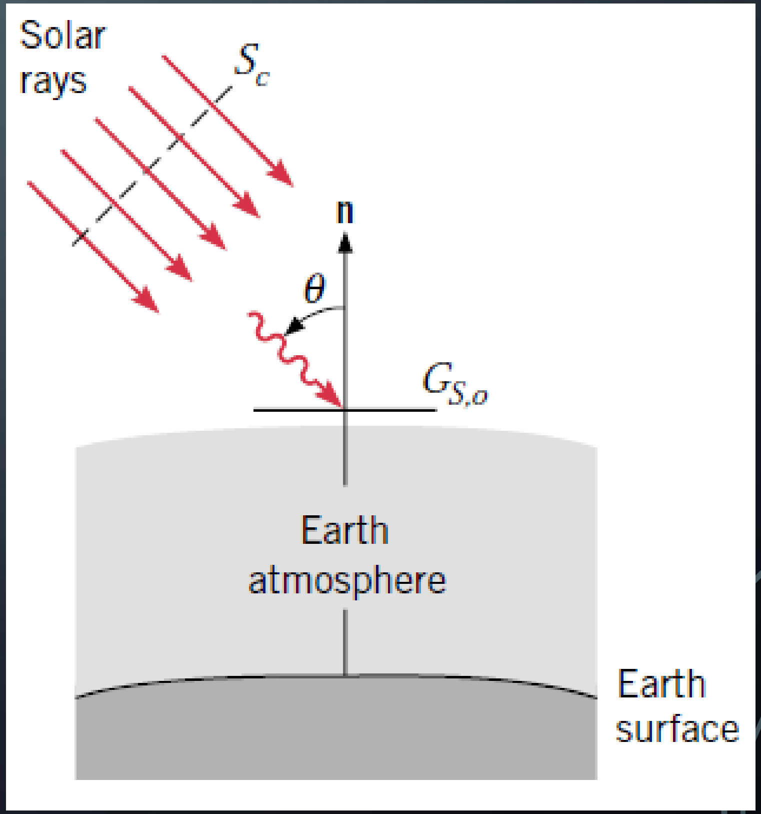
1.0
0.8
0.6
0.4
0.2
0
Spectral, normal emissivity, $\varepsilon_{\lambda,n}$
Silicon carbide, 1000 K
Aluminum oxide, 1400 K
Stainless steel, 1200 K heavily oxidized
2800 K
Tungsten
1600 K
Stainless steel, 800 K polished
0.1
0.2
0.4
0.6
1
2
4
6
10
20
40
60
100
Wavelength, $\lambda(\mu m)$



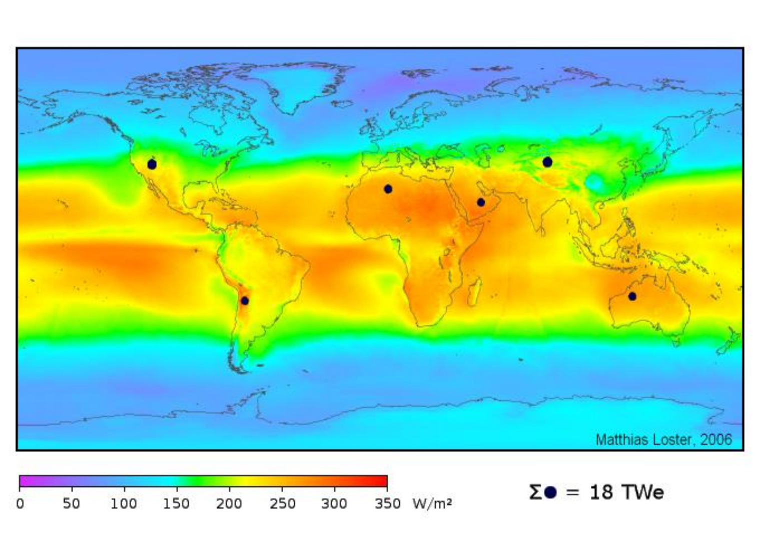
1.0
0.8
0.6
0.4
0.2
0
Total, normal emissivity, ε_n
Silicon carbide
Stainless steel, heavily oxidized
Aluminum oxide
Stainless steel polished
Tungsten
300
700
1100
1500
1900
2300
2700
3100
Temperature (K)

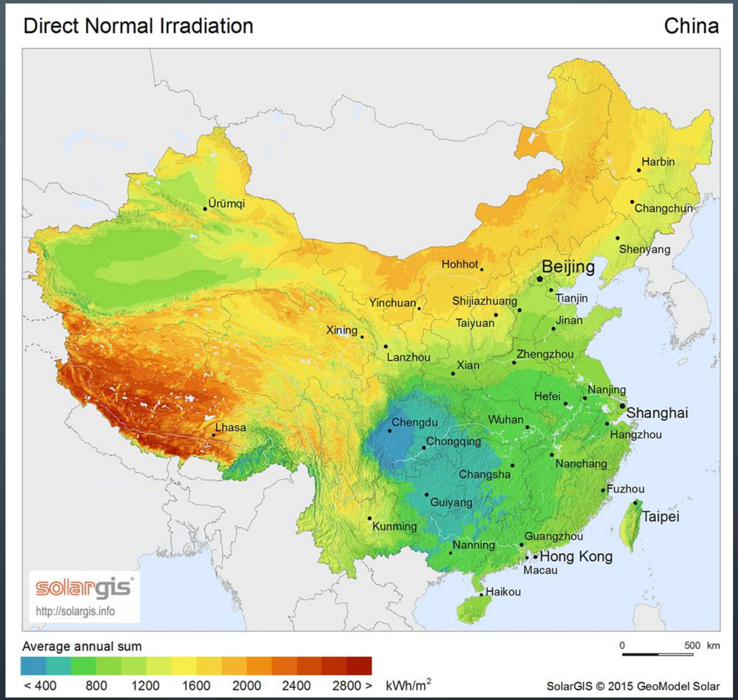
SOLAR HEAT FLUX

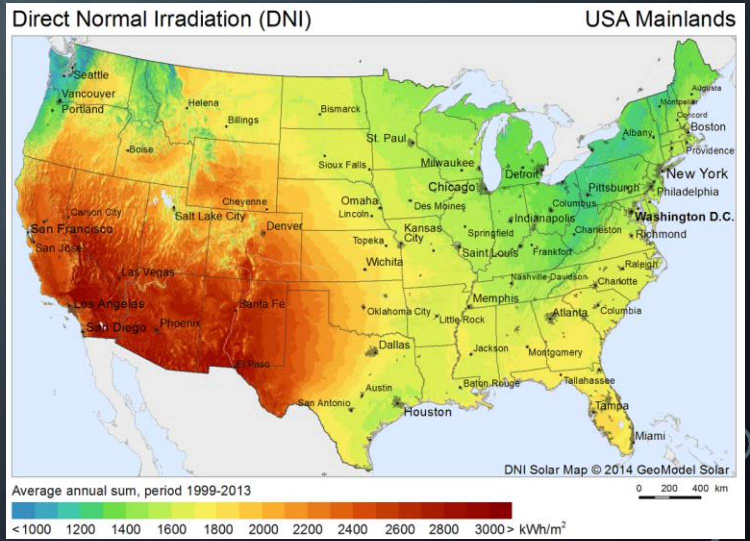
- The sun is located $1.5 \times 10^{11}\ m$ from the earth and emits as a blackbody at 5800 K.
- Solar Flux at the outer edge of the Earth's atmosphere is 1368 W/m^2, 950 W/m^2 at Earth's surface.
- Photovoltaics
  - Conversion into Electrical Energy
- Concentrated Solar Power
  - Conversion into Heat



SOLAR FLUX


Matthias Loster, 2006
0 50 100 150 200 250 300 350 W/m²
Σ● = 18 TWe


Direct Normal Irradiation
China
Ürümqi
Harbin
Changchun
Shenyang
Hohhot
Beijing
Tianjin
Yinchuan
Shijiazhuang
Taiyuan
Jinan
Xining
Lanzhou
Zhengzhou
Xian
Nanjing
Hefei
Shanghai
Chengdu
Wuhan
Hangzhou
Lhasa
Chongqing
Nanchang
Changsha
Fuzhou
Guiyang
Taipei
Kunming
Guangzhou
Nanning
Hong Kong
Macau
Haikou
solargis
http://solargis.info
Average annual sum
0 500 km
< 400 800 1200 1600 2000 2400 2800 > kWh/m²
SolarGIS © 2015 GeoModel Solar


Direct Normal Irradiation (DNI)
USA Mainlands
Seattle
Vancouver
Portland
Helena
Billings
Bismarck
Boise
St. Paul
Boston
Milwaukee
Detroit
New York
Chicago
Pittsburgh
Philadelphia
Washington D.C.
Richmond
Salt Lake City
Denver
Omaha
Lincoln
Des Moines
Kansas City
Indianapolis
Saint Louis
San Francisco
San Jose
Las Vegas
Wichita
Los Angeles
San Diego
Phoenix
Santa Fe
Oklahoma City
Memphis
Atlanta
Dallas
El Paso
Austin
San Antonio
Houston
Tampa
Miami
DNI Solar Map © 2014 GeoModel Solar
Average annual sum, period 1999-2013
0 200 400 km
<1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000> kWh/m²

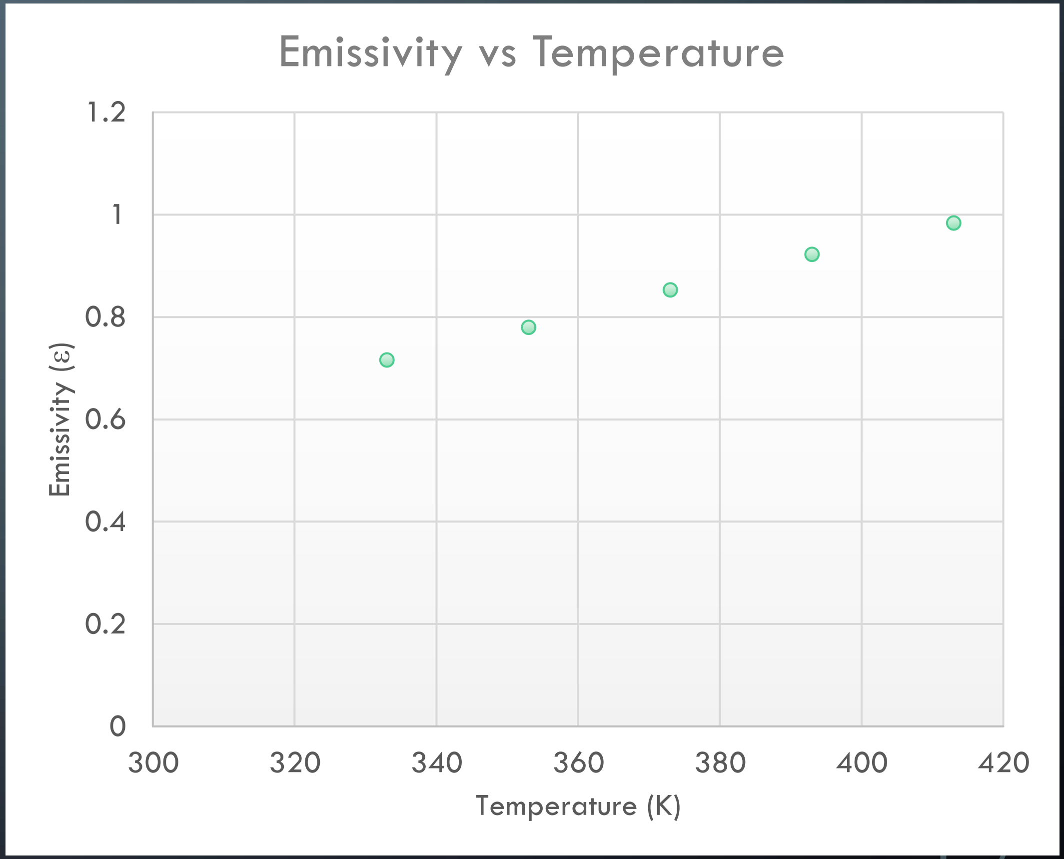
LAB 10

- Radiative temperature measurement from a conductively heated source
  - Please briefly describe what you observed in relation to “heat conduction” during this experimental step.
  - Explain the temperature difference between different samples under different heat up times.
- Radiative temperature measurement from a conductively heated source
  - Why is there a temperature difference between the samples with and without black tape?
  - How do emissivity values differ for each of the materials tested?
- Radiative emission at different temperatures
  - Log-log plot used to verify the Stefan-Boltzmann Law
  - A non-log scale plot of the same data
  - A plot of the emissivity as a function of the temperature
  - A table showing the equations used to calculate uncertainty in emissivity and listing uncertainty in emissivity for each temperature point.

LAB 10

- Diameter of Sensor: 5 cm
- Distance to Heat Source: 350 mm
- Blackbody Heat Source Emission: $E_b = \sigma T^4$
- Theoretical Irradiance at Sensor: $\frac{E_b A_{sensor}}{r^2}$

Heat Source E_b (W/m$^{2)}$	Theoretical (W/m^2)	Emissivity
697.2041972	11.17516	0.715873
880.4037434	14.11158	0.779502
1097.535019	17.59188	0.852666
1352.549787	21.67939	0.922535
1649.617539	26.44095	0.983323



LAB 10

Room T	Heat Source T (°C)	Heat Source T (K)	Heat Source T^4 (K^4)	Measured I (W/m^2)
21	60	333	12296370321	8
21	80	353	15527402881	11
21	100	373	19356878641	15
21	120	393	23854493601	20
21	140	413	29093783761	26

Log Heat Source (K)	Log Adjusted I (W/m^2)
2.522444234	0.903089987
2.547774705	1.041392685
2.571708832	1.176091259
2.59439255	1.301029996
2.615950052	1.414973348