TRANSMISSÃO DE CALOR E MASSA

CAPÍTULO 12
RADIAÇÃO:
PROCESSOS E PROPRIEDADES

Radiation: Processes and Properties
-Basic Principles and Definitions-

Chapter 12

Sections 12.1 through 12.3

General Considerations

- Attention is focused on thermal radiation, whose origins are associated with emission from matter at an absolute temperature $T > 0$.

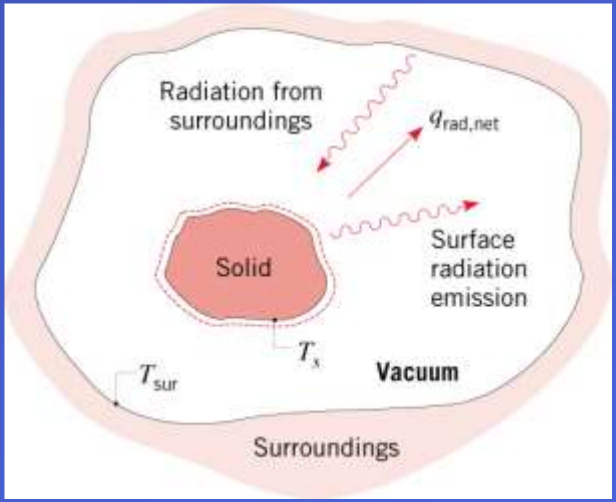
- Emission is due to oscillations and transitions of the many electrons that comprise matter, which are, in turn, sustained by the thermal energy of the matter.

- Emission corresponds to heat transfer from the matter and hence to a reduction in thermal energy stored by the matter.

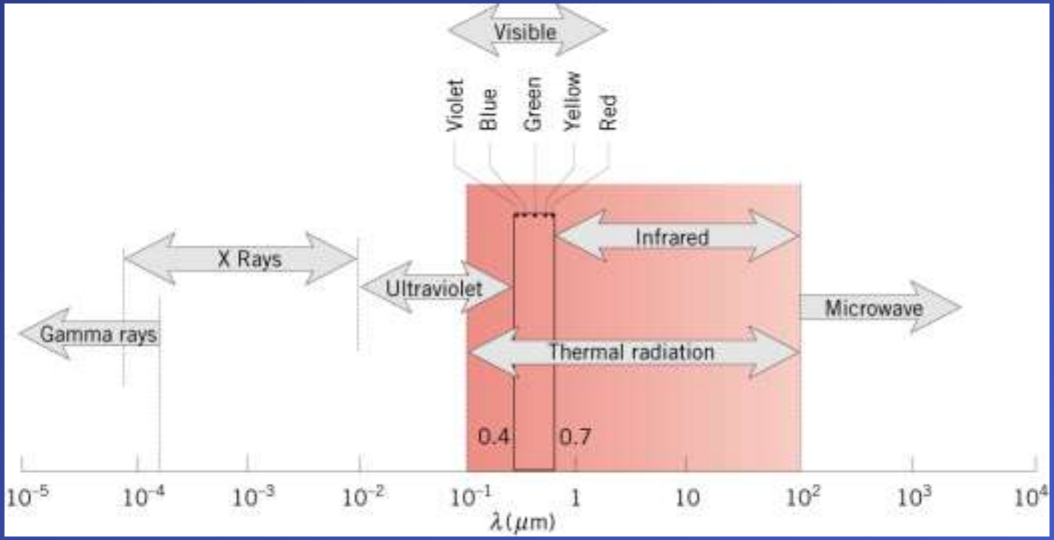
- Radiation may also be intercepted and absorbed by matter.

- Absorption results in heat transfer to the matter and hence an increase in thermal energy stored by the matter.

- Consider a solid of temperature T_s in an evacuated enclosure whose walls are at a fixed temperature T_{sur} :

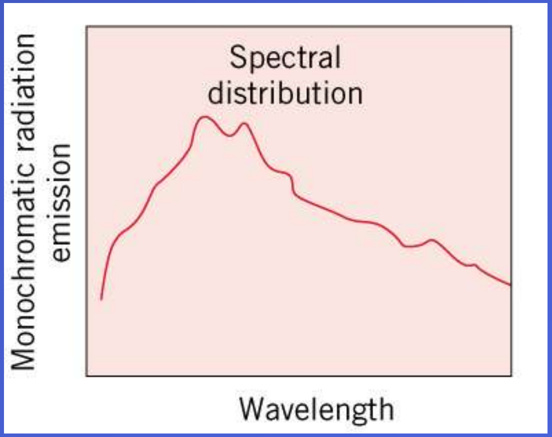


The Electromagnetic Spectrum



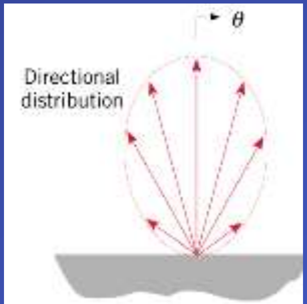
- Thermal radiation is confined to the infrared, visible and ultraviolet regions of the spectrum $(0.1 < \lambda < 100\mu m)$.

- The amount of radiation emitted by an opaque surface varies with wavelength, and we may speak of the spectral distribution over all wavelengths or of monochromatic/spectral components associated with particular wavelengths.

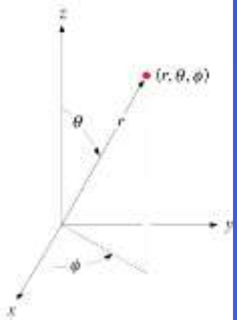


Directional Considerations and the Concept of Radiation Intensity

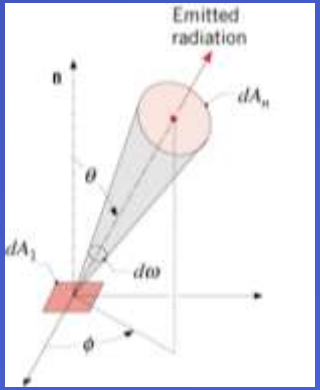
- Radiation emitted by a surface will be in all directions associated with a hypothetical hemisphere about the surface and is characterized by a directional distribution.



- Direction may be represented in a spherical coordinate system characterized by the zenith or polar angle θ and the azimuthal angle ϕ .



- The amount of radiation emitted from a surface, dA_1, and propagating in a particular direction, θ, ϕ, is quantified in terms of a differential solid angle associated with the direction.



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

$dA_n \rightarrow$ unit element of surface on a hypothetical sphere and normal to the θ, ϕ direction.

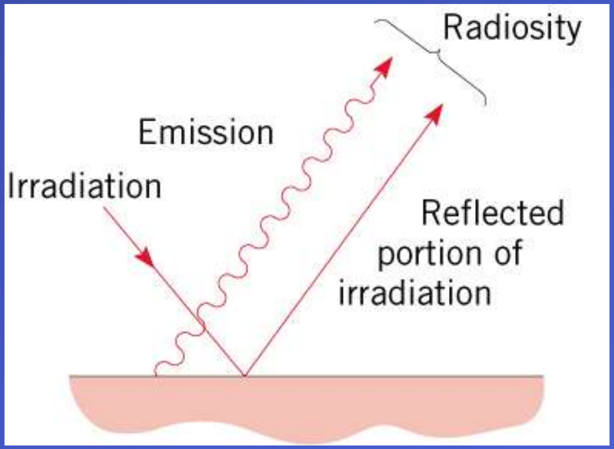
- The spectral irradiation $\left(\mathrm{W/m^2 \cdot \mu m}\right)$ is then:

$$G_\lambda(\lambda) = \int_0^{2\pi} \int_0^{\pi/2} I_{\lambda,i}(\lambda,\theta,\phi) \cos\theta \sin\theta \, d\theta \, d\phi$$

and the total irradiation $\left(\mathrm{W/m^2}\right)$ is

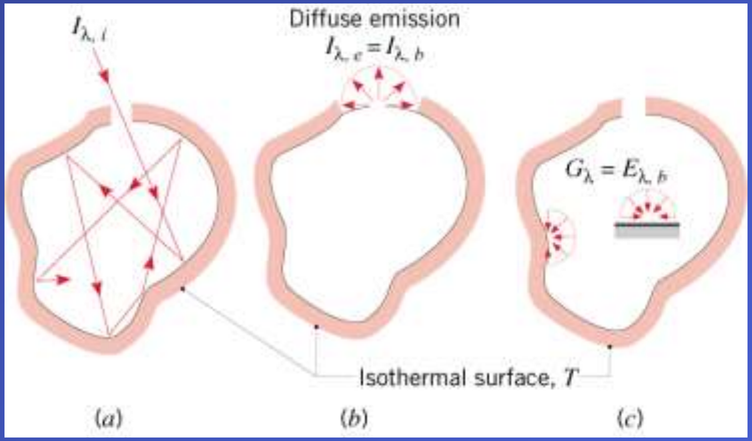
$$G = \int_0^{\infty} G_\lambda(\lambda) \, d\lambda$$

- The radiosity of an opaque surface accounts for all of the radiation leaving the surface in all directions and may include contributions to both reflection and emission.



Blackbody Radiation

- The Blackbody
  - ➢ An idealization providing limits on radiation emission and absorption by matter.
    - – For a prescribed temperature and wavelength, no surface can emit more radiation than a blackbody: the ideal emitter.
    - – A blackbody is a diffuse emitter.
    - – A blackbody absorbs all incident radiation: the ideal absorber.
- The Isothermal Cavity (Hohlraum).



(a) After multiple reflections, virtually all radiation entering the cavity is absorbed.

(b) Emission from the aperture is the maximum possible emission achievable for the temperature associated with the cavity and is diffuse.

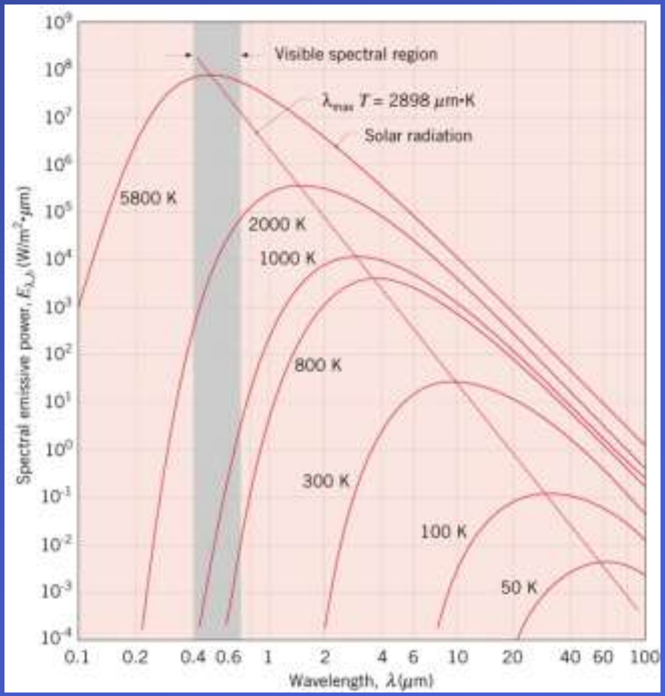
The Spectral (Planck) Distribution of Blackbody Radiation

- The spectral distribution of the blackbody emissive power (determined theoretically and confirmed experimentally) is

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

First radiation constant: $C_1 = 3.742\, x 10^8\, \mathrm{W}\cdot\mu\mathrm{m}^4/\mathrm{m}^2$

Second radiation constant: $C_2 = 1.439\, x 10^4\, \mu\mathrm{m}\cdot\mathrm{K}$



Radiation: Processes and Properties
Surface Radiative Properties

Chapter 12

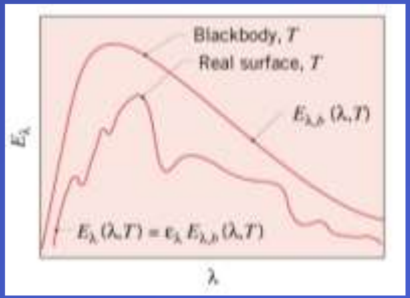
Sections 12.4 through 12.7

Surface Emissivity

- Radiation emitted by a surface may be determined by introducing a property (the emissivity) that contrasts its emission with the ideal behavior of a blackbody at the same temperature.

- The spectral, hemispherical emissivity (a directional average):

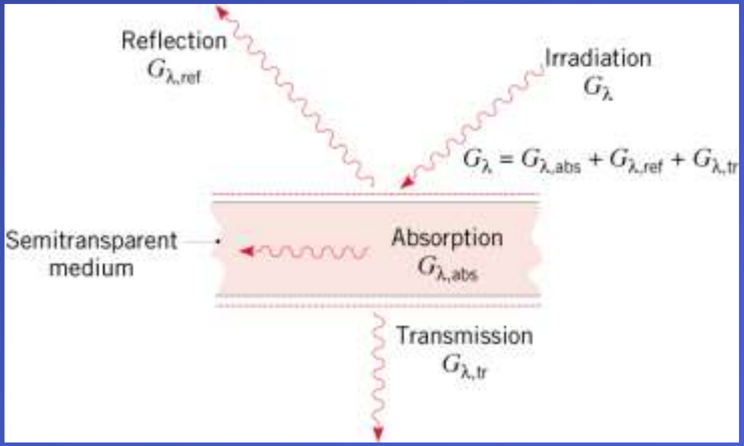
$$\varepsilon_\lambda(\lambda,T) \equiv \frac{E_\lambda(\lambda,T)}{E_{\lambda,b}(\lambda,T)} = \frac{\int_0^{2\pi}\int_0^{\pi/2} I_{\lambda,e}(\lambda,\theta,\phi,T)\cos\theta\sin\theta d\theta d\phi}{\int_0^{2\pi}\int_0^{\pi/2} I_{\lambda,b}(\lambda,T)\cos\theta\sin\theta d\theta d\phi}$$



Response to Surface Irradiation: Absorption, Reflection and Transmission

- There may be three responses of a semitransparent medium to irradiation:

  - Reflection from the medium $\left(G_{\lambda,ref}\right)$.
  - Absorption within the medium $\left(G_{\lambda,abs}\right)$.
  - Transmission through the medium $\left(G_{\lambda,tr}\right)$.



Radiation balance →

$$G_\lambda = G_{\lambda,ref} + G_{\lambda,abs} + G_{\lambda,tr}$$

- In contrast to the foregoing volumetric effects, the response of an opaque material to irradiation is governed by surface phenomena and $G_{\lambda,tr} = 0$.

$$G_\lambda = G_{\lambda,ref} + G_{\lambda,tr}$$

Radiation: Processes and Properties
- Environmental Radiation -

Chapter 12

Section 12.8

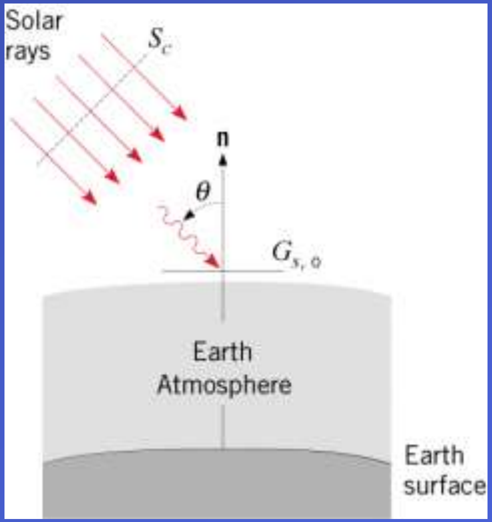
Solar Radiation

- The sun is a nearly spherical source of radiation whose outer diameter is 1.39×10^9 m and whose emissive power approximates that of a blackbody at 5800K.

- The distance from the center of the sun to the center of the earth varies with time of year from a minimum of 1.471×10^{11} m to a maximum of 1.521×10^{11} m, with an annual average of 1.496×10^{11} m.

- Due to the large sun-to-earth distance, the sun's rays are nearly parallel at the outer edge of the earth's atmosphere, and the corresponding radiation flux is

$$q''_S = f \times S_c$$



$S_c \rightarrow$ the solar constant or heat flux $\left(1353 \text{ W/m}^2\right)$ when the earth is at its mean distance from the sun.

$f \rightarrow$ correction factor accounting for eccentricity of the earth's orbit $\left(0.97 < f < 1.03\right)$

Terrestrial Radiation

- Emission by Earth's Surface:

$$E = \varepsilon \sigma T^4$$

➢ Emissivities are typically large. For example, from Table A.11:

Sand/Soil:	$\varepsilon > 0.90$
Water/Ice:	$\varepsilon > 0.95$
Vegetation:	$\varepsilon > 0.92$
Snow:	$\varepsilon > 0.82$
Concrete/Asphalt:	$\varepsilon > 0.85$

➢ Emission is typically from surfaces with temperatures in the range of $250 < T < 320$K and hence concentrated in the spectral region $4 < \lambda < 40\mu$m, with peak emission at $\lambda \approx 10\mu$m.

- Atmospheric Emission:

  - Largely due to emission from CO_2 and H_2O (v) and concentrated in the spectral regions $5 < \lambda < 8\ \mu$m and $\lambda > 13\mu$m.

  - Although far from exhibiting the spectral characteristics of blackbody emission, earth irradiation due to atmospheric emission is often approximated by a blackbody emissive power of the form

$$G_{atm} = \sigma T_{sky}^4$$

$T_{sky} \rightarrow$ the effective sky temperature

230K< T_{sky} < 285K

$\hookrightarrow$ Cold, clear sky $\hookrightarrow$ Warm, overcast sky