CH EN 3453 – Heat Transfer

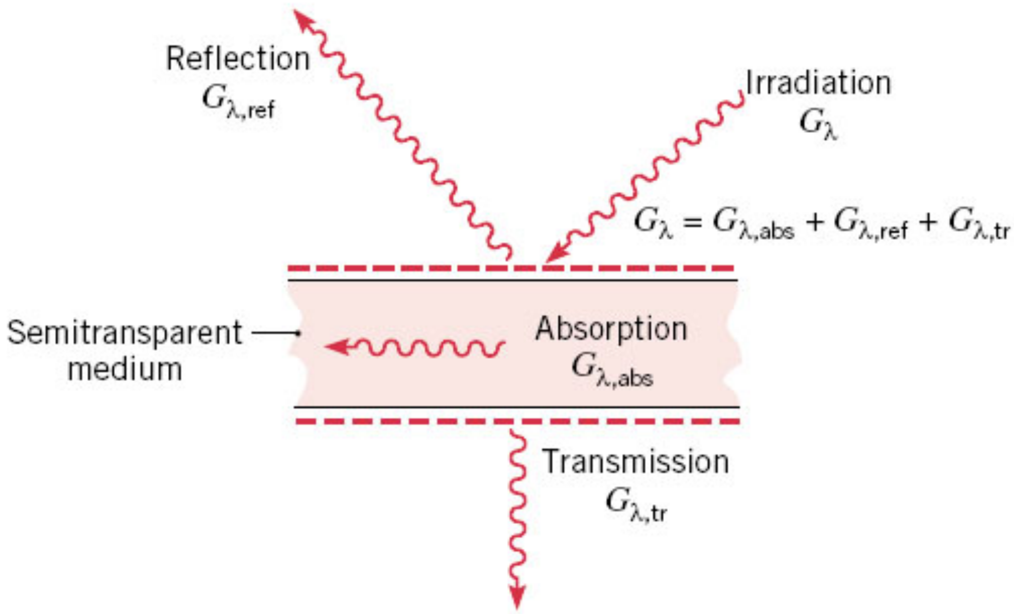
Radiation: Gray Surfaces in Enclosures and Network Representations

Section 13.2

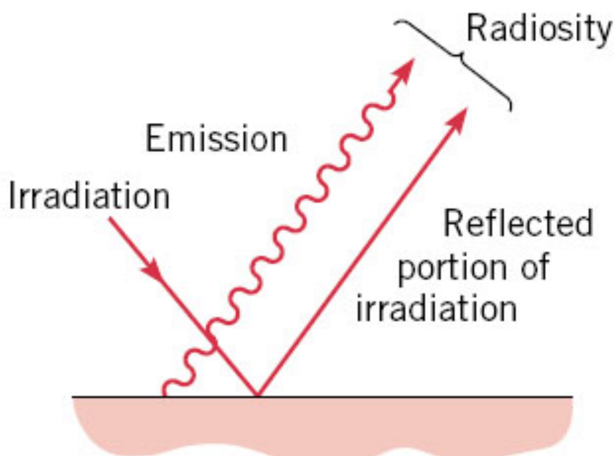
Reminders…

- Homework #11 due Monday, Dec 1
  - No help session for this one
  - ...but all the solutions are on the web
- Remember to peer review the reports you were assigned
  - Due Wednesday, Dec 3

Absorption, Reflection, Transmission

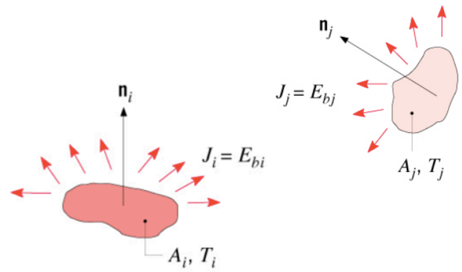


Radiosity



Blackbody Radiation Exchange

- For a blackbody, $J_i = E_{bi}$.



- Net radiative exchange between two surfaces that can be approximated as blackbodies ⟶ *net* rate at which radiation leaves surface *i* due to its interaction with *j*

  or net rate at which surface *j* gains radiation due to its interaction with *i*

$$q_{ij} = q_{i\to j} - q_{j\to i}$$

$$q_{ij} = A_i F_{ij} E_{bi} - A_j F_{ji} E_{bj}$$

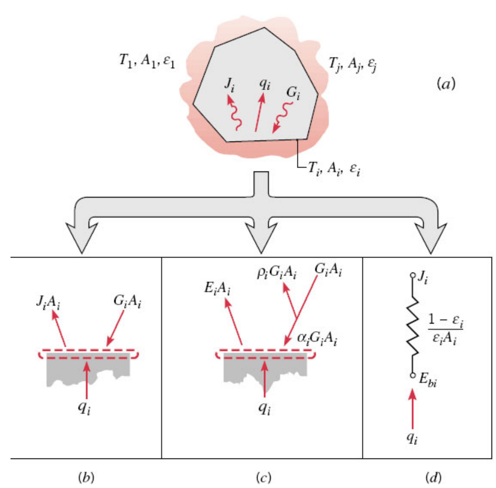
$$q_{ij} = A_i F_{ij} \sigma \left(T_i^4 - T_j^4 \right)$$

- Net radiation transfer from surface *i* due to exchange with all (*N*) surfaces of an enclosure:

$$q_i = \sum_{j=1}^{N} A_i F_{ij} \sigma \left(T_i^4 - T_j^4 \right)$$

General Radiation Analysis for Exchange between the *N* Opaque, Diffuse, Gray Surfaces of an Enclosure

- Alternative expressions for net radiative transfer from surface *i*:



$$q_i = A_i \left(J_i - G_i \right) \to \text{Fig. (b)} \qquad (1)$$

$$q_i = A_i \left(E_i - \alpha_i G_i \right) \to \text{Fig. (c)} \qquad (2)$$

$$q_i = \frac{E_{bi} - J_i}{\left(1-\varepsilon_i\right)/\varepsilon_i A_i} \to \text{Fig. (d)} \qquad (3)$$

↳ Suggests a surface radiative resistance of the form: $\left(1-\varepsilon_i\right)/\varepsilon_i A_i$

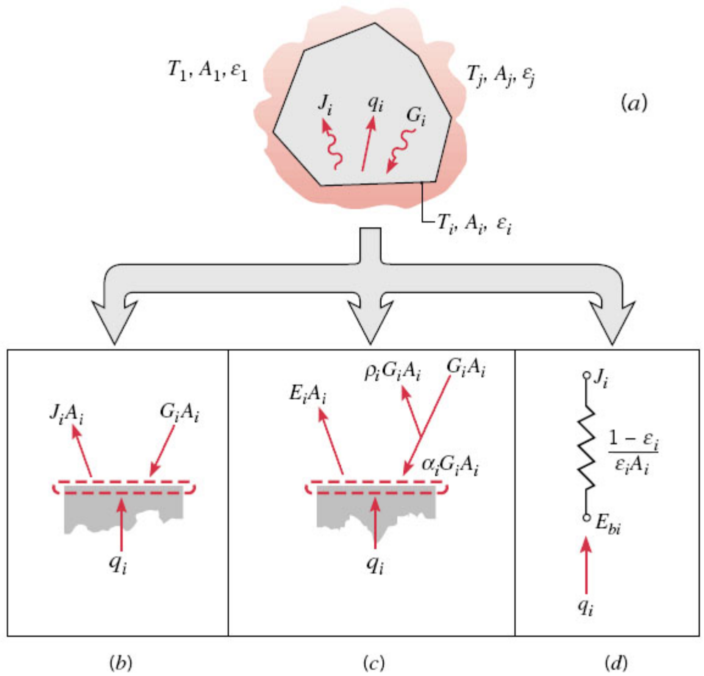


FIGURE 13.8 Radiation exchange in an enclosure of diffuse, gray surfaces with a nonparticipating medium. (*a*) Schematic of the enclosure. (*b*) Radiative balance according to Equation 13.9. (*c*) Radiative balance according to Equation 13.11. (*d*) Network element representing the net radiation transfer from a surface.

continued...

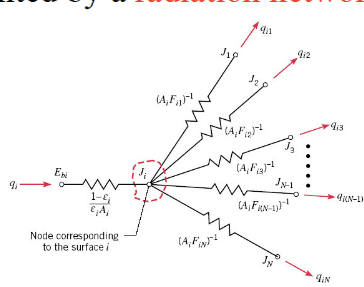
$$q_i = \sum_{j=1}^{N} A_iF_{ij}\left(J_i - J_j\right) = \sum_{j=1}^{N} \frac{J_i - J_j}{\left(A_iF_{ij}\right)^{-1}} \tag{4}$$

Suggests a space or geometrical resistance of the form: $\left(A_iF_{ij}\right)^{-1}$

- Equating Eqs. (3) and (4) corresponds to a radiation balance on surface i:

$$\frac{E_{bi} - J_i}{\left(1-\varepsilon_i\right)/\varepsilon_iA_i} = \sum_{j=1}^{N} \frac{J_i - J_j}{\left(A_iF_{ij}\right)^{-1}} \tag{5}$$

which may be represented by a radiation network of the form



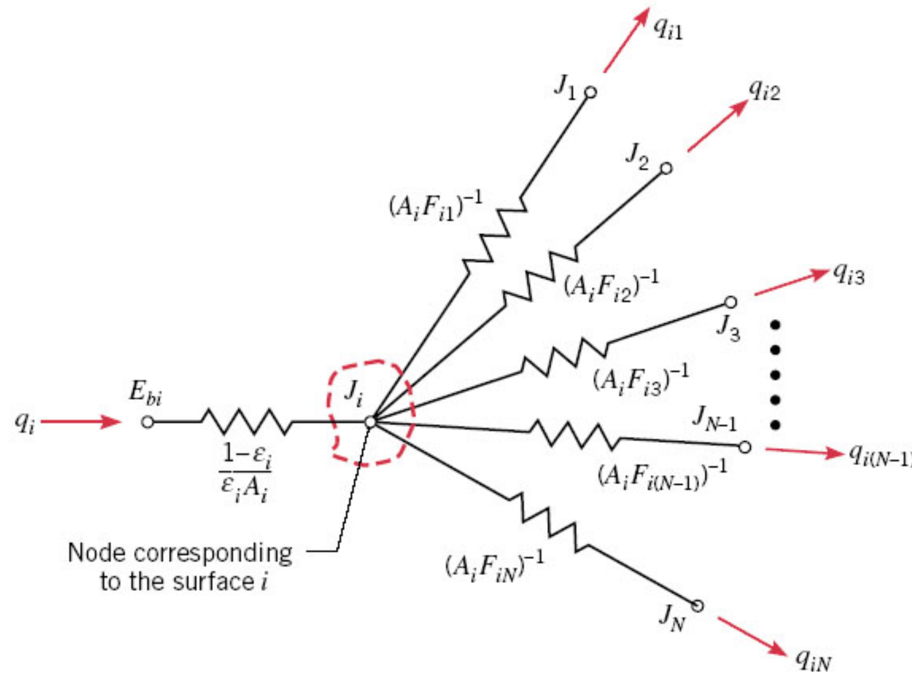


FIGURE 13.9 Network representation of radiative exchange between surface i and the remaining surfaces of an enclosure.

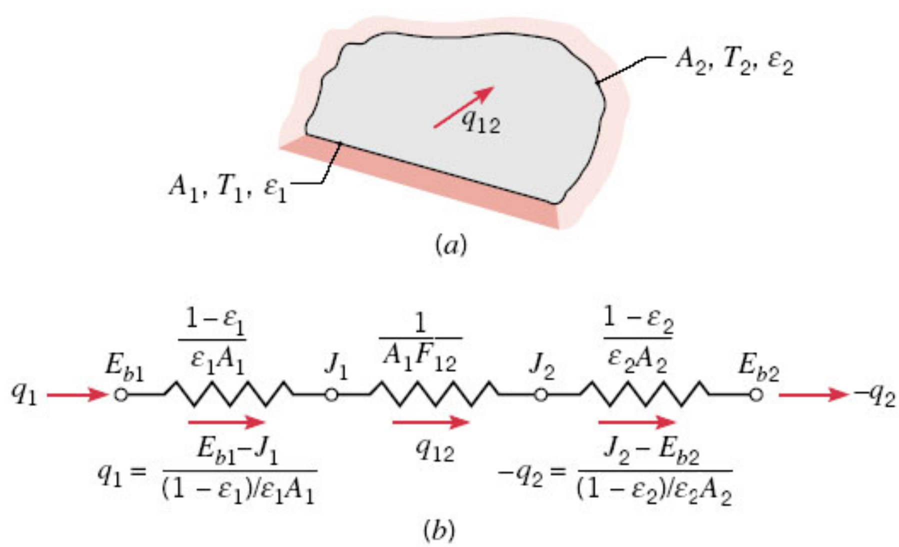
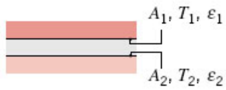


FIGURE 13.10 The two-surface enclosure. (*a*) Schematic. (*b*) Network representation.

Table 13.3 Special Diffuse, Gray, Two-Surface Enclosures

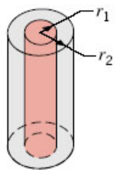
Large (Infinite) Parallel Planes



$$A_1 = A_2 = A \qquad F_{12} = 1$$

$$q_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1} \tag{13.19}$$

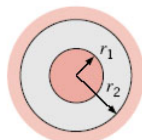
Long (Infinite) Concentric Cylinders



$$\frac{A_1}{A_2} = \frac{r_1}{r_2} \qquad F_{12} = 1$$

$$q_{12} = \frac{\sigma A_1(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1 - \varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)} \tag{13.20}$$

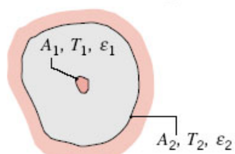
Concentric Spheres



$$\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} \qquad F_{12} = 1$$

$$q_{12} = \frac{\sigma A_1(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1 - \varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)^2} \tag{13.21}$$

Small Convex Object in a Large Cavity



$$\frac{A_1}{A_2} \approx 0 \qquad F_{12} = 1$$

$$q_{12} = \sigma A_1 \varepsilon_1 (T_1^4 - T_2^4) \tag{13.22}$$