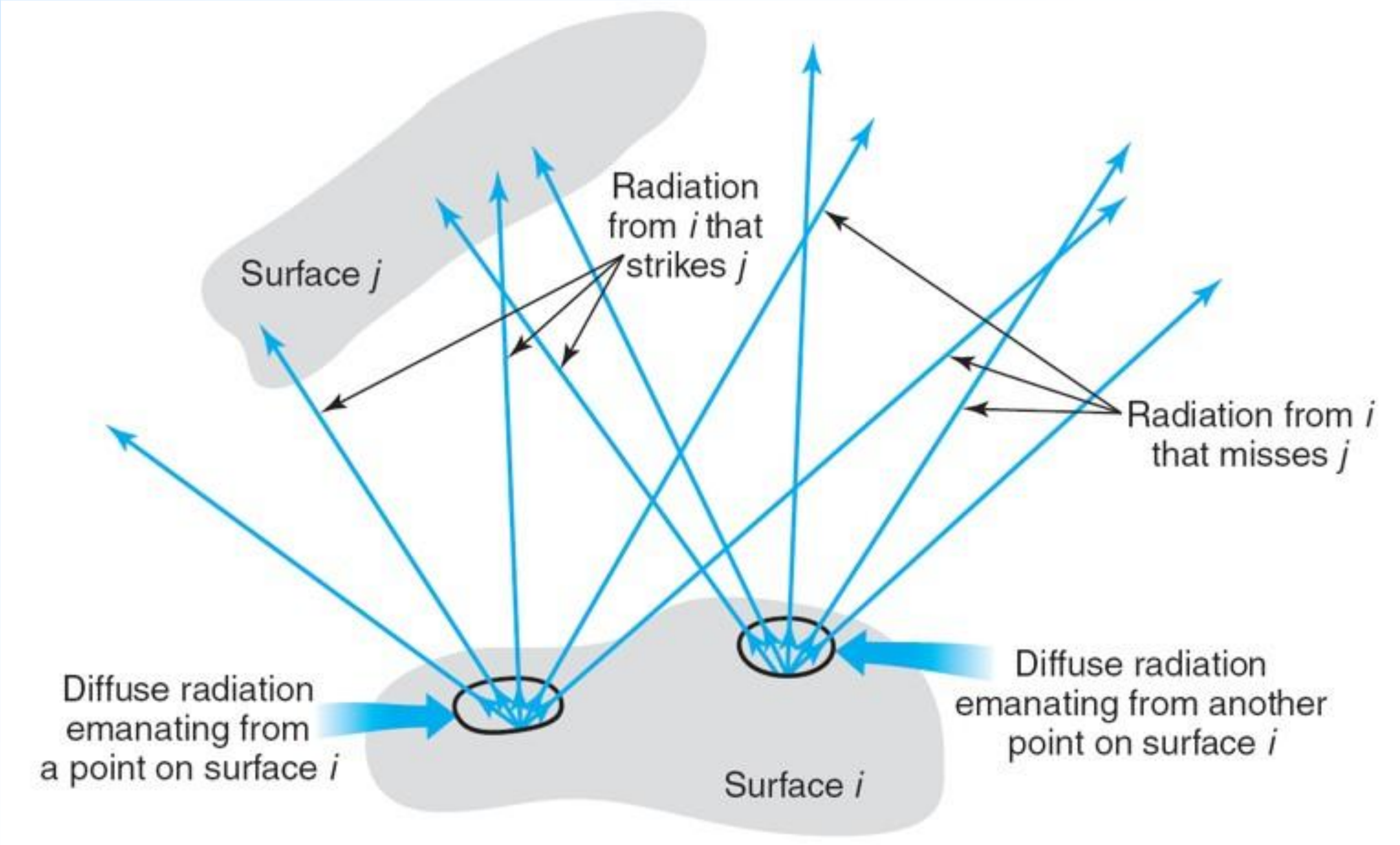
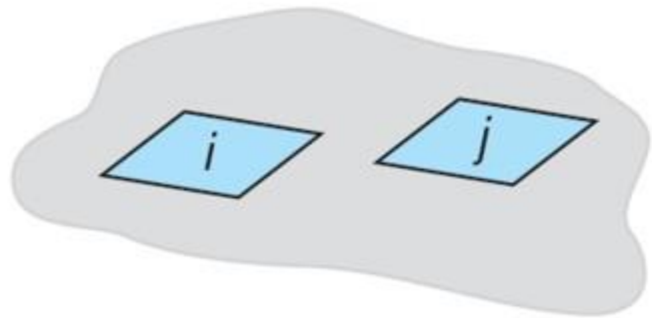
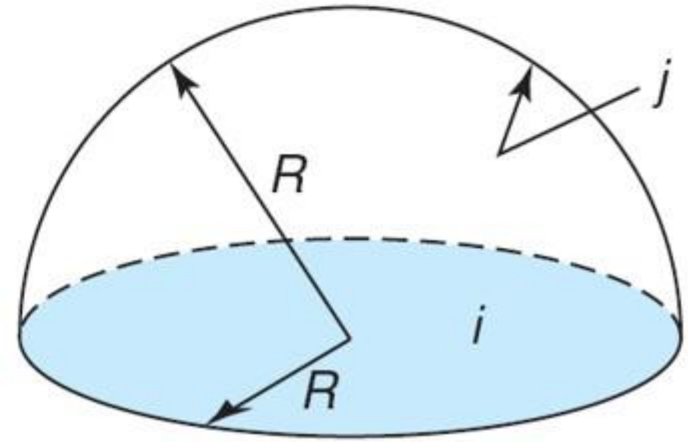


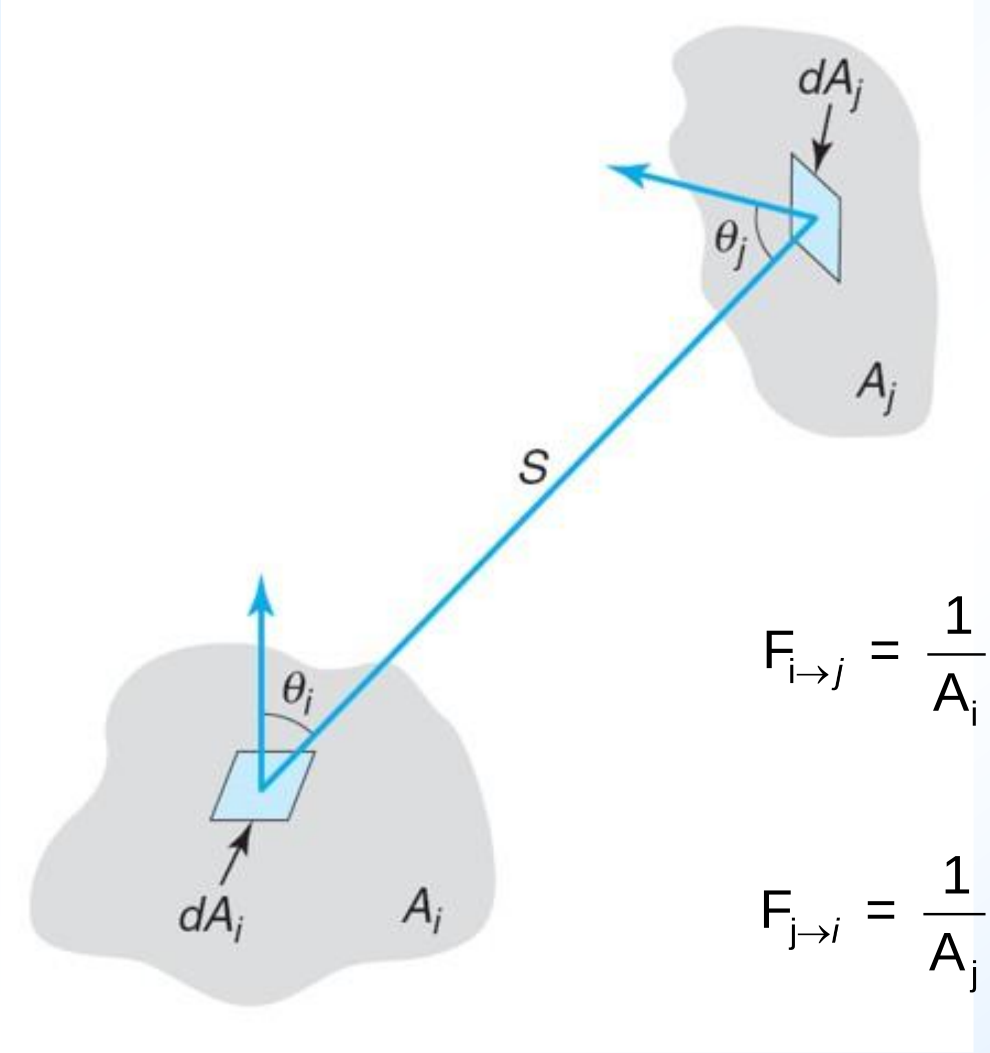
View Factor: $F_{i \rightarrow j}$ is the fraction of diffuse radiation leaving surface i that arrives at surface j by a straight-line route, and depends on size, orientation and spacing.





View factor is zero

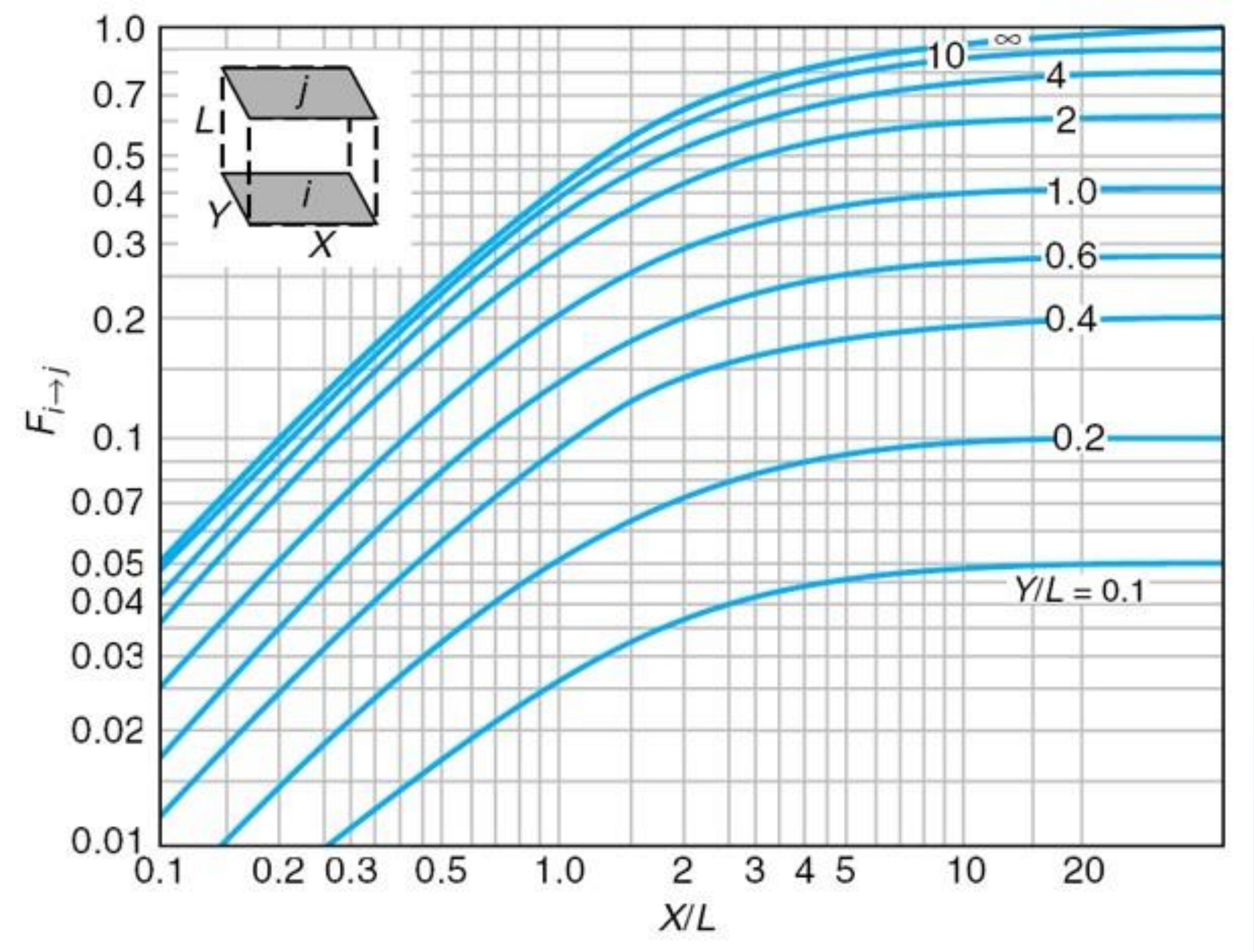
View factor is one

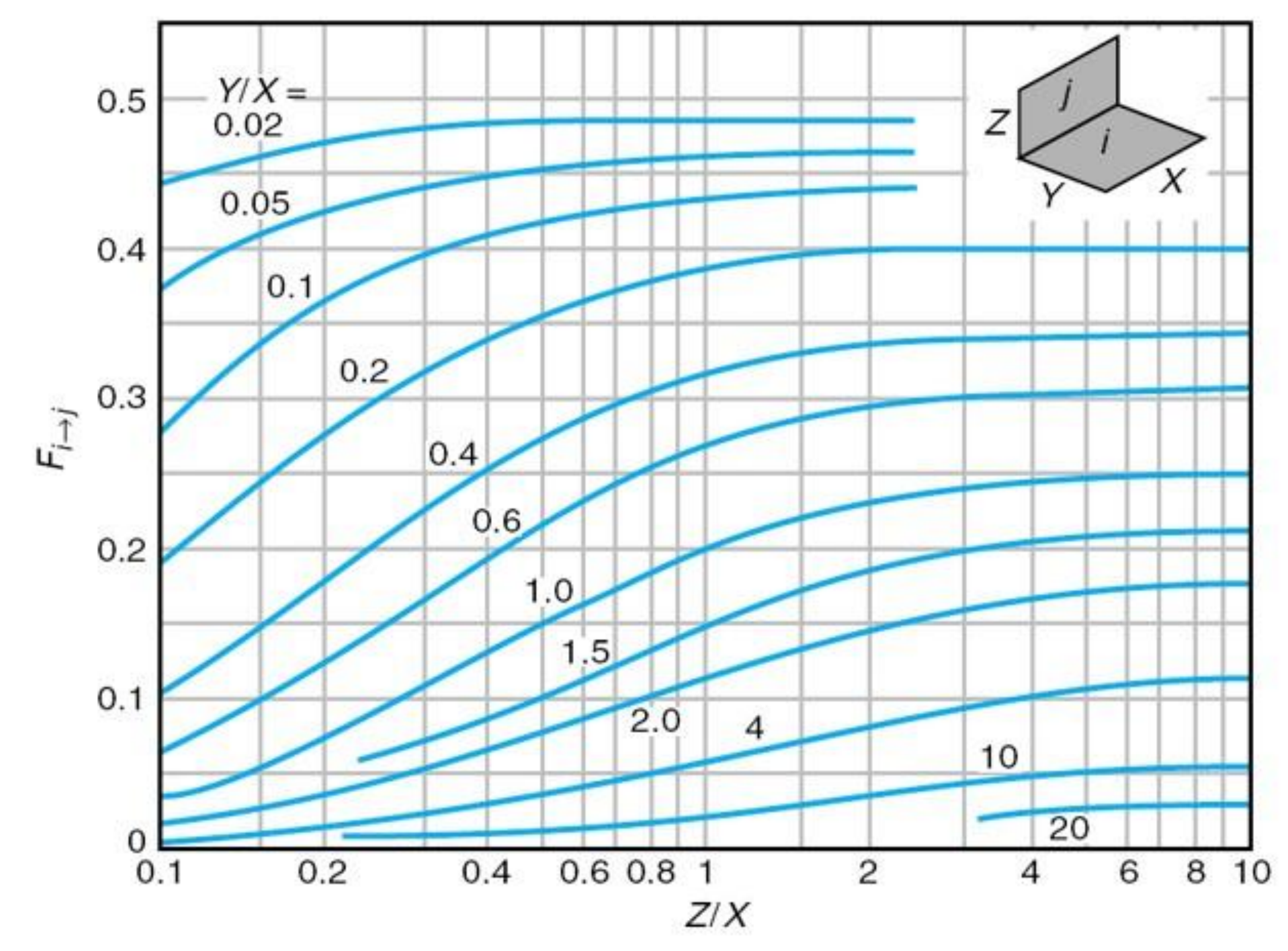


See Figures 14-16, 17, 18 and Table 14-2

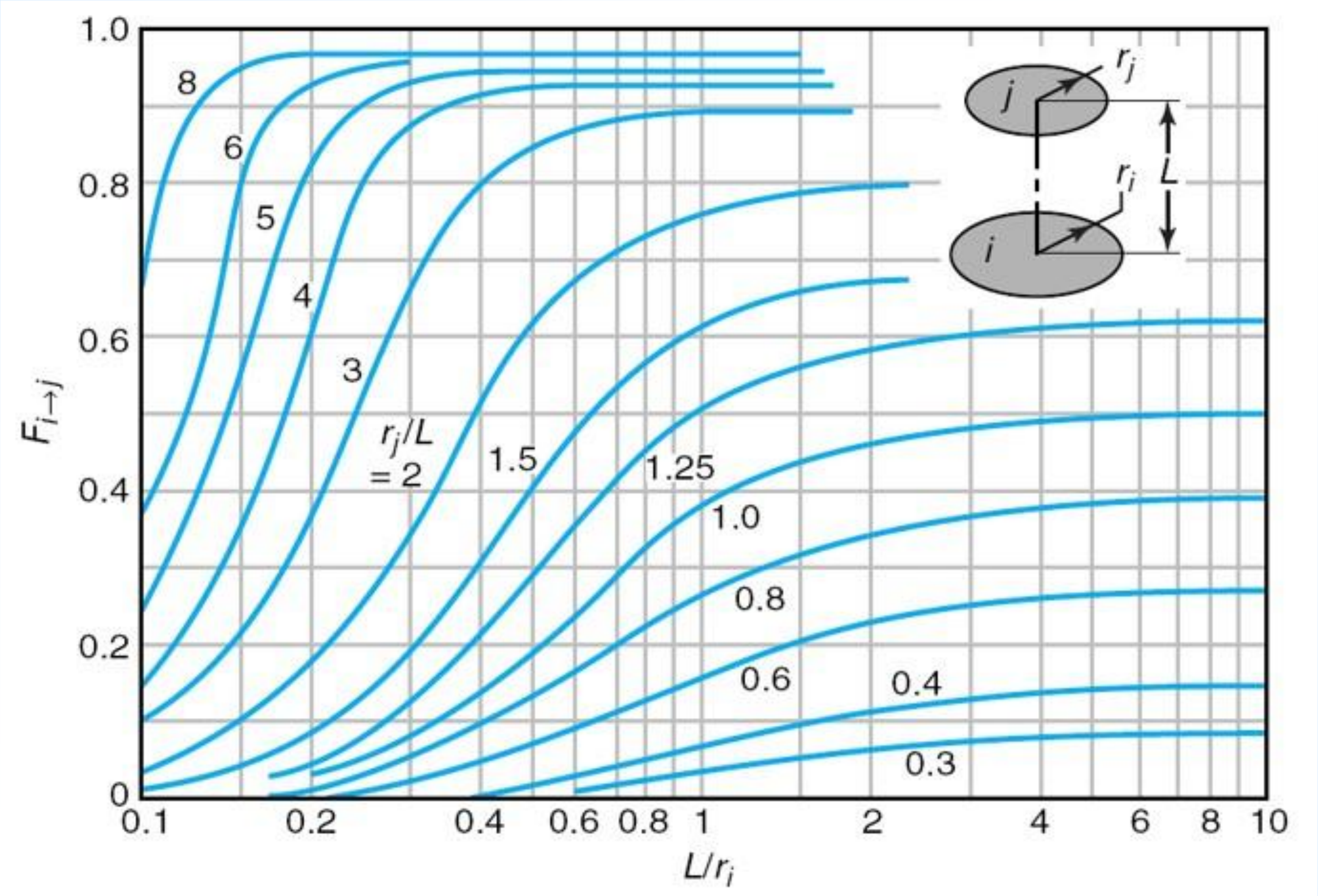
$$F_{i\to j} = \frac{1}{A_i} \int_{A_i}\int_{A_j} \frac{\cos(\theta_i)\ \cos(\theta_j)\ dA_i\ dA_j}{\pi\ S^2}$$

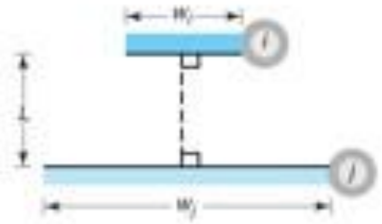
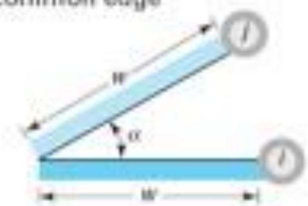
$$F_{j\to i} = \frac{1}{A_j} \int_{A_j}\int_{A_i} \frac{\cos(\theta_j)\ \cos(\theta_i)\ dA_j\ dA_i}{\pi\ S^2}$$


1.0
0.7
0.5
0.4
0.3
0.2
0.1
0.07
0.05
0.04
0.03
0.02
0.01
F_{i→j}
j
L
i
Y
X
∞
10
4
2
1.0
0.6
0.4
0.2
Y/L = 0.1
0.1
0.2
0.3
0.5
1.0
2
3
4
5
10
20
X/L



Y/X =
0.02
0.05
0.1
0.2
0.4
0.6
1.0
1.5
2.0
4
10
20
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.4
0.6
0.8
1
2
4
6
8
10
Z/X
Z
j
i
Y
X


1.0
0.8
0.6
0.4
0.2
0
$F_{i \to j}$
8
6
5
4
3
r_j/L = 2
1.5
1.25
1.0
0.8
0.6
0.4
0.3
0.1
0.2
0.4
0.6
0.8
1
2
4
6
8
10
L/r_i
r_j
j
r_i
i
L

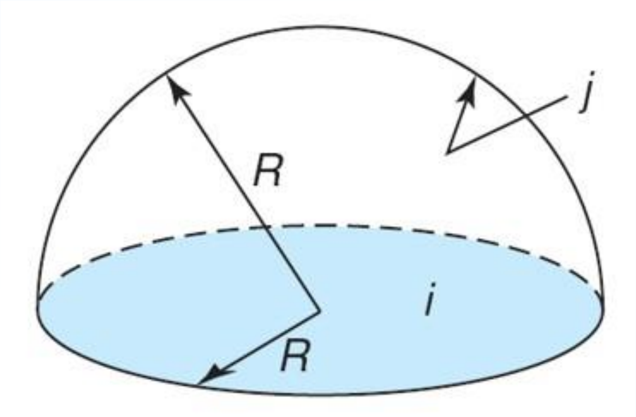
Geometry	Relation
Parallel plates with midlines connected by perpendicular 	$F_{i\to j} = \dfrac{[(W_i + W_j)^2 + 4]^{1/2} - [(W_j - W_i)^2 + 4]^{1/2}}{2W_i}$ $W_i = w_i/L,\ W_j = w_j/L$
Inclined parallel plates of equal width and a common edge 	$F_{i\to j} = 1 - \sin\left(\dfrac{\alpha}{2}\right)$
Perpendicular plates with a common edge 	$F_{i\to j} = \dfrac{1 + (w_j / w_i) - [1 + (w_j / w_i)^2]^{1/2}}{2}$
Three-sided enclosure	

$$F_{i\rightarrow j} = \frac{1}{A_i} \int_{A_i}\int_{A_j} \frac{\cos(\theta_i)\ \cos(\theta_j)\ dA_i\ dA_j}{\pi\ S^2}$$

$$F_{j\rightarrow i} = \frac{1}{A_j} \int_{A_j}\int_{A_i} \frac{\cos(\theta_j)\ \cos(\theta_i)\ dA_j\ dA_i}{\pi\ S^2}$$

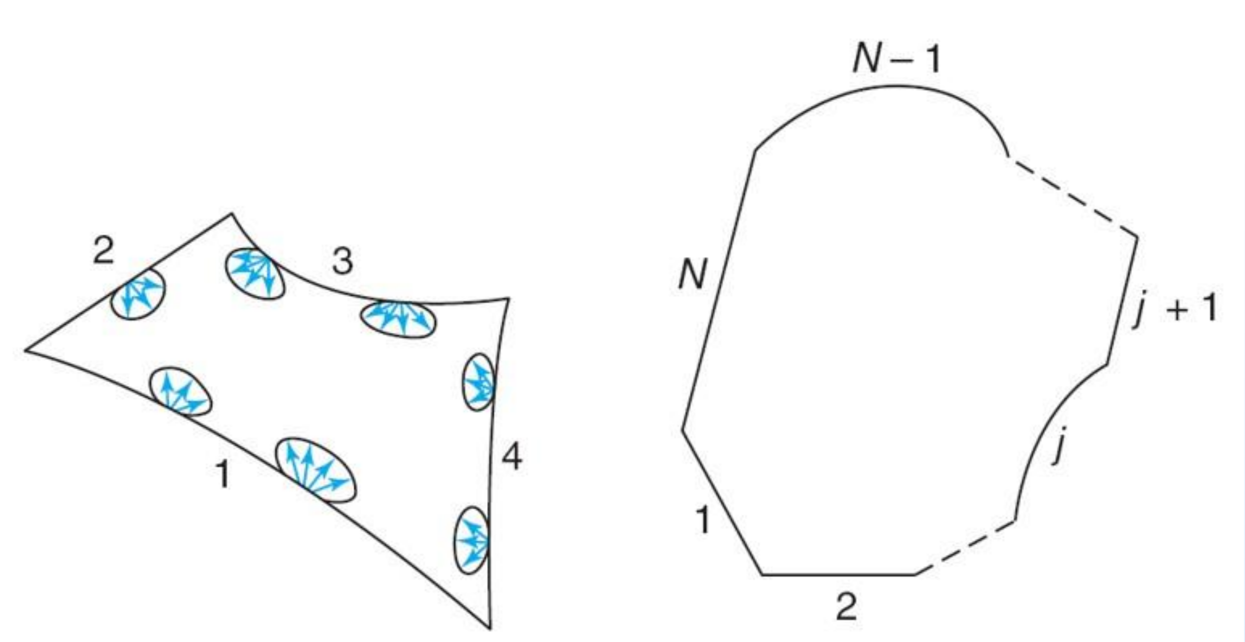
$$A_i\ F_{i\rightarrow j} = A_j\ F_{j\rightarrow i}$$

Reciprocity relation



$$F_{j\rightarrow i} = \frac{A_i\ F_{i\rightarrow j}}{A_j} = \frac{A_i}{A_j} = \frac{\pi\ R^2}{2\ \pi\ R^2} = \frac{1}{2}$$

An **enclosure** is a three-dimensional region in space completely encased by bounding surfaces.

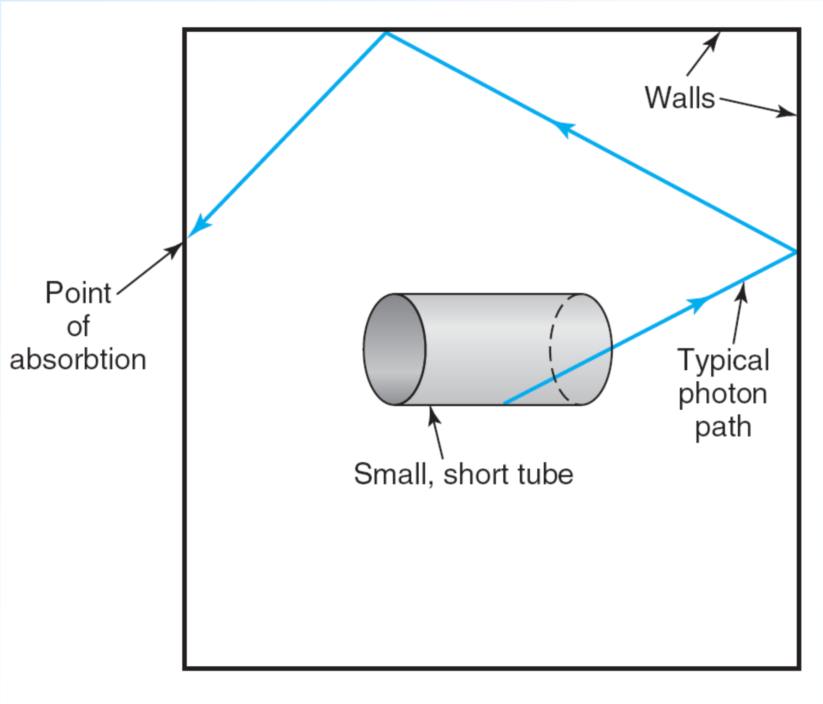


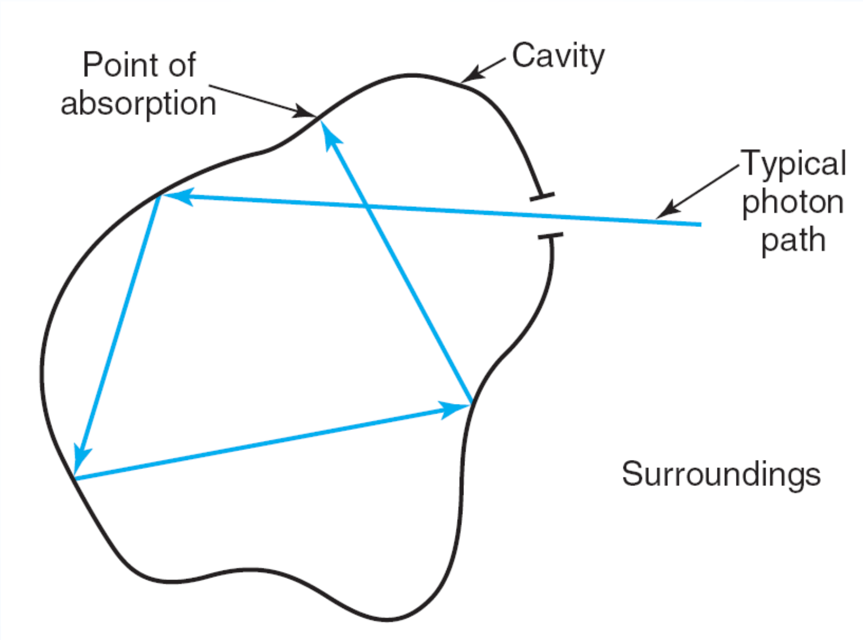
$$F_{1\to 2} + F_{1\to 3} + F_{1\to 3} = 1$$

$$\sum_{i=1}^{N} F_{i\to j} = 1$$

Summation relation

Openings (holes, cavities) that behave like a black body:

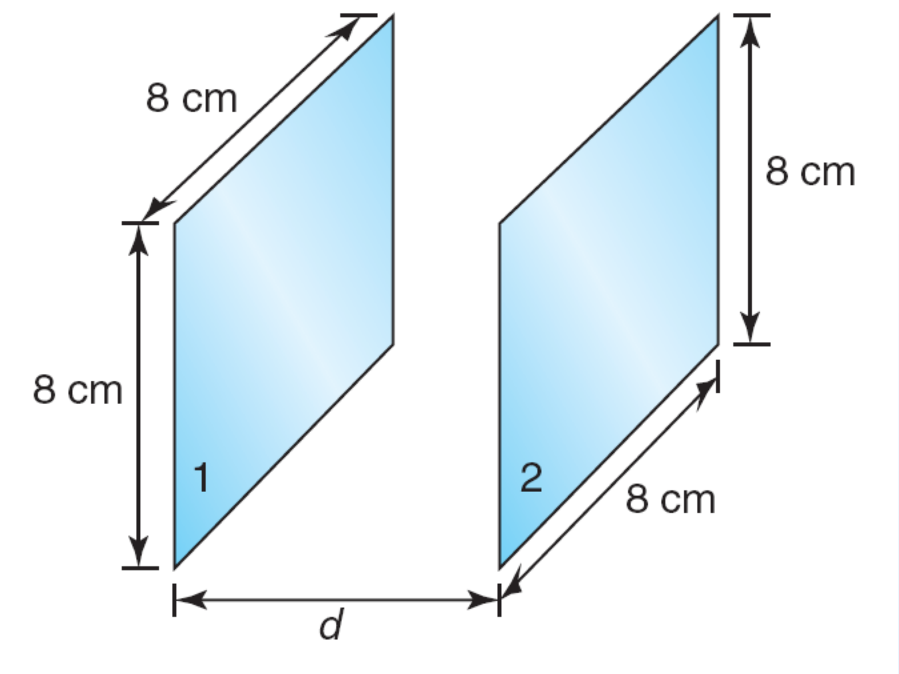




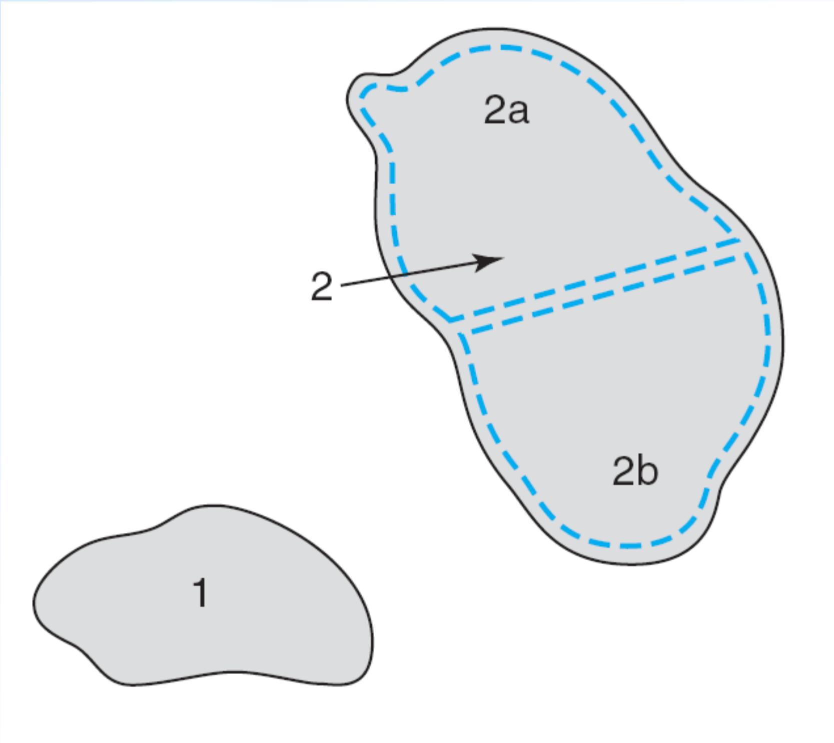
Read the text book about interior of rooms that appear black in day light, and the people that appear red-eyed in a picture.

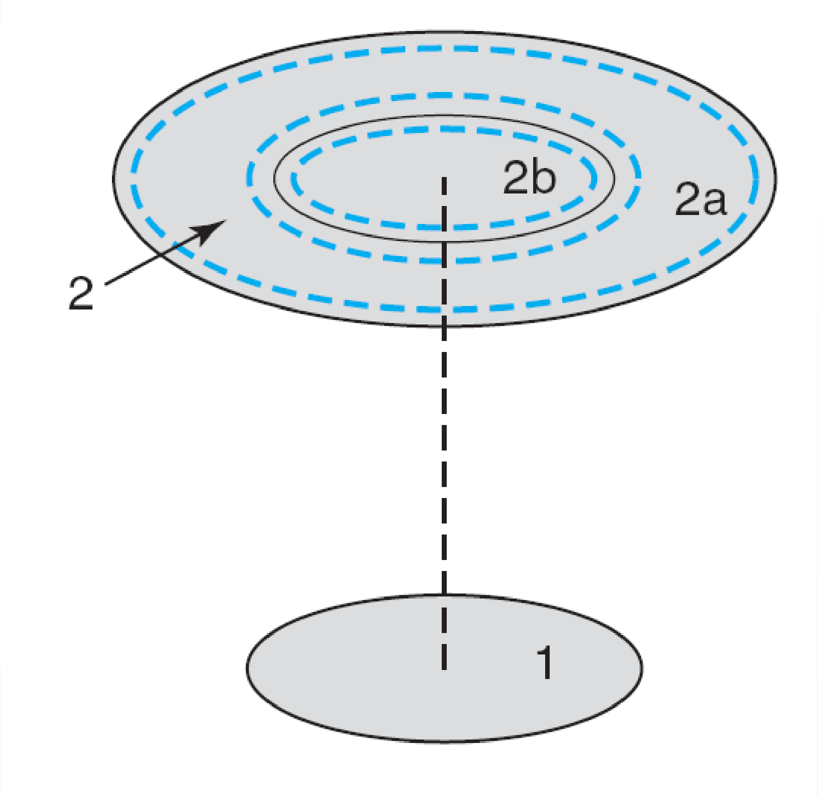
Example P.14-7

Two square plates of size 8 cm by 8 cm are directly opposite each other in parallel planes. What should the spacing between the plates be so that the view factor from one to the other is 0.5?



Shape decomposition



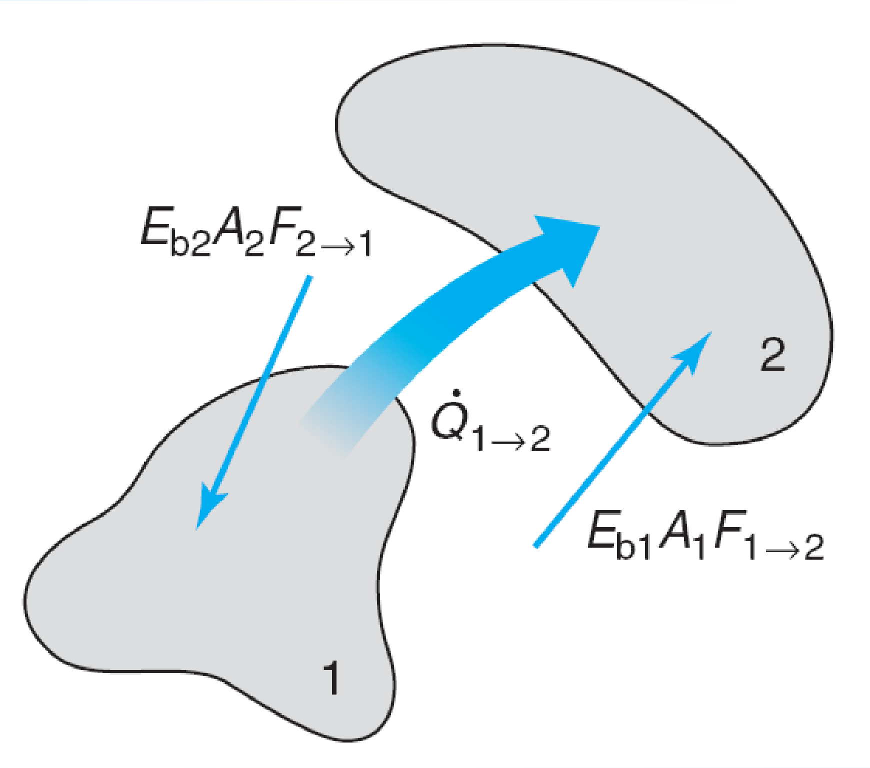


$$F_{1\to 2} = F_{1\to 2a} + F_{1\to 2b}$$

$$F_{1\to 2} = F_{1\to 2a} + F_{1\to 2b} + \ldots = \sum_{i=1}^{N} F_{1\to 2i}$$

Radiative heat exchange between black bodies

[Net radiative transfer between 1 and 2] = [Radiation leaving 1 and arriving at 2] - [Radiation leaving 2 and arriving at 1]



$$\dot{Q}_{1\to2} = E_{b1}\,A_1\,F_{1\to2} - E_{b2}\,A_2\,F_{2\to1}$$

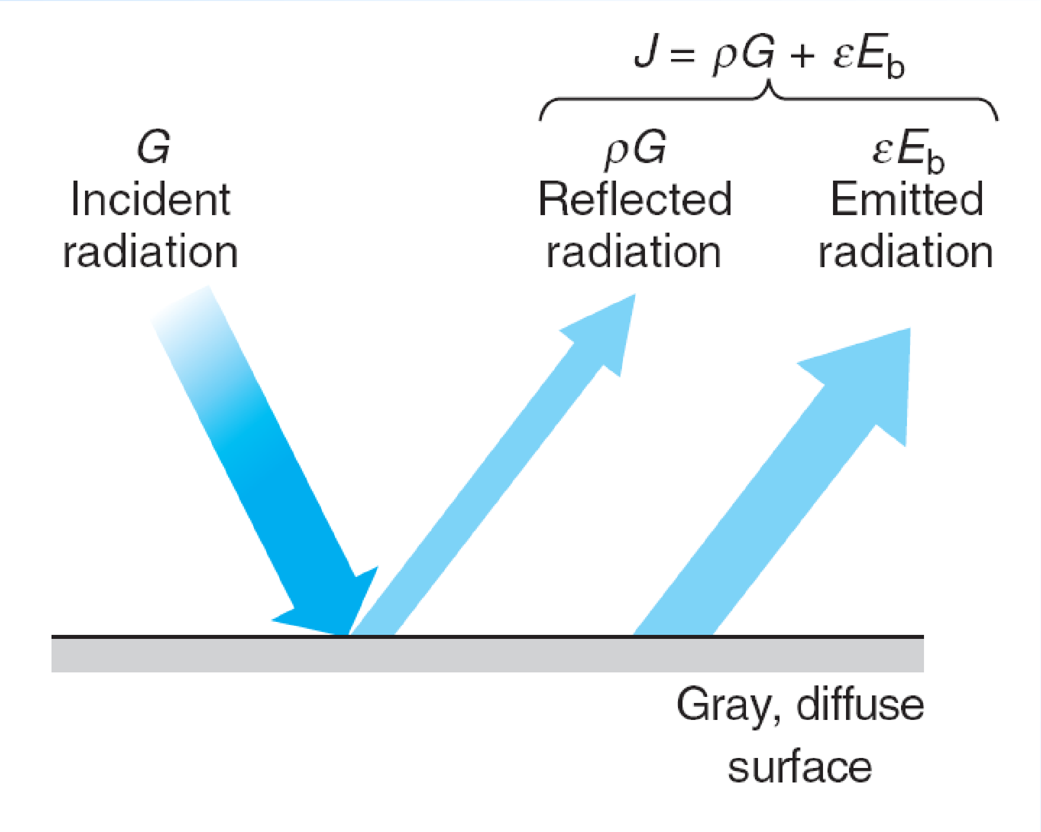
$$A_1\,F_{1\to2} = A_2\,F_{2\to1}$$

$$E_b = \sigma\,T^4$$

$$\dot{Q}_{1\to2} = A_1\,F_{1\to2}\,\sigma\left(T_1^4 - T_2^4\right)$$

$$\dot{Q}_i = \sum_{j=1}^{N} A_i\,F_{i\to j}\,\sigma\left(T_i^4 - T_j^4\right)$$

Radiative heat exchange between diffuse and gray bodies



Define radiocity as the sum of emitted and reflected radiation from a gray surface:

$$J = \varepsilon E_b + \rho G$$

$$\rho = 1 - \alpha$$

$$= 1 - \varepsilon$$

$$J = \varepsilon E_b + (1 - \varepsilon) G$$

$J = E_b$ for a black surface

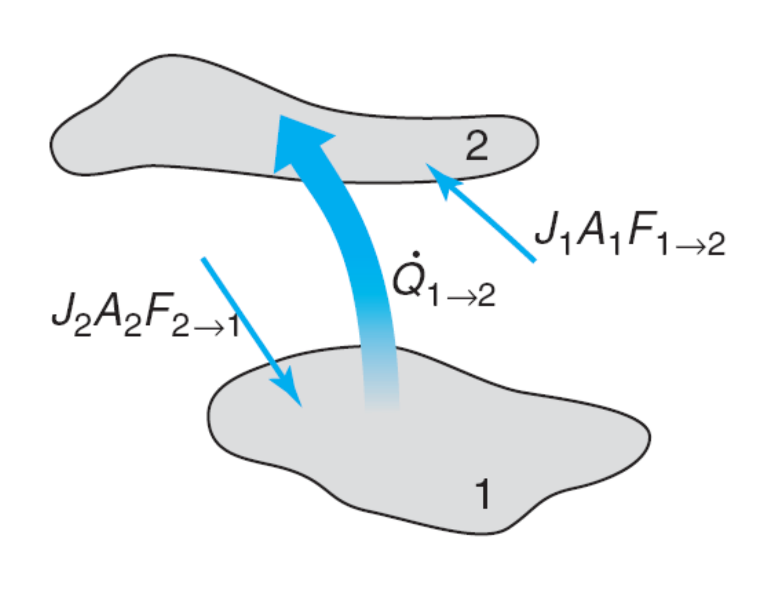
Net heat flux leaving surface i by radiation is the difference between outgoing and incoming radiation:

$$\frac{\dot{Q}_i}{A_i} = J_i - G_i$$

Substitute for G_i

For a gray, diffuse, isothermal surface:

$$\dot{Q}_i = \frac{A_i\ \varepsilon_i}{1 - \varepsilon_i}\left(E_{bi} - J_i\right)$$



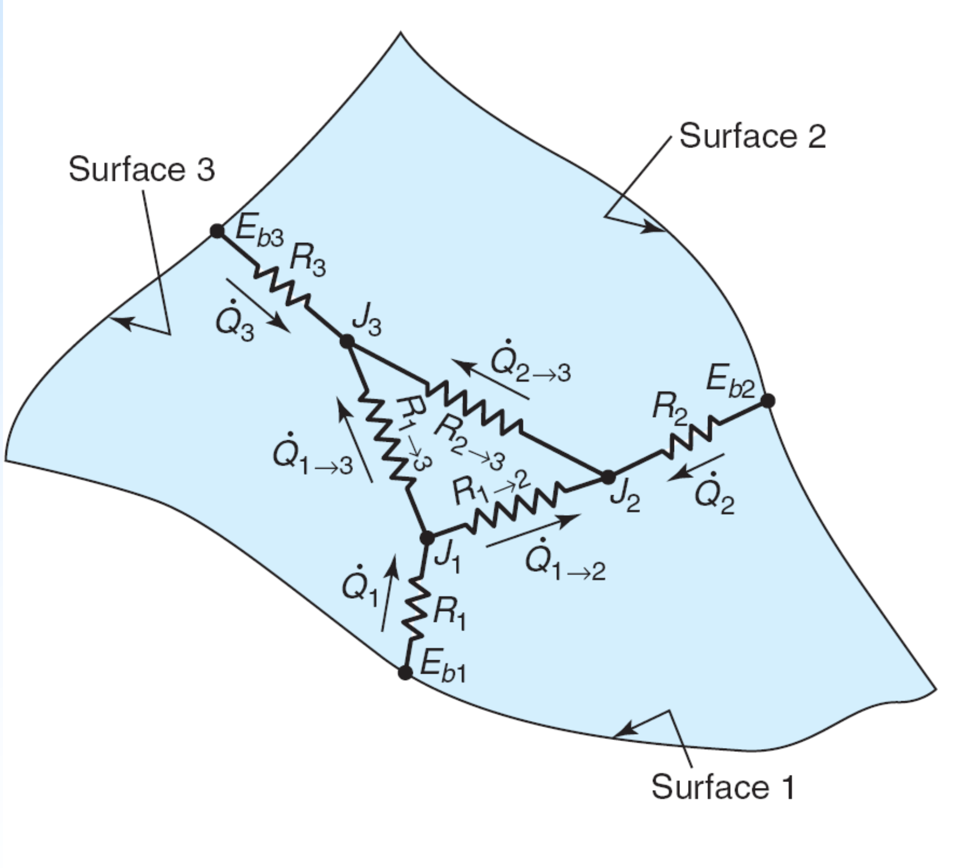
$$\dot{Q}_{1\to2} = J_1\ A_1\ F_{1\to2} - J_2\ A_2\ F_{2\to1}$$

$$\dot{Q}_{1\to2} = A_1\ F_{1\to2}\ \left(J_1 - J_2\right)$$

$$\dot{Q}_{2\to1} = A_2\ F_{2\to1}\ \left(J_2 - J_1\right) = -\dot{Q}_{1\to2}$$

$$\dot{Q}_i = \sum_{j=1}^{N} \dot{Q}_{i\to j}$$

Electrical resistance analogy for an enclosure with gray, diffuse, isothermal surfaces



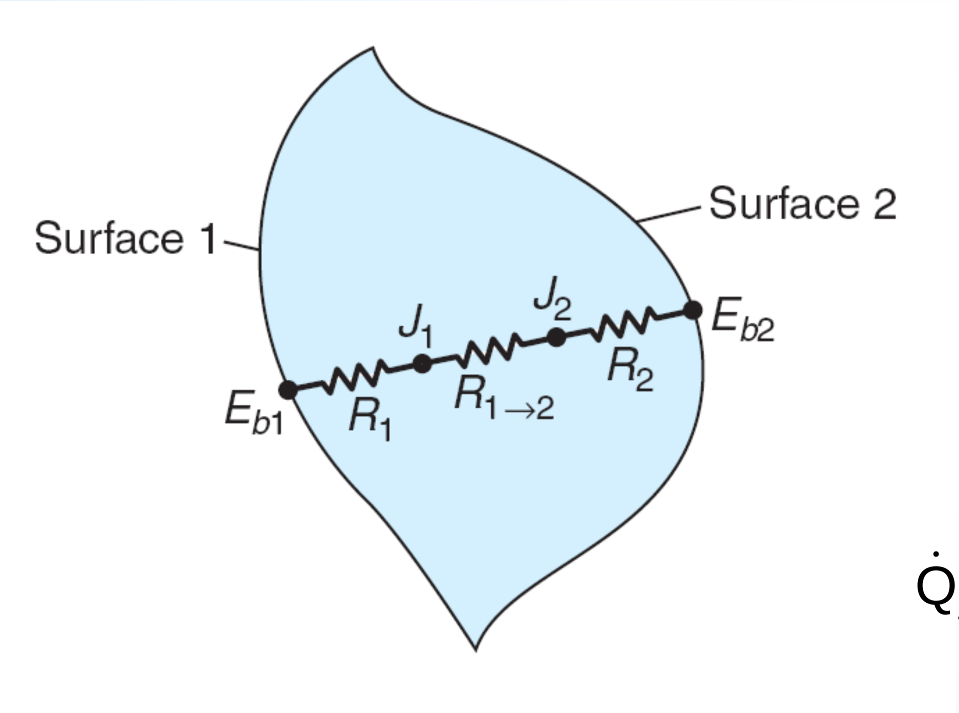
$$\dot{Q}_i = \frac{A_i\ \varepsilon_i}{1-\varepsilon_i}\left(E_{bi} - J_i\right) = \frac{E_{bi} - J_i}{\dfrac{A_i\ \varepsilon_i}{1-\varepsilon_i}} = \frac{E_{bi} - J_i}{R_i}$$

For a black surface $R_i = 0$ and $J_i = E_{bi}$

$$\dot{Q}_{1\to2} = A_1\ F_{1\to2}\ \left(J_1 - J_2\right) = \frac{J_1 - J_2}{A_1\ F_{1\to2}} = \frac{J_1 - J_2}{R_{1\to2}}$$

Two-surface enclosures

$$R_{tot} = R_1 + R_{1\to2} + R_2$$



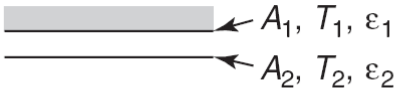
$$R_{tot} = \frac{1-\varepsilon_1}{A_1\,\varepsilon_1} + \frac{1}{A_1\,F_{1\to2}} + \frac{1}{A_2\,\varepsilon_2}$$

$$\dot{Q}_{1\to2} = \frac{E_{b1} - E_{b2}}{R_{tot}} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{R_{tot}}$$

$$\dot{Q}_{1\to2} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\dfrac{1-\varepsilon_1}{A_1\,\varepsilon_1} + \dfrac{1}{A_1\,F_{1\to2}} + \dfrac{1}{A_2\,\varepsilon_2}}$$

For small surfaces: $\dot{Q}_{1\to2} = \varepsilon_1\,\sigma\,A_1\left(T_1^4 - T_2^4\right)$

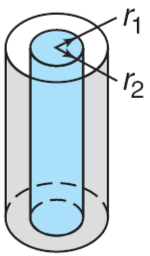
Large (infinite) parallel planes



$$A_1 = A_2 = A$$
$$F_{1\to2} = 1$$

$$\dot{Q}_{1\to2} = \frac{A\,\sigma\,(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$$

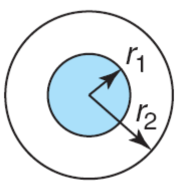
Long (infinite) concentric cylinders



$$\frac{A_1}{A_2} = \frac{r_1}{r_2}$$
$$F_{1\to2} = 1$$

$$\dot{Q}_{1\to2} = \frac{\sigma A_1\,(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)}$$

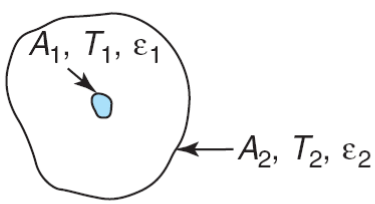
Concentric spheres



$$\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2}$$
$$F_{1\to2} = 1$$

$$\dot{Q}_{1\to2} = \frac{\sigma A_1\,(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)^2}$$

Small convex object in large surroundings

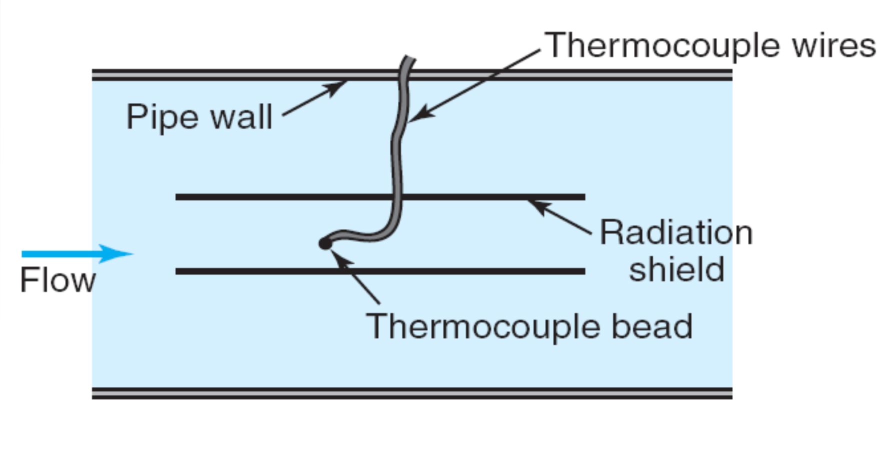


$$\frac{A_1}{A_2} \approx 0$$
$$F_{1\to2} = 1$$

$$\dot{Q}_{1\to2} = \sigma A_1 \varepsilon_1 (T_1^4 - T_2^4)$$

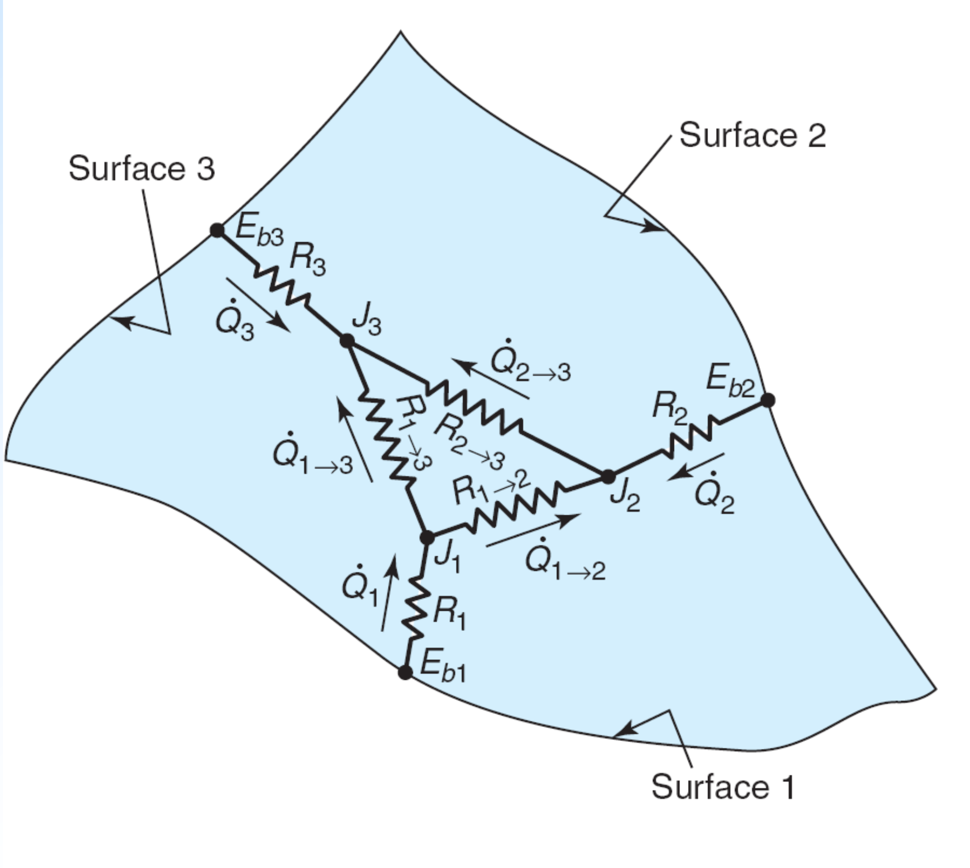
Example P.14-23

A thermocouple is used to measure the temperature of a hot gas flowing in a pipe whose wall is at 350 C. A cylindrical radiation shield, large compared to the size of the thermocouple, encloses the thermocouple, as shown. The shield has an emissivity of 0.13. The emissivity of the thermocouple bead is 0.68 and the emissivity of the pipe wall is 0.94. The convective heat transfer coefficient on the thermocouple is 70 $W/m^2.K$, and the thermocouple reads 500 C. The convective



heat transfer coefficient on the shield is 35 $W/m^2.K$. The shield has a diameter of 6 cm. Calculate the actual gas temperature.

Three-surface enclosures



$$\dot{Q}_1 = \frac{J_1 - J_2}{R_{1\to2}} + \frac{J_1 - J_3}{R_{1\to3}}$$

$$\dot{Q}_2 = \frac{J_2 - J_3}{R_{2\to3}} + \frac{J_2 - J_1}{R_{2\to1}}$$

$$\dot{Q}_3 = \frac{J_3 - J_1}{R_{3\to1}} + \frac{J_3 - J_2}{R_{3\to2}}$$

$$J_1 = \sigma T_1^4 - R_1 \dot{Q}_1$$

$$J_2 = \sigma T_2^4 - R_2 \dot{Q}_2$$

$$J_3 = \sigma T_3^4 - R_3 \dot{Q}_3$$

There are 6 equations and 6 unknowns to be solved simultaneously

Example P.14-30

A very long enclosure is formed from two perpendicular, equal-width plates and a slanted cover plate as shown. The cross section of the enclosure is in the shape of of an isosceles right triangle. Assuming gray and diffuse surfaces, calculate the net radiative heat transfer from the hottest plate.