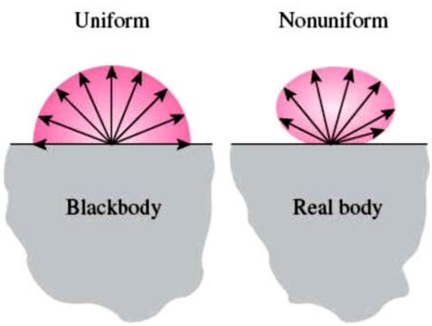
THE RADIATIVE HEAT TRANSFER

Every object produces radiative heat transfer, and it's difficult to calculate its.

A ***black-body*** is an idealized body that emits the maximum amount of radiation: it is a perfect emitter and absorber of all incident radiation.
It has the highest possible emissive power at a certain temperature,
has the same emissive power in every direction,
but it hasn't the same emissive power at every wavelength.



The **radiation energy** emitted by a blackbody:

$E_b(T) = \sigma T^4$ $[\frac{W}{m^2}]$ Blackbody **emissive power**

$\sigma = 5.670 * 10^{-8}$ $\frac{W}{m^2 * K^4}$ Stefan–Boltzmann constant

So, the emissive power of a black-body related to temperature is T^4.

The **radiation intensity "I"** is the magnitude of radiation emitted (or incident) in a specified direction in space. Knowing it allows me to find the heat transfer between two surfaces:

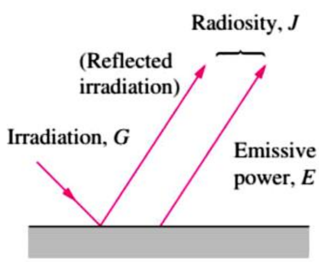
$E_b(T) = \pi I_b = \sigma T^4$ $[\frac{W}{m^2}]$

$I_b(T) = \frac{Eb(T)}{\pi}$

Diffuse radiation is a surface that has the same radiation in every direction.

Incident radiation is a surface that is receiving radiation.

Radiosity *J* is the sum of the Emissive power of an object and Reflected irradiation.
Is the quantity that represents the rate at which radiation energy leaves a unit area of a surface in all directions.



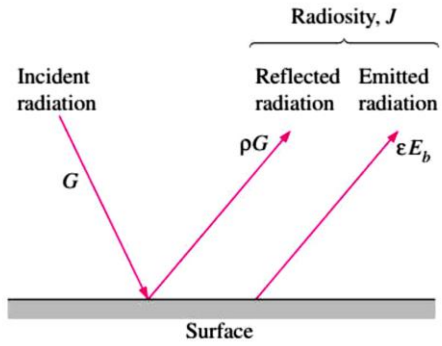
Irradiation *G* (for ex. the solar irradiation on a certain volume) is the radiation that is received, the radiation's flux on a surface.

Emissivity ε is how much radiation is emitted by a surface respect to a black-body. It depends on temperature and direction.
In a black-body **ε**=1

ε of an object's surface $= \frac{\text{E of the object}}{\text{E blackbody} \rightarrow \sigma T4}$

Synthesizing:

$$J_i = \begin{pmatrix}\text{Radiation emitted}\\ \text{by surface } i\end{pmatrix} + \begin{pmatrix}\text{Radiation reflected}\\ \text{by surface } i\end{pmatrix}$$
$$= \varepsilon_i E_{bi} + \rho_i G_i$$
$$= \varepsilon_i E_{bi} + (1-\varepsilon_i) G_i \qquad (\text{W/m}^2)$$



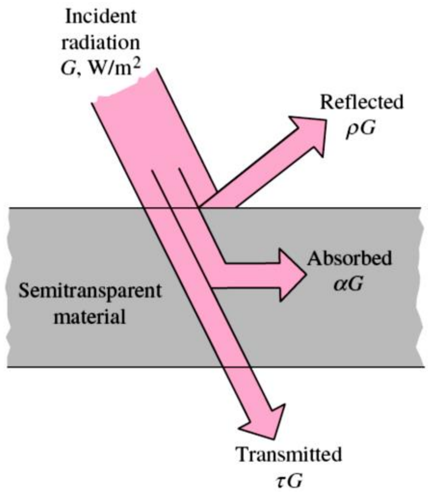
$$\dot{Q}_i = \begin{pmatrix}\text{Radiation leaving}\\ \text{entire surface } i\end{pmatrix} - \begin{pmatrix}\text{Radiation incident}\\ \text{on entire surface } i\end{pmatrix}$$
$$= A_i(J_i - G_i) \qquad (\text{W})$$

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

Absorptivity $\alpha = \frac{\text{Absorbed radiation}}{\text{Incident radiation}} = \frac{\text{G abs}}{\text{G}}$ $\quad 0 \leq \alpha \leq 1$

Reflectivity $\rho = \frac{\text{Reflected radiation}}{\text{Incident radiation}} = \frac{\text{G ref}}{\text{G}}$ $\quad 0 \leq \rho \leq 1$

Transmissivity $\tau = \frac{\text{Trasmitted radiation}}{\text{Incident radiation}} = \frac{\text{G tr}}{\text{G}}$ $\quad 0 \leq \tau \leq 1$



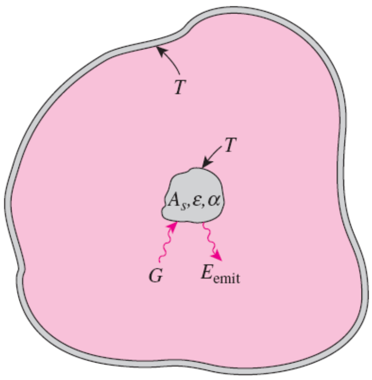
$G = G_{abs} + G_{ref} + G_{tr}$

$\alpha + \rho + \tau = 1$,but in the opaque surface $\tau = 0$ (because nothing pass through an opaque surface)

There is also a relationship between α and ε: $\varepsilon(T) = \alpha(T)$ **Kirchhoff's Law**:

the total hemispherical emissivity of a surface at temperature T is equal to its total hemispherical absorptivity for radiation coming from a blackbody at the same temperature.

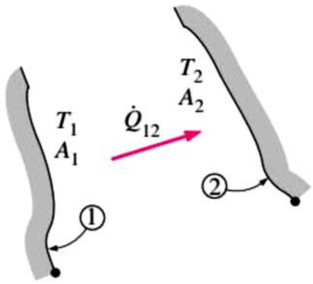
$$G_{abs} = \alpha G = \alpha\sigma T^4 = E_{emit} = \varepsilon\sigma T^4$$



View Factor F_{12} is a geometrical quantity that represents the fraction of the emissive power/radiation leaving from surface 1 that is received by surface 2. It doesn't depend on the surface properties.

$$\mathbf{F_{12}} = \frac{\dot{q}\text{ emitted by surface 1 and received by surface2}}{\dot{q}\ emitted\ by\ surface\ 1}$$

The net radiative heat exchange between <u>black</u> surface 1 and 2 is



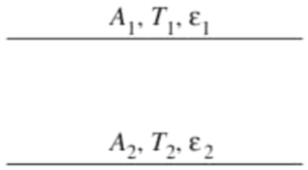
$$\dot{Q}_{1\rightarrow 2} = \begin{pmatrix}\text{Radiation leaving}\\ \text{the entire surface 1}\\ \text{that strikes surface 2}\end{pmatrix} - \begin{pmatrix}\text{Radiation leaving}\\ \text{the entire surface 2}\\ \text{that strikes surface 1}\end{pmatrix}$$

$$= A_1 E_{b1} F_{1\rightarrow 2} - A_2 E_{b2} F_{2\rightarrow 1} \qquad \text{(W)}$$

$\dot{Q}_{1\text{->}2} = A_1 * F_{12} * \sigma\ (T_1^4 - T_2^4)$

The net radiative heat exchange between <u>gray/opaque</u> surface 1 (that leaves) and 2 (that is receiving) is:

Infinitely large parallel plates



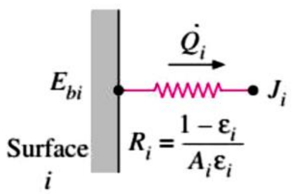
$A_1 = A_2 = A$
$F_{12} = 1$

$$\dot{Q}_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Radiative resistance

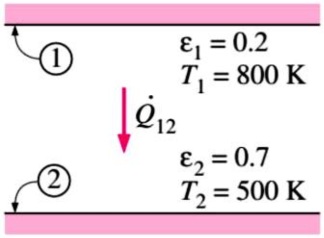
$\dot{Q}_i = A_i \frac{\varepsilon i}{1-\varepsilon i} (E_b - J_i)$ => $\dot{Q}_i = \frac{Eb - Ji}{Ri}$ is the net heat exchange from surface i with environmental

$R_i = \frac{1-\varepsilon i}{Ai\ \varepsilon i}$



Exercise:

Calculate the heat exchange between the two parallel plates:



$$\dot{Q}_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$\dot{Q}_{12} = A\,\frac{5.670 * 10^{-8} * (800^4 - 500^4)}{\frac{1}{0.2} + \frac{1}{0.7} - 1} = A * \frac{19680{,}57}{5.4286} = 3625{,}35 * A \quad [W]$$

If the two emissivities of the plates are 0.1:

$$\dot{Q}_{12} = A\,\frac{5.670 * 10^{-8} * (800^4 - 500^4)}{\frac{1}{0.1} + \frac{1}{0.1} - 1} = A * \frac{19680{,}57}{19} = 1035{,}82 * A \quad [W]$$

Conclusion:

With the same area and variation of temperature, increasing the emissivity it also increases the heat exchange between the two parallel plates