POLITECNICO
MILANO 1863

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Submission Date: 05/11/2019
Assignment #: 5th Week

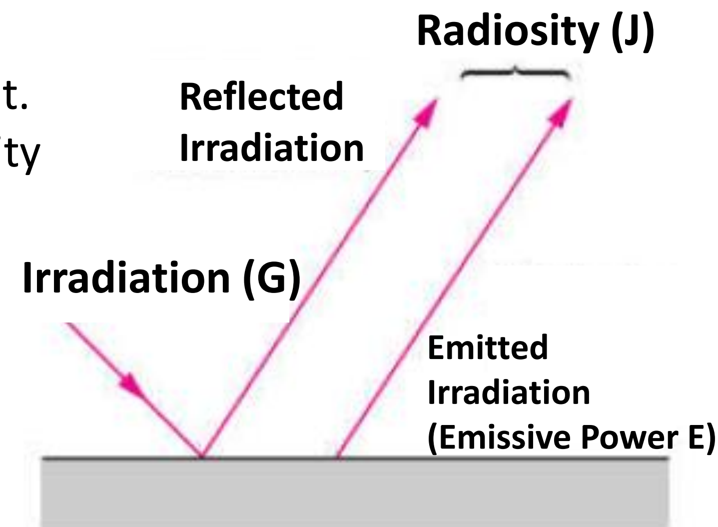
Summary

As we described within the last assignment, every object or person emits energy through radiation. In real world this radiation happens in all directions and the distribution of this emitted radiation is definitely not uniform. **Radiation Intensity (I)** is an imaginary quantity which frames radiation in a specific direction. In order to calculate the radiation intensity in practice, we should approximate the surfaces to be diffuse so that we conclude on constant emissivity.

Surfaces which emit radiation, receive and absorb it as well. Receiving radiation also doesn't happen in a uniform direction thus we need to introduce another phenomenon called **Irradiation (G)** to describe incident radiation on a surface for further calculations.

Another important fact to know is that surfaces emit radiation as well as reflecting it in a certain amount. **Radiosity (J)** is another key player which sums both reflected and emitted irradiation.

As we know, black body is an idealized body which absorbs and emits all the irradiation and does not reflect any of it. This means that the amounts of radiosity and irradiation are equal. This scenario happens in another way in other (grey & diffuse) surfaces. **Emissivity (ε)** is a number between 0 and 1 (1 for black body) which defines the ratio of the Emitted radiation by a certain surface. At a given temperature to the radiation emitted by a black body at the same temperature.



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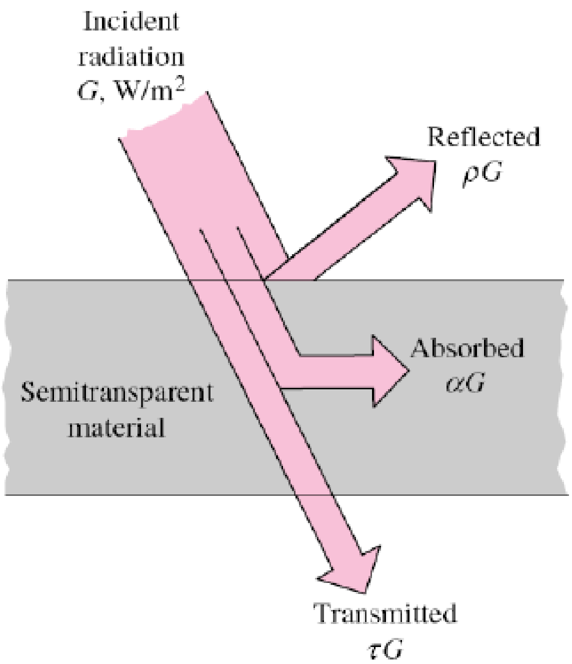
In semitransparent and opaque surfaces we can define other ratios which we need while determining the heat exchange between surfaces:

1- **Absorptivity (α)**: Ratio of absorbed radiation to irradiation at a certain Temperature which is between 0 and 1.

2- **Reflectivity (ρ)**: Ratio of reflected radiation to irradiation at a certain temperature which is between 0 and 1.

2- **Transmissivity (τ)**: Ratio of transmitted radiation to irradiation at a certain Temperature which is between 0 and 1.



Based on the picture we can conclude that $\alpha + \rho + \tau = 1$. Since opaque surfaces do not transmit light then their transmissivity is equal to zero. Therefore $\alpha + \rho = 1$.

According to Kirchhoff's law, emissivity of a surface at certain temperature, direction and wavelength is equal to it's absorptivity. What we can conclude from this statement is that in most surfaces:
$\alpha = \varepsilon$, then $\varepsilon + \rho = 1$.

Another element which affects the head exchange rate between different surfaces is called **View Factor**. It represents the proportion of radiation leaving one surface and being received by another one. In concave surfaces we can also define internal view factor since part of radiation is received by itself.

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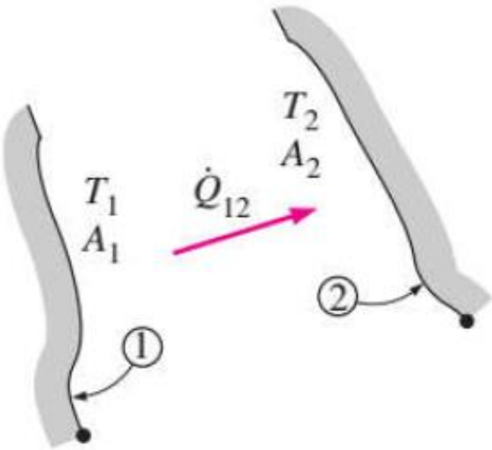
In order to measure the heat exchange rate between surfaces we can divide them into two categories:

1- **Black Surfaces:** In this case the net heat exchange from one surface to another is equal to (radiation leaving the surface 1 that is received by surface 2) - (radiation leaving the surface 2 that is received by surface 1) which means:



- $A_1 \times E_{b1} \times F_{1\to 2} - A_2 \times E_{b2} \times F_{2\to 1}$

According to reciprocity relation:

- $A_1 \times F_{1\to 2} = A_2 \times F_{2\to 1}$

And as we mentioned in previous assignment:

- $E_b = \sigma \times T^4 \Rightarrow \dot{Q}_{1\to 2} = A_1 \times F_{1\to 2} \times \sigma \times (T_1^4 - T_2^4)$

To calculate the heat transfer within an enclosed with multiple black surfaces we should calculate the summation of all $\dot{Q}$s in different directions.

2- Diffuse Grey Surfaces: In this case the first thing to do is to calculate the $\dot{Q}$ from a single surface and then to apply it on the whole situation. Transferred heat from the first surface (i) is equal to (radiation leaving the surface i on a certain unit area) - (radiation incident on surface i on a certain unit area) :

$$\dot{Q}_i = A_i \times (J_i - G_i)$$

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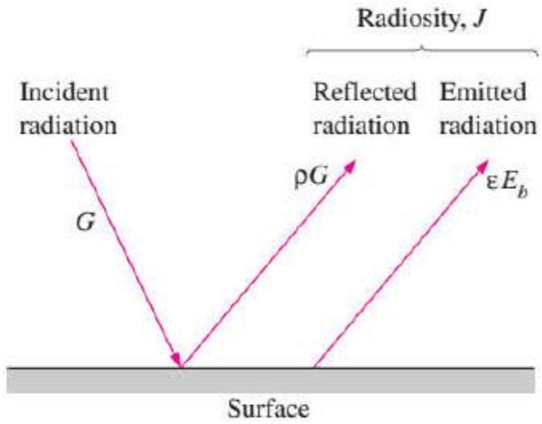
As we know from previous explanations:

- $J_i = (\rho_i \times G_i) + (\varepsilon_i \times E_{bi})$
- $\rho_i = 1 - \varepsilon_i$

$\Rightarrow \quad J_i = ((1 - \varepsilon_i) \times G_i) + (\varepsilon_i \times E_{bi})$

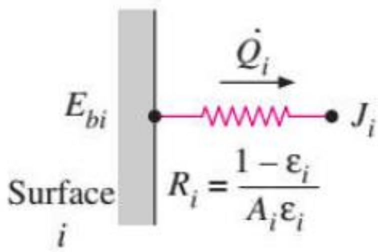


By replacing G in the first equation we will have:

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

Here we can define another important factor which is called **Radiation Resistance (R).** It defines the resistance of any particular medium to the flow of heat through it's surfaces:

$$R_i = \frac{1 - \varepsilon_i}{A_i \times \varepsilon_i} \quad \Rightarrow \quad \dot{Q}_i = \frac{E_{bi} - J_i}{R_i}$$



Now we can measure the heat exchange rate between to diffuse grey surfaces (radiation leaving the surface i and received by surface j) - (radiation leaving surface j and received by surface i) like below:

- $\dot{Q}_{i \to j} = (A_i \times J_i \times F_i) - (A_i \times J_i \times F_i)$
- Based on reciprocity relation: $A_1 \times F_{1 \to 2} = A_2 \times F_{2 \to 1}$

$$\Rightarrow \quad \dot{Q}_{i \to j} = A_i \times F_i \times (J_i - J_j) \quad \Rightarrow \quad \dot{Q}_{i \to j} = \frac{J_i - J_j}{R_{i \to j}}$$

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Exercise

Find the radiation heat transfer between to parallel surfaces of i and j where the area is 1 m^2, ε_1 = 0.1 , ε_2 = 0.1 , T_1 = 800 K and T_2 = 500 K

In parallel surfaces the situation is a little bit different. We have to calculate the summation of all radiation resentences which are R_1 , $R_{1\longrightarrow 2}$ and R_2 . The formula will be as following for parallel heat exchange:

- $$\dot{Q}_{12} = \frac{E_{b1} - E_{b2}}{R_1 + R_{12} + R_2} = \frac{\sigma \times (T_1^4 - T_2^4)}{\frac{1-\varepsilon_i}{A_1 \times \varepsilon_1} + \frac{1}{A_2 \times F_{12}} + \frac{1-\varepsilon_i}{A_2 \times \varepsilon_2}}$$

In parallel surfaces A_1 = A_2 = A and $F_{1\longrightarrow 2}$ = 1, then:

- $$\dot{Q}_{12} = \frac{A \times \sigma \times (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \Rightarrow \dot{Q}_{12} = \frac{1 \times 5.67 \times 10^{-8} \times (800^4 - 500^4)}{\frac{1}{0.1} + \frac{1}{0.1} - 1}$$

$$\Rightarrow \dot{Q}_{12} = \boxed{1035.81 \text{ W}}$$

In the example which we solved in the class we had the following figures: ε_1 = 0.2 , ε_2 = 0.7 and the final answer was around 3625 Watts. We can see that how significant emissivity ratios of both surfaces can affect the radiation heat transfer between two parallel surfaces.