Learning activities after - Lecture 5:

You have joined the fifth Lecture of our E&H course. Below you will find some activities that will help you to bring your learning into practice and/or to learn more about the topics that were addressed.

Thermal radiation Questions

Try to think and find out the answers for below questions :

1. What is radiation heat transfer?
2. What is black body ?
3. What is **Stefan-Boltzmann law** ?
4. How to calculate radiation heat transfer for non-ideal cases?
5. Can you define the ***Absorptivity***, ***Reflectivity*** and ***Transmissivity*** ?
6. Can you define which shape factor rules to be uses for different radiation cases?

please watch below video which will show you the basic of thermal radiation :

https://www.youtube.com/watch?v=otdK1x-WCsk&feature=emb_imp_woyt

Radiation Heat Transfer

Radiation differs from *Conduction* and *Convection* heat t transfer mechanisms, in the sense that it does not require the presence of a material medium to occur.

Energy transfer by radiation occurs at the *speed of light* and suffers no attenuation in vacuum.

Radiation can occur between two bodies separated by a medium colder than both bodies.

According to *Maxwell theory*, energy transfer takes place via *electromagnetic waves* in radiation. Electromagnetic waves transport energy like other waves and travel at the speed of light.

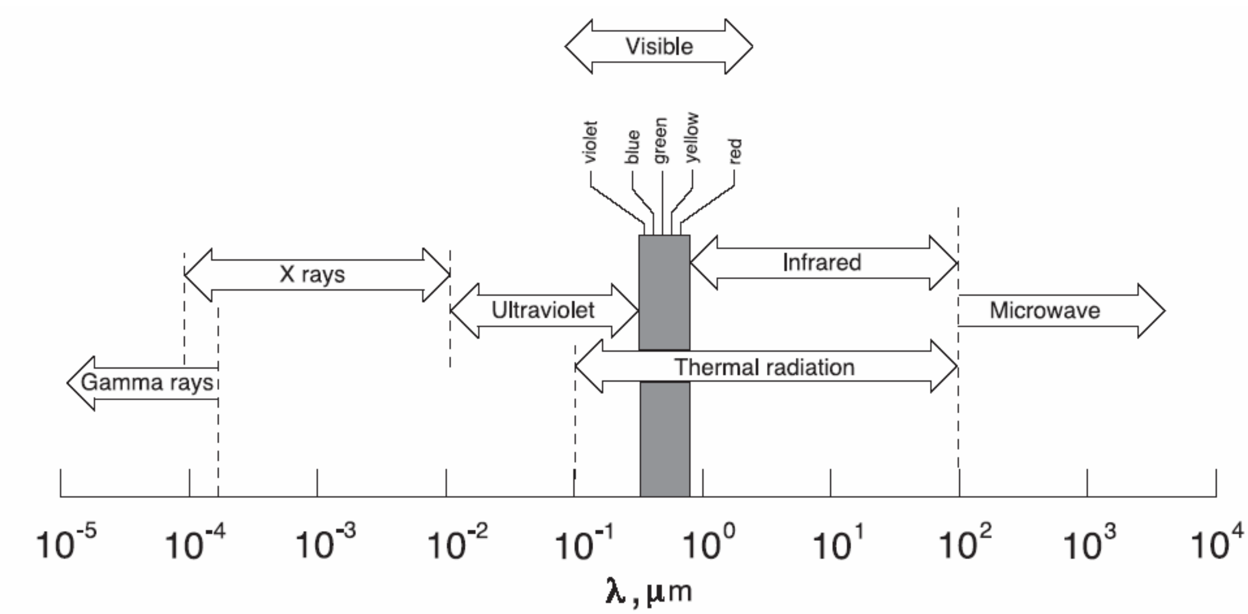


Fig. 1: Electromagnetic spectrum.

Electromagnetic radiation covers a wide range of wavelength, from 10-10 μm for cosmic rays to 1010 μm for electrical power waves.

As shown in Fig. 1, thermal radiation wave is a narrow band on the electromagnetic wave spectrum.

Thermal radiation emission is a direct result of vibrational and rotational motions of molecules, atoms, and electrons of a substance. Temperature is a measure of these activities. Thus, the rate of thermal radiation emission increases with increasing temperature.

What we call light is the visible portion of the electromagnetic spectrum which lies within the thermal radiation band.

Thermal radiation is a volumetric phenomenon. However, for opaque solids such as metals, radiation is considered to be a surface phenomenon, since the radiation emitted by the interior region never reach the surface.

Note that the radiation characteristics of surfaces can be changed completely by applying thin layers of coatings on them.

Blackbody Radiation

A blackbody is defined as a perfect emitter and absorber of radiation. At a specified temperature and wavelength, no surface can emit more energy than a blackbody.

A blackbody is a *diffuse emitter* which means it emits radiation uniformly in all direction. Also a blackbody absorbs all incident radiation regardless of wavelength and direction.

The radiation energy emitted by a blackbody per unit time and per unit surface area can be determined from the *Stefan-Boltzmann* Law:

$$E_b = \sigma T^4 \quad \left(W/m^2\right)$$

$$where$$

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

where T is the absolute temperature of the surface in K and E_b is called the blackbody emissive power.

A large cavity with a small opening closely resembles a blackbody.

Radiation Properties

A blackbody can serve as a convenient reference in describing the emission and absorption characteristics of real surfaces.

Emissivity

The emissivity of a surface is defined as the ratio of the radiation emitted by the surface to the radiation emitted by a blackbody at the same temperature. Thus,

$$0 \le \varepsilon \le 1$$

Emissivity is a measure of how closely a surface approximate a blackbody, $\varepsilon_{blackbody} = 1$.

The emissivity of a surface is not a constant; it is a function of temperature of the surface and wavelength and the direction of the emitted radiation, $\varepsilon = \varepsilon\ (T, \lambda, \theta)$ where θ is the angle between the direction and the normal of the surface.

The *total emissivity* of a surface is the average emissivity of a surface over all direction and wavelengths:

$$\varepsilon(T) = \frac{E(T)}{E_b(T)} = \frac{E(T)}{\sigma\, T^4} \rightarrow E(T) = \varepsilon(T)\,\sigma\, T^4$$

Spectral emissivity is defined in a similar manner:

$$\varepsilon_\lambda(T) = \frac{E_\lambda(T)}{E_{b\lambda}(T)}$$

where $E_\lambda(T)$ is the spectral emissive power of the real surface. As shown, the radiation emission from a real surface differs from the Planck's distribution.

Absorptivity, Reflectivity, and Transmissivity

The radiation energy incident on a surface per unit area per unit time is called *irradiation*, G.

Absorptivity **α**: is the fraction of irradiation absorbed by the surface.

Reflectivity **ρ**: is the fraction of irradiation reflected by the surface.

Transmissivity **τ:** is the fraction of irradiation transmitted through the surface.)

$$\text{absorptivity}: \qquad \alpha = \frac{\text{absorbed radiation}}{\text{incident radiation}} = \frac{G_{abs}}{G} \qquad 0 \le \alpha \le 1$$

$$\text{reflectivity}: \qquad \rho = \frac{\text{reflected radiation}}{\text{incident radiation}} = \frac{G_{ref}}{G} \qquad 0 \le \rho \le 1$$

$$\text{transmissivity}: \qquad \tau = \frac{\text{transmitted radiation}}{\text{incident radiation}} = \frac{G_{tr}}{G} \qquad 0 \le \tau \le 1$$

Applying the first law of thermodynamics, the sum of the absorbed, reflected, and the transmitted radiation radiations must be equal to the incident radiation:

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

Divide by G:

$$\alpha + \rho + \tau = 1$$

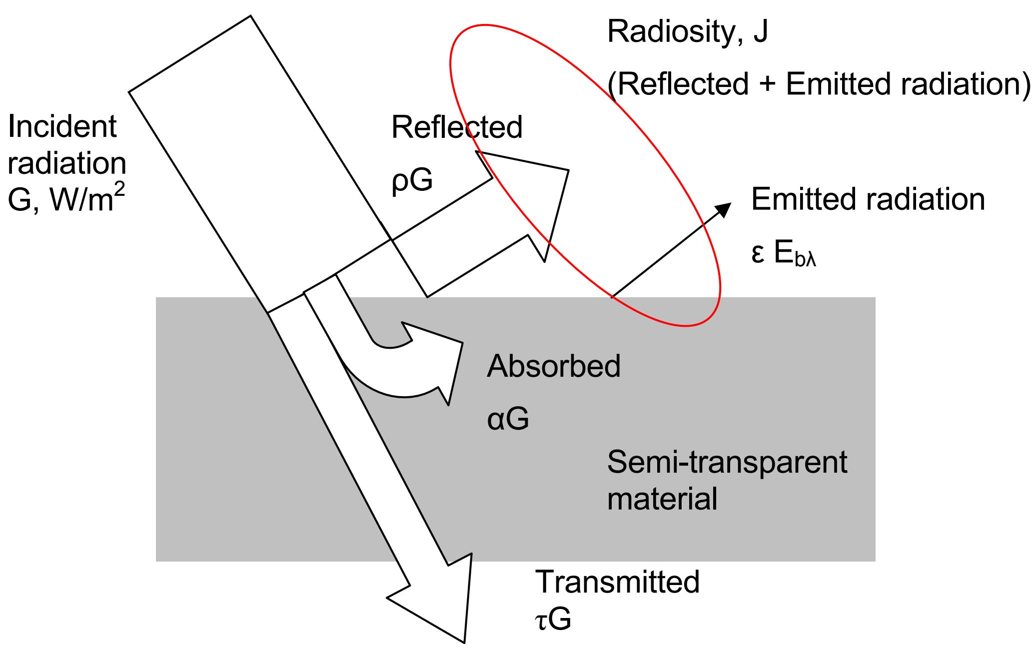


Fig. 2: The absorption, reflection, and transmission of irradiation by a semi-transparent material.

For opaque surfaces τ = 0 and thus: $\alpha + \rho = 1$. The above definitions are for total hemi-spherical properties (over all direction and all frequencies). We can also define these properties in terms of their spectral counterparts:

$$
\begin{aligned}
&G_\lambda = \rho_\lambda G_\lambda + \tau_\lambda G_\lambda + \alpha_\lambda G_\lambda \\
&where \\
&\rho_\lambda = \rho_\lambda(T,\lambda) \qquad \text{spectral reflectivity} \\
&\alpha_\lambda = \alpha_\lambda(T,\lambda) \qquad \text{spectral absorptivity} \\
&\tau_\lambda = \tau_\lambda(T,\lambda) \qquad \text{spectral transmissivity} \\
&\text{thus} \\
&1 = \rho_\lambda + \tau_\lambda + \alpha_\lambda
\end{aligned}
$$

Note that the *absorptivity* α is almost *independent of surface temperature* and it strongly depends on the temperature of the *source* at which the incident radiation is originating. For example α of the concrete roof is about 0.6 for solar radiation (source temperature 5762 K) and 0.9 for radiation originating from the surroundings (source temperature 300 K).

Kirchhoff's Law

Consider an isothermal cavity and a surface at the same temperature T. At the steady state (equilibrium) thermal condition

$$G_{abs} = \alpha\, G = \alpha\, \sigma\, T^4$$

and radiation emitted

$$E_{emit} = \varepsilon\, \sigma\, T^4$$

Since the small body is in thermal equilibrium, $G_{abs} = E_{emit}$

$$\varepsilon(T) = \alpha(T)$$

The total hemispherical emissivity of a surface at temperature T is equal to its total hemi-spherical absorptivity for radiation coming from a blackbody at the same temperature T. This is called the *Kirchhoff's law*.

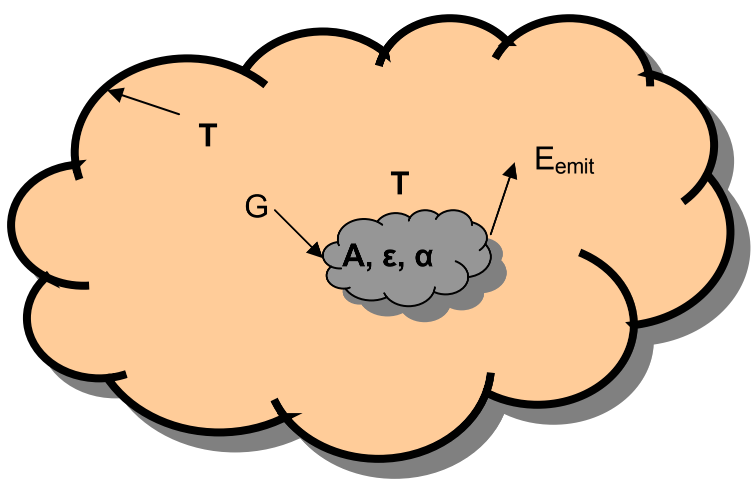


Fig. 3: Small body contained in a large isothermal cavity.

The Kirchhoff's law can be written in the spectral form:

$$\varepsilon_{\lambda}(T) = \alpha_{\lambda}(T)$$

and in the spectral directional form

$$\varepsilon_{\lambda,\theta}(T) = \alpha_{\lambda,\theta}(T)$$

The Kirchhoff's law makes the radiation analysis easier (ε = α), especially for opaque surfaces where ρ = 1 – α.
Note that Kirchhoff's law cannot be used when there is a large temperature difference (more than 100 K) between the surface and the source temperature.

The View Factor

Radiation heat transfer between surfaces depends on the orientation of the surfaces relative to each other as well as their radiation properties and temperatures.

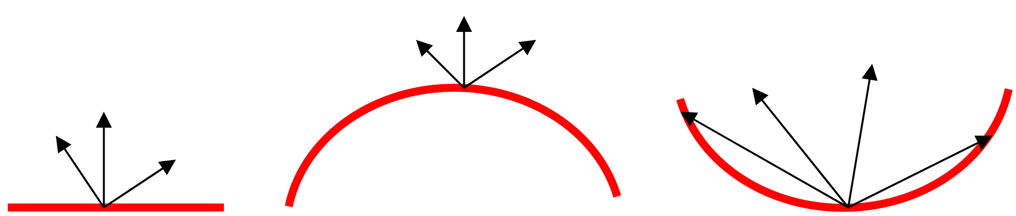
View factor (or shape factor) is a purely geometrical parameter that accounts for the effects of orientation on radiation between surfaces.

In view factor calculations, we assume uniform radiation in all directions throughout the surface, i.e., surfaces are *isothermal* and *diffuse*. Also the medium between two surfaces *does not absorb, emit, or scatter radiation*.

$F_{i \to j}$ *or* F_{ij} = the fraction of the radiation leaving surface *i* that strikes surface *j* directly.

Note the following:

- The view factor ranges between zero and one.
- F_{ij} = 0 indicates that two surfaces do not see each other directly. F_{ij} = 1 indicates that the surface j completely surrounds surface i.
- The radiation that strikes a surface does not need to be absorbed by that surface.
- F_{ii} is the fraction of radiation leaving surface *i* that strikes itself directly. F_{ii} = 0 for plane or convex surfaces, and $F_{ii} \neq 0$ for concave surfaces.



Plane surface, $F_{ii} = 0$

Convex surface, $F_{ii} = 0$

Concave surface, $F_{ii} \neq 0$

Fig. 4: View factor between surface and itself.

Calculating view factors between surfaces are usually very complex and difficult to perform. View factors for selected geometries are given in Table 12-4 and 12-5 and Figs. 12-41 to 12-44 in Cengel book.

Learning activities before - Lecture 5:

To make the session more efficient we would like to ask you to do some preparation beforehand. This will help you to be prepared for the lecture in advance by having the overall view of the content.

The learning objective of the session are:

- Concept of Radiation
- Radiation Laws
- Non- Ideal Radiation
- Radiation Heat Transfer
- Resistance Networks – (Radiation and Convection)

Please prepare yourself in the following way:

Question to make you think:

How can we feel heat from the sun even though we are millions of kilometres away?

Thermal Radiation

Thermal Radiation is the transfer of heat by the means of the electromagnetic radiation generated by the thermal motion of particles in matter. For most bodies on Earth, this electromagnetic radiation (Links to an external site.) lies in the invisible region of the spectrum known as the Infrared region. Everybody with a temperature above absolute zero emits thermal radiation. Thermal radiation is caused by the motion of the particles inside the body, at absolute zero this motion is completely suspended which is why a body at absolute zero emits no radiation and everything above absolute zero does. The particles moving through the body collide with other particles causing the kinetic energy of these particles to change. The difference between the energy state before and after is emitted as radiation heat loss. Thermal Radiation is responsible for the glow of hot objects i.e. iron is termed as being red-hot because at that temperature most of the thermal energy emitted falls in the red band of the spectrum. At an even higher temperature, it starts emitting a different color.

The colors emitted by metals at different temperatures.

color	approximate temperature		
	℉	℃	K
faint red	930	500	770
blood red	1075	580	855
dark cherry	1175	635	910
medium cherry	1275	0680	0955
cherry	1375	0745	1020
bright cherry	1450	0790	1060
salmon	1550	0845	1115
dark orange	1630	0890	1160
orange	1725	0940	1215
lemon	1830	1000	1270
light yellow	1975	1080	1355
white	2200	1205	1480

The discovery of heat radiation is a very curious one. It was discovered by the English Astronomer, William Herschel. He noticed that a thermometer, when moved from one end of a prism spectrum to another, would register a temperature change. The highest temperature was observed below the red band of the visible light. Hence, the name Infrared. Infrared waves though, are not to be confused with Heatwaves. Since all forms of electromagnetic radiation transfer energy from place to place, they could all be termed as Heat Waves.

How Is Radiation Different From Other Two Modes?

Unlike Conduction and Convection, Thermal Radiation requires no medium to transfer heat. The heat that the Earth receives from the sun is through Radiation. This is because radiation occurs through electromagnetic waves, and they do not need a medium for transmission. Thermal Radiation has another interesting property. It has been found that darker bodies absorb and emit heat radiation better than bodies with lighter colors. This is why people prefer to wear white colors in summers and darker colors in winters. Black especially is faster at both absorption and emission of heat that White. For humans, the thermal emissivity is independent of the color of the skin. Skin is a perfect absorber and emitter of Infrared Radiation. If you saw a human through infrared waves, we would all appear black. We lose half our energy through radiation even if the surrounding atmosphere is not much colder than our body.

Absorptivity, Reflectivity, and Transmissivity

The radiation energy incident on a surface per unit area per unit time is called irradiation, G.
Absorptivity α: is the fraction of irradiation absorbed by the surface.
Reflectivity ρ: is the fraction of irradiation reflected by the surface.
Transmissivity τ: is the fraction of irradiation transmitted through the surface.

You can watch the below video to understand the radiation heat transfer concept much better :

https://www.youtube.com/watch?v=5GoZZKcNZiQ&feature=emb_imp_woyt

To see some interesting demonstrations for radiation heat transfer you can watch below video :

https://www.youtube.com/watch?v=48eE9ToxB6k&feature=emb_imp_woyt

Notes – Lecture 5: