Intro to Thermal Radiation

Thermal Radiation in Heat Transfer Analysis – Lesson 1

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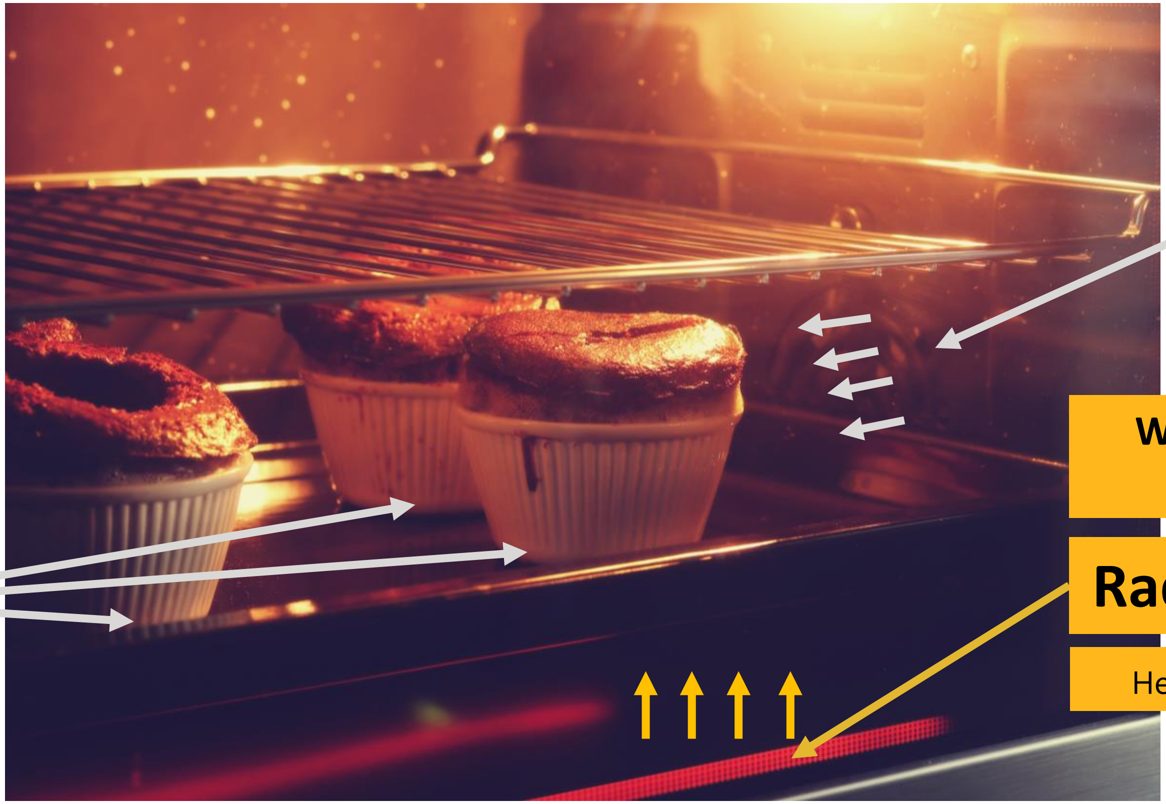
What is Radiation?

- **Radiation** is one of the three heat transfer modes: conduction, convection and radiation. The energy transfer occurs in the form of electromagnetic waves due to temperature difference without any material medium (fluid, solid).

Conduction

Convection

Radiation



Convection

Fan

What is happening here?

Radiation

Heat radiated by the coils

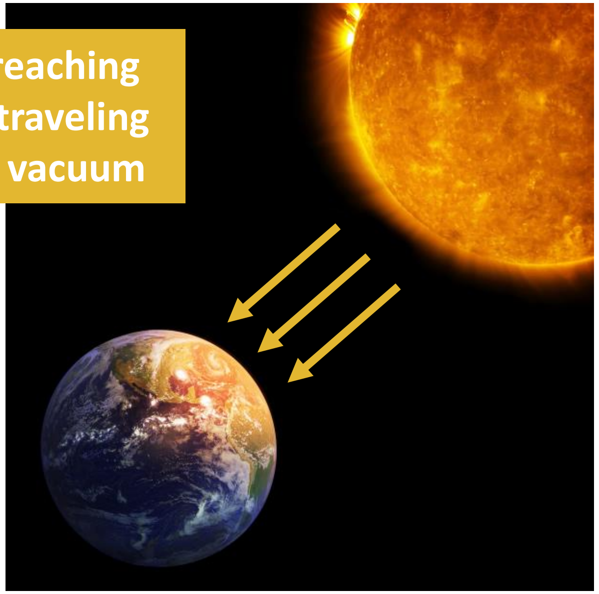
Conduction

Between Tray and Mold

On the Mechanism of Radiation

- Because the mechanism of transmission is electromagnetic waves, unlike conduction and convection, no intermediate matter is required for transmission.
- In a vacuum, radiation will be the only mode of heat transfer.
- In this course, transparent media, such as glass or a thick gas, will not be considered.

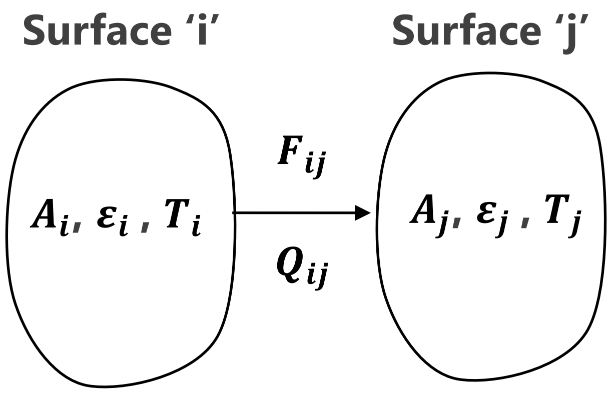
Sun rays reaching the earth traveling through a vacuum



Radiative Heat Transfer

Radiation is a highly nonlinear mode of heat transfer. A simplified form of the equation describing radiation from one surface to another is:

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



Where:

A = Surface area.

ε = Emissivity of the surface, which determines the amount of thermal radiation emitted

F_{ij} = View factor between the surfaces, defined as the fraction of total radiant energy that leaves surface 'I' which arrives directly on surface 'j'

σ = Stefan-Boltzmann constant, 5.67. 10^{-8} W/m^{2}· K^4

$T_{i,}$ T_j = Surface temperatures in absolute units (K)

Note: Radiation is always in absolute scale (Kelvin, K or deg Rankine, ^{0}R). Everything else in thermal simulations (phase change, conduction, temp-dependent material definition, convection) can be in relative temperature units.

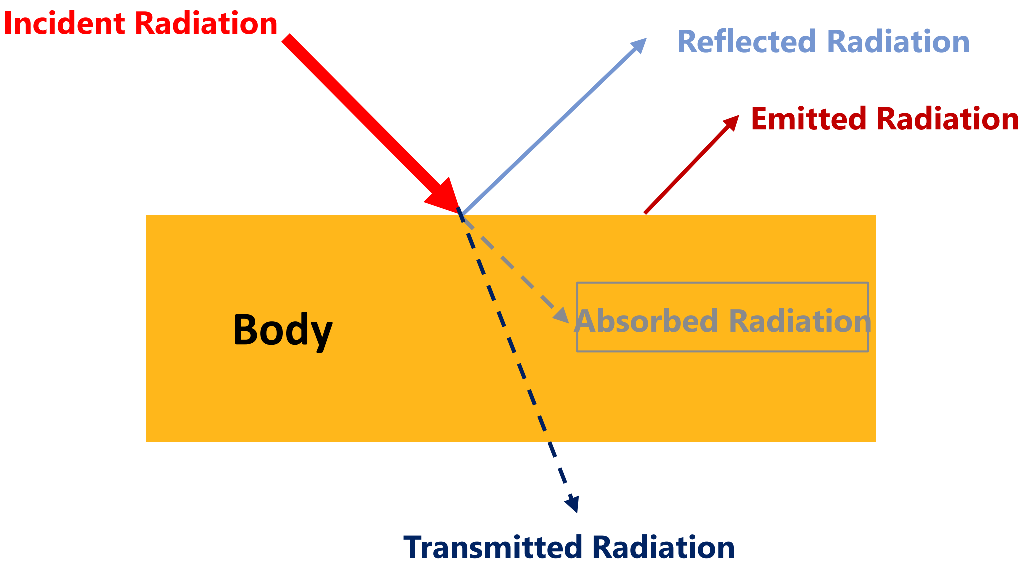
Radiative Heat Transfer: A Few Points

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

- All materials having temperature greater than absolute zero (= 0 K) will emit thermal radiation.
- Radiant energy exchange is directly proportional to the fourth order of absolute temperature.
- As per the above statement, thermal radiation may become more pronounced as the temperature increases. For example, let's consider a heat transfer problem between two surfaces, with temperature T_1, T_2 with $\Delta T = 20°\text{C}$. If $T_2 = 540°\text{C}$ ($T_1 = 520°\text{C}$) compared with $T_2 = 40°\text{C}$ ($T_1 = 20°\text{C}$) the radiated heat is almost 20x greater, even though it's the same temperature difference (this is due to use of absolute temperatures and difference of temperature to the fourth power)
- In this course, we will focus on how radiation is modeled as a boundary condition in conduction-based solvers.

Incident Radiation (Irradiation): Reflection, Absorption, Transmission and Emission

- Incident radiation (Irradiation) on a surface will be reflected, absorbed and transmitted by the body.
- If the temperature of the body is above absolute zero (0 K), it will also emit radiation.
- The behavior of a body can be characterized by its transmissivity τ, absorptivity α and reflectivity ρ.

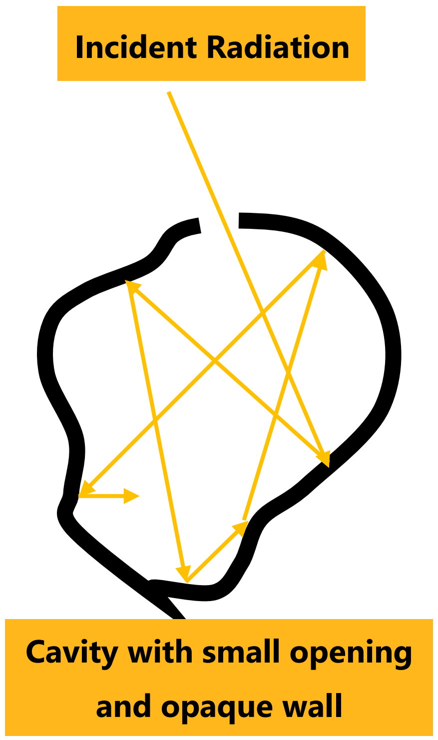


$$\tau + \alpha + \rho = 1$$

τ	α	ρ	Type of Body	Comments
0	>0	>0	**Opaque**	Transmits none of the radiation, Reflects some. **α+ρ=1**
1	0	0	**Transparent**	Transmits all the radiation
>=0	>0	>0	**Gray**	May transmit, reflect and absorb the incident radiation
0	0	1	**White**	Uniformly reflects all incident radiation in all directions
0	1	0	**Black**	Idealized physical state not found in nature

Black Body

- An idealized black body absorbs all incident radiation , no matter the incidence angle or the frequency. Hence it is a perfect absorber.
- For thermal equilibrium, at a given temperature, it emits radiation at the same rate at which it absorbs. Hence it is also an ideal emitter.
- The radiation emitted does not depend upon the body shape and composition and is a function of temperature only.
- One close approximation of a black body is a small hole/opening in a cavity with opaque walls.



Emissivity (ε) and Gray Body

- A body having temperature above absolute zero will emit radiation. The amount of thermal radiation emitted depends on the body's surface property - **emissivity**.
- **Emissivity:** $\varepsilon = \left\{ \dfrac{\textit{Energy radiated from a material's surface}}{\textit{Energy radiated from a blackbody's surface}} \right\}$ at the same wavelength, temperature and viewing conditions. Emissivity is a dimensionless quantity.
- The absorptivity α is equal to the emissivity ε. Thus, surfaces which are good absorbers of radiations are also good emitters.
- **ε =0, α=0** (perfect reflector/white body) and **ε =1, α=1** (perfect emitter/perfect absorber/black body).
- A body having emissivity and absorptivity lower than the black body and independent of wavelength (frequency) is a **gray body.**

Dependence of Emissivity on Material and Nature of Surface

- Emissivity (ε) is a function of the material of the surface, the nature of the surface, temperature, wavelength and angle.
- Mirror-like metallic surfaces reflect light well and have low emissivity, while rough surfaces are more likely to have a higher emissivity and absorptivity.
- For example, aluminum foil has $\varepsilon = 0.03$. But asphalt absorbs thermal radiation well, with $\alpha=\varepsilon=0.88$, closer to an ideal black body.
- Apart from bare, polished metals, the appearance of a surface to the eye is not a good guide to emissivity.
- For example, pure water absorbs very little visible light, but water is a strong infrared absorber and hence has a high absorptivity and high emissivity.

Material / Object	Emissivity, ε
Aluminum foil	0.03
Aluminum, anodized	0.9
Asphalt	0.88
Brick	0.9
Rough concrete	0.91
Uncoated glass	0.95
Ice	0.97
Water	0.96
White paper	0.86-0.88
Snow	0.8-0.9

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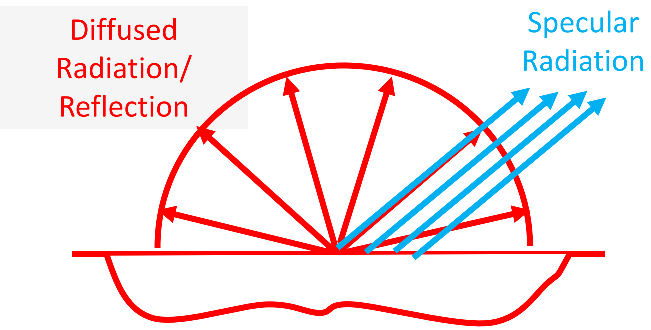
Dependence of Emissivity on Direction, Wavelength and Temperature

- If a surface emits the same amount of radiation in different direction, then the surface is known as diffuse surface. If the amount of radiation emitted by a surface changes with direction, it is known as specular surface.

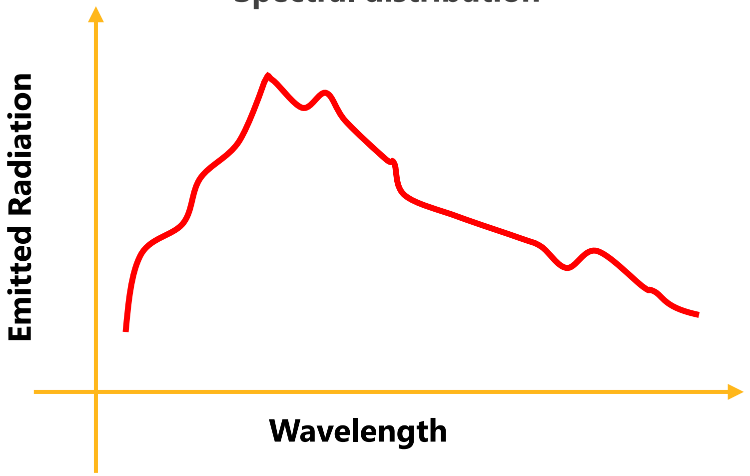
- For opaque surfaces, the emitted radiation, and hence emissivity and absorptivity, may vary with the wavelength. A spectral distribution plot gives the variation of radiation over all the wavelengths.

- Emissivity may depend on temperature. E.g. for certain Aluminum alloys, ε=0.3 at T = 600 K and ε=0.1 at T = 800 K.



Diffuse vs specular radiation

Spectral distribution



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