Comprehensive Notes on Thermal Radiations

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Introduction to Thermal Radiations

Thermal radiation is the emission of electromagnetic waves from all objects due to their temperature. It is a form of heat transfer that does not require a medium and can occur in a vacuum.

Black Body

A black body is an idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence. It is also a perfect emitter of thermal radiation.

Properties of a Black Body

- Absorbs all incident radiation.
- Emits radiation at all wavelengths.
- The radiation emitted depends only on its temperature.

Black Body Radiation

The radiation emitted by a black body is called black body radiation. It is characterized by the following properties:

Spectral Radiance

The spectral radiance (B_λ) of a black body at a wavelength λ and temperature T is given by Planck's Law:

$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \tag{1}$$

where:

- h = Planck's constant (6.626×10^{-34} Js)
- c = Speed of light (3×10^8 m/s)

- k = Boltzmann constant (1.38×10^{-23} J/K)
- λ = Wavelength of radiation (in meters, m)
- T = Absolute temperature (in Kelvin, K)

Total Radiant Energy

The total energy radiated per unit area by a black body is given by Stefan-Boltzmann Law:

$$E = \sigma T^4 \tag{2}$$

where:

- E = Total radiant energy (in W/m^2)
- σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^{2}K^4)
- T = Absolute temperature (in Kelvin, K)

Stefan's Law

Stefan's Law states that the total energy radiated per unit surface area of a black body is directly proportional to the fourth power of its absolute temperature.

$$E = \sigma T^4 \tag{3}$$

Kirchhoff's Law

Kirchhoff's Law states that for a body in thermal equilibrium, the emissivity (ϵ) of a surface is equal to its absorptivity (α).

$$\epsilon = \alpha \tag{4}$$

where:

- ϵ = Emissivity (ratio of radiation emitted by the body to that emitted by a black body)
- α = Absorptivity (ratio of radiation absorbed by the body to that incident on it)

Wein's Displacement Law

Wein's Displacement Law states that the wavelength ($\lambda_{\max}$) at which the emission of a black body spectrum is maximized is inversely proportional to its absolute temperature.

$$\lambda_{\max} T = b \tag{5}$$

where:

- $\lambda_{\max}$ = Wavelength of maximum emission (in meters, m)
- T = Absolute temperature (in Kelvin, K)
- b = Wein's displacement constant ($2.898 \times 10^{-3}\,\mathrm{m{\cdot}K}$)

Newton's Law of Cooling

Newton's Law of Cooling states that the rate of cooling of a body is directly proportional to the temperature difference between the body and its surroundings.

$$\frac{dT}{dt} = -k(T - T_s) \tag{6}$$

where:

- $\frac{dT}{dt}$ = Rate of cooling (in K/s)
- k = Cooling constant (depends on the properties of the body and its surroundings)
- T = Temperature of the body (in Kelvin, K)
- T_s = Temperature of the surroundings (in Kelvin, K)

Emissivity and Absorptivity

The emissivity (ϵ) of a material is a measure of its ability to emit thermal radiation compared to a black body. The absorptivity (α) is a measure of its ability to absorb radiation.

$$\epsilon = \frac{E}{E_b} \tag{7}$$

where:

- E = Energy radiated by the material
- E_b = Energy radiated by a black body at the same temperature

Spectral Distribution of Black Body Radiation

The spectral distribution of black body radiation is described by Planck's Law. The following figure shows the spectral radiance as a function of wavelength for different temperatures.

Figure: Spectral Radiance vs. Wavelength for Different Temperatures

Applications of Thermal Radiations

- **Thermal Imaging**: Used in night vision devices and medical imaging.
- **Solar Energy**: Solar panels absorb thermal radiation from the sun.
- **Astronomy**: Used to study the temperature and composition of stars.