Radiative Heat Transfer

2A- Concepts & Definitions

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Basis Concepts

• There are two views by which the theory of radiant energy transfer can be examined:
  1) Classical Electromagnetic Wave Theory

2) Quantum Mechanics (photons).

Quantum theory

\[ E_{\text{photon}} = h \cdot v \quad h = 6.63 \cdot 10^{-34} \quad \text{J} \cdot \text{s} \]
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Basis Concepts

- In most cases, the resulting equations describing the interaction of radiation and matter using either classical electromagnetic (EM) theory or quantum mechanics are similar.
- Exceptions where quantum effects are important, occur when one considers the spectral distribution of energy emitted from a body and the radiative properties of gases.
- The true nature of EM radiation (electromagnetic energy, i.e., waves or photons) is not yet known.

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Basis Concepts

- Electromagnetic (EM) waves come from transitions between energy states.
- Ultraviolet, visible, and infrared light typically originates from electronic transitions in atoms.
- EM waves can be emitted from solids, liquids, and gases.
- All matter with T > 0 K emit radiation at all times.
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Basis Concepts

- Electromagnetic radiation includes cosmic rays, gamma rays, X rays, ultraviolet, visible and infrared radiation, microwaves, and broadcasting waves.

Electro-Magnetic Spectrum

- Within the framework of wave theory, all electromagnetic radiation follows the laws governing transverse waves which oscillate in a direction perpendicular to the direction of propagation (travel).
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Basis Concepts

- All electromagnetic waves are characterized by their wavelength ($\lambda$) and frequency ($\nu$).

- The wavelength ($\lambda$) and frequency ($\nu$) is related to the propagation velocity (or speed) and is equal to $c$, which is the speed of light in that medium,

$$\lambda = \frac{c}{\nu}$$

- The speed of light in a vacuum, $c_0 = 2.9979 \times 10^8$ m/sec.

- One can also relate the speed of light in a medium (solid, liquid or gas) to the index of refraction ($n$) and $c_0$ by,

$$n = \frac{c_0}{c}$$

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Basis Concepts

- The index of refraction, $n$, for most gases (including air) is approximately 1, while for liquids (e.g. water) and solids (e.g. glass), $n$ is approximately 1.5.

- Rewriting the frequency of electromagnetic (EM) radiation as follows:

$$\nu = \frac{c}{\lambda}$$

$$\nu \equiv \frac{\omega}{2\pi} = \frac{c}{\lambda}$$

$$\nu \equiv \frac{\omega}{2\pi} = \frac{c}{\lambda} = ck$$

Where $\omega$ is the angular frequency and the wavenumber ($k$) is the number of waves in one unit length. $k = 1/\lambda$. 
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Basis Concepts

• Although the propagation velocity ($c$) and the $\lambda$ of a radiant beam (EM wave) depend on the medium, the frequency ($\nu$) depends only on the radiant source.

• So to rephrase this, the frequency of an EM wave depends only on the source and is independent of the medium.

$$\nu = \frac{c}{\lambda}$$

• The frequency of an electromagnetic wave can range from a few cycles per second to millions of cycles per second.

• Common wavelength units are:
  1) microns ($\mu$m = $10^{-6}$ m),
  2) nanometers (nm = $10^{-9}$ m),
  3) angstroms ($\AA$ = $10^{-10}$ m).

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Basic Physics' of Radiation

• *Einstein* postulated that electromagnetic radiation is the propagation of a collection of discrete packets of energy called *quanta or photons* that travel at the speed of light $c$.

• In the latter case, energy is being transported by photons moving at the speed of light, which differs from molecular transport in which all molecules move at different speeds.

• In this view, each photon of frequency $\nu$ is considered to have an energy of,

$$e = h\nu = \frac{hc}{\lambda}$$

where Planck’s constant ($h$) = $6.625 \times 10^{-34}$ J sec

• Photon energy ($e$) is related to photon momentum ($p$) by:

$$e = pc$$
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basic physics' of radiation

- Further, each photon has linear momentum (mom):

\[ \text{Mom} = \frac{h \nu}{c} \]
\[ \text{Mom} = \frac{h}{\lambda} \]
\[ \text{Mom} = hk \]

- In Einstein’s theory, \( h \) and \( c \) are constants, thus the energy of a photon is inversely proportional to its wavelength.

\[ e = h \nu = \frac{hc}{\lambda} \]

- Therefore, shorter wavelength radiation possesses greater photon energies and therefore, gamma rays and X-rays are highly destructive.

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basic physics' of radiation

thermal radiation

production mechanisms

- Electronic Transitions
- Vibration-Rotation Transitions
- Rotational Transitions
- Lattice Vibrations
- Bound Electron Transitions
- Molecular Vibrations

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figure 1: spectrum of electromagnetic radiation (wavelength and wavelength) in various types of radiation, production mechanisms.
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Basic Physics’ of Radiation

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Basic Physics’ of Radiation

Thermal radiation is defined as radiant energy emitted by a body or medium that is solely due to its temperature.

Solar radiation reaching the earth resides between $\lambda = 0.1 \, \text{um to} \, 100 \, \text{um}$. 
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Basic Physics’ of Radiation

- Ultraviolet Radiation (UV) - the UV region, forms the lower λ boundary of the thermal radiation spectrum.

  - Radiation within this region is mainly produced by changes in the atomic energy levels which occurs when outer electrons of an atom are displaced. (λ → 0.1 μm to 0.4 μm)

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Basic Physics’ of Radiation

- Visible Radiation (VISIBLE) - emanates from the sun along with other EM radiation and is primarily due to electronic transitions in gases.
  - It can be artificially produced in lasers, Light Emitting Diode (LED’s), incandescent lamps, & fluorescent tubes.
  - The summation of all visible wavelengths is referred to as white light. (λ → 0.4 μm to 0.76 μm)
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Basic Physics of Radiation

- **Infrared Radiation (IR)** - thermal radiation in the IR range is primarily associated with molecular or lattice vibrations.
  - All bodies at a temperature above absolute zero emit IR radiation.
  - In general, hot solid bodies emit more IR energy than visible and UV radiation. (λ → 0.76 to 1000 μm).

![Diagram of the electromagnetic spectrum showing the location of infrared radiation between 0.76 and 1000 μm.](image)