

# MODULE I

## BASICS OF HEAT TRANSFER

### 1.1 Difference between heat and temperature

In describing heat transfer problems, we often make the mistake of interchangeably using the terms heat and temperature. Actually, there is a distinct difference between the two. *Temperature* is a measure of the amount of energy possessed by the molecules of a substance. It is a relative measure of how hot or cold a substance is and can be used to predict the direction of heat transfer. The usual symbol for temperature is  $T$ . The scales for measuring temperature in SI units are the Celsius and Kelvin temperature scales. On the other hand, *heat* is energy in transit. The transfer of energy as heat occurs at the molecular level as a result of a temperature difference. The usual symbol for heat is  $Q$ . Common units for measuring heat are the Joule and calorie in the SI system.

What is Heat Transfer?

*“Energy in transit due to temperature difference.”*

### 1.2 Difference between thermodynamics and heat transfer

*Thermodynamics* tells us:

- how much heat is transferred ( $\delta Q$ )
- how much work is done ( $\delta W$ )
- final state of the system

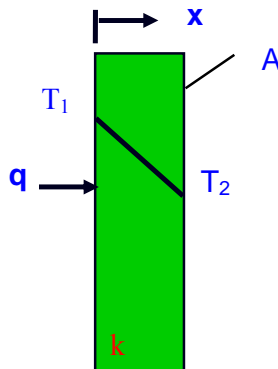
*Heat transfer* tells us:

- how (with what **modes**)  $\delta Q$  is transferred
- at what **rate**  $\delta Q$  is transferred
- temperature distribution inside the body



### 1.3 Modes of Heat Transfer

- **Conduction:** An energy transfer across a system boundary due to a temperature difference by the mechanism of inter-molecular interactions. Conduction needs matter and does not require any bulk motion of matter.



Conduction rate equation is described by the Fourier Law:

$$\vec{q} = -kA\nabla T$$

where:  $q$  = heat flow vector, (W)  
 $k$  = thermal conductivity, a thermodynamic property of the material.  
 (W/m K)  
 $A$  = Cross sectional area in direction of heat flow. ( $m^2$ )  
 $\nabla T$  = Gradient of temperature (K/m)  
 $= \partial T/\partial x \mathbf{i} + \partial T/\partial y \mathbf{j} + \partial T/\partial z \mathbf{k}$

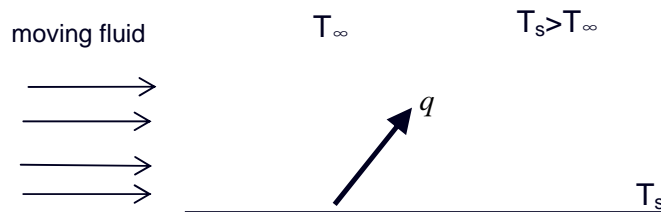
Note: Since this is a vector equation, it is often convenient to work with one component of the vector. For example, in the x direction:

$$q_x = -k A_x dT/dx$$

In circular coordinates it may convenient to work in the radial direction:

$$q_r = -k A_r dT/dr$$

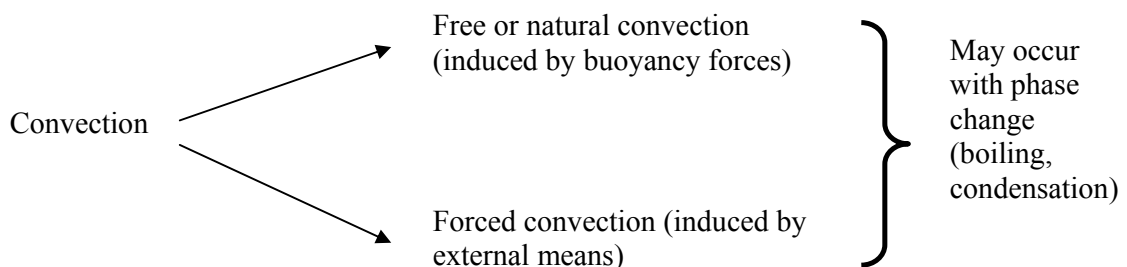
- **Convection:** An energy transfer across a system boundary due to a temperature difference by the combined mechanisms of intermolecular interactions and bulk transport. Convection needs fluid matter.



Newton's Law of Cooling:

$$q = h A_s \Delta T$$

where:  $q$  = heat flow from surface, a scalar, (W)  
 $h$  = heat transfer coefficient (which is not a thermodynamic property of the material, but may depend on geometry of surface, flow characteristics, thermodynamic properties of the fluid, etc. (W/m<sup>2</sup> K)  
 $A_s$  = Surface area from which convection is occurring. ( $m^2$ )  
 $\Delta T = T_s - T_\infty$  = Temperature Difference between surface and coolant. (K)



**Table 1.** Typical values of h (W/m<sup>2</sup>K)

Free convection	gases: 2 - 25 liquid: 50 – 100
Forced convection	gases: 25 - 250 liquid: 50 - 20,000
Boiling/Condensation	2500 -100,000

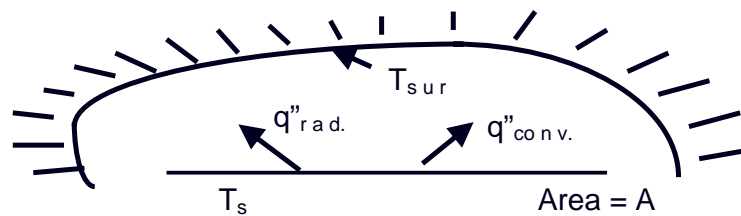
- **Radiation:** Radiation heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of the body. Radiation does not need matter.

Emissive power of a surface:

$$E = \sigma \epsilon T_s^4 \text{ (W/ m}^2\text{)}$$

where:  $\epsilon$  = emissivity, which is a surface property ( $\epsilon = 1$  is black body)  
 $\sigma$  = Steffan Boltzman constant =  $5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$ .  
 $T_s$  = Absolute temperature of the surface (K)

The above equation is derived from Stefan Boltzman law, which describes a gross heat emission rather than heat transfer. The expression for the actual radiation heat transfer rate between surfaces having arbitrary orientations can be quite complex, and will be dealt with in Module 9. However, the rate of radiation heat exchange between a small surface and a large surrounding is given by the following expression:



$$q = \epsilon \cdot \sigma \cdot A \cdot (T_s^4 - T_{sur}^4)$$

where:  $\epsilon$  = Surface Emissivity  
 $A$  = Surface Area  
 $T_s$  = Absolute temperature of surface. (K)  
 $T_{sur}$  = Absolute temperature of surroundings.(K)

## 1.4 Thermal Conductivity, $k$

As noted previously, thermal conductivity is a thermodynamic property of a material. From the State Postulate given in thermodynamics, it may be recalled that thermodynamic properties of pure substances are functions of two independent thermodynamic intensive properties, say temperature and pressure. Thermal conductivity of real gases is largely independent of pressure and may be considered a function of temperature alone. For solids and liquids, properties are largely independent of pressure and depend on temperature alone.

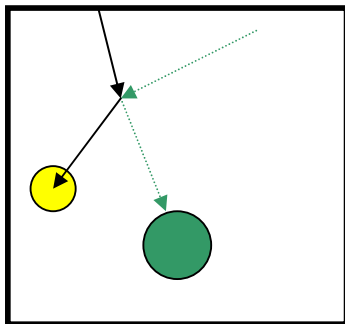
$$k = k(T)$$

Table 2 gives the values of thermal conductivity for a variety of materials.

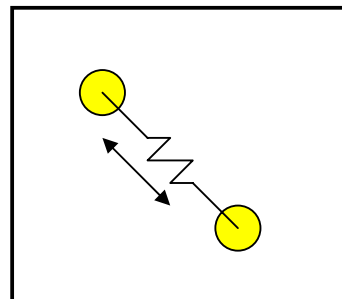
**Table 2.** Thermal Conductivities of Selected Materials at Room Temperature.

Material	Thermal Conductivity, W/m K
Copper	401
Silver	429
Gold	317
Aluminum	237
Steel	60.5
Limestone	2.15
Bakelite	1.4
Water	0.613
Air	0.0263

It is important that the student gain a basic perspective of the magnitude of thermal conductivity for various materials. The background for this comes from the introductory Chemistry courses. Molecules of various materials gain energy through various mechanisms. Gases exhibit energy through the kinetic energy of the molecule. Energy is gained or lost through collisions of gaseous molecules as they travel through the medium.



*Kinetic energy transfer  
between gaseous molecules.*



Lattice vibration may be transferred  
between molecules as nuclei  
attract/repel each other.

Solids, being much more stationary, cannot effectively transfer energy through these same mechanisms. Instead, solids may exhibit energy through vibration or rotation of the nucleus.

Another important mechanism in which materials maintain energy is by shifting electrons into higher orbital rings. In the case of electrical conductors the electrons are weakly bonded to the molecule and can drift from one molecule to another transporting their energy with them. This is an especially effective transport mechanism, so that materials which are excellent electrical conductors are excellent thermal conductors.