Subject: (ME-303) HEAT TRANSFER
Name of Teacher: S.S.SEHGAL Branch: ME Semester: 5th

Module -1

Concept of heat transfer, Difference between the subject of "Heat Transfer" and its parent subject "Thermodynamics". Different modes of heat transfer -conditions, convection, radiation

Module 1: INTRODUCTION

- Overview: Although much of the material of this module will be discussed in greater detail, the objective of this module is to give you a reasonable overview of heat transfer.

- Heat transfer modes: You should be aware of the several modes of transfer modes of transfer and their physical origins.

- Physical insight: Given a physical situation, you should be able to perceive the relevant transport phenomena. The importance of developing this insight must not be underestimated. You will be investing a lot of time to acquire the tools needed to calculate heat transfer phenomena. However, before you can begin to use these tools to solve practical problems, you must have the intuition to determine what is happening physically. In short, you must be able to look at a problem and identify the pertinent transport phenomenon. The example and problems at the end of this module should help you to begin developing this intuition.

- Rate equations and conservation laws: You should also appreciate the significance of the rate equations and feel comfortable in using them to compute transport rates. You must also recognize the importance of the conservation laws and the need to carefully identify control volumes. With the rate equations, the conservation laws may be used to solve numerous heat transfer problems.

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:

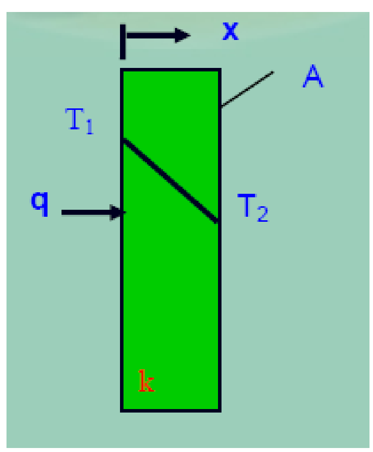
- how much heat is transferred (δQ)
- how much work is done (δW)
- final state of the system

Heat transfer tells us:

- how (with what **modes**) δQ is transferred
- at what **rate** δQ 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)
∇T = Gradient of temperature (K/m)
$= \partial T/\partial x\ \mathbf{i} + \partial T/\partial y\ \mathbf{j} + \partial T/\partial z\ \mathbf{k}$

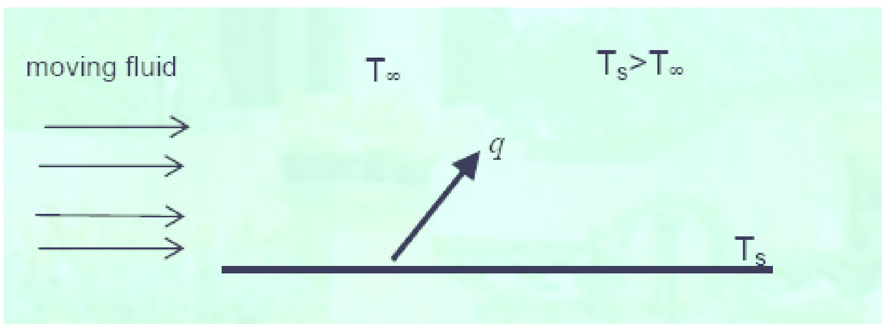
Note: Since this is a vector equation, it is often convenient to work with one component of the vector. For example, in the x direction:

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

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^2 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)

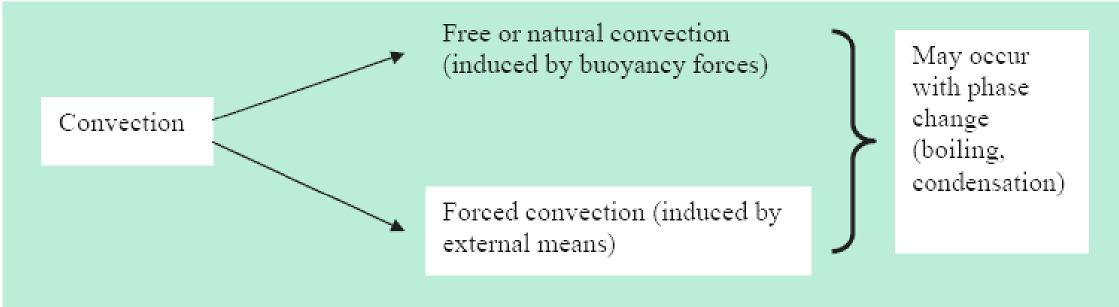


Table 1. Typical values of h (W/m^2K)

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

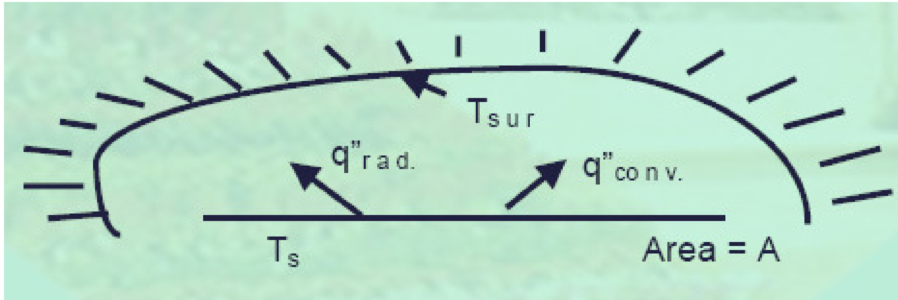
- **Radiation:** Radiation heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of the body. Radiation does not need matter.

Emissive power of a surface:

$$E = \sigma \varepsilon T_s^4 \ (W/m^2)$$

where: ε = emissivity, which is a surface property (ε = 1 is black body
σ = Steffan Boltzman constant = 5.67×10^{-8} $W/m^2 K^4$.
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:



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

Where: ε = 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.

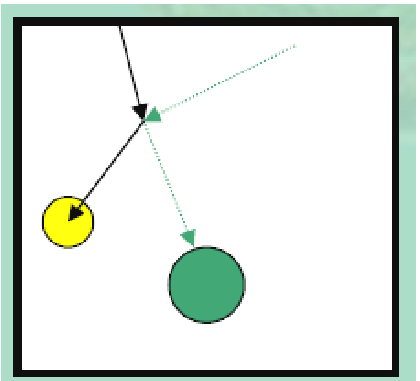
$$k = k\ (T)$$

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

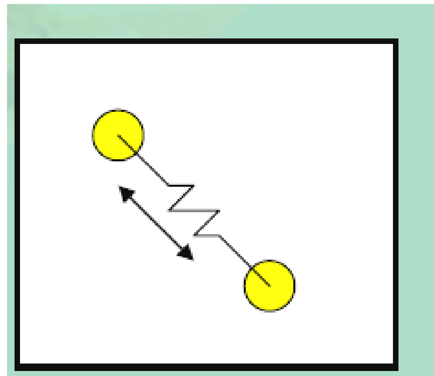
Table 2. Thermal Conductivities of Selected Materials at Room Temperature.

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 collusions 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 are 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.

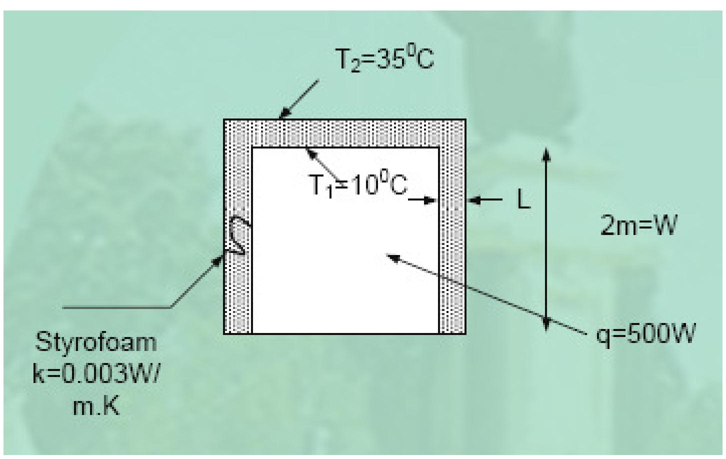
Problem 1:

A freezer compartment consists of a cubical cavity that is 2 m on a side. Assume the bottom to be perfectly insulated. What is the minimum thickness of Styrofoam insulation (k=0.030W/m.K) which must be applied to the top and side walls to ensure a heat load less than 500 W, when the inner and outer surfaces are -10 ºC and 35ºC ?

Solution:

Known: Dimensions of freezer component, inner and outer surfaces temperatures.

Find: Thickness of Styrofoam insulation needed to maintain heat load below prescribed value.



Assumptions: (1) perfectly insulted bottom, (2) one-dimensional conduction through five walls of areas $A=4m^2$, (3) steady-state conditions

Analysis: Using Fourier's law, the heat rate is given by

$$q = q''.A = k\frac{\Delta T}{L}A_{total}$$

Solving for L and recognizing that $A_{total}=5*W^2$

$$L = \frac{5k\Delta TW^2}{q}$$

$$L = \frac{5*0.03W/m.k*45^0C*4m^2}{500W}$$

$$L = 0.054m = 54mm$$