Debre Markos University
Mechanical Engineering Department

HEAT TRANSFER

(MEng 3121)

Chapter 1

INTROUCTION
TO
HEAT TRANSFER

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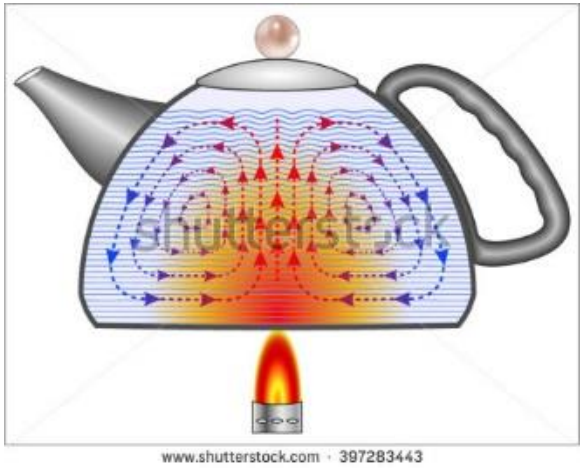
1.1 Definition of Heat and Mass Transfer

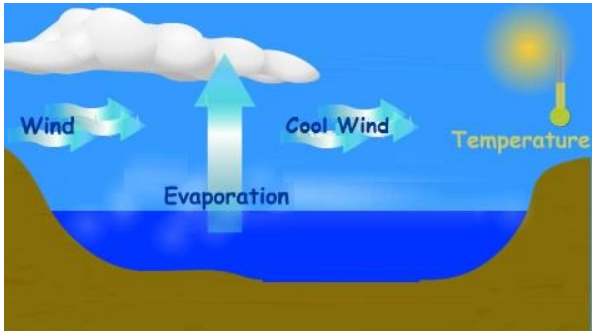
a. Heat Transfer



Flow of energy due solely to a temperature difference

- from 2nd Law of Thermodynamics, heat flows in direction of decreasing temperature
- heat energy can be transported through a solid, liquid, gas, or vacuum.

b. Mass Transfer



- Mass transfer is the net movement of mass from one location, usually meaning stream, phase, fraction or component, to another. Or
- From the region of high concentration to the lower concentration.

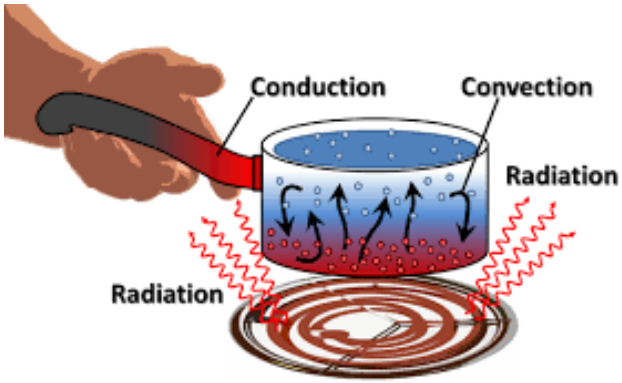
Examples: Evaporation of water from a pond to the atmosphere.

1.2 MODES OF HEAT TRANSFER

Heat can be transferred in three different modes:

Conduction, Convection, & Radiation.

A. Conduction: The transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles.



- In solids, it is due to the combination of *vibrations* of the molecules in a lattice and the energy transport by *free electrons* (*i.e. solids in metallic form)*.
- In gases and liquids, conduction is due to the *collisions* and *diffusion* of the molecules during their random motion.

The rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

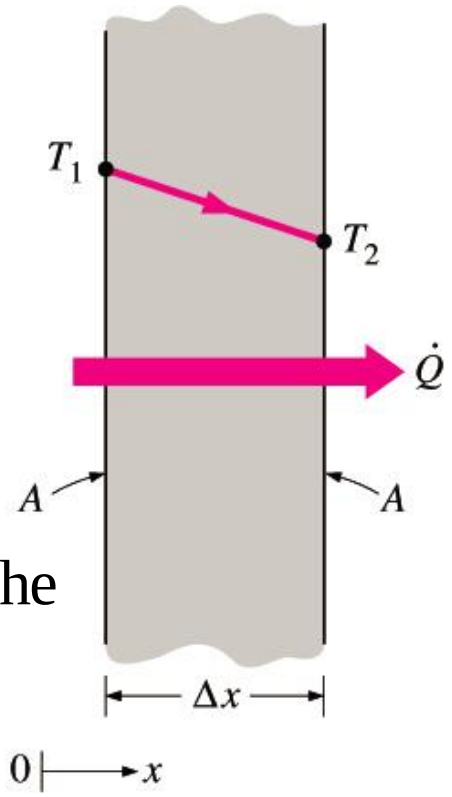
$$\text{Rate of heat conduction} \propto \frac{(\text{Area})(\text{Temperature difference})}{\text{Thickness}}$$

$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \qquad \text{(W)}$$

Where:-

***K* = Thermal conductivity,** : A measure of the ability of a material to conduct heat.

***dT/dx* = Temperature gradient** : The slope of the temperature curve on a *T*-*x* diagram.



Material	Thermal conductivity k ($W.m^{-1}.K^{-1}$)
Diamond	2450
Cu	385
Al	205
Brick	0.2
Glass	0.8
Body fat	0.2
Water	0.6
Wood	0.2
Styrofoam	0.01
Air	0.024

Thermal conductivity, k
property of the material

$k_{diamond}$ very high: perfect heat sink, e.g. for high power laser diodes

k_{human} low: core temp relatively constant (37°C)

k_{air} very low: good insulator

* home insulation
* woolen clothing
* windows double glazing

i.e, Metals – good conductors: electrons transfer energy from hot to cold

B. Convection: The mode of energy transfer between a solid surface and the adjacent liquid or gas that is in **motion,** and it involves the combined effects of *conduction* and *fluid motion*.

Example:. Cold air flows above the hot copper plate.

In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

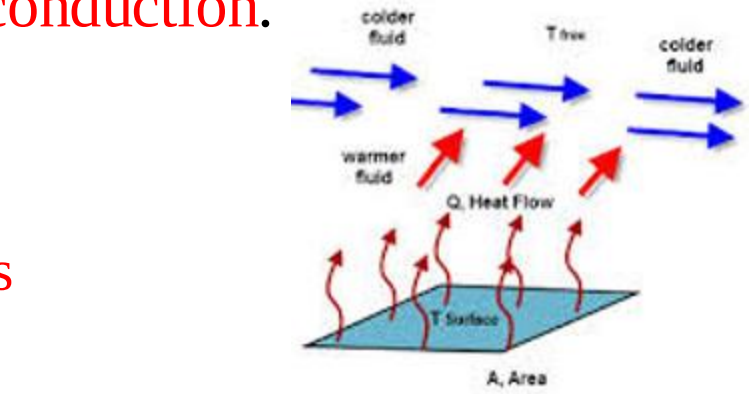
Types of convection

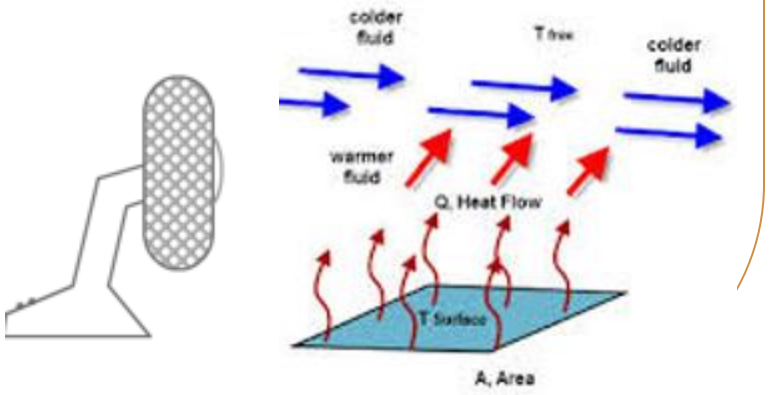
Natural Convection:

Fluid motion occurs due to density variations caused by temperature difference

Forced convection:

Fluid motion caused by an external agency





Newton's law of cooling

$$\dot{Q}_{\text{conv}} = hA_s\,(T_s - T_\infty) \qquad \text{(W)}$$

h	convection heat transfer coefficient, W/m^2 · °C
A_s	the surface area through which convection heat transfer takes place
T_s	the surface temperature
T_∞	the temperature of the fluid sufficiently far from the surface

C. Radiation: The energy emitted by matter in the form of *electromagnetic waves* (or *photons*) as a result of the changes in the electronic configurations of the atoms or molecules.

- Unlike conduction and convection, the transfer of heat by radiation does not require the presence of an *intervening medium.*

- In fact, heat transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum.
- This is how the energy of the sun reaches the earth.

- In heat transfer studies we are interested in *thermal radiation*, which is the form of radiation emitted by bodies because of their temperature.
- All bodies at a temperature above absolute zero emit thermal radiation.

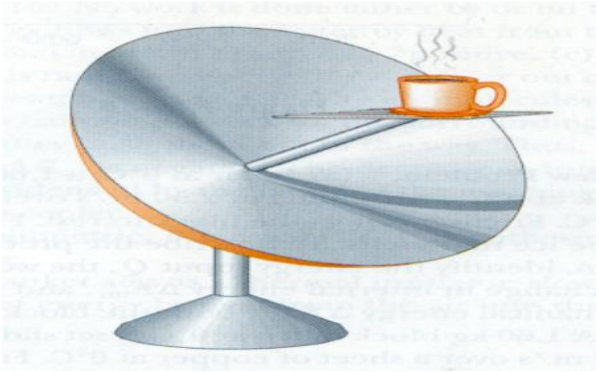
Absorption & Stefan-Boltzmann Law

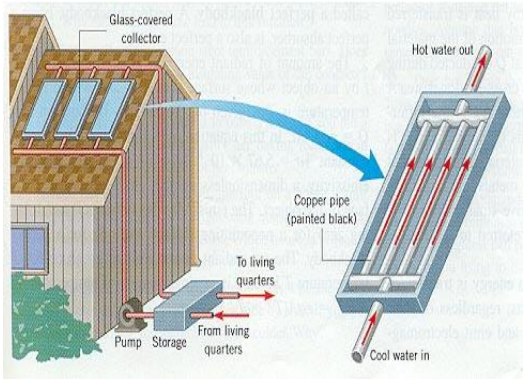
$$\dot{Q}_{\text{emit, max}} = \sigma A_s T_s^4 \qquad \text{(W)}$$ Stefan–Boltzmann law

Where:-

- Surface Area, A
- Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}\ \text{W.m}^{-2}\text{.K}^{-4}$

Applications on radiation heat transfer





Think about

- *Why are fireplace pokers made of iron and not copper?*
- *Some animals have hair which is composed of solid tubular strands, while others have hollow, air-filled tubes. Where would one more likely find the latter animal: In cold climates, or warm?*
- *Two different materials at the same temperature have different emissivities. Which one glows the brightest?*
- *Steel reinforcement bars add stability to concrete walls. Do they also enhance the insulating value of concrete?*
- *Should you lower the blinds and draw the curtains on a hot day?*
- *When one steps from a shower on a cold morning, why does the tile floor seem so much colder than the air?*
- *Place a wooden spoon and a metal spoon in the freezer. Which will cool faster? After several hours, what would they feel like?*
- *Why do people become "flushed" when overheated?*
- *What is thermal energy? What is the difference between thermal energy and heat?*