ENG 3165 LECTURE 13

THERMODYNAMICS COMPONENT

Heat Transfer

Introduction

- This lecture concludes the Thermodynamics component of the ENG 3165 Course.
- It provides an overview of the three main heat transfer methods; mainly **Conduction**, **Convection** and **Radiation**.

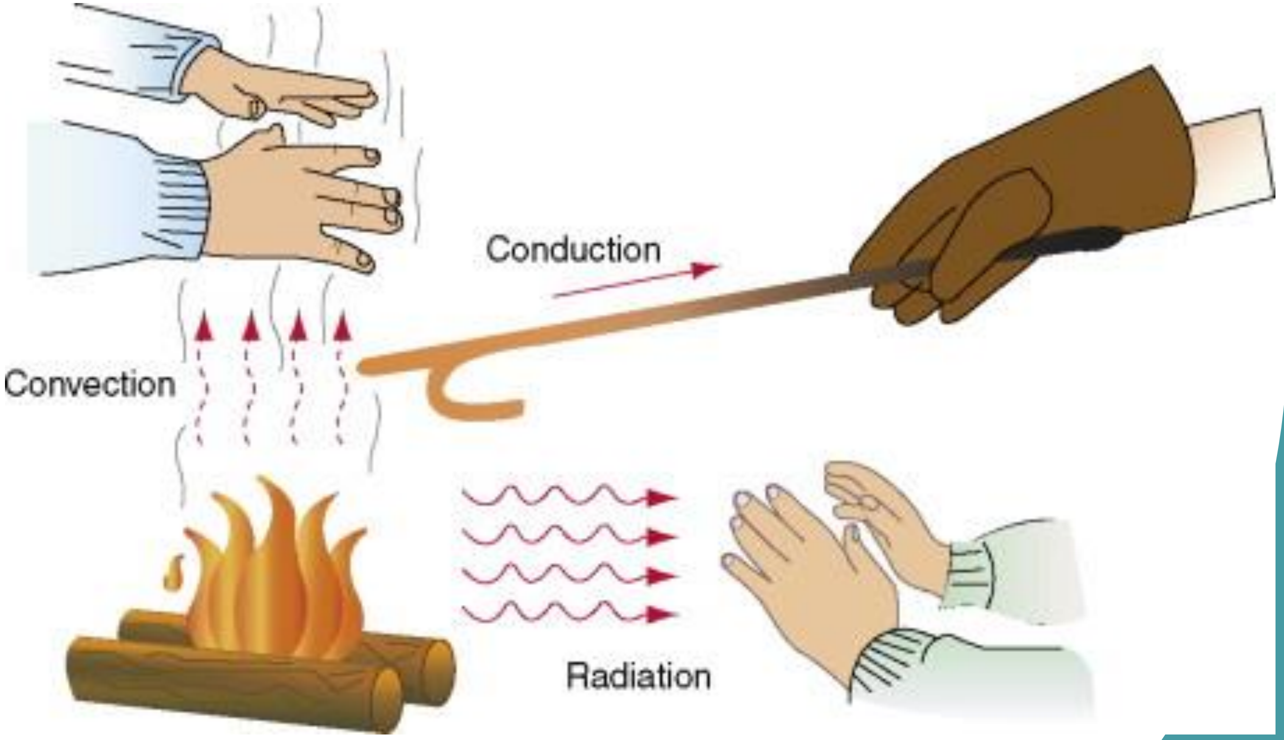
GENERAL INTRODUCTION

- So far we have discussed different thermodynamic states and observed the property changes and from this deduced the heat transfer.
- Heat flow is transient problem so its analysis will involve more than investigation of equilibrium states.
- The laws of heat transfer obey the first and second laws of thermodynamics; energy is conserved and heat must flow from hot to cold.
- The transfer of heat can take place by two phenomena known as **conduction** and **radiation**. These phenomena may take place in a given system on their own or they may occur simultaneously. As the result of conduction and for radiation occurring into a fluid media then a transport transfer of heat may occur called **convection**.

GENERAL INTRODUCTION

Heat Transfer

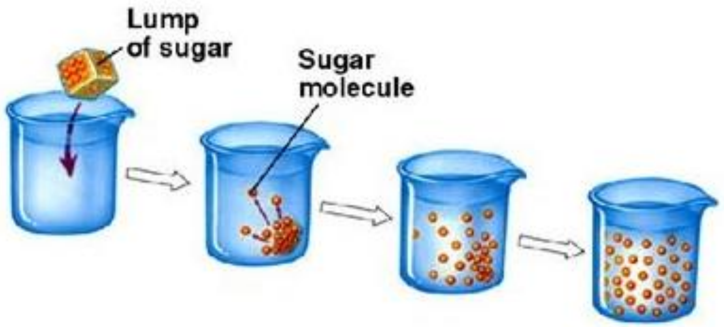
- Heat transfer is flow of energy **solely** due to a **temperature difference** or **gradient**
- From the Second Law of Thermodynamics, **heat flows in the direction of decreasing temperature** – down a temperature gradient.
- Heat energy can be transported through a **solid, liquid, gas or even a vacuum**.

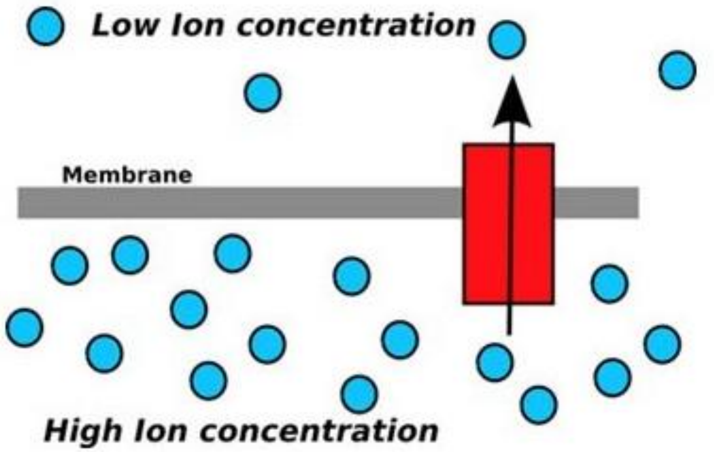


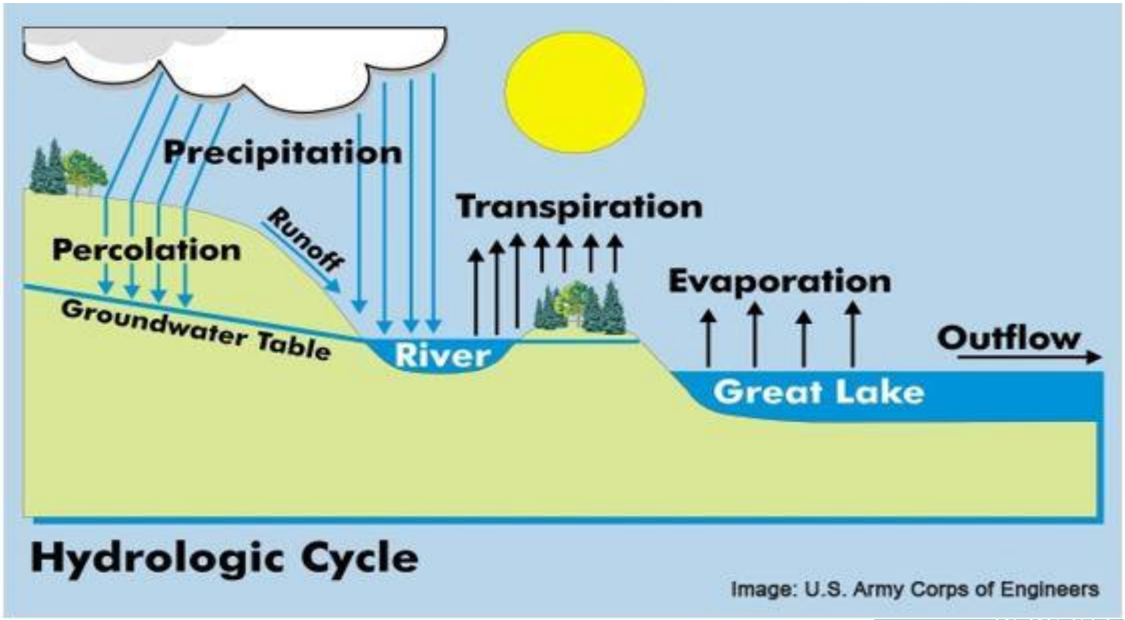
GENERAL INTRODUCTION

Mass Transfer

- Mass transfer is the **net movement of mass** from one location, usually meaning stream, phase, fraction or component , to another.
- This is most commonly from the region of high concentration to the lower concentration. An example is the evaporation of water from a pond to the atmosphere.



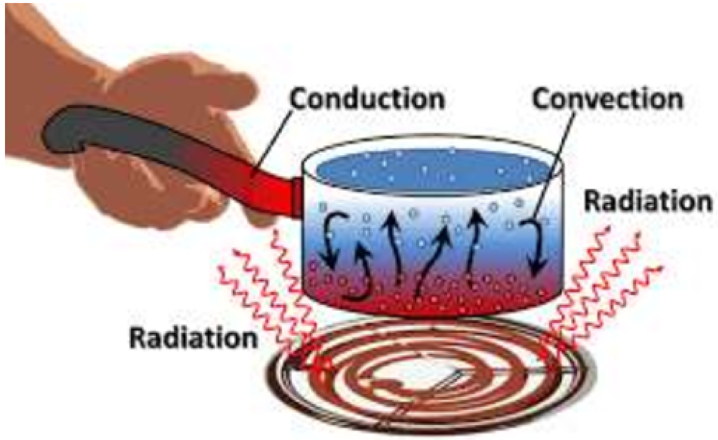




CONDUCTION

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)*.

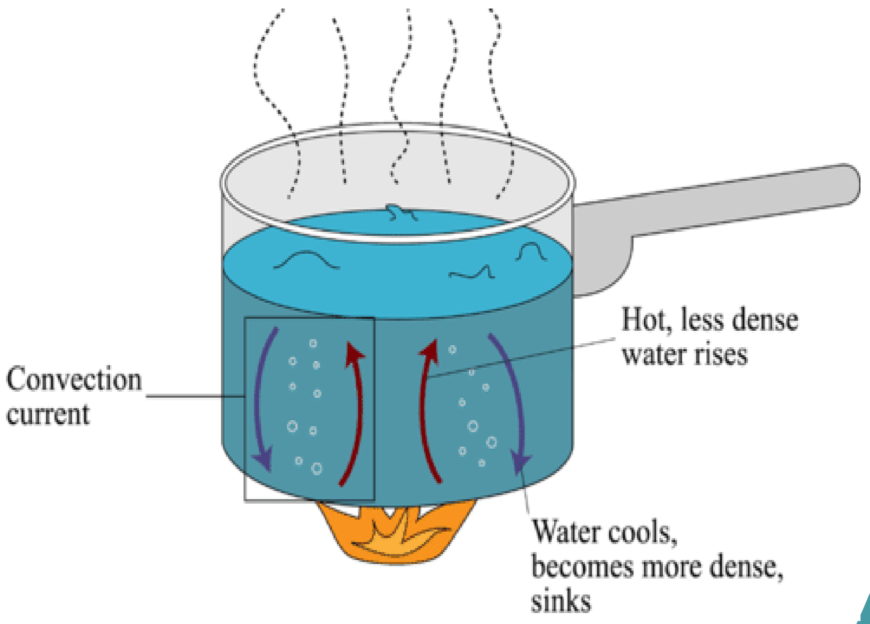


- In gases and liquids, conduction is due to the *collisions* and *diffusion* of the molecules during their random motion.

CONVECTION

B. Convection: Thermal convection is the process by which heat transfer occurs via bulk motion or currents of moving fluid .

- Heat is transferred through molecular collisions between the fluid molecules.
- As a result of these collisions, the temperature in the fluid changes, the density varies, and the bulk fluid motion occurs. The high- and low-temperature fluid elements mix, and heat is transferred through convection.



RADIATION

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.

LAWS OF HEAT TRANSFER

$$q = h\Delta T$$

where

q is the local heat flux density [$W.m^{-2}$]

h is the heat transfer coefficient [$W.m^{-2}.K$]

ΔT is the temperature difference [K]

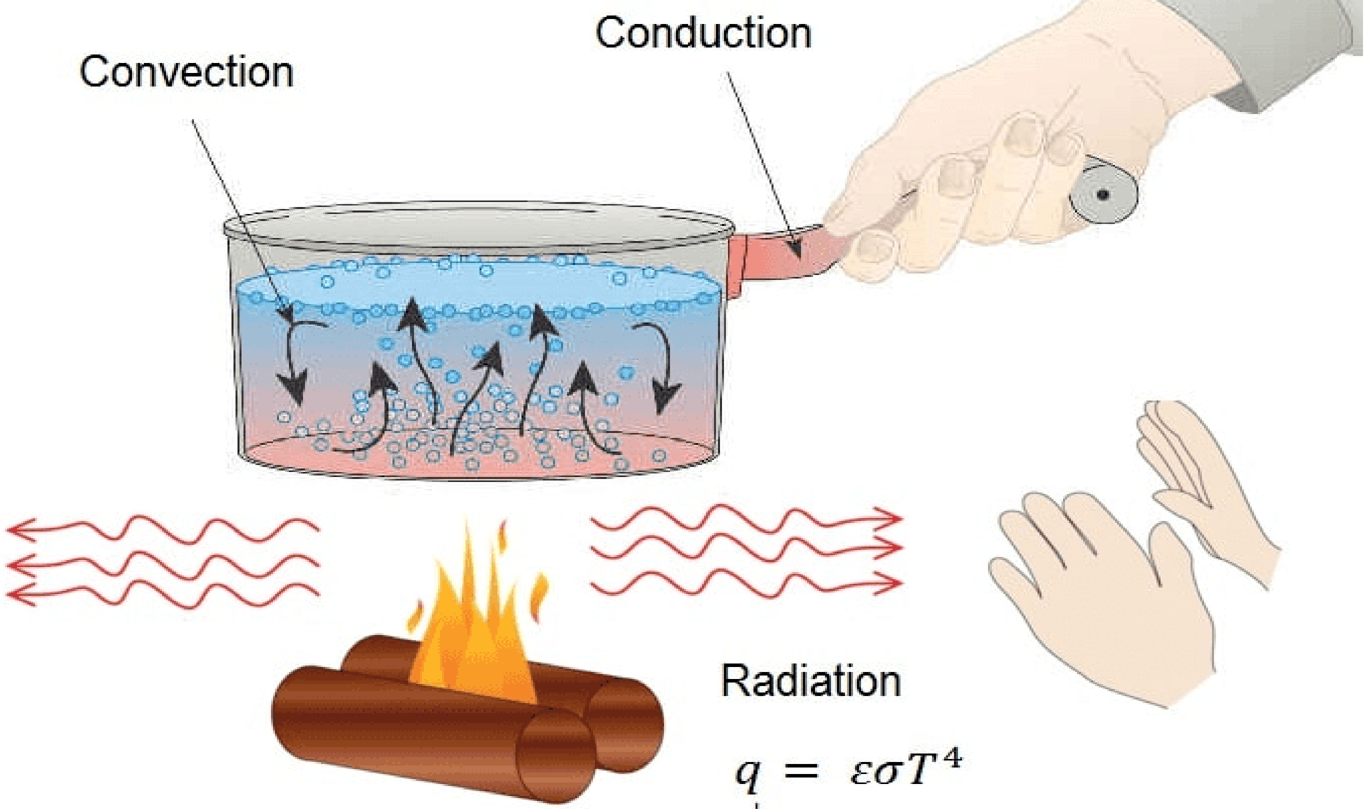
$$q = -k\nabla T$$

where

q is the local heat flux density [$W.m^{-2}$]

k is the materials conductivity [$W.m^{-1}.K^{-1}$]

∇T is the temperature gradient [$K.m^{-1}$]



$$q = \varepsilon \sigma T^4$$

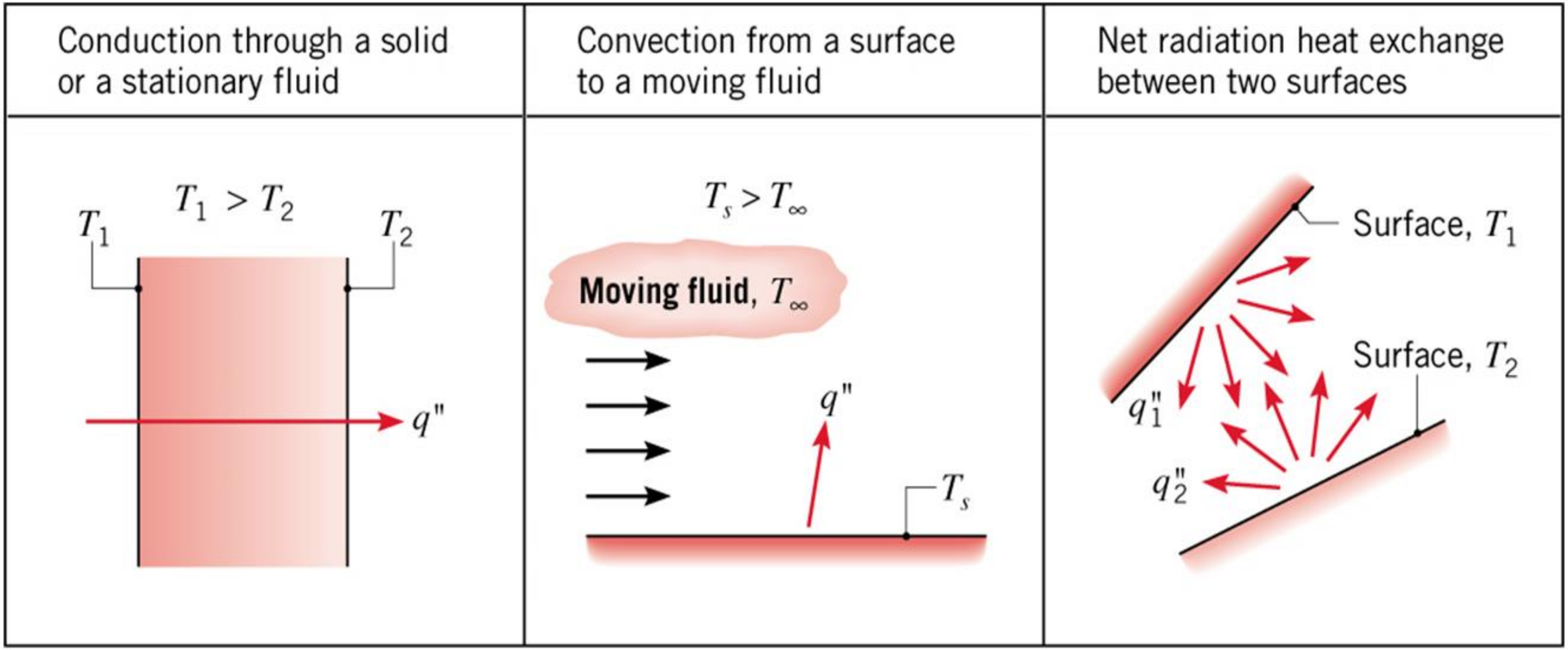
where

q is the power radiated from an object [$W.m^{-2}$]

σ is the Stefan–Boltzmann constant [$W.m^2K^4$]

ε is the emissivity of the surface of a material [-]

LAWS OF HEAT TRANSFER



LAWS OF HEAT TRANSFER

CONDUCTION: FOURIER'S LAW

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.

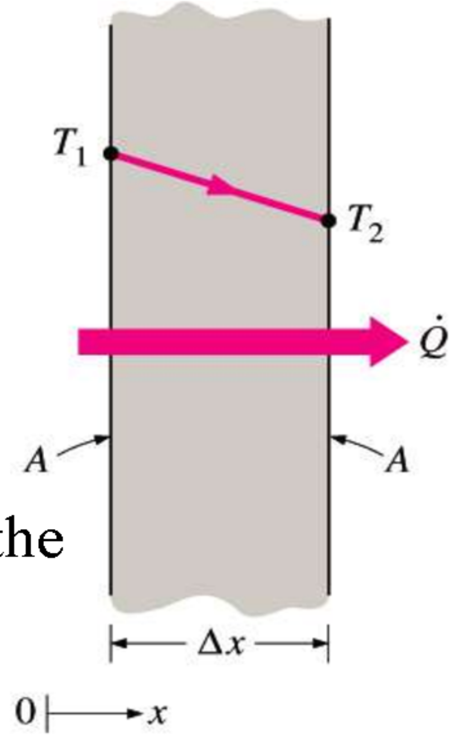
$$\text{Rate of heat conduction} \propto \frac{(\text{Area})(\text{Temperature difference})}{\text{Thickness}}$$

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

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.



LAWS OF HEAT TRANSFER

CONDUCTION: FOURIER'S LAW

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

LAWS OF HEAT TRANSFER

CONDUCTION: FOURIER'S LAW

THERMAL DIFFUSIVITY

- In heat transfer analysis, the ratio of the thermal conductivity to the heat capacity is an important property termed the *thermal diffusivity* $\boldsymbol{\alpha}$, *which is*

$$\alpha = \frac{k}{\rho c_p} \quad m^2/s.$$

This value describes how quickly a material reacts to a change in temperature.

Proof its SI units and what is the similar property in fluid flow?

- It measures the ability of a material to **conduct thermal energy** relative to its ability to **store thermal energy**.
- So what does it mean when materials have **large** and **small** value of α?
- For a large α *will respond quickly to changes in their thermal environment, and* ,For a small α will respond more sluggishly, taking longer to reach a new equilibrium condition.

  Example: WAX
- In order to predict cooling processes or to simulate temperature fields, the thermal diffusivity must be known; it is a requisite for solving the Fourier Differential Equation for unsteady heat conduction.

Example

A brick wall 250 mm thick is faced with concrete 50 mm thick. The brick has a coefficient of thermal conductivity of 0·69 W/m K while that of the concrete is 0·93 W/m K. If the temperature of the exposed brick face is 30°C and that of the concrete is 5°C, determine the heat lost/h through a wall 10 m long and 5 m high. Determine, also, the interface temperature.

$$\dot{Q} = \frac{A(t_1 - t_2)}{x_1/k_1 + x_2/k_2} = \frac{(10 \times 5) \times (30 - 5)}{0{\cdot}25/0{\cdot}69 + 0{\cdot}05/0{\cdot}93}$$

$$= \frac{50 \times 25}{0{\cdot}362 + 0{\cdot}054} = \frac{1250}{0{\cdot}416} = \underline{3005\ \text{W}} = \underline{3005\ \text{J/s}}$$

$$= \underline{3{\cdot}005\ \text{kJ/s}}$$

$$\therefore\ \text{Heat lost/h} = 3 \times 3600 = \underline{10800\ \text{kJ}}$$

Example

For the brick wall,

$$\dot{Q} = \frac{k_1 A(t_1 - t_2)}{x_1}$$

$$\therefore \quad t_2 = t_1 - \frac{\dot{Q}x_1}{k_1 A} = 30 - \frac{3000 \times 0{\cdot}25}{0{\cdot}69 \times 50}$$

$$= 30 - 21{\cdot}7 = 8{\cdot}3°\text{C} = \text{interface temperature}$$

Alternatively, for the concrete,

$$\dot{Q} = \frac{k_2 A(t_2 - t_3)}{x_2}$$

$$\therefore \quad t_2 = t_3 + \frac{\dot{Q}x_2}{k_2 A} = 5 + \frac{3000 \times 0{\cdot}05}{0{\cdot}93 \times 50}$$

$$= 5 + 3{\cdot}3 = \underline{8{\cdot}3°\text{C}}$$

LAWS OF HEAT TRANSFER

CONVECTION: NEWTON'S LAW OF COOLING

Newton's law of cooling

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

h	convection heat transfer coefficient, $W/m^2 \cdot °C$
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

LAWS OF HEAT TRANSFER

RADIATION: STEFAN-BOLTZMANN LAW

- 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.

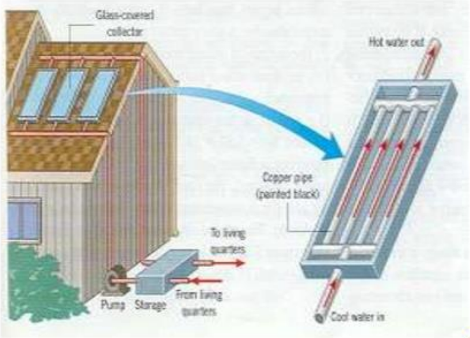
Absorption & Stefan-Boltzmann Law

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

Where:-

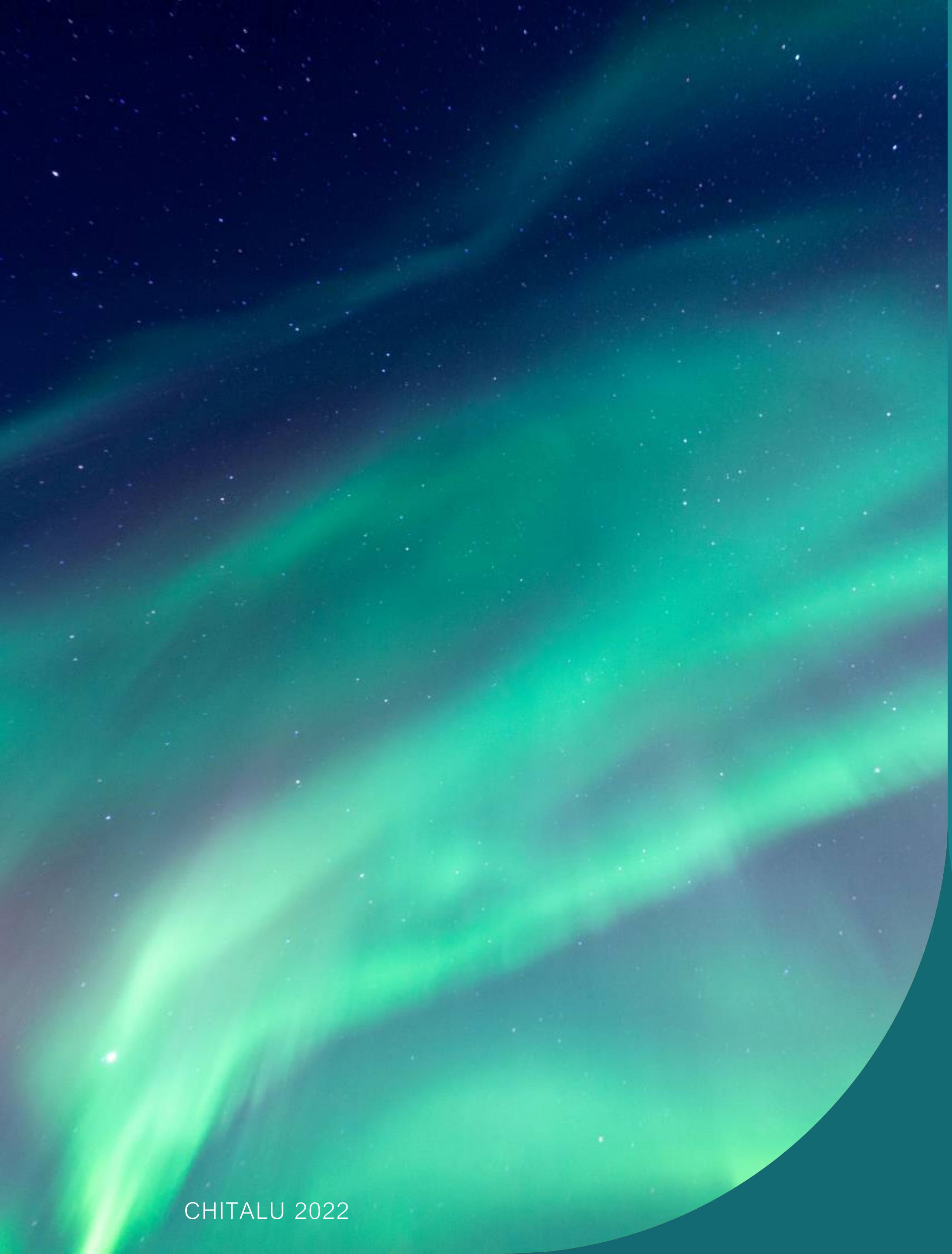
- Surface Area, A
- Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ W.m^{-2}.K^{-4}

Applications on radiation heat transfer



“Is not fire a body heated so hot as to emit light copiously? For what as is a red hot iron than fire? And what else is a burning hot coal than red hot wood?”

Isaac Newton



Thank You

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