Chapter (1)

Introduction

Heat Transfer Course

( )

Reference:

- **Heat Transfer; A Practical Approach, Yunus A. Cengel.**
- **Fundamentals of Heat and Mass Transfer, F.P. Incropera & D.P. DeWitt, John Wiley, 6th Edition**

Goals:

By the end of today's lecture, you should be able to:

- Understand and Distinguish between the different mechanisms of Heat Transfer
- Define the physical origins of the three modes.
- Define and use the Fourier's Law of Conduction
- Define and use the Newton's Law of Cooling
- Define and use the Stefan-Boltzman Law of Radiation

What is Heat Transfer?

How is Heat Transfer?

Why is it important?

Thermodynamic & Heat Transfer

- **Thermodynamics** deals with the end states of the energy transfer processes during which an interaction (work and heat) occurs and provides no information concerning
  - The nature of the interaction or simply how the energy is transferred ?
  - The time rate at which energy is transferred.

- **Heat transfer** extends the thermodynamic analysis
  - through study of the modes of heat transfer and
  - through development of relations to calculate heat transfer rates.

Temperature & Heat

Heat and Temperature are **not** the same thing

- **Temperature** is a measure of the **average** kinetic energy of the air molecules.
  - High temperature – faster molecules.
  - Low temperature – slower molecules.

- **Heat** is the **total** Kinetic Energy of the molecules.

- through study of the modes of heat transfer and
- through development of relations to calculate heat transfer rates.

What is Heat Transfer?

- ✓ It is a science that deals with methods by which thermal energy is able to move from one location to another due to temperature differences

- ✓ It is thermal energy in transit due to a temperature difference.

Units of Heat ….

- Heat is energy in transit, and is measured in energy units.

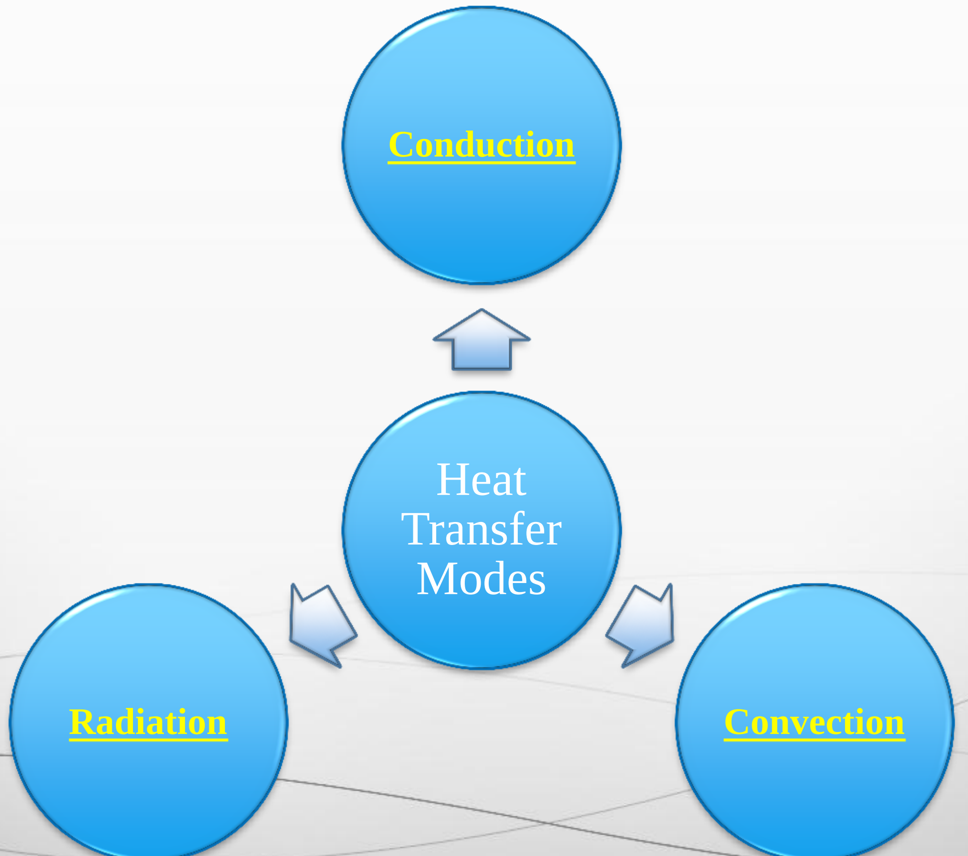
- The SI unit is the joule (J), or Newton-meter (Nm).

- Historically, heat was measured in terms of the ability to raise the temperature of water.

- In industry, the British thermal unit (Btu) is still used: amount of heat needed to raise the temperature of 1 lb of water by 1 F.

How is Heat Transfer?

There are three modes of heat transfer mechanisms



Physics origins and Rate Equations

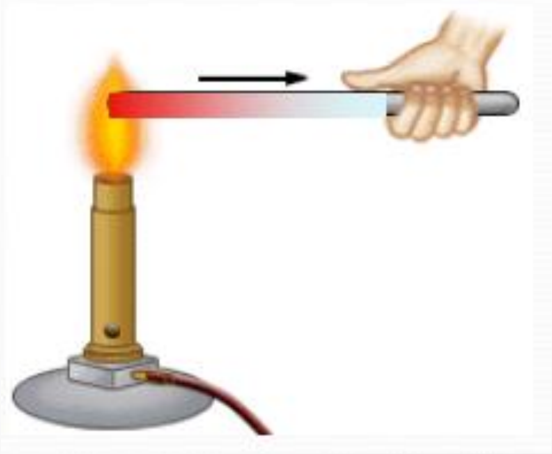
Conduction

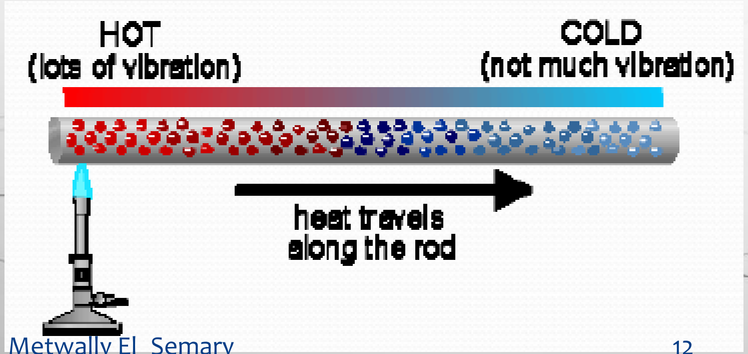
It is the transfer of energy from the more energetic to the less energetic particles of a substance due to interaction between the particles

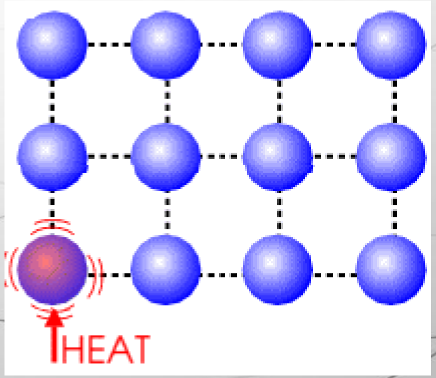
It is the transfer of thermal energy from a region of higher temperature to a region of lower temperature through direct molecular communication within a medium or between mediums in direct physical contact without a flow of the material.

Conduction

- When you heat a metal strip at one end, the heat travels to the other end.
- The molecules in direct contact with the flame will gain energy and vibrate faster
- The heated molecules will come in contact with nearby molecules, and gradually spread the heat through the material.
- The measurement of how well (or how fast) a material can transfer heat through conduction depends on how the material's molecules are structurally bounded together.

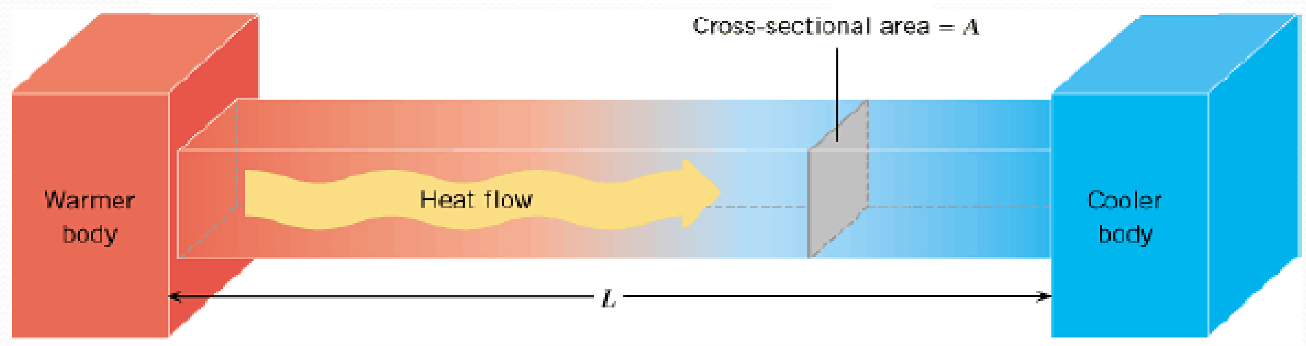


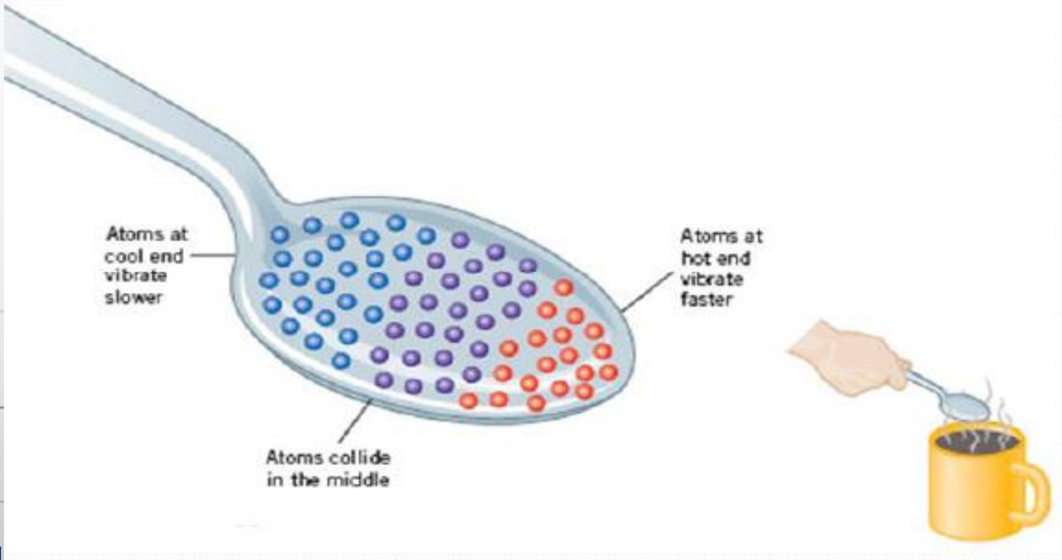




Conduction

Conduction Of Heat Through A Material

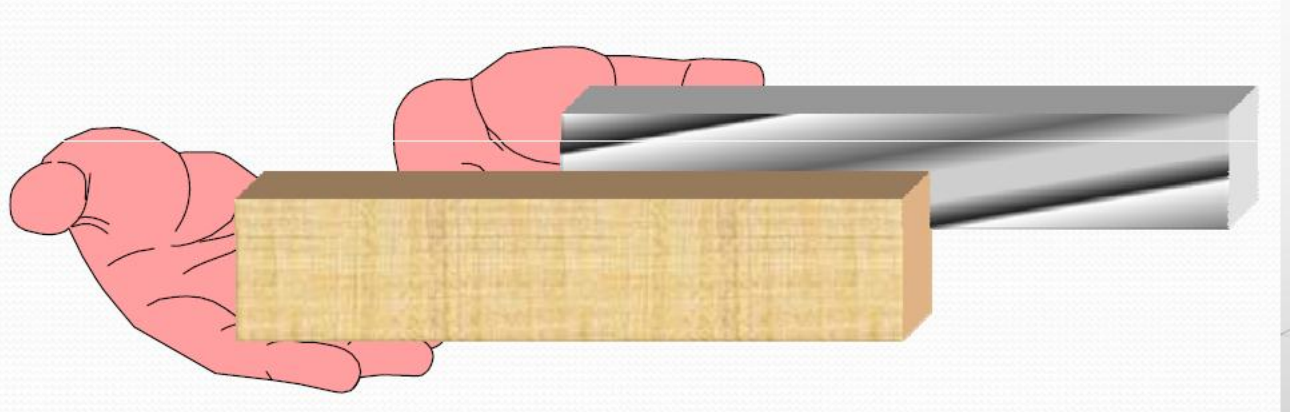




Conduction

Why does metal feel colder than wood, if they are both at the same temperature?

Metal is a conductor, wood is an insulator. The metal conducts the heat away from your hands, the wood does not conduct the heat away from your hands as well as the metal, so the wood feels warmer than the metal.

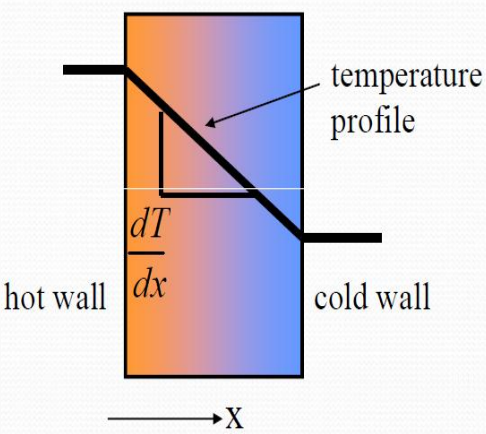


Those materials that conduct heat well are called **thermal conductors,** while those that conduct heat poorly are known as **thermal insulators.**

Conduction

Fourier's Law

$$\dot{q}_x = -kA\frac{dT}{dx}$$



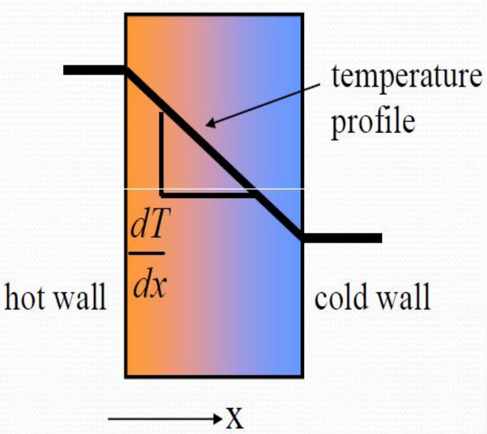
Where:

q_x	Rate of heat transfer in x direction
K	Thermal conductivity (Watts/ m K)
A	Cross sectional area
$\frac{dT}{dx}$	Temperature gradient in x direction
L	Distance between the two ends

Conduction

Under Steady State conditions where the temperature distribution is linear, the temperature gradient may be expressed as:

$$\frac{dT}{dx} = \frac{T_h - T_c}{L}$$



Then the rate of heat flow by conduction is:

$$\dot{q}_x = kA\frac{T_h - T_c}{L}$$

Conduction

Thermal conductivity, also known as the conductivity constant or conduction coefficient, k.

The main article on thermal conductivity defines k as "the quantity of heat, Q, transmitted in time t through a thickness L, in a direction normal to a surface of area A, due to a temperature difference ΔT“.

Simply it is a measure of the amount of conduction for a given gradient

Thermal conductivity is a material property that is primarily dependent on the medium's phase, temperature, density, and molecular bonding.

Conduction

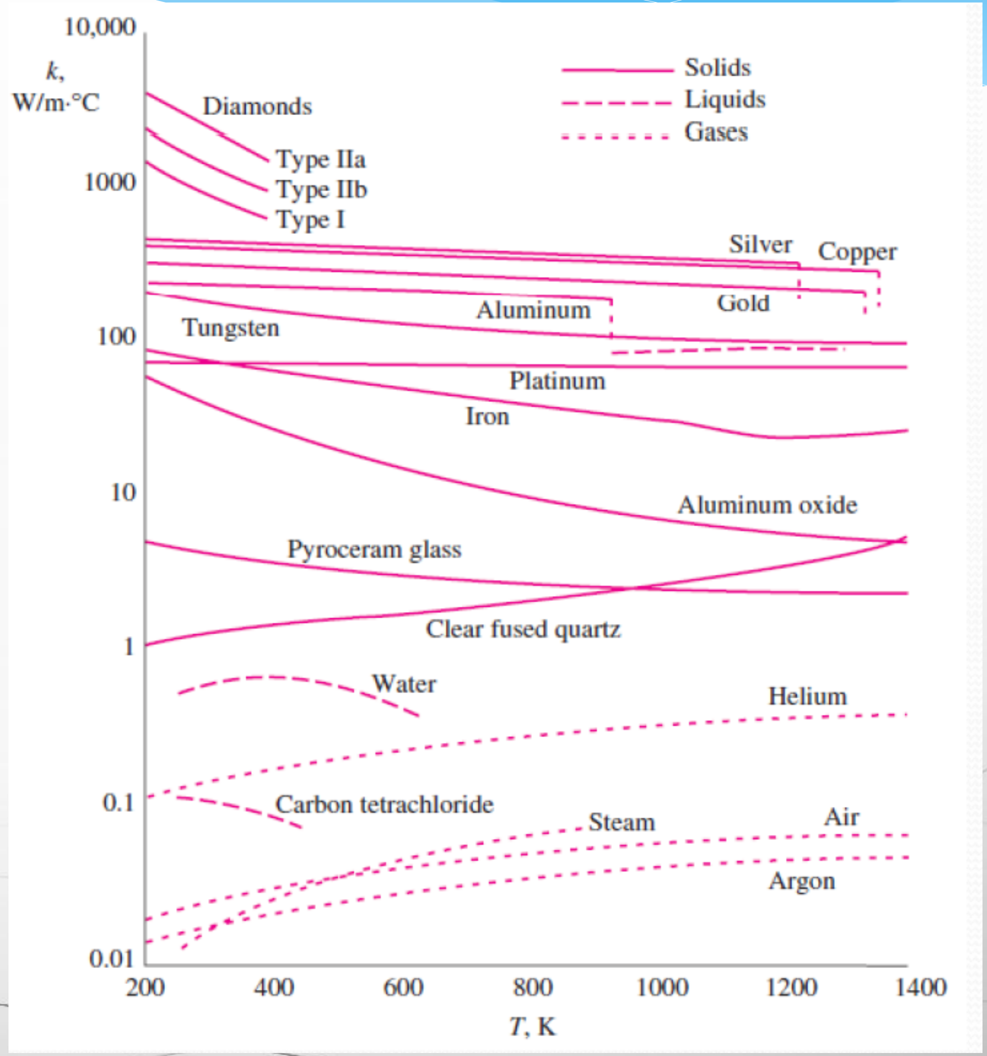
Thermal Conductivities of Selected Materials

Substance	Thermal Conductivity, k [J/(s · m · C°)]
Metals	
Aluminum	240
Brass	110
Copper	390
Iron	79
Lead	35
Silver	420
Steel (stainless)	14
Gases	
Air	0.0256
Hydrogen (H_2)	0.180
Nitrogen (N_2)	0.0258

In general, metals have very large conductivities. Thus, when they are heated metal heated, molecules will rapidly transfer heat through the metal.

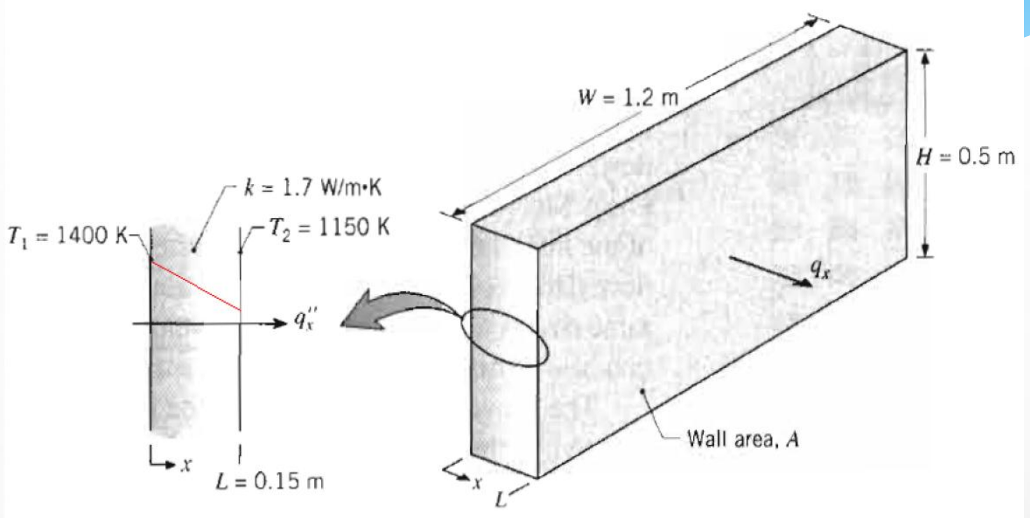
Conduction

The variation of the thermal conductivity of various solids, liquids, and gases with temperature



Conduction

Example 1.1
Req: Wall heat loss



Solution:

The heat flux by conduction:

$$q_x'' = k\frac{\Delta T}{L} = 1.7\ \text{W/m}\cdot\text{K} \times \frac{250\ \text{K}}{0.15\ \text{m}} = 2833\ \text{W/m}^2$$

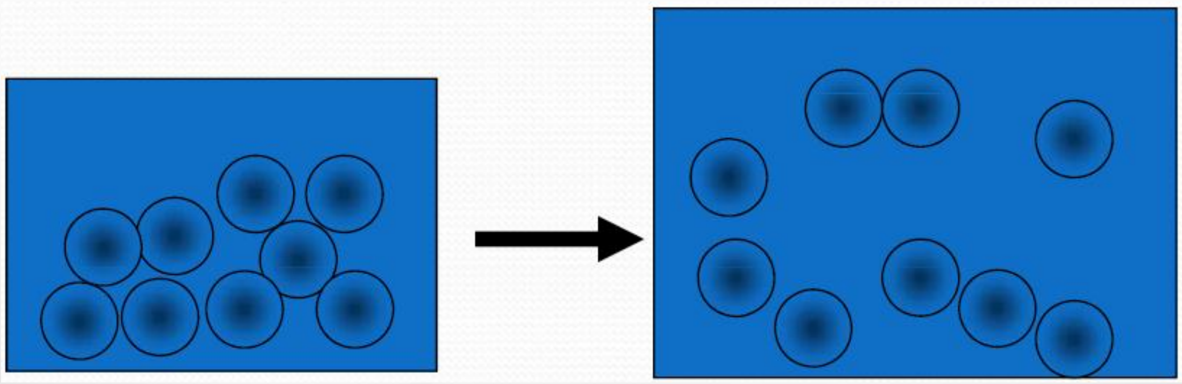
The heat flow through the uniform surface area :

$$q_x = (HW)\,q_x'' = (0.5\ \text{m} \times 1.2\ \text{m})\,2833\ \text{W/m}^2 = 1700\ \text{W}$$

Convection

What happens to the particles in a liquid or a gas when you heat them?

The particles spread out and become less dense (lighter).



Convection

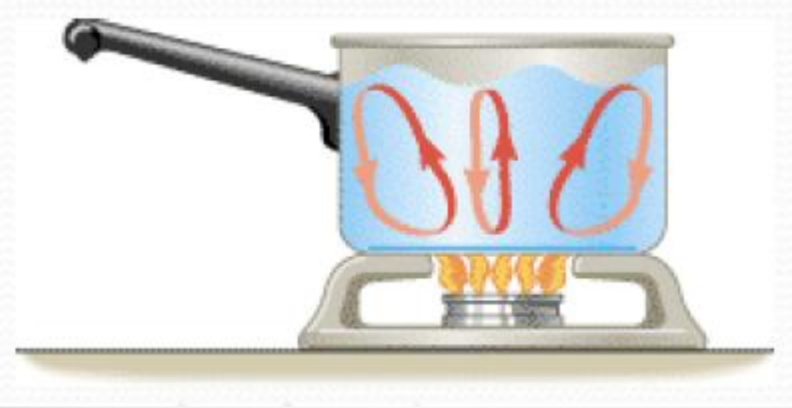
The mechanical transportation of a mass of fluid from one place to another Convection is a combination of conduction and the transfer of thermal energy by fluid circulation or movement of the hot particles in bulk to cooler areas in a material medium.

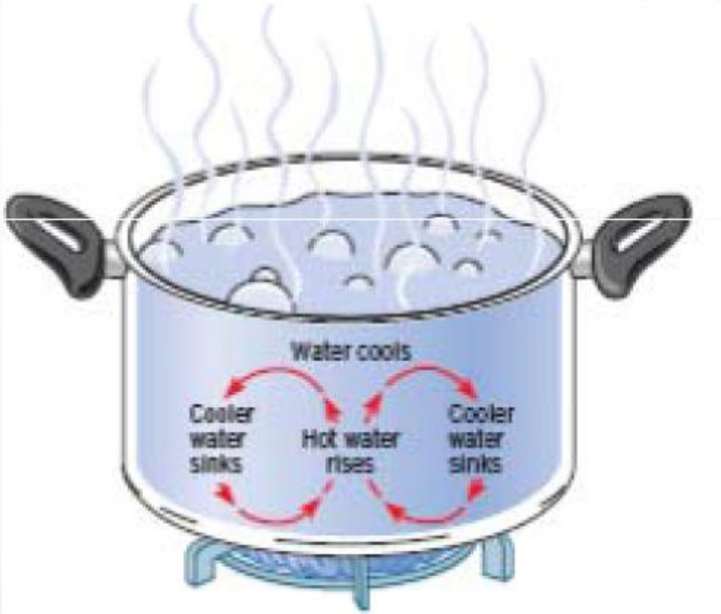
TWO TYPES OF CONVECTION

- Natural
  - Occurs when there are differences in the density of different parts of the fluid. The difference in density are usually caused by a temperature difference.
- Forced
  - Occurs when some mechanical device, such as a pump or a fan, produces movement

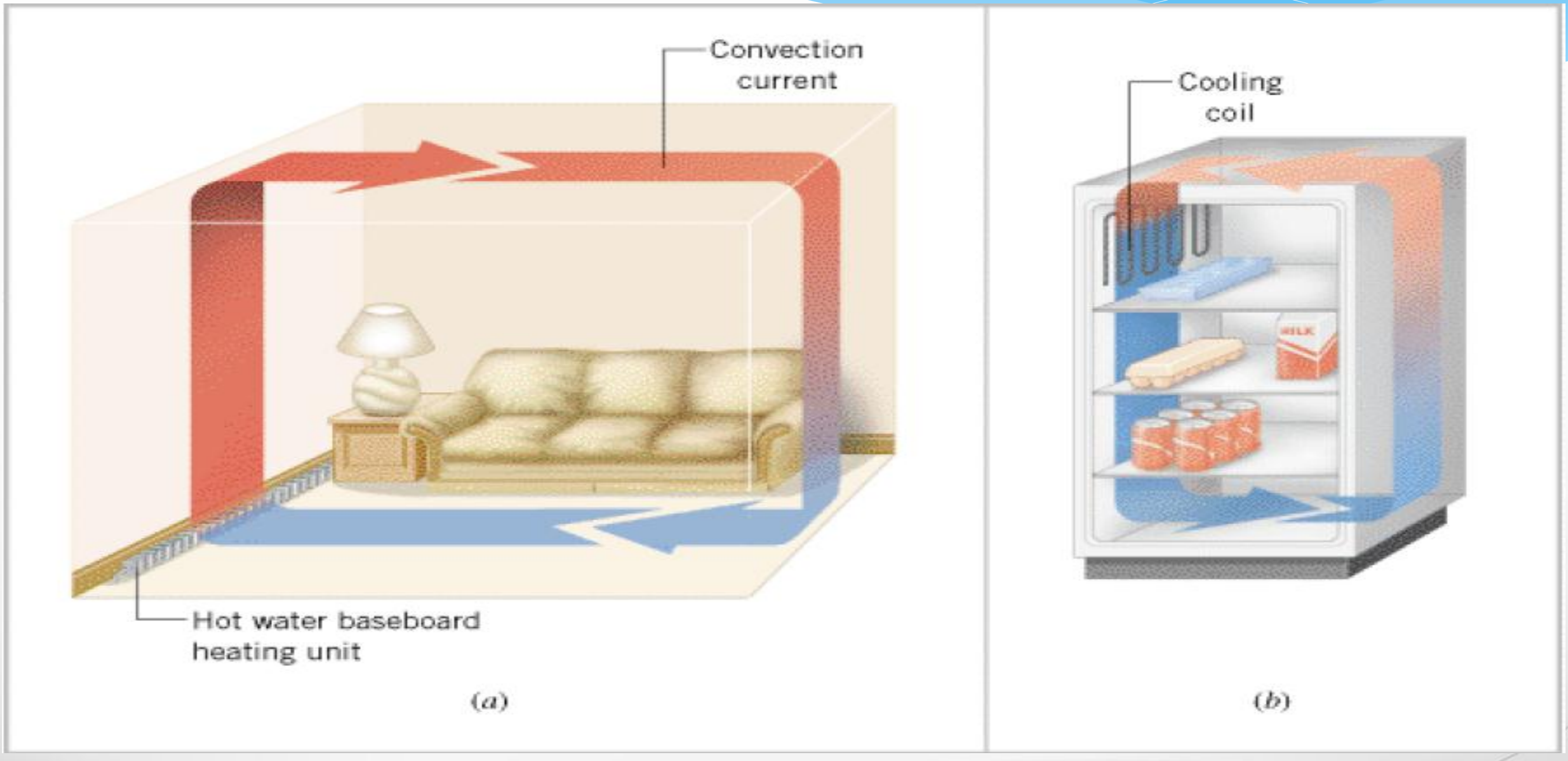
Convection

Convection currents are set up when a pan of water is heated.





Convection



When a liquid is **heated** it becomes less dense (lighter) so it **rises, cold liquid** takes its place.

The same thing happens when air is heated . The **hot air** rises and **cold air** takes its place

Convection

Basic heat transfer equation is known as:

"Newton's Law of Cooling"

Rate equation. $$\dot{q} = hA\left(T_s - T_\infty\right)$$

where h is the individual heat transfer coefficient and is obtained from purely **EMPIRICAL** methods.

Heat transfer coefficient, h. Unlike the thermal conductivity, the heat transfer coefficient is not a material property. The heat transfer coefficient depends upon the geometry, fluid, temperature, velocity, and other characteristics of the system in which convection occurs. Therefore, the heat transfer coefficient must be derived or found experimentally for every system analyzed.

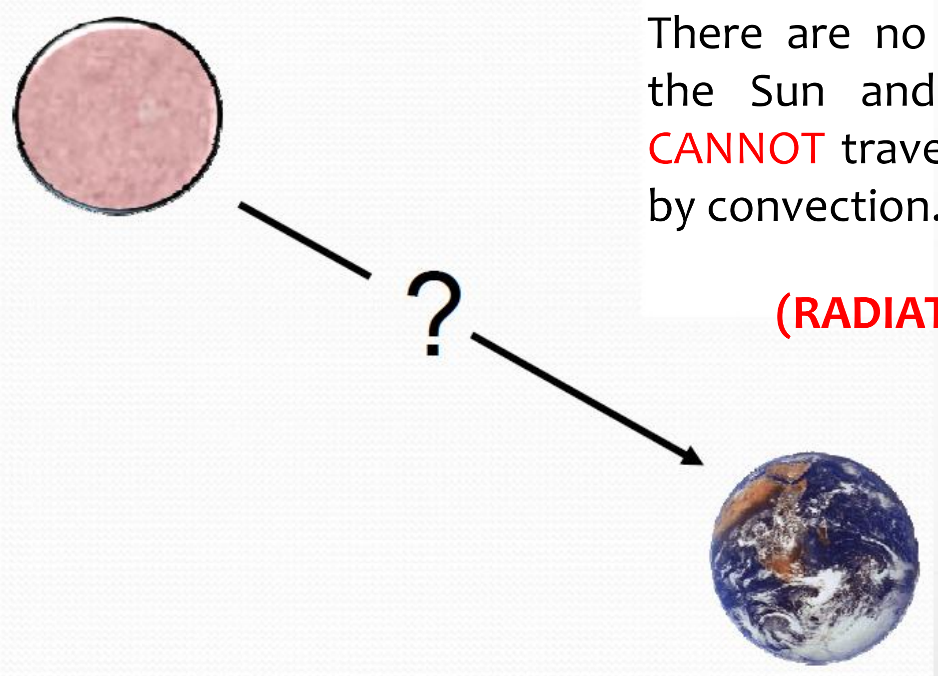
Convection

Typical values of the convection heat transfer coefficient (Incropera)

Process	h $(W/m^2 \cdot K)$
Free convection	
Gases	2–25
Liquids	50–1000
Forced convection	
Gases	25–250
Liquids	100–20,000
Convection with phase change	
Boiling or condensation	2500–100,000

Radiation

How does heat energy get from the Sun to the Earth?



There are no particles between the Sun and the Earth so it CANNOT travel by conduction or by convection.

(RADIATION)

Radiation

- **Radiation:** heat exchange between two surfaces in the form of electromagnetic waves.

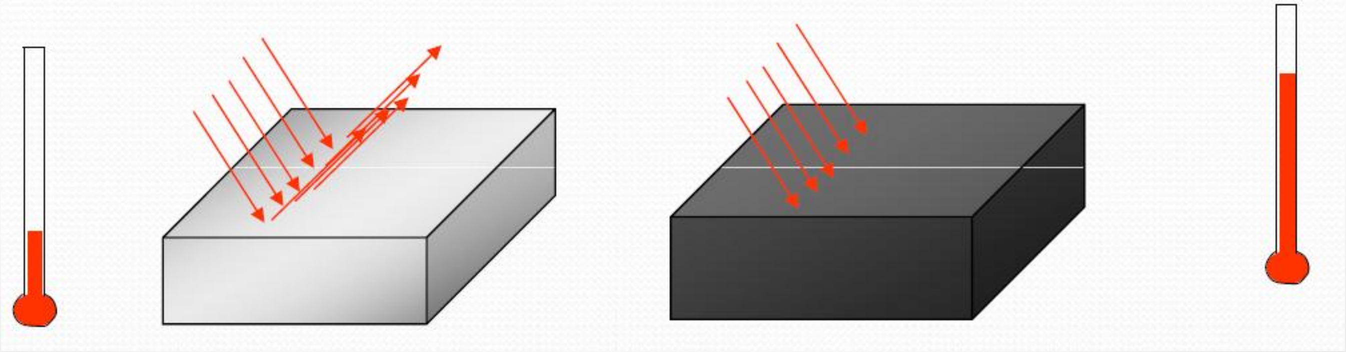
Or it is the process in which energy is transferred by means of electromagnetic waves.

- Electromagnetic waves include visible light, infrared radiation, radio and microwaves and Gamma rays.
- No medium is necessary for radiation to occur; radiation works even in and through a perfect vacuum. The energy from the Sun travels through the vacuum of space before warming the earth. Also, the only way that energy can leave earth is by being radiated to space.
- Hot or cold, all objects radiate energy
- The surface colour of an object makes a difference

Radiation

Absorption of Radiation

Matt dark surfaces are **better absorbers** of infrared radiation than shiny light surfaces.

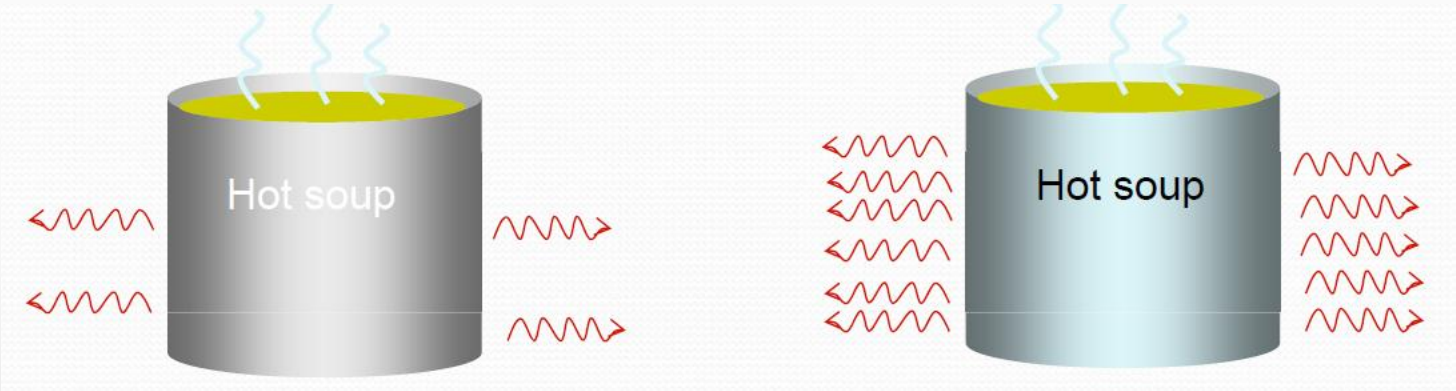


Which metal block will heat up quicker?

Radiation

Emission of Radiation

Matt dark surfaces are **better emitters** of infrared radiation than shiny light surfaces.



Which hot soup cup will lose heat quicker?
If you had a food home delivery business, would you deliver the hot food in dark coloured containers or Aluminium foil?

Radiation

The STEFAN–BOLTZMANN Law Of Radiation

All things radiate electromagnetic energy.

$$q_{emit} = \varepsilon\sigma(T_b^4)$$

All things absorb electromagnetic energy from surroundings.

$$q_{absorb} = \varepsilon\sigma(T_{sur}^4)$$

All things radiate and absorb electromagnetic energy.
Net rate heat exchange for real (gray) surface

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

σ - Stefan-Boltzmann constant =5.67x10-8 (Watts/K^4 m^2)
A - is the surface area T - is the temperature of the radiator in A **Kelvin**

Radiation

The STEFAN–BOLTZMANN Law Of Radiation

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

ε- Emissivity which is a number between 0 and 1.

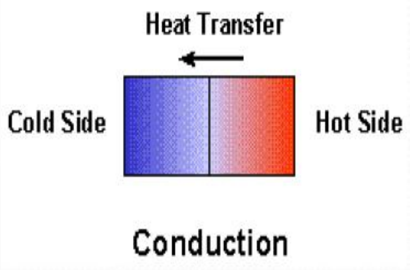
The emissivity of a material is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature.

Radiation

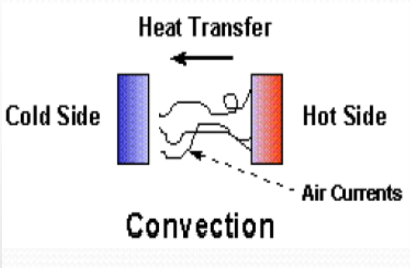
Good emitters (ε close to 1) are also good absorbers

Black body: perfect absorber → perfect emitter (at all wave lengths)

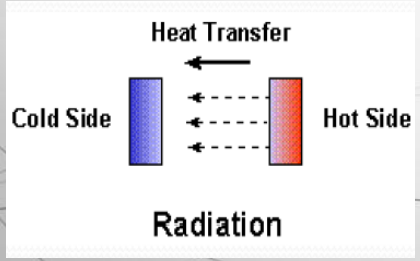
Summary & Review



The most efficient method is conduction, which is the transfer of heat between two objects in contact. The transfer occurs as the fast-moving molecules of the hot object bump into the slower moving molecules of the cold object. The fast molecules give up some of their energy, slowing down, and this energy goes into speeding up (and thus heating up) the slow molecules.

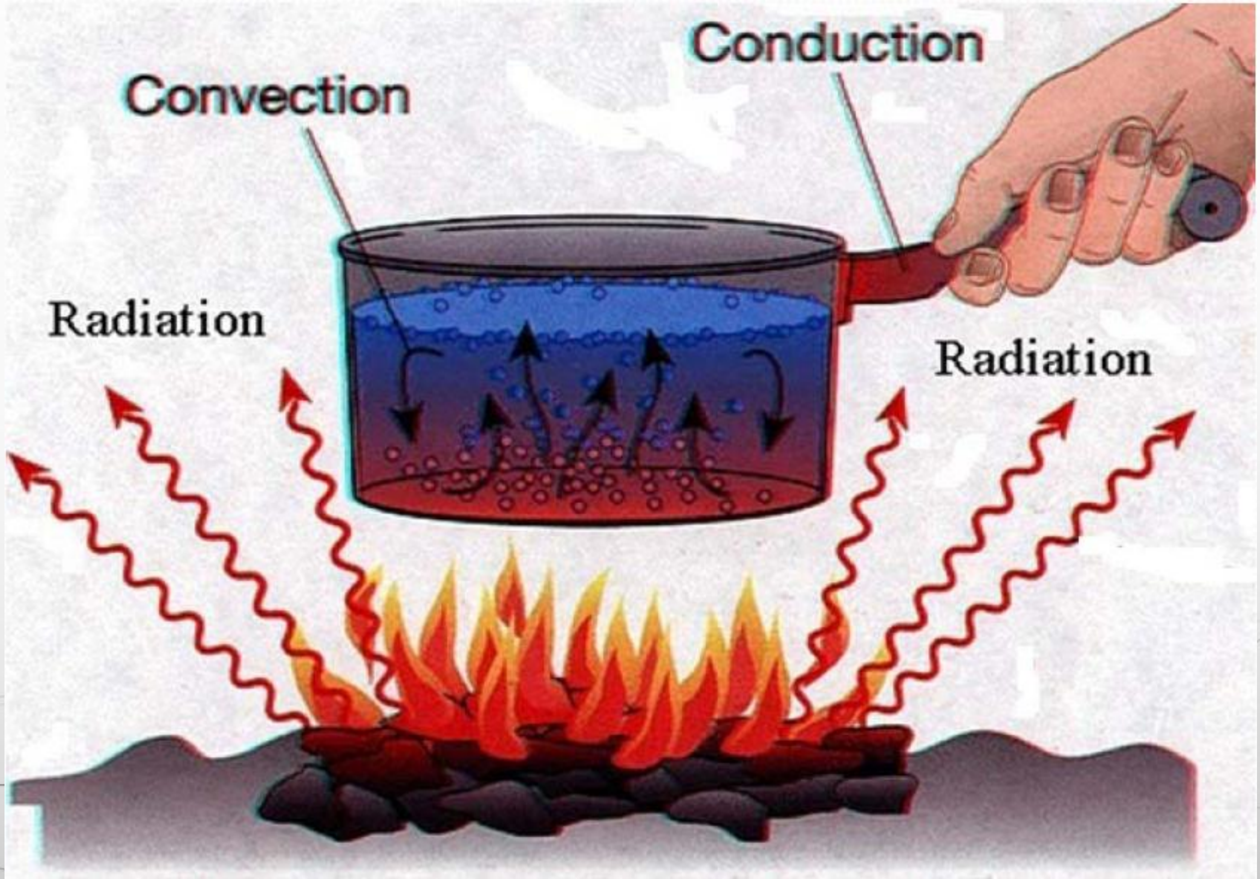


A slower method of heat transfer is convection, which occurs in fluids or gases. A cool fluid in contact with a warm solid will heat up through conduction. The warmer fluid drifts into the cooler fluid, setting up a convective current. Because material must actually be moved, convection is less efficient than conduction.



The least efficient method of heat transfer is radiation. In this case, heat moves through space without the assistance of a physical substance. This is how the Sun's heat reaches the Earth. The radiative heat is transferred directly into a solid object, but it passes readily through transparent materials such as air and glass

In most practical situations **conduction**, **convection**, and **radiation** appear in combination.



1. Radiation travels in straight lines
   True
   False

2. Radiation can travel through a vacuum
   True
   False

3. Radiation requires particles to travel
   True
   False

4. Radiation travels at the speed of light
   True
   False

5. Heat will not flow between two objects of the same temperature.
   True
   False

6. The driving force for heat transfer is temperature gradient
   True
   False

7. The more motion, the more heat is generated
   True
   False

1. Which of the following is not a method of heat transfer?
    - A. Radiation
    - B. Insulation
    - C. Conduction
    - D. Convection

2. Which is the best surface for reflecting heat radiation?
    - A. Shiny white
    - B. Dull white
    - C. Shiny black
    - D. Dull black

3. Which is the best surface for absorbing heat radiation?
    - A. Shiny white
    - B. Dull white
    - C. Shiny black
    - D. Dull black

Q: If you lived in a hot country, would you paint your house a light colour or a dark colour?

Q: Several days after the end of a snowstorm, the roof of a house is completely covered with snow, another house's roof has no snow. Which house is probably better insulated?

Q. Why is it possible for you to hold a lighted match, even when it is burned to within a few millimeters of your fingertips?

Q: What type of heat transfer is involved ?

- **Heating a room with a fireplace**
- **Egg cooking in a frying pan**
- **Roof of a house becoming hot**

Q: In the living room, the heating unit is placed in the floor but the refrigerator has a top-mounted cooling coil. Why?