1.5 Heat Transfer Mechanism

Principles of Heat Transfer

- Heat transfer is one way of transferring energy to a body (Work is the other)
- Occures only when there is a *temperature difference* between the two bodies
  (heat flows from hot to cold)
- Occurs through three processes: *conduction*, *convection*, and *radiation*

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1. Conduction

- **Conduction**: Heat is transferred through a material that does not include any fluid motion.

- ❑ Direct contact of materials
- ❑ Without any bulk movement of fluid
- ❑ Conduction heat transfer is due to the microscopic motion of electrons, atoms, and molecules.

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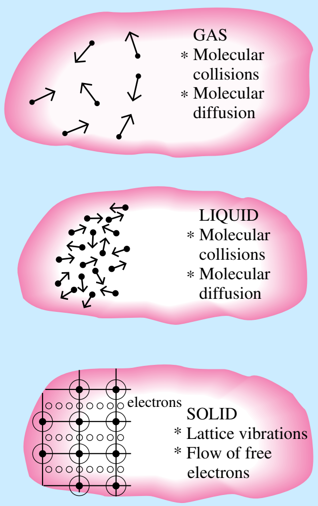

- In *gases and liquids* conduction is due to the collision and diffusion of the molecules during their random motion.
- In *solids* conduction is due to the vibration of the molecules in a lattice (nonmetallic solids) and the energy transfer by free electrons (metal solids).

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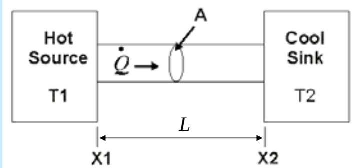
Conduction

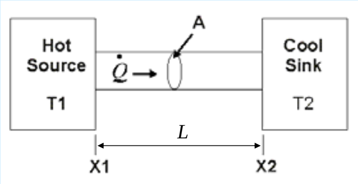
- The rate of heat conduction, $\dot{Q}$, depends on:
  - temperature difference, $T_1 - T_2$
  - thickness of material in direction of heat flow, $x_2 - x_1$ (L)
  - cross-sectional area, A, perpendicular to heat flow
  - thermal conductivity



Conduction: **Fourier's Law**

- Experiments show that for many substances, the rate of heat conduction is:

$$\dot{Q} = kA\frac{(T_1 - T_2)}{L} = -kA\frac{(T_2 - T_1)}{(x_2 - x_1)} = -kA\frac{\Delta T}{\Delta x}$$

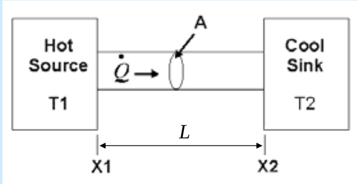


$$\dot{Q} = -kA\frac{\Delta T}{\Delta x}$$

- units :
  - ***A***: m²
  - ***L***: m
  - ***ΔT***: °C
  - ***K***: W/m·°C
  - $\dot{Q}$: W

• The constant *k* is called the thermal conductivity and depends on the material [see TABLE 1-1]

• It is a thermo-physical property of the material.



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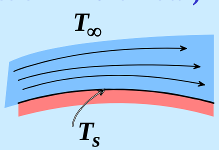
2. Convection

Convection: Heat is transferred by the bulk movement of a fluid (air or water currents) (e.g. ocean currents)

Convection

- **Convection: Energy is transported by means of mass motion.** *(Pure thermal convection)*
- **Of primary interest here is heat transfer *between a surface and a fluid* which is moving <u>adjacent</u> to it.** ***(Convection heat transfer*** **: conduction + fluid flow)**

Note: No pure thermal convection exists in the nature.



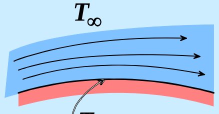
- **Classification:**
  - **(1)** ***Free convection***
  - **(2)** ***Forced convection***

Convection
Two types: *Free* and *Forced*

- In *free convection* fluid motion is driven by gravity, which is a natural force.
- In *forced convection* the fluid is set in motion by mechanical means such as fans and blowers.
  - Forced convection is more effective than free convection.

Newton's Law of Cooling

$$\dot{Q} = h\,A\,(T_s - T_\infty)$$



- $\dot{Q}$ is the heat transfer rate
- T_s is surface temperature
- T_∞ is the fluid temperature far away from the surface.
- h is the *heat transfer coefficient* ($W/m^2 \cdot {}^oC$) .

1) h is not a property of material.
2) It depends on geometry, fluid velocity, fluid properties.
3) Major objective in convection: Determination of h

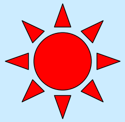
TABLE 1-5	
Typical values for *h*	
	h **(W/m2 - °C)**
Free Convection	
Gases	2 - 25
Liquids	10 - 1000
Forced Convection	
Gases	25 - 250
Liquids	50 - 20,000
Liquid metals	5,000 - 50,000

$$\dot{Q} = h\,A\,(T_s - T_\infty)$$

Examples of Convection

- The sea breeze is caused by differences in temperature between the ocean and the shore
- In fact, *all weather and ocean currents* are caused by convection
- A draft in a cold room is caused by convection currents from air leaking through a window or door
- A “rolling boil” in a pot is the result of convection
- Convection Currents in heating & cooling appliances

3. Radiation



Radiation: Heat is transferred by means of electromagnetic waves (radiant energy or light) when a hot body emits radiation

(e.g. Solar radiation)

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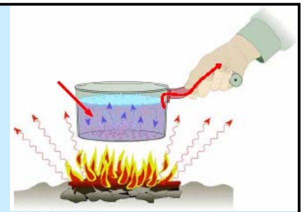
Radiation



- Transmission by electromagnetic waves (e.g. light)
- No medium (e.g. air) is needed. Best in a vacuum
- Propagate "at the speed of light"
- Of our interest here is thermal radiation emitted by bodies because of temperature.
- All bodies at a temperature above $0K$ emit thermal radiation.

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Thermal Radiation: Stefan-Boltzmann law

$$\dot{Q}_{\text{emit}} = \varepsilon \sigma A T^4$$

- σ = 5.67×10^{-8} W/m^2·K^4 , Stefan-Boltzmann constant
- T_s , Kelvin (absolute degrees),the surface temperature
- ε , surface emissivity, $0 \le \varepsilon \le 1$

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Emissivity ε

Emissivity depends on *surface roughness, color and oxidation extent*.

ε = 1 for black bodies (perfect emitter)

ε = 0 for poorest emitters

ε = number between 0 and 1 for all real surfaces.

Emissivities of some materials at 300 K

Material	Emissivity
Aluminum foil	0.07
Anodized aluminum	0.82
Polished copper	0.03
Polished stainless steel	0.17
Black paint	0.98
White paint	0.90
Human skin	0.95
Wood	0.82-0.92
Soil	0.93-0.96
Water	0.96
Vegetation	0.92-0.96

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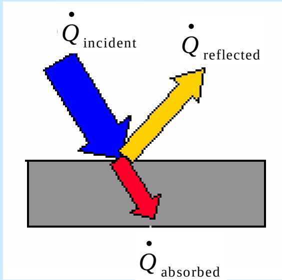
Absorptivity α

- All bodies emit as well as absorb radiant energy
- **Absorptivity α** : Fraction of radiation incident on a surface which is absorbed ($0 \le \alpha \le 1$)

$$Q_{absorbed} = \alpha\, Q_{incident}$$



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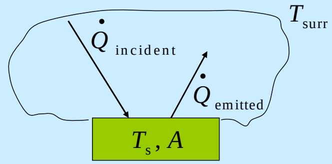
Net rate of radiation heat transfer

- The net rate of radiation heat transfer between an object and its surrounding



$$\dot{Q}_{rad} = \varepsilon\sigma A(T_s^4 - T_{surr}^4)$$

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Examples of Radiation

- A hot burner on a stove or a fire emits large amounts of infrared and a smaller amount of visible radiation
- Mammals (~40 º C) emit mostly infrared radiation
- Incandescent lights (regular light bulbs) have heated filaments (~1000 º C) that emit visible light
- Our sun (~6000 º C) emits a large amount of visible light

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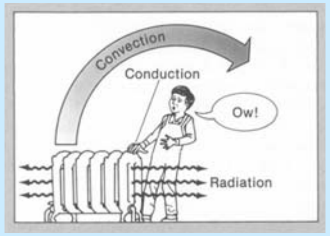
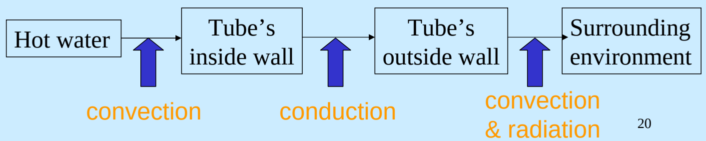
4.Simultaneous Heat Transfer

e.g.

- A radiator works by circulating water through a series of pipes, where it cools and releases heat





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