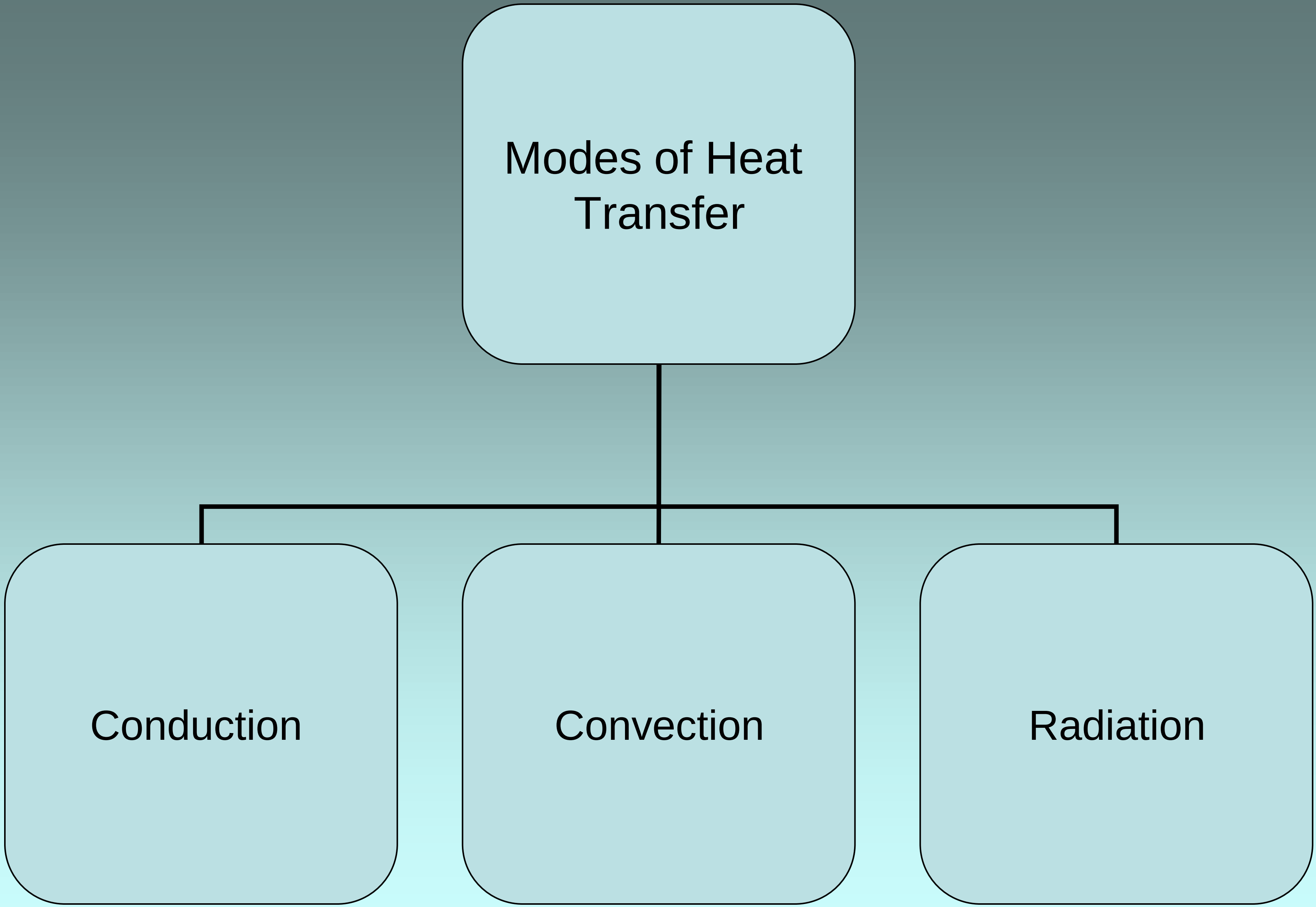

Modes of Heat Transfer
Conduction
Convection
Radiation

Conduction

- When heat is transferred by the energy of motion between adjacent molecules, heat transfer by conduction is said to take place.
- Conduction is transport of heat by statistical molecular movement, i.e. medium is stationary.
- This type takes place in solids and fluids in rest.
- In gases, molecules which have greater energy and motion ‘hotter molecules’ impart energy to the adjacent molecules which are at lower energy levels.
- In solids and liquids the previous mechanism also takes place. Moreover, in metallic solids, heat transfer takes place by ‘free electrons’.

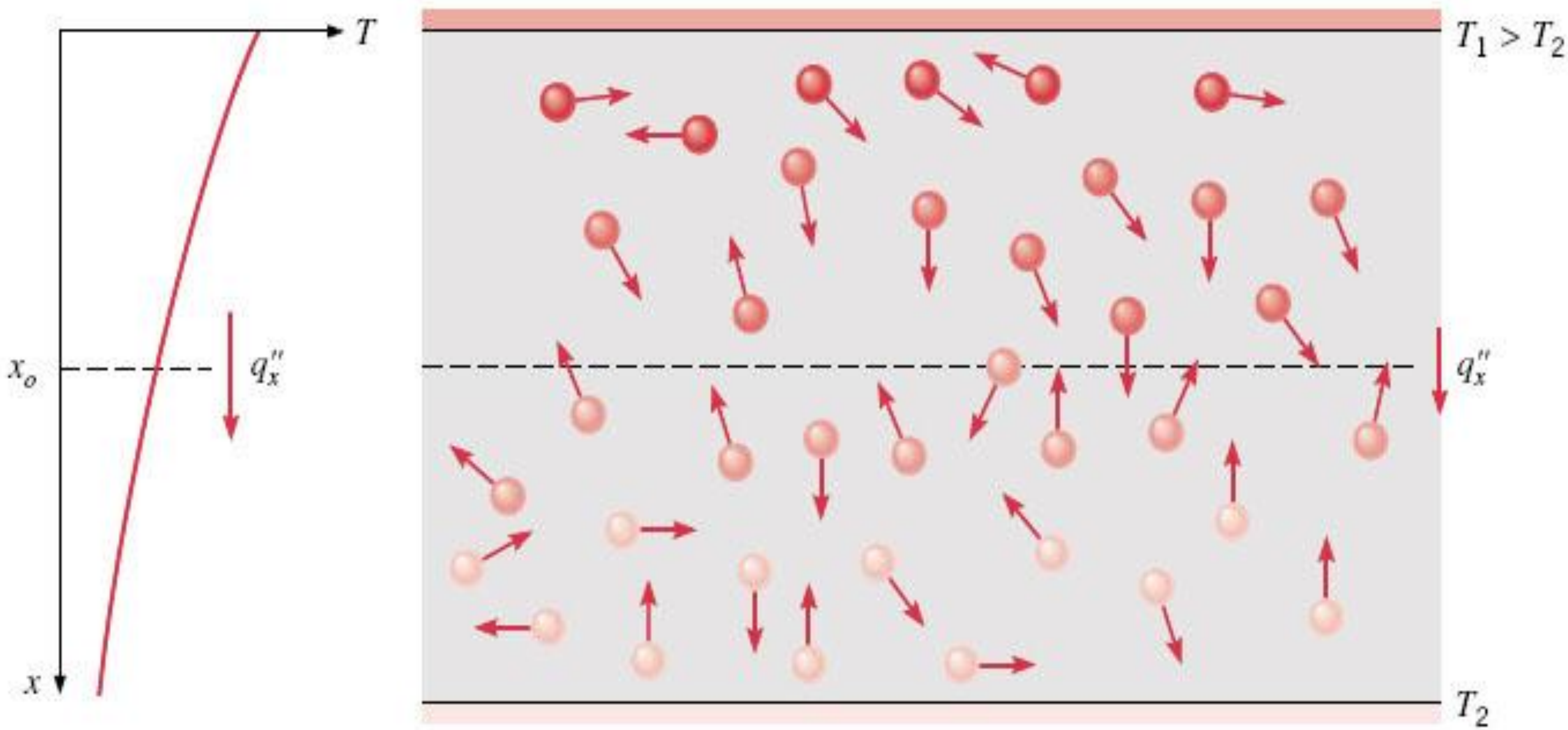
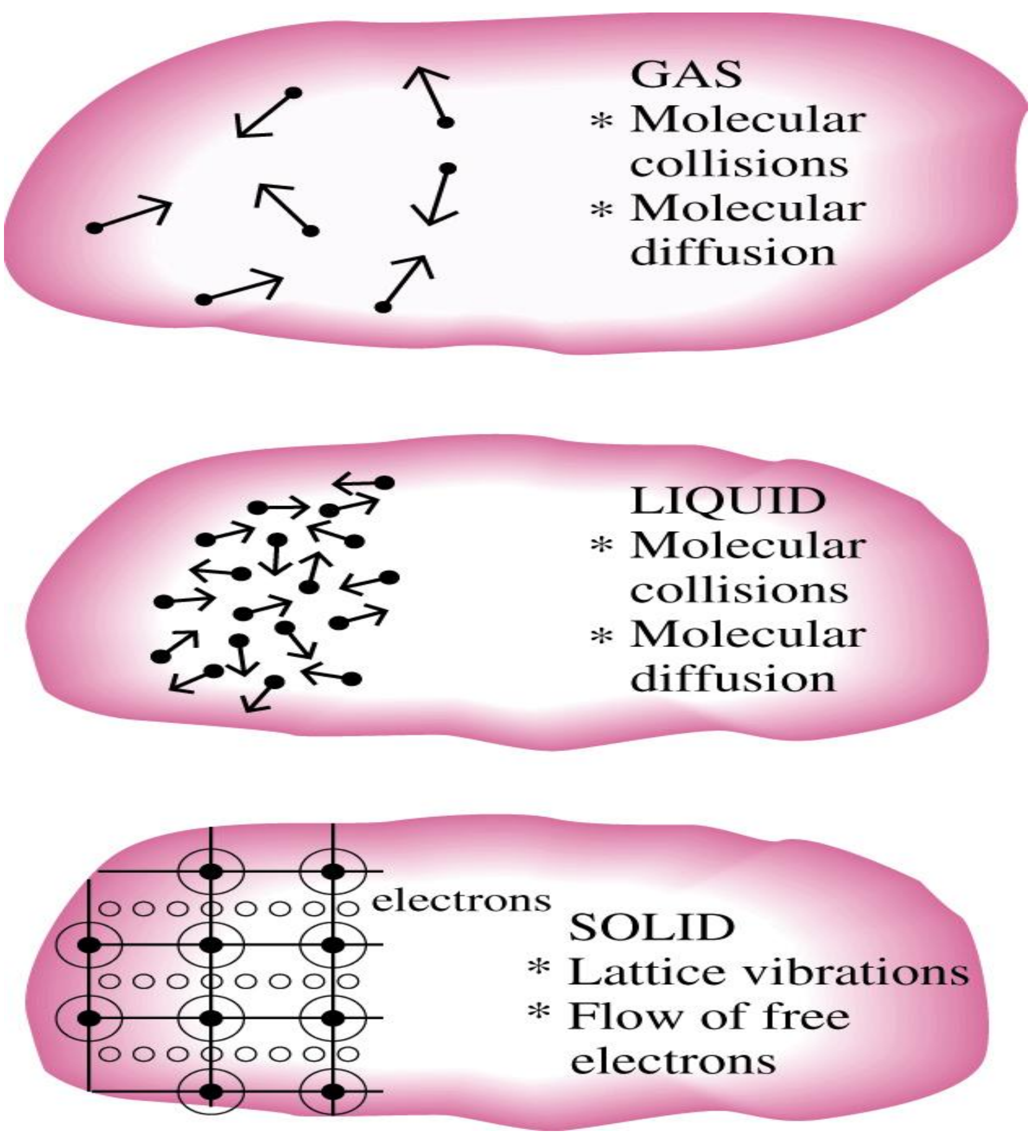


FIGURE 1.2 Association of conduction heat transfer with diffusion of energy due to molecular activity.

Conduction

The mechanisms of heat conduction in different phases of a substance



Convection

- It takes place through bulk transport and the mixing of macroscopic hot and cold particles of a fluid.
- It also includes the transfer of heat between a solid surface and a fluid.
- Convection heat transfer is of two parts:

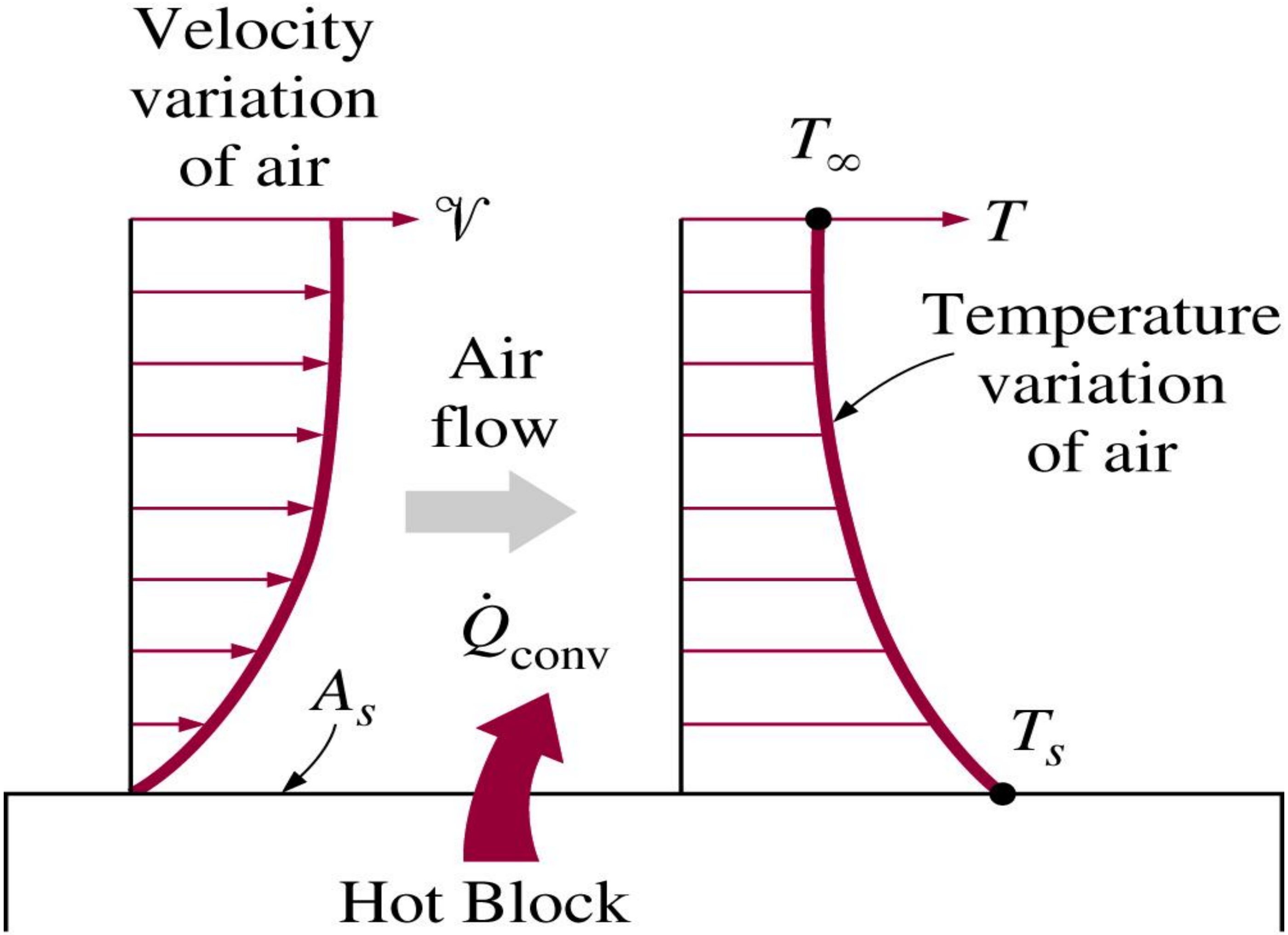
  i) forced convection heat transfer, where fluid is forced over a surface by any mechanical means (such as pumps, compressors and fans).

ii) Natural or free convection i.e driven by density differences resulting from (buoyancy forces) temperature gradient.

- In either case, convection may be turbulent or laminar depending on conditions.
- Examples of heat transfer by convection are:

1. Cooling or heating of fluids in heat exchangers
2. Cooling of cup of coffee by blowing over the surface.
3. Baking a cake in a gas oven.

Convection
Heat transfer from a hot surface to air by convection



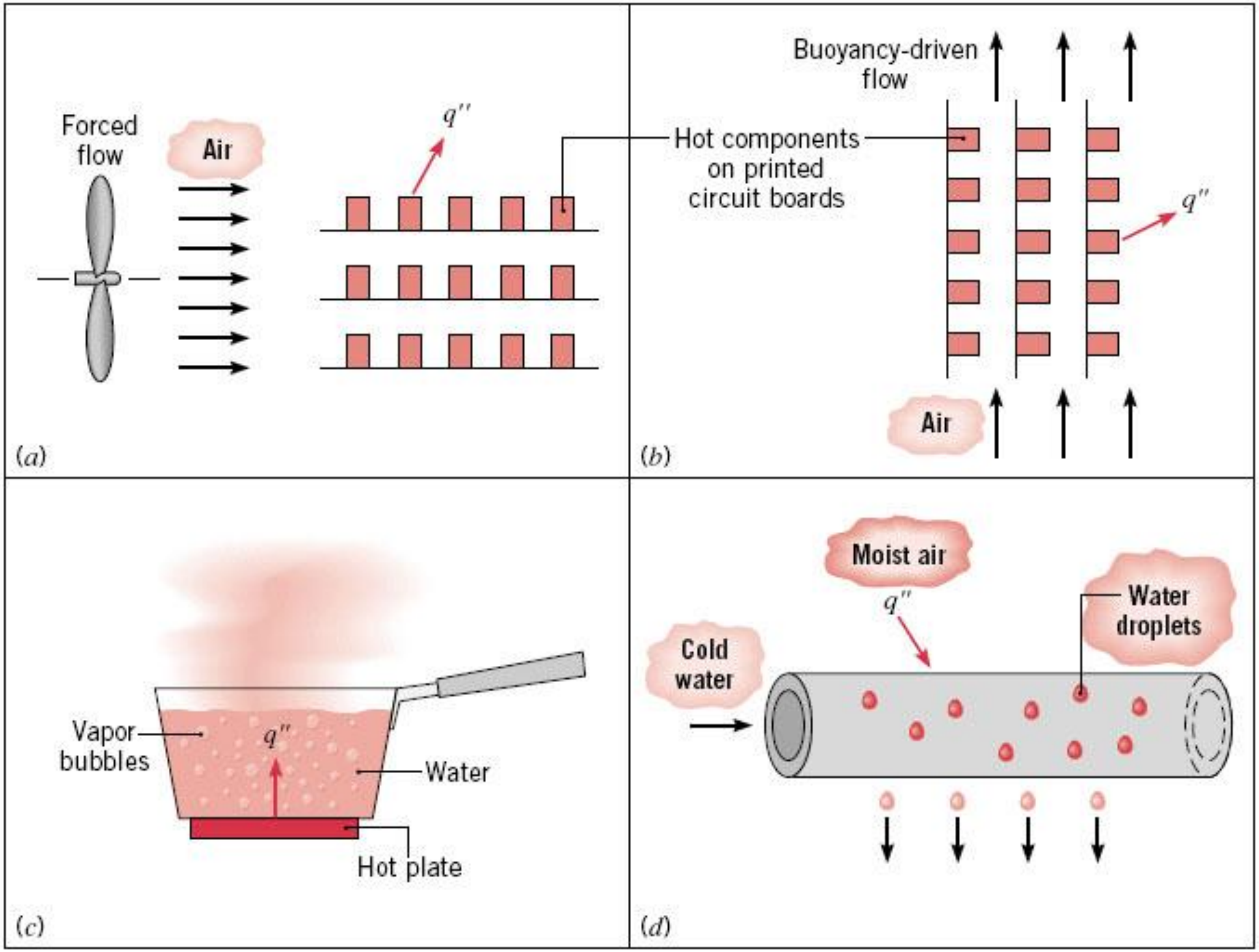


FIGURE 1.5 Convection heat transfer processes. (*a*) Forced convection. (*b*) Natural convection. (*c*) Boiling. (*d*) Condensation.

Radiation

- Radiation is a transport of heat by electromagnetic waves; similar to the transport of electromagnetic light waves .
- No physical medium is required. It can take place in a vacuum.
- Hence, radiation heat transfer is governed by the same laws that govern the transfer of light.
- Solids and liquids have the tendency to absorb the radiation that is being transferred through them, therefore, radiation is of primary importance in the transfer of heat through gases and space.

- Examples of radiation heat transfer are:

I. The transfer of heat from the sun to the earth.

II. Cooking of food over electric coil radiators.

III. Heating of tubes in a furnace.

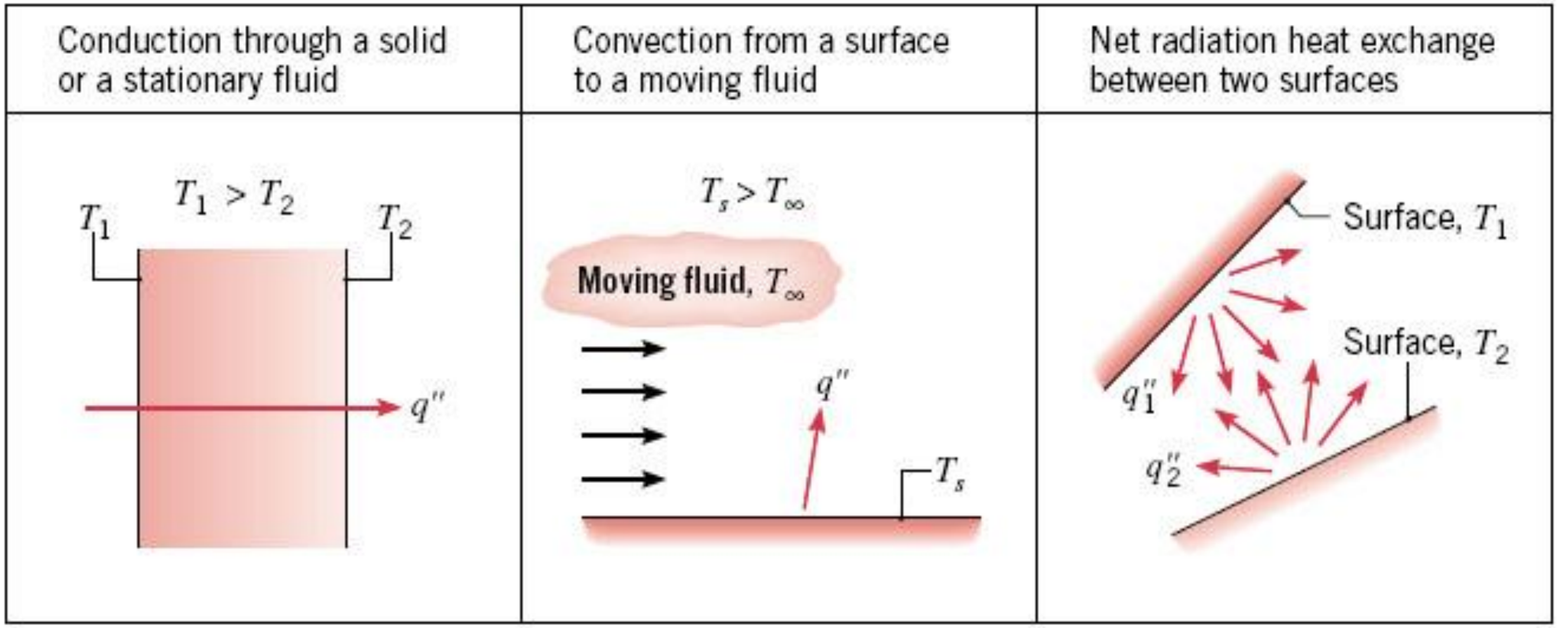


FIGURE 1.1 Conduction, convection, and radiation heat transfer modes.

- Conduction and radiation are the two basic modes of heat flow; convection can be regarded as conduction with fluid in motion.

- It is very difficult to completely isolate one mechanism from the others. But if one mode is dominant, the others may be neglected.

  Example:

  Heat loss from lagged pipe through which hot oil is pumped, to surrounding environment.

Rate Equations

Conduction

- Fourier's Law

❑ The rate equation of heat transfer by conduction cannot be derived from the first principles. However, it is based on experimental observations made by Biot and named after Fourier.

❑ The Fourier law states that the rate of heat flow by conduction in a given direction is proportional to:

a) the gradient of temperature in that direction, dT/dx

b) the area normal to the direction of heat flow, A

Then

$$q_x = -k A \frac{dT}{dx}$$

Where k is the proportionality constant called the thermal conductivity.

For 'S.S' linear

temperature gradient

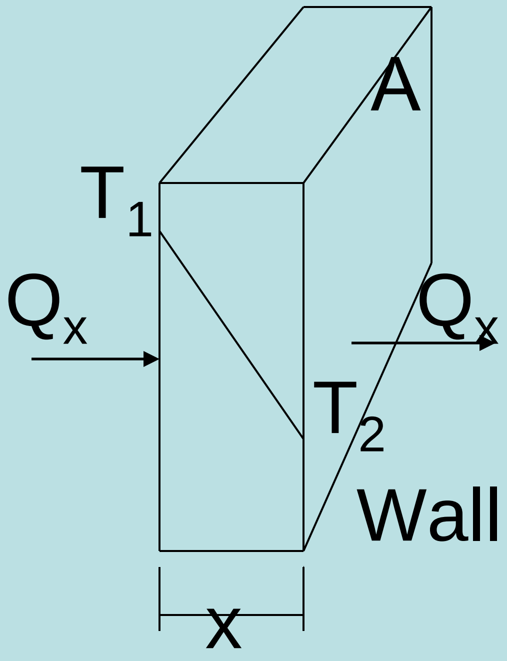
$Q_x = -k\, A\, \Delta T / x$

$Q_x = k\, A\, (T_1 - T_2)/x$

Or

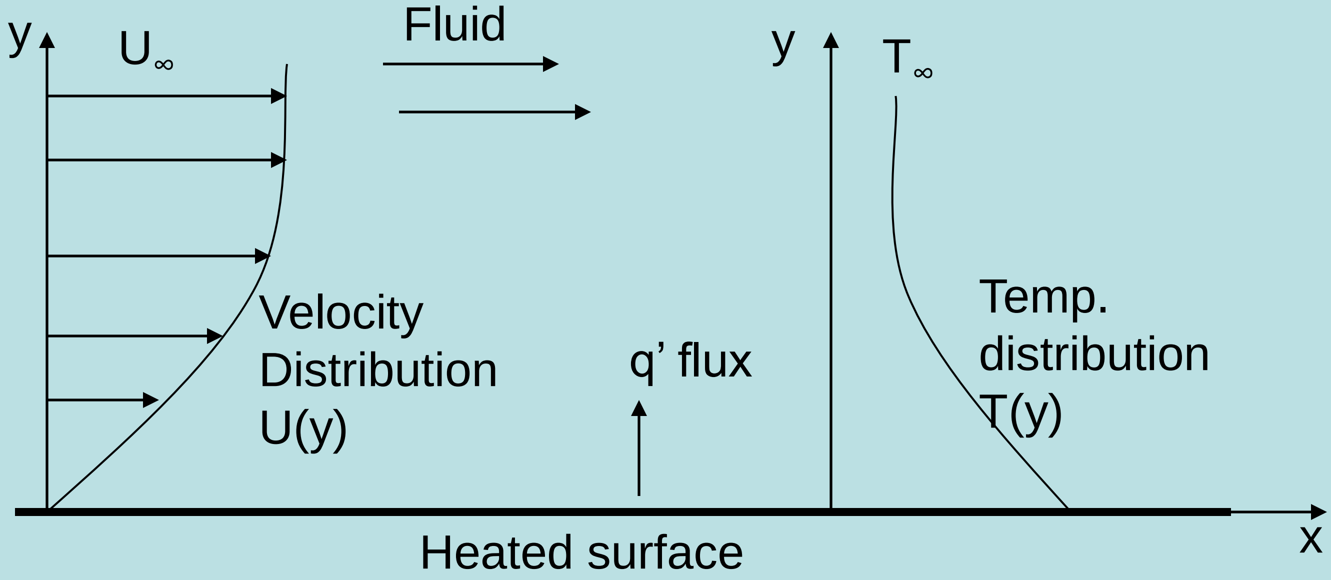
$q_x = k\, (T_1 - T_2)/x$

Where q_x is the heat flux or the heat rate per unit area



Convection

Boundary layer developed in convection heated transfer



The rate of heat flow for a cold fluid, T_∞ passes over a hot surface, T_s as shown in the previous figure is given by:

$$Q = h A (T_s - T_\infty)$$

Or the convection Heat Flux, q` is

$$q` = h (T_s - T_\infty)$$

The previous expression is known as *Newton's law of cooling*, and the parameter h is termed the *convection heat transfer coefficient*.

In general, the determination of h is a very complex problem because h is affected by:

1. The type of flow i.e laminar, turbulent or transitional.
2. The geometry of the body.
3. The physical properties of fluid.
4. The temperature difference.
5. The position a long the surface of the body.
6. Whether the mechanism is forced or free.

Note: h is found experimentally or analytically (for simple shapes)

Mean value of h

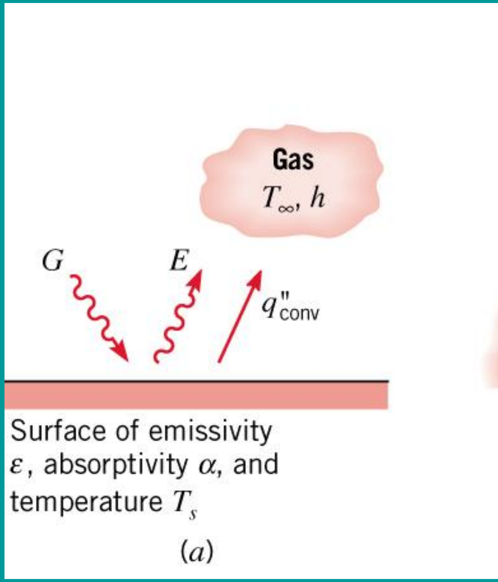
Since h varies with the position along the surface of the body, for simplicity its mean value over the surface is considered.

Typical values of h

Process	**h, W/m^2 .K**
Free convection	
Gases	2 - 25
Liquid	50 – 1000
Forced convection	
Gases	25 - 250
Liquid	100 -20,000
Convection with phase change Boiling or condensation	2500 -100,000

Heat Transfer Rates

Radiation



Heat transfer at a gas/surface interface involves radiation emission from the surface and may also involve the absorption of radiation incident from the surroundings (irradiation, G), as well as convection $\left(\text{if } T_s \neq T_\infty\right)$.

Energy outflow due to emission:

$$E = \varepsilon E_b = \varepsilon \sigma T_s^4 \qquad (1.5)$$

E : Emissive power $\left(\text{W/m}^2\right)$

ε : Surface emissivity $\left(0 \leq \varepsilon \leq 1\right)$

E_b : Emissive power of a blackbody (the perfect emitter)

σ : Stefan-Boltzmann constant $\left(5.67\times10^{-8}\text{W/m}^2\cdot\text{K}^4\right)$

Energy absorption due to irradiation:

$$G_{abs} = \alpha G$$

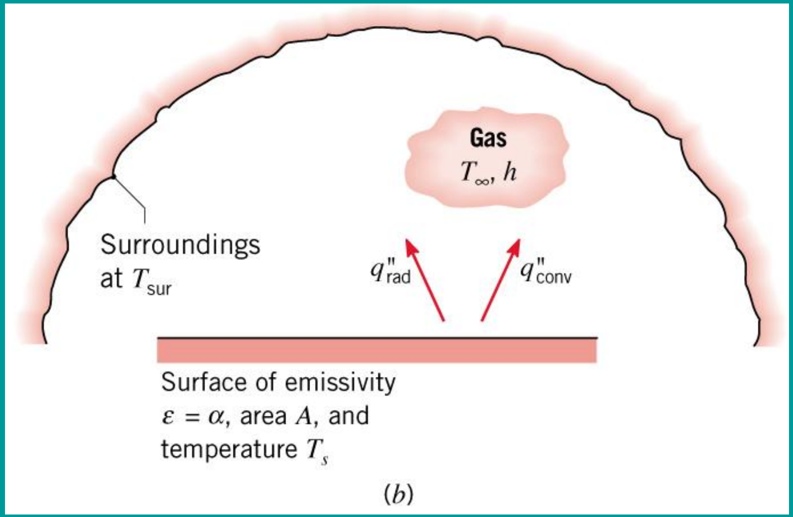
G_{abs} : Absorbed incident radiation (W/m^2)

α : Surface absorptivity $\left(0 \leq \alpha \leq 1\right)$

G : Irradiation $\left(\text{W/m}^2\right)$

Heat Transfer Rates

Irradiation: Special case of surface exposed to large surroundings of uniform temperature, T_{sur}



$$G = G_{sur} = \sigma T_{sur}^4$$

If $\alpha = \varepsilon$, the net radiation heat flux from the surface due to exchange with the surroundings is:

$$q''_{rad} = \varepsilon E_b\left(T_s\right) - \alpha G = \varepsilon\sigma\left(T_s^4 - T_{sur}^4\right) \qquad (1.7)$$

Heat Transfer Rates

Alternatively,

$$q''_{rad} = \mathrm{h}_r \left(T_s - T_{sur}\right) \qquad (1.8)$$

h_r: Radiation heat transfer coefficient $\left(\mathrm{W/m^2 \cdot K}\right)$

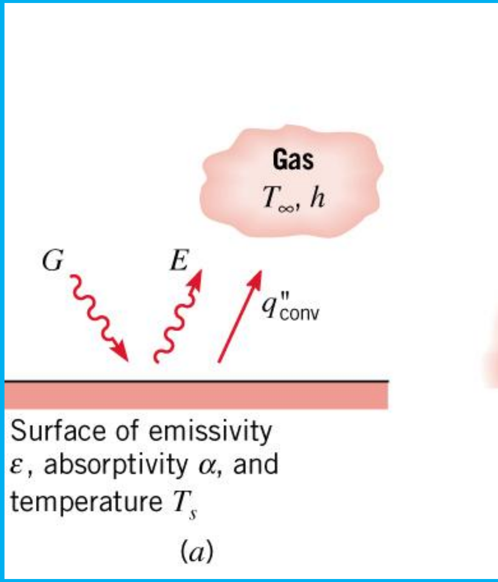
$$\mathrm{h}_r = \varepsilon\sigma\left(T_s + T_{sur}\right)\left(T_s^2 + T_{sur}^2\right) \qquad (1.9)$$

For combined convection and radiation,

$$q'' = q''_{conv} + q''_{rad} = h\left(T_s - T_\infty\right) + h_r\left(T_s - T_{sur}\right) \qquad (1.10)$$

Heat Transfer Rates

Radiation



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Heat Transfer Rates

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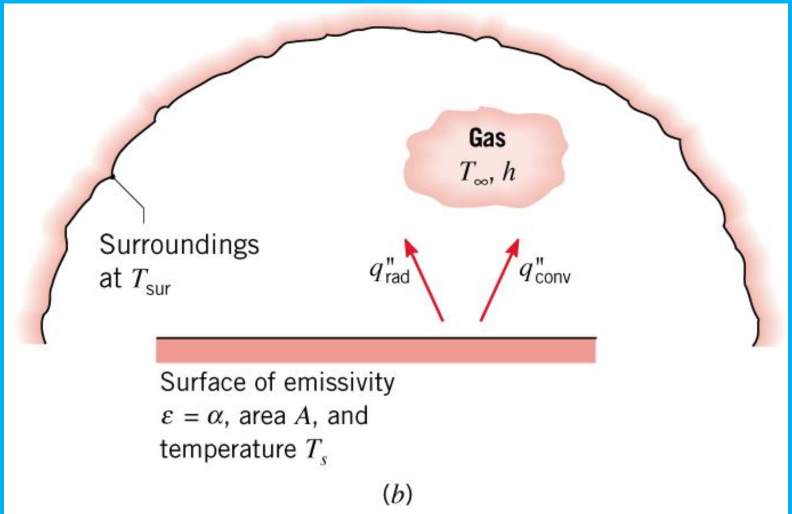

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For combined convection and radiation, (1.10)

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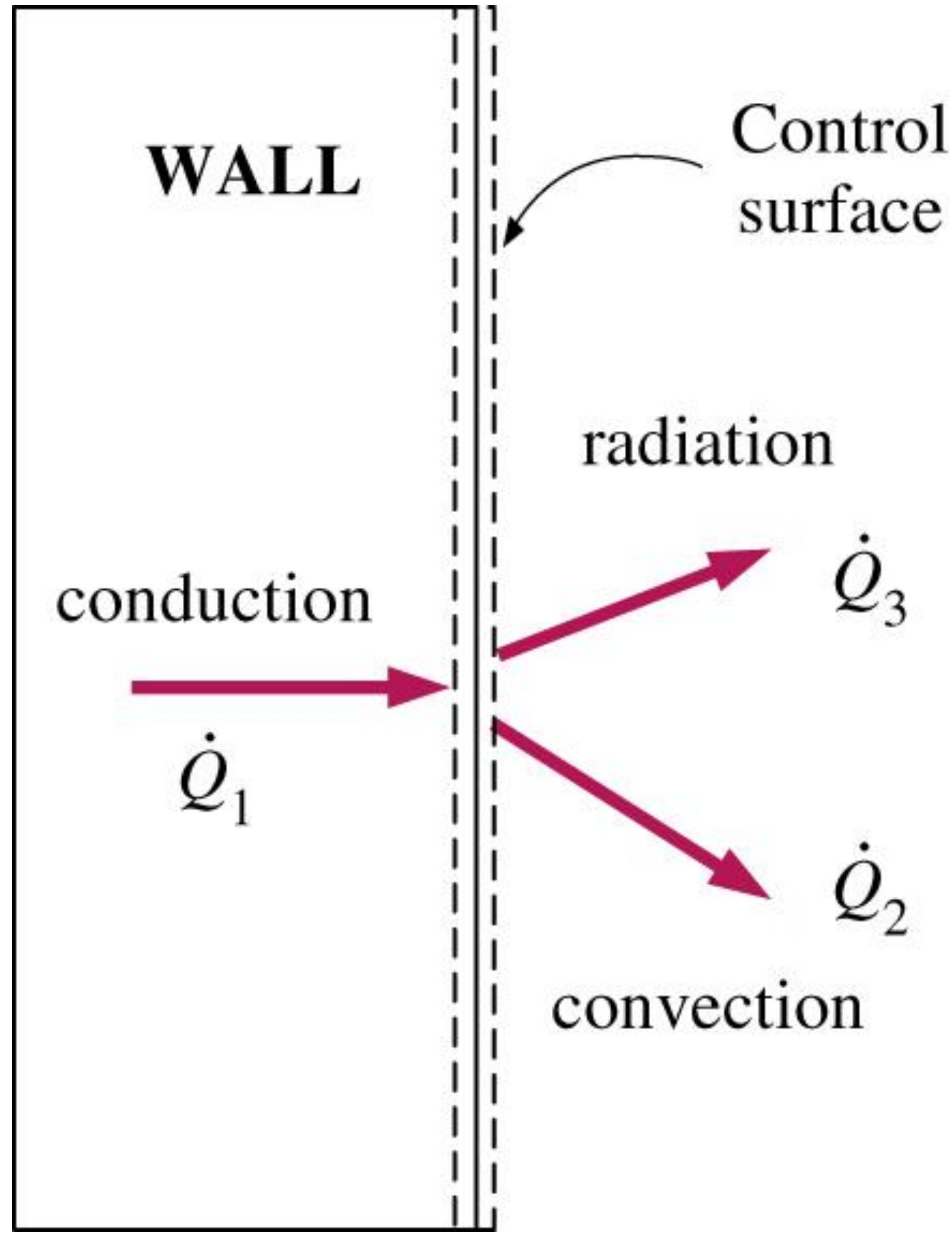

WALL
Control surface
radiation
$\dot{Q}_3$
conduction
$\dot{Q}_1$
$\dot{Q}_2$
convection