Process Heat Transfer

Basic Fundamentals and Definitions

Basic Fundamentals and Definition

Process: A change of a state of a system.

Heat: A type of energy ‘ thermal energy”

Heat transfer: Energy in transit due to temperature difference

Process Heat Transfer: A study which focuses on the heat transfer during the physical or chemical processes. For Examples: Heating of crude oil in heat exchangers and pipe still heater

Modes of Heat Transfer:

- Conduction
- Convection
- Radiation

- Temperature: it is a measure of the amount of thermal energy in a body.
- Temperature difference ΔT: It is the difference of temperatures between hot and cold surfaces or streams. It represents the driving force in heat transfer phenomena.
- Temperature gradient: change of temperature w.r.t. distance.
- Temperature distribution: it is very important to be known in order to compute the heat flow.

Applications of Heat Transfer in Process Industries

Heat is transferred out of or into the process

1. Chemical Reactions: ‘Exothermic’ or ‘Endothermic’ such as combustion, pyrolysis, polymerization

2. Biological Reactions: such as cooling and freezing of foodstuffs, fermentation

3. Physical Changes: such as ‘Evaporation’ and ‘Condensation’ ,e.g., distillation, Melting and freezing

4. Power Generation
5. Air conditioning and Space Heating
6. Waste Heat Recovery
7. Insulations
8. Control of temperature
9. Process Integration
10. Enhancement of heat transfer

Examples

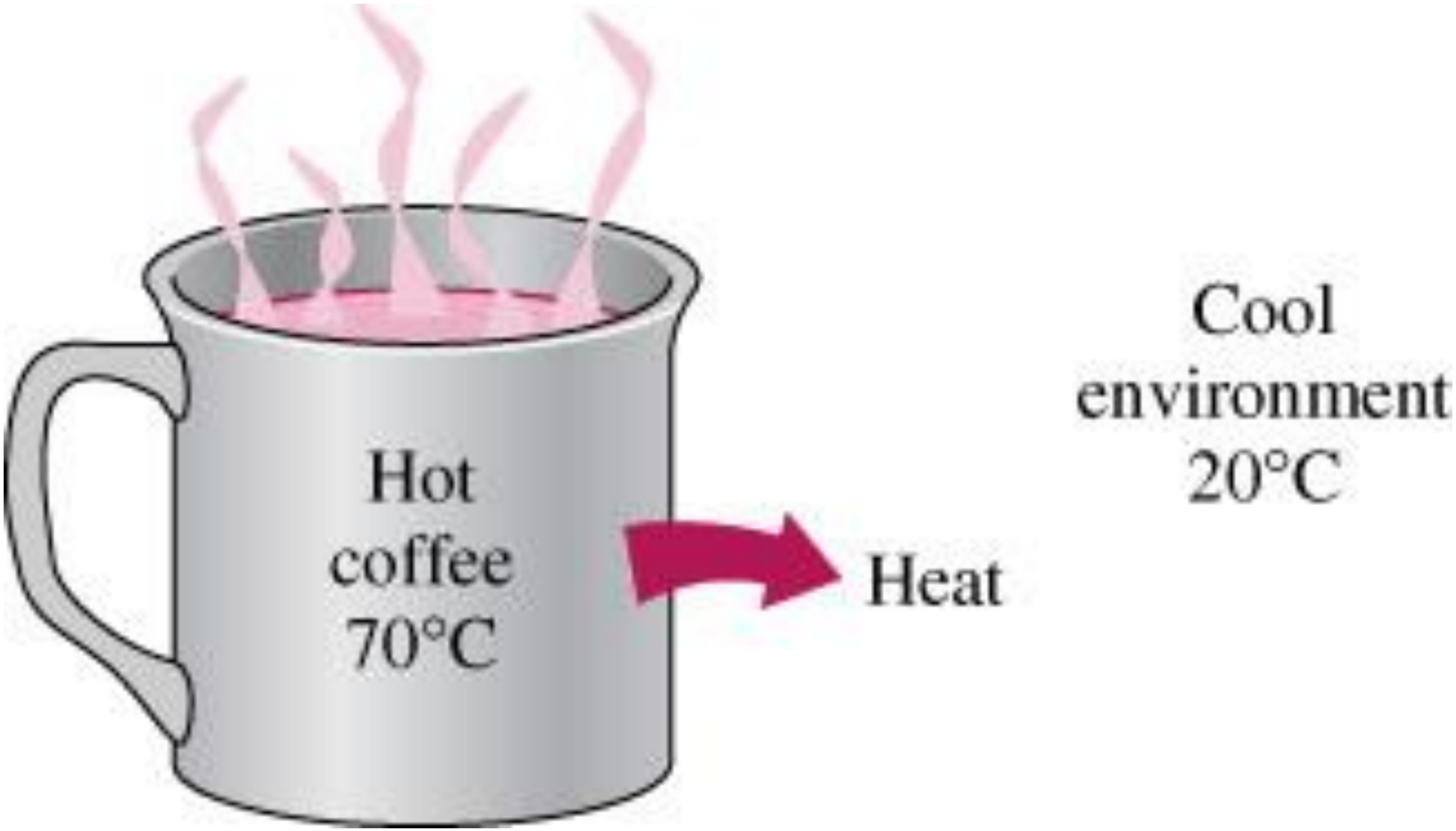
Domestic examples:

- Broiling a turkey
- Roasting bread
- Heating water

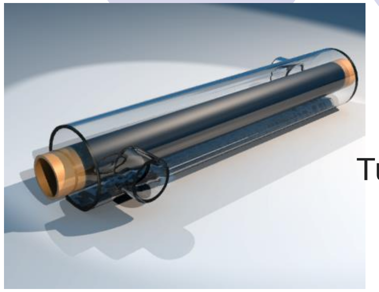
Industrial examples:

- Curing rubber
- Heat treating steel forgings
- Dissipating waste heat from a power plant

Examples

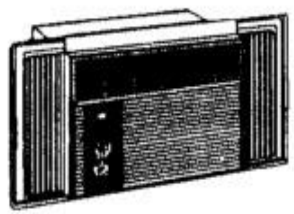


Examples

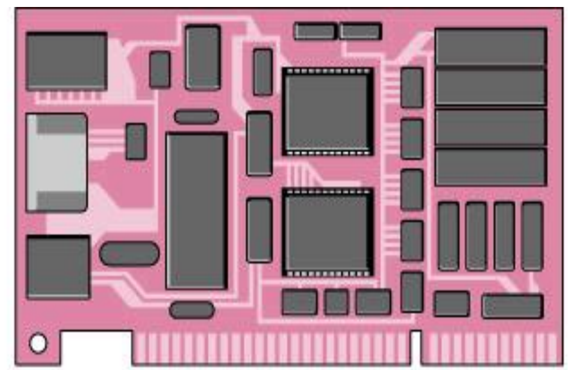


Tubular heat exchanger

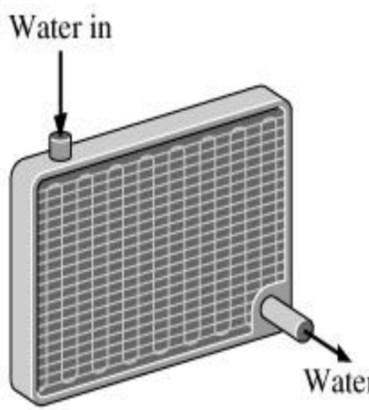
The human body



Air-conditioning systems



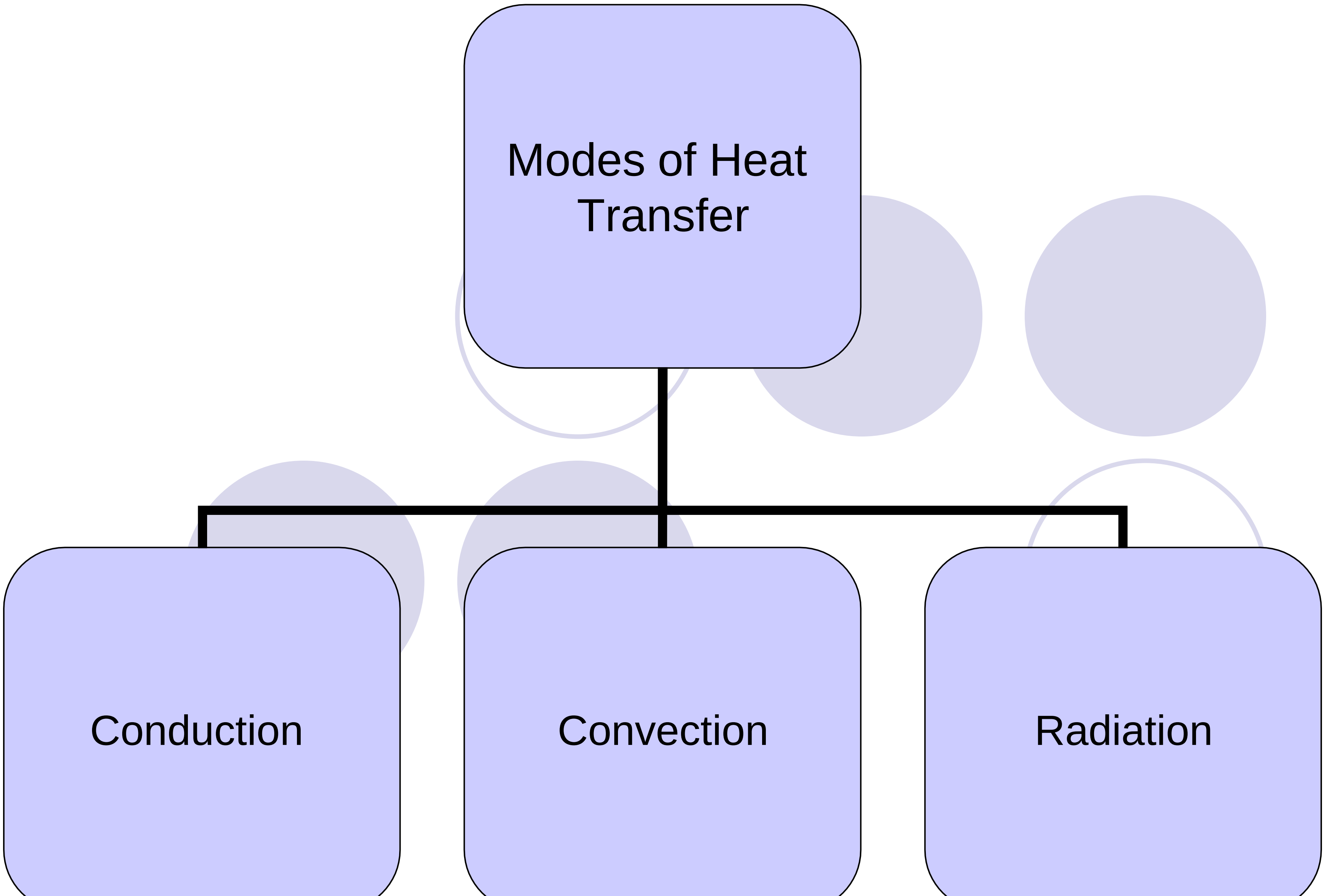
Circuit boards



Car radiators

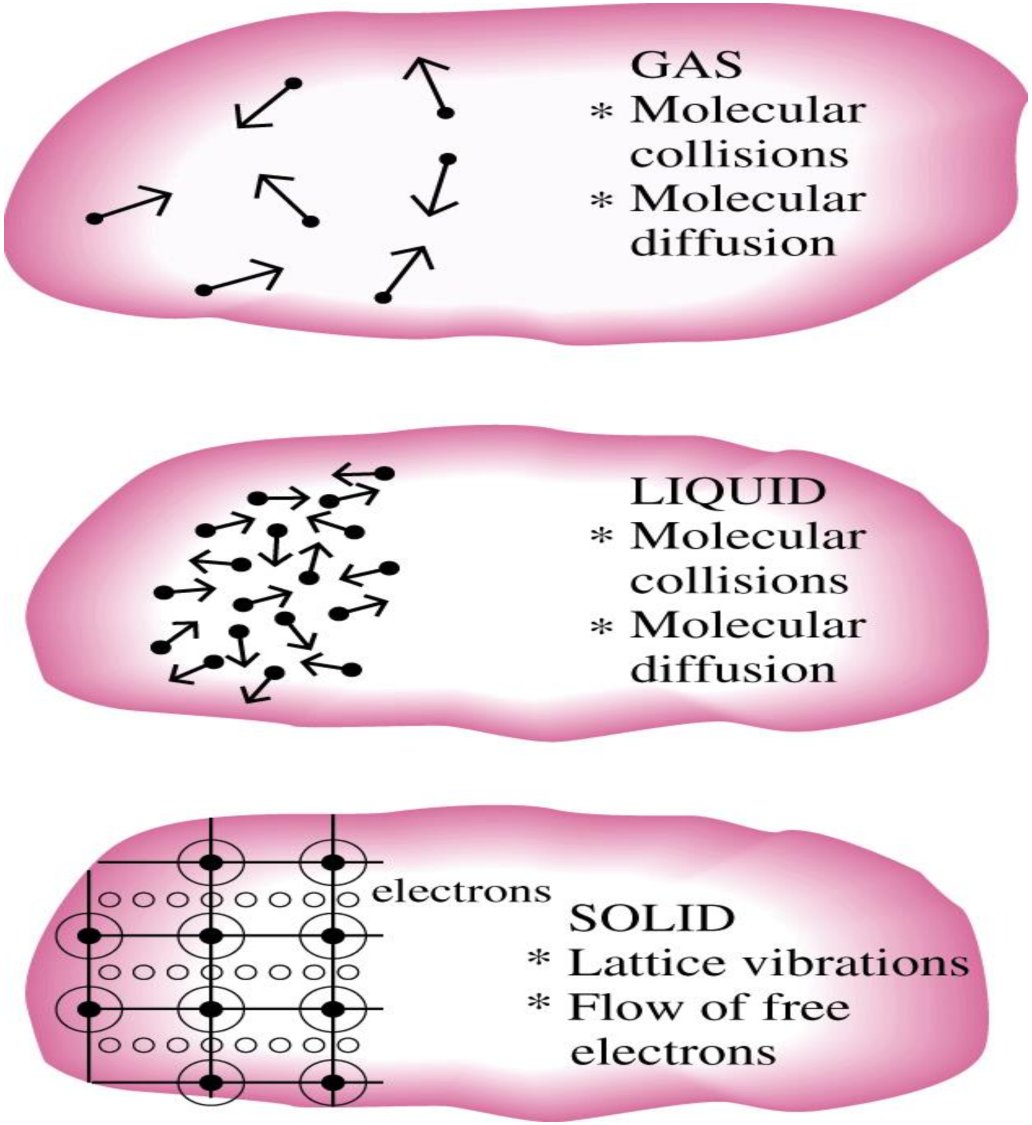
Power plants

Refrigeration systems


Modes of Heat Transfer
Conduction
Convection
Radiation

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:

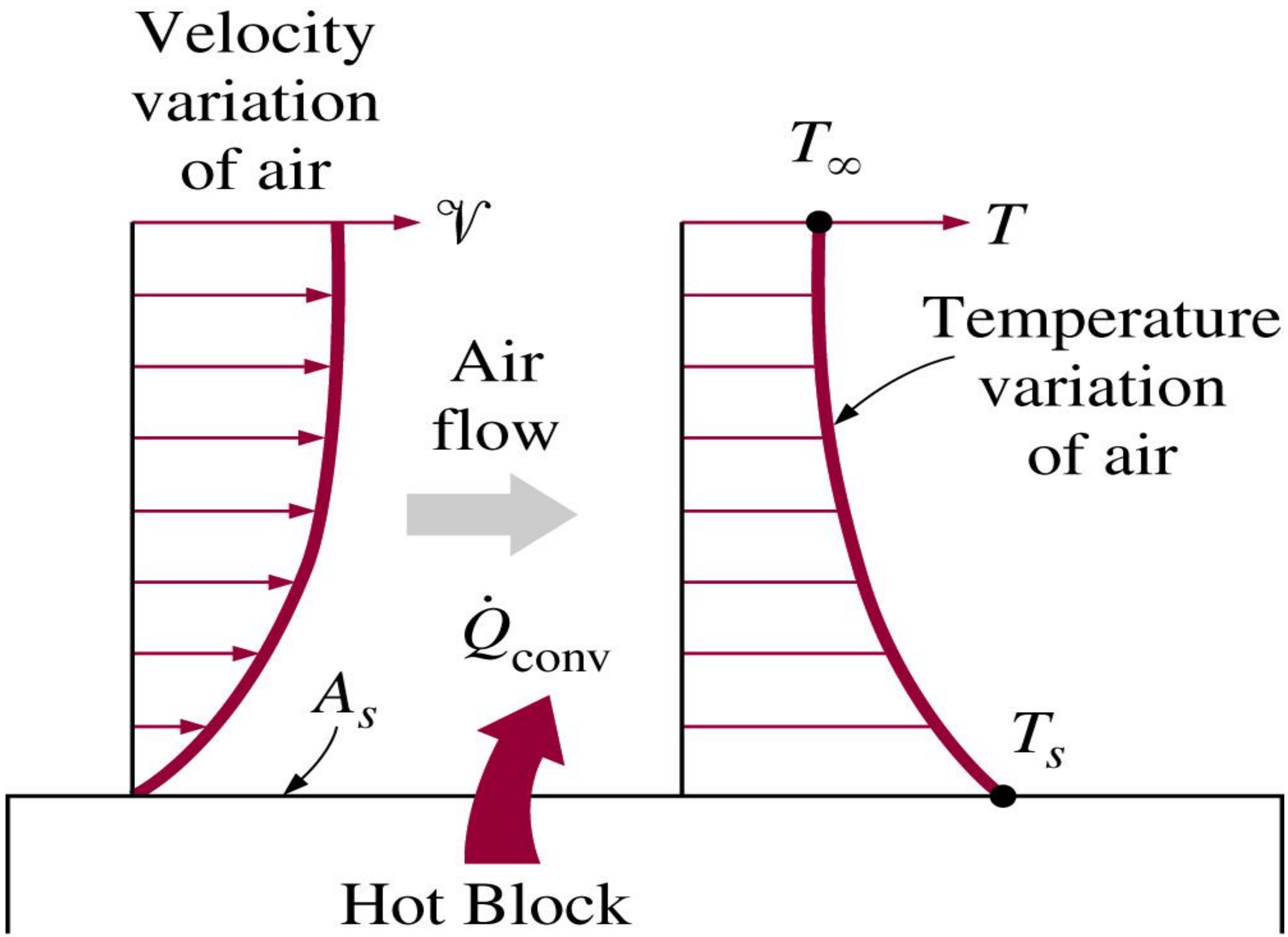
i) forced convection heat transfer, where fluid is forced over a surface by any mechanical means (such as pumps, compressors and fans).

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



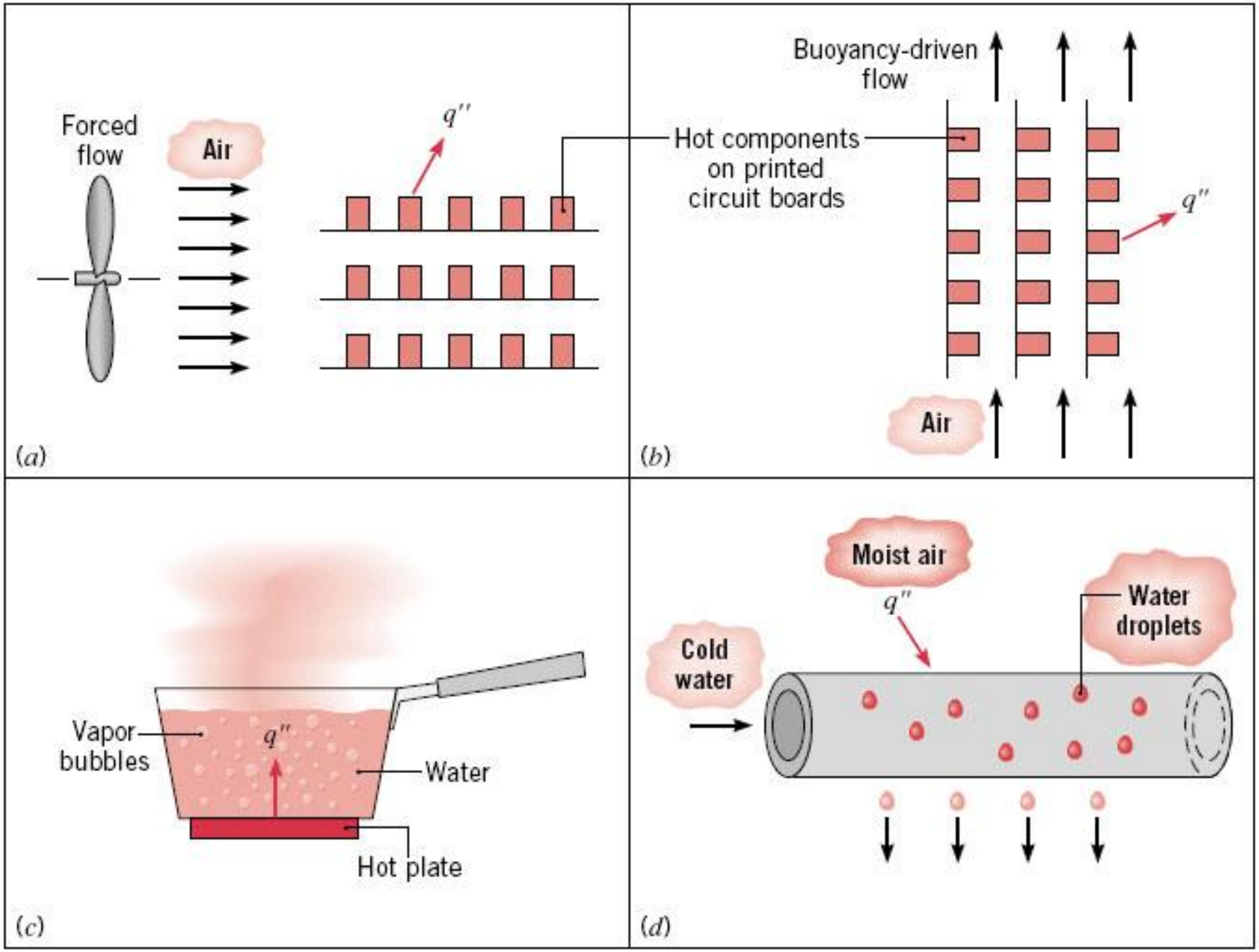


FIGURE 1.5 Convection heat transfer processes. (*a*) Forced convection. (*b*) Natural convection. (*c*) Boiling. (*d*) Condensation.

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.

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

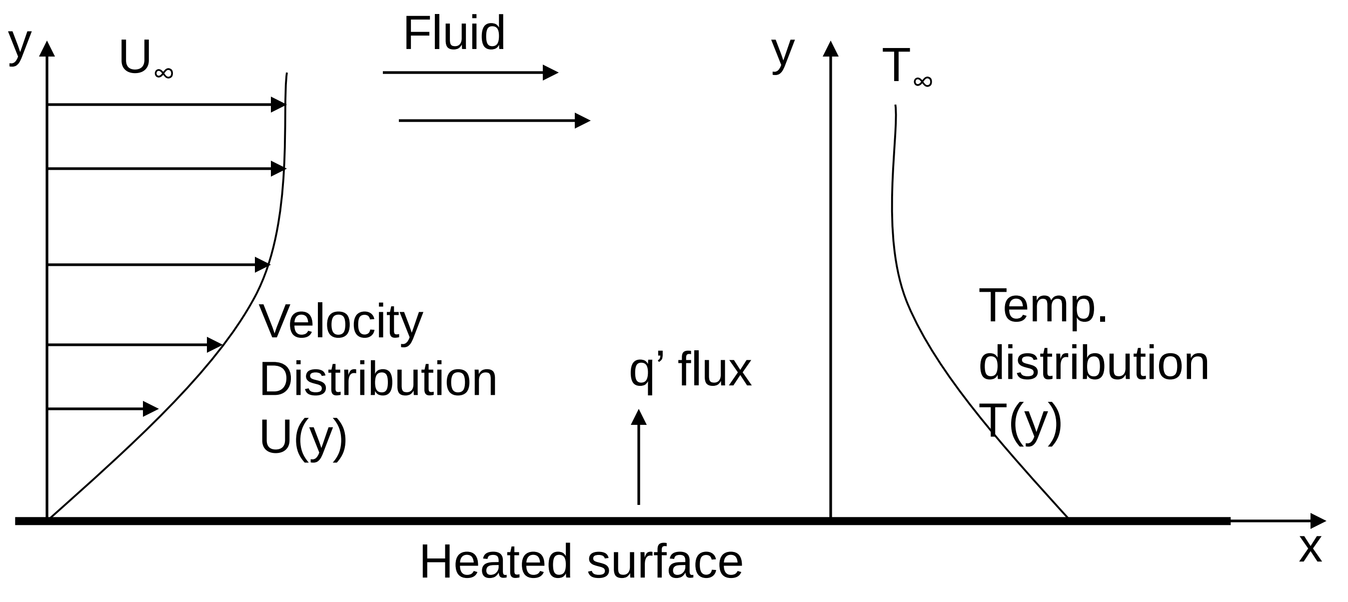
b) the area normal to the direction of heat flow, A

Then

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

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)

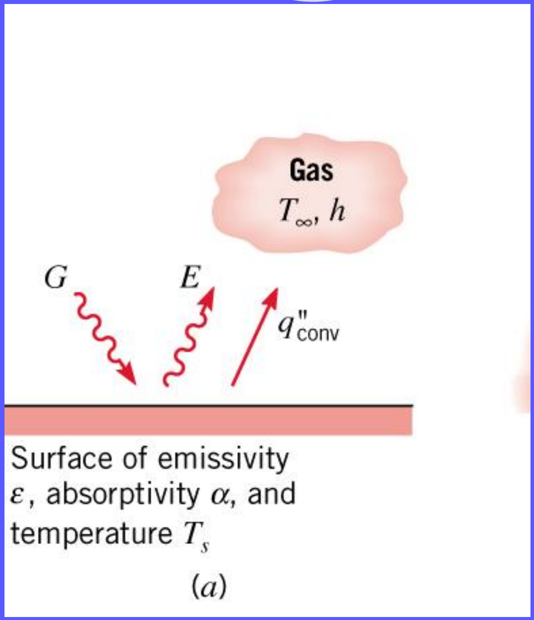
Mean value of h

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 $\left(\mathrm{W/m^2}\right)$

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

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

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

Energy absorption due to irradiation:

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

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

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

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

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,

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