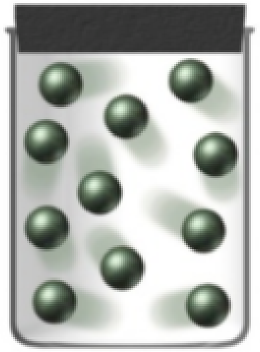
Latent Heat ,Phase Changes & Heat Transfer

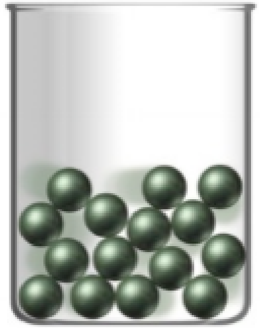
Phases of matter

Matter can exist in different *phases*:

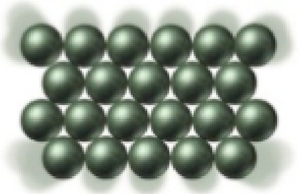
- **gas**: very weak intermolecular forces, rapid random motion



- **liquid**: intermolecular forces bind closest neighbors



- **solid**: strong intermolecular forces



A transition from one phase to another is called phase change.

Phase changes

Phase changes involve absorption or emission of heat.

So the transfer of heat into a system can change the *temperature* of the system, or the *phase*, or both.

Temperature change
(no phase change)

The amount of heat Q needed to increase the temperature of a mass m from T_1 to T_2 is proportional to the temperature change $\Delta T = T_2 - T_1$:

$$\boxed{Q = m c \Delta T}$$

c is the *specific heat* of the material, and depends on the material.

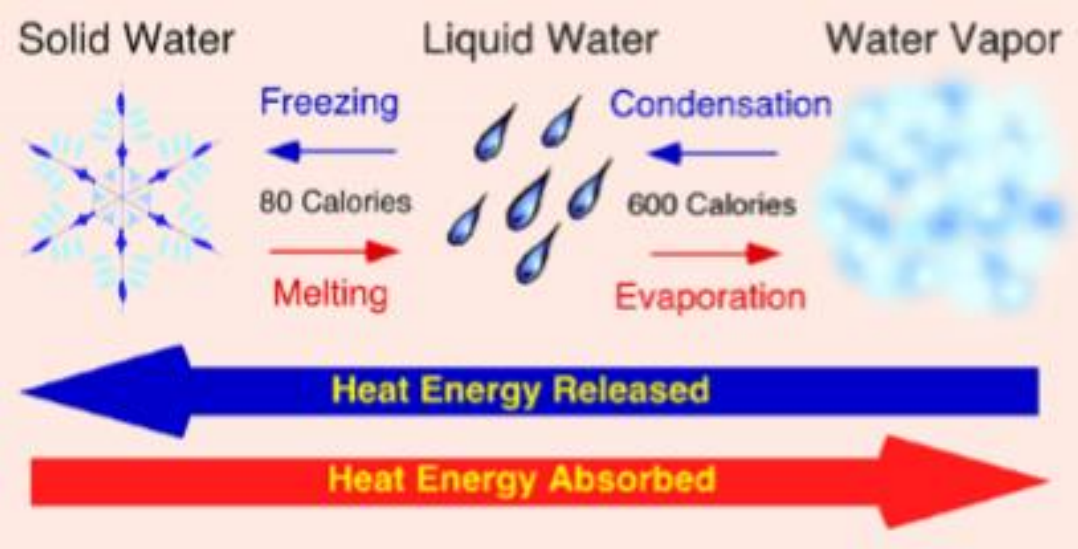
Units: $\mathrm{J.kg^{-1}.K^{-1}}$

Specific heat

Water has a remarkably large specific heat.

Substance	c ($J.kg^{-1}.K^{-1}$)
Aluminum	910
Copper	390
Ice	2100
Water	**4190**
Steam	2010
Air	1000
Soils / sand	~500

- Heat required for phase changes:
  - Vaporization: liquid → vapour
  - Melting: liquid → solid
  - Sublimation: solid → vapour
- Heat released by phase changes:
  - Condensation: vapour → liquid
  - Fusion: liquid → solid
  - Deposition: vapour → solid



At the melting point

$$Q = \pm m L_f$$

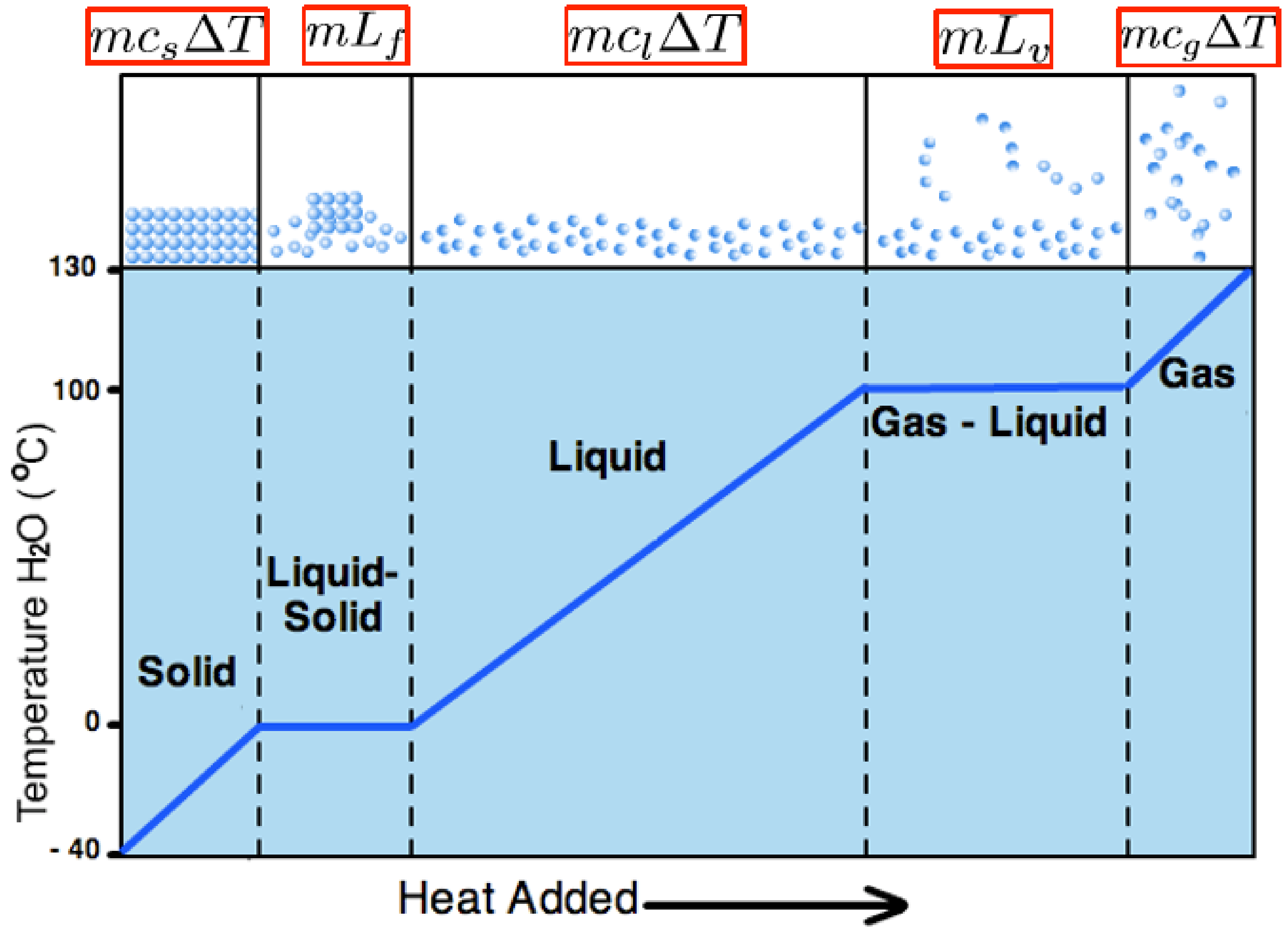
L_f is the *heat of fusion*.

At the boiling point

$$Q = \pm m L_v$$

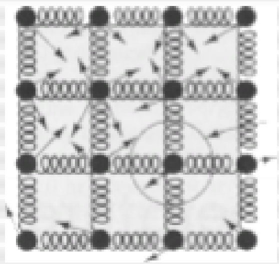
L_f is the *heat of vaporisation*.

The process is reversible, and there is no change in T.
$Q > 0$: energy *absorbed*, $Q < 0$: energy *released* during the phase change.



$mc_s\Delta T$
mL_f
$mc_l\Delta T$
mL_v
$mc_g\Delta T$
130
100
0
- 40
Temperature H_2O (°C)
Solid
Liquid-
Solid
Liquid
Gas - Liquid
Gas
Heat Added

To understand where energy goes during a phase change, first consider melting and boiling; both require energy input. There are attractive forces between molecules that must be overcome during melting and boiling. For a solid to melt, the spring-like forces that hold molecules in place must be broken, and a certain amount of energy is required to break each "spring." For a liquid to boil, attractive forces between molecules must be overcome, and work must be done to move the molecules to the larger separations found in gases. The amount of energy required is thus proportional to the number of molecules in the object and also to the strength of the forces acting between molecules.



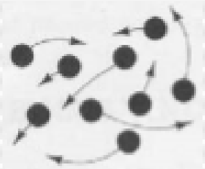
solid

h_f

liquid

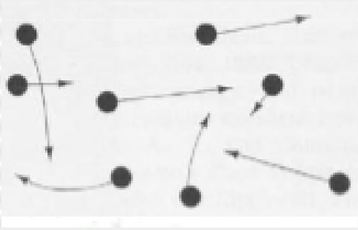
$$Q = m \cdot h_f$$

$$Q = m \cdot h_v$$



liquid

h_v



gas

Example

How much heat is released from 50g of water as it
(a) Changes from liquid to ice at 0°C.
(b) Changes from steam to liquid water at 100°C.

Water $L_v = 2260kJ/kg$ $L_f = 335kJ/kg$

If you have 1.0 kg of water at a temperature of 10°C, how much heat energy needs to be added for it all to become steam?

$$c_{water} = 4200\ J.kg^{-1}.K^{-1}$$

$$L_v = 2.3\times10^6 J.kg^{-1}$$

Specific heat

Substance	c (J.kg^{-1}.K^{-1})
Aluminum	910
Copper	390
Ice	2100
Water	**4190**
Steam	2010
Air	1000
Soils / sand	~500

Latent heats

Latent heat – phase change

Water - large values of latent heats at atmospheric pressure

L_f = 3.34x10^5 J.kg^{-1} (273 K)

L_v = 2.26x10^6 J.kg^{-1}(373 K)

Evaporation

Water slowly evaporates from a container

Water will evaporate from pool after rainfall

This evaporation occurs at temperatures lower than boiling point of water. Why?

Molecules in a liquid are held tightly together by strong forces.

Molecules have a range of kinetic energies. Some molecules will have large kinetic energy----far above average.

Molecules with enough energy can escape from the surface and change from the liquid state to the gaseous state---- *evaporation*

As a liquid evaporates, it extracts heat from its surroundings and hence the surroundings are cooled.

Humidity

As evaporation progresses the surrounding air contains an increasing amount of water vapour and begins to feel humid.

Humidity effects the net evaporation rate of water

Higher the humidity –lower the evaporation rate

Humidity - Definition

The capacity of air to hold water vapour increases with air temperature

vapour density is a measure of the amount of water vapour in the air.

Relative humidity

The amount of vapor in a saturated air is called the saturation vapor density.

This value increases strongly with temperature (hot air can contain much more vapour than cold air).

When air is **not saturated**, its actual vapour density is lower than the saturation vapour density.

The *relative humidity* is defined as the ratio of the actual vapour density to the saturation vapour density, expressed as a percentage:

$$relative\ humidity = \frac{actual\ vapor\ density}{saturated\ vapor\ density} 100$$

Relative humidity of 100%
---air saturated and can hold no more water

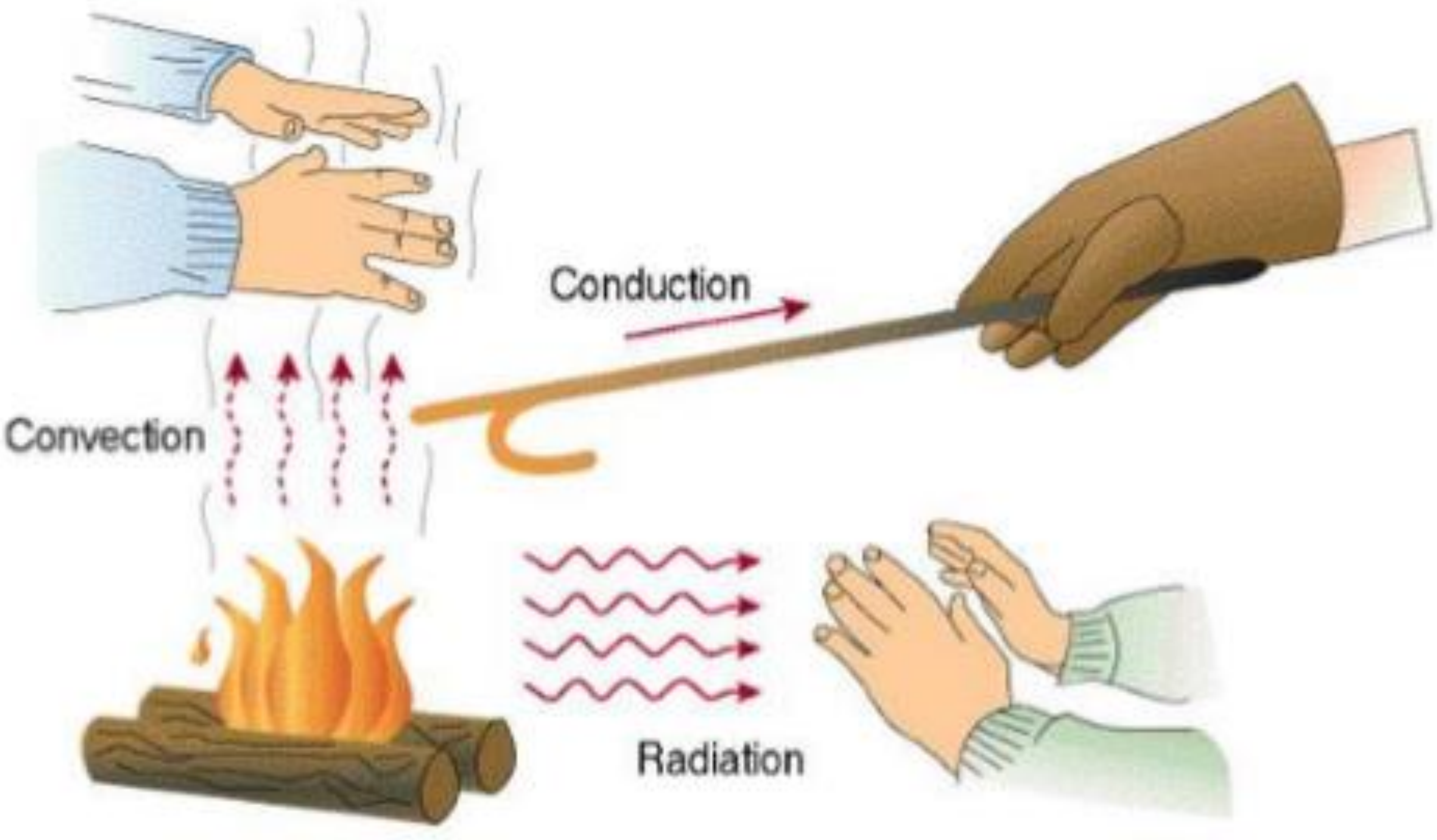
Relative humidity 40%--50%..... feels comfortable

Low relative humidity dries out skin and mucous membranes, may cause sinus and other respiratory problems.

High relative humidity suppresses the evaporation rate of perspiration; may be uncomfortable even at moderate temperatures.

HEAT TRANSFER

Heat Transfer Methods



Application Areas of Heat Transfer

- Many ordinary household appliances are designed, in whole or in part, by using the principles of heat transfer. Some examples:
- Design of the heating and air-conditioning system, the refrigerator and freezer, the water heater, the iron, and even the computer, the TV, and the VCR
- Energy-efficient homes are designed on the basis of minimizing heat loss in winter and heat gain in summer.
- Heat transfer plays a major role in the design of many other devices, such as car radiators, solar collectors, various components of power plants, and even spacecraft.
- The optimal insulation thickness in the walls and roofs of the houses, on hot water or steam pipes, or on water heaters is again determined on the basis of a heat transfer analysis with economic consideration (Figure 1.3)

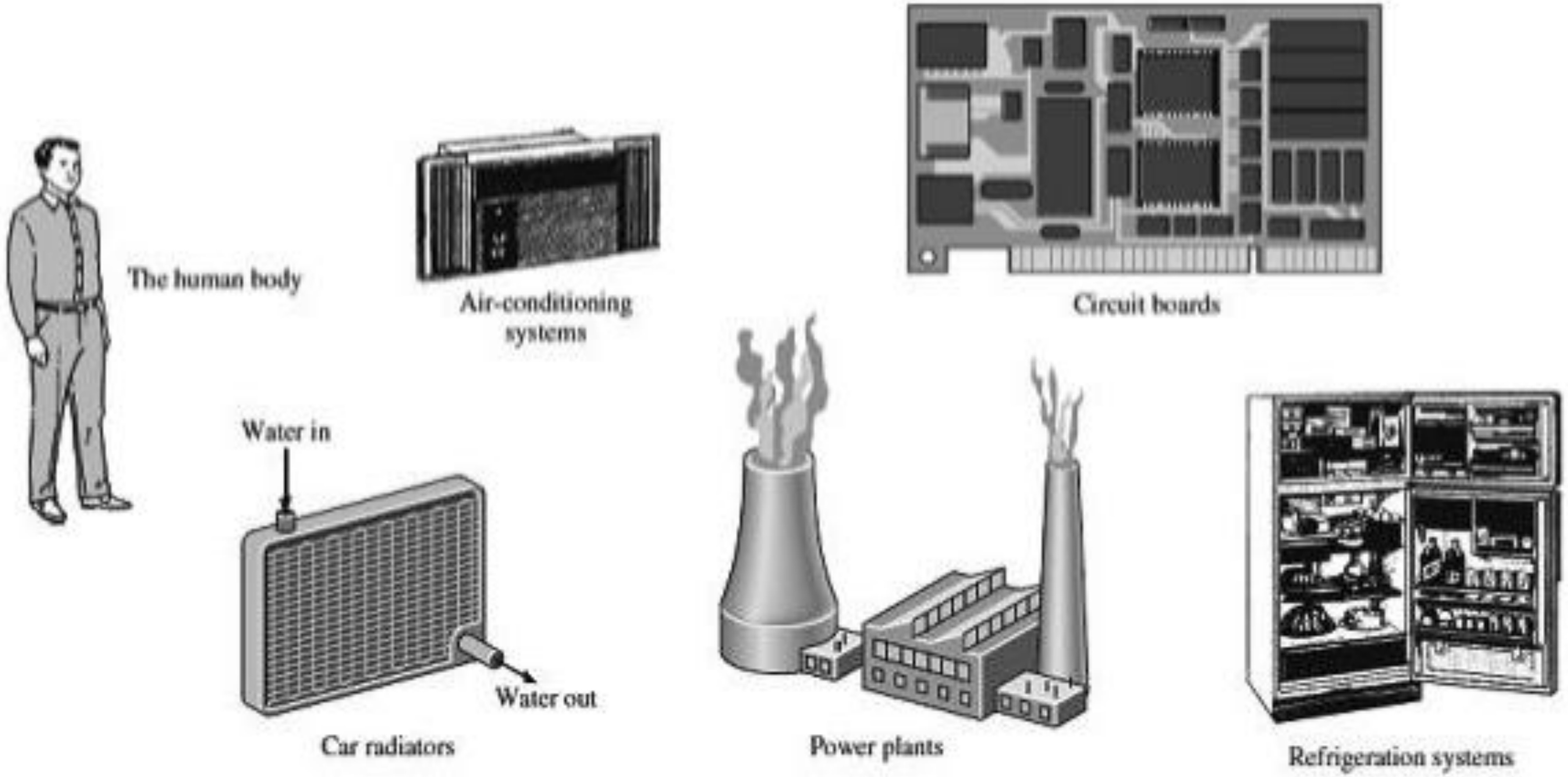


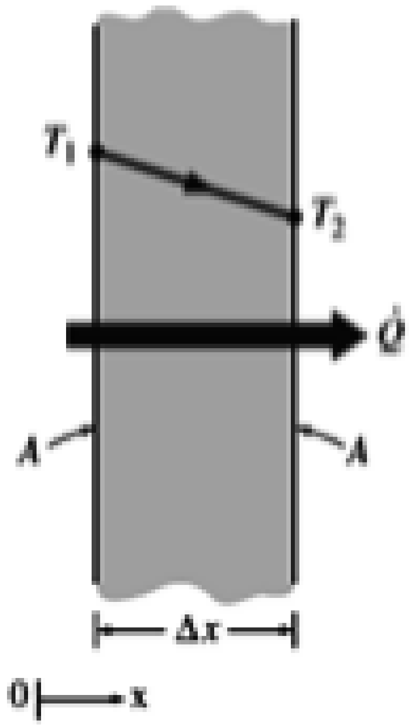
Fig. 1.3 Application of heat transfer

Heat Transfer Mechanisms

– Heat can be transferred in three different modes: conduction, convection, and radiation. All modes of heat transfer require the existence of a temperature difference, and all modes are from the high-temperature medium to a lower-temperature one.

Conduction

- Conduction is 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. Conduction can take place in solids, liquids, or gases.
- In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.
- In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons.
- The rate of heat conduction through a medium depends on the geometry of the medium, its thickness, and the material of the medium, as well as the temperature difference across the medium.
- We know that wrapping a hot water tank with glass wool (an insulating material) reduces the rate of heat loss from the tank. The thicker the insulation, the smaller the heat loss.
- We also know that a hot water tank will lose heat at a higher rate when the temperature of the room housing the tank is lowered. Further, the larger the tank, the larger the surface area and thus the rate of heat loss.



– Consider steady heat conduction through a large plane wall of thickness $\Delta x = L$ and area A, as shown in figure 1.4. The temperature difference across the wall is $\Delta T = T_2 - T_1$.

- Experiments have shown that the rate of heat transfer $\dot{Q}$ through the wall is doubled when the temperature difference ΔT across the wall or the area A normal to the direction of heat transfer is doubled, but is halved when the wall thickness L is doubled.
- Thus we conclude that 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. That is,

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

or

$$\dot{Q}_{cond} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x}\ (W) --------(1.1)$$

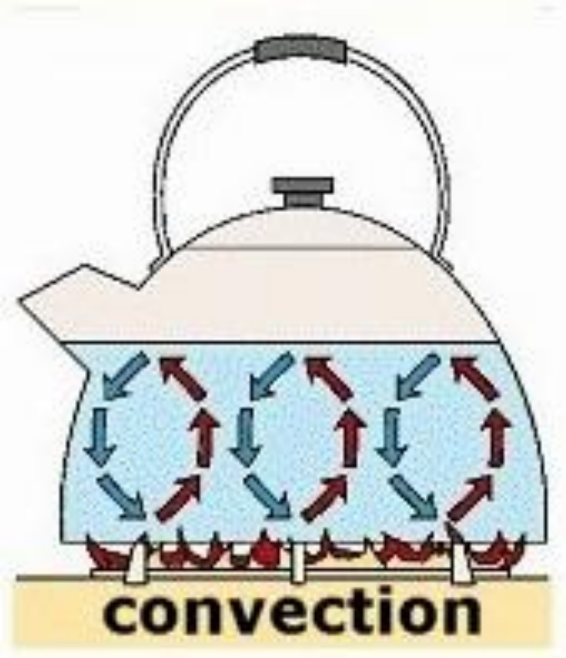
- The relation above indicates that the rate of heat conduction in a direction is proportional to the temperature gradient in that direction.

- The heat transfer area A is always normal to the direction of heat transfer.

Thermal Conductivity

- The thermal conductivity of a material can be defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.
- The thermal conductivity of a material is a measure of the ability of the material to conduct heat.
- A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or insulator.
- Note that materials such as copper and silver that are good electric conductors are also good heat conductors, and have high values of thermal conductivity.
- Materials such as rubber, wood, and styrofoam are poor conductors of heat and have low conductivity values.

Convection



- Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion.
- The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

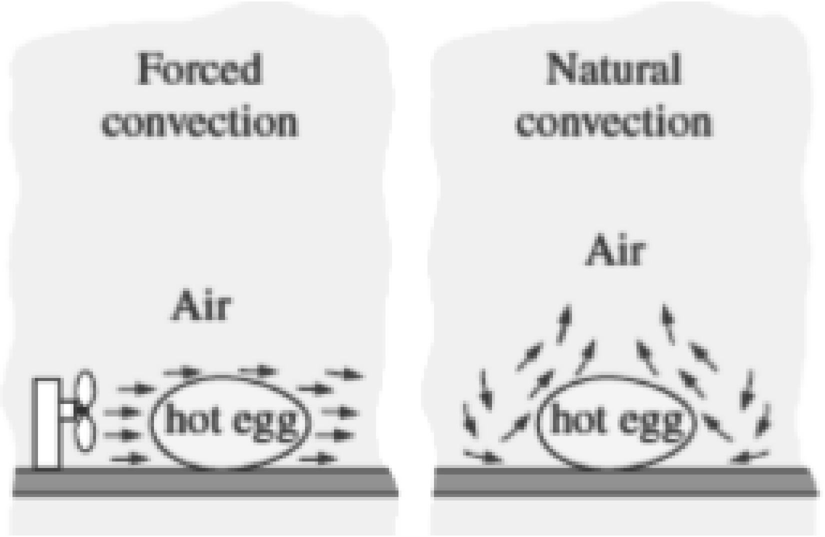


Fig. 1.6 Forced and Free (Natural) convection

Convection is called forced convection if the fluid is forced to flow over the surface by external means such as a fan, pump, or the wind.
In contrast, convection is called natural (or free) convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid (Figure 1.6).

- It is an experimentally determined parameter whose value depends on all the variables influencing convection such as the surface geometry, the nature of fluid motion, the properties of the fluid, and the bulk fluid velocity.

Radiation

- Radiation is 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 energy by radiation does not require the presence of an intervening medium. In fact, energy 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.

- In heat transfer studies we are interested in thermal radiation, which is the form of radiation emitted by bodies because of their temperature. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temperature.

Thermal Expansion