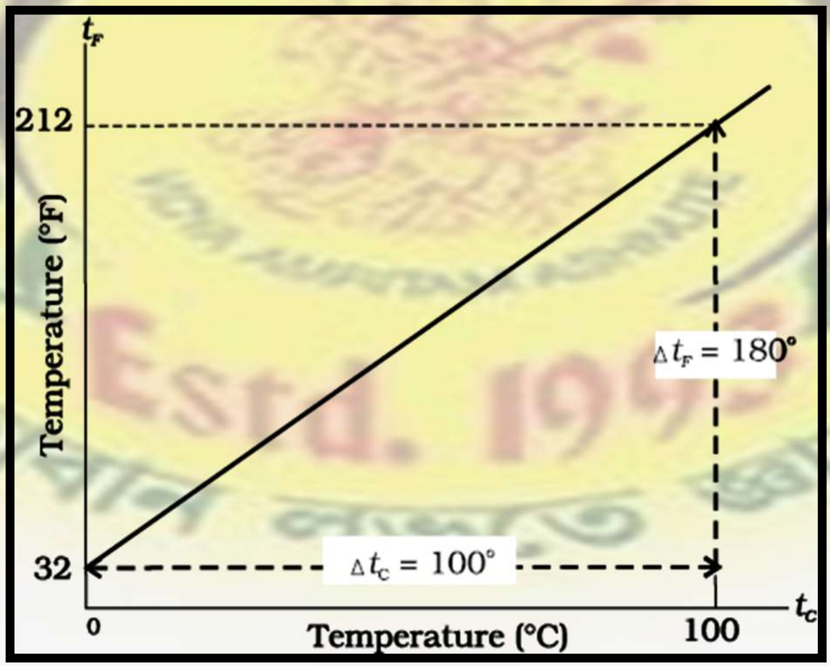
Temperature

- Temperature is a relative measure, or indication of hotness or coldness. It is a relative concept saying whether an object is hot or cold, just like saying how tall or short an object is.
- The heat transfer takes place between the system and the surrounding medium, until the body and the surrounding medium are at the same temperature.
- In practical day to day life, the temperature of an object or a body is measured by thermometer.
- SI unit of temperature is Kelvin (K), and degree Celsius (^{o}C) is a commonly used unit of temperature.

- A necessary fixed point is taken as a reference so that the temperatures can be calculated or calibrated. The ice point (freezing point) and the steam point (boiling point) of water are two convenient fixed points and are known as the freezing and boiling points, respectively.
- The two familiar temperature scales are the Fahrenheit temperature scale and the Celsius temperature scale.
- The ice and steam point have values 32 °F and 212 °F, respectively, on the Fahrenheit scale and 0 °C and 100 °C on the Celsius scale.
- On the Fahrenheit scale, there are 180 equal intervals between two reference points, and on the Celsius scale, there are 100.

- A relationship for converting between the two scales may be obtained from a graph of Fahrenheit temperature (t_F) versus celsius temperature (t_C) in a straight line (Fig. 10.1), whose equation is –

$$(t_F - 32)/180 = t_C /100$$



Heat

- Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference. In other words it is a form of energy associated with the motion of atoms and molecules in a substance.
- When heat is transferred to a substance, it causes the particles to move more rapidly, increasing their kinetic energy. This increase in kinetic energy is perceived as a rise in temperature. Conversely, when heat is removed from a substance, the particles move more slowly, and the temperature decreases.
- The SI unit of heat energy transferred is expressed in joule (J)

Thermal Expansion

- The increase in the dimensions of a body due to the increase in its temperature is called thermal expansion.
- You may have observed that sometimes sealed bottles with metallic lids are so tightly screwed that one has to put the lid in hot water for some time to open it. This would allow the metallic lid to expand, thereby loosening it to unscrew easily.
- In case of liquids, you may have observed that mercury in a thermometer rises, when the thermometer is put in slightly warm water. If we take out the thermometer from the warm water the level of mercury falls again.

- Similarly, in case of gases, a balloon partially inflated in a cool room may expand to full size when placed in warm water. On the other hand, a fully inflated balloon when immersed in cold water would start shrinking due to contraction of the air inside.
- Objects expand when heat is applied due to the increase in the average kinetic energy of their constituent particles, typically atoms or molecules. As you heat a substance, you are providing energy to its particles, causing them to vibrate and move more rapidly.
- This increased motion results in the particles pushing against each other and exerting greater force on the boundaries of the substance. In solids, the particles are arranged in a relatively fixed structure, and their increased movement disrupts this structure, causing the substance to expand.

- Linear expansion – The expansion in length is called linear expansion.

Mathematically - $\Delta l/l = \alpha_l \Delta T$; α_l = coefficient o f linear expansion

- Area expansion - The expansion in area is called area expansion.

Mathematically - $\Delta A/A = 2\alpha_a \Delta T$; α_a = coefficient of area expansion

- Volume expansion - The expansion in volume is called volume expansion.

Mathematically - $\Delta V/V = 3\alpha_v \Delta T$; α_v = coefficient of volume expansion

Thermal expansion of Water

- Water exhibits an anomalous behavior; it contracts on heating between 0 °C and 4 °C.
- The volume of a given amount of water decreases as it is cooled from room temperature, until its temperature reaches 4 °C.
- Below 4 °C, the volume increases, and therefore, the density decreases.
- This means that water has the maximum density at 4 °C. This property has an important environmental effect: bodies of water, such as lakes and ponds, freeze at the top first.

- As a lake cools toward 4 °C, water near the surface loses energy to the atmosphere, becomes denser, and sinks; the warmer, less dense water near the bottom rises. However, once the colder water on top reaches temperature below 4 °C, it becomes less dense and remains at the surface, where it freezes. If water did not have this property, lakes and ponds would freeze from the bottom up, which would destroy much of their animal and plant life.

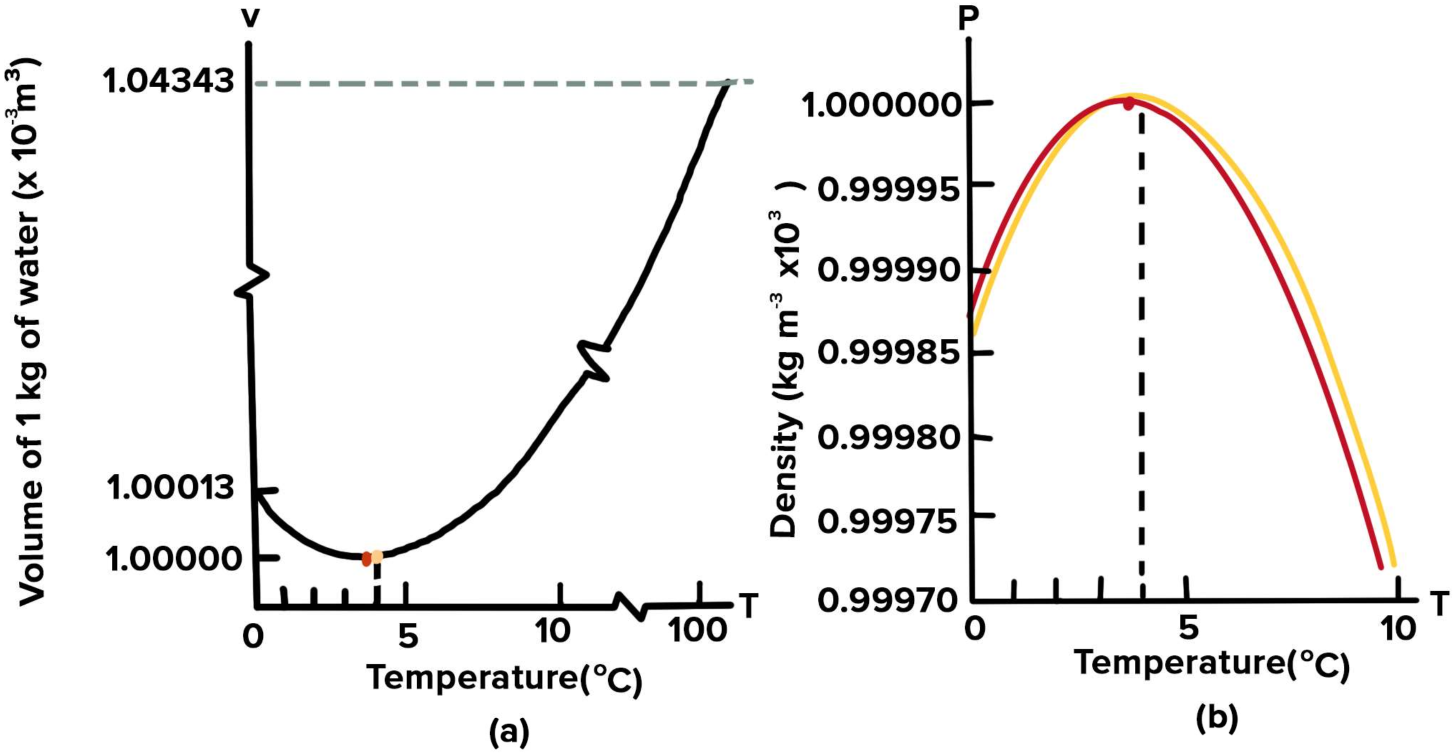


Fig 7.1 (a) Above 4°C water expands with increasing temperature, but form 4°C down to 0°C. it expands. (b) Water has its maximum density at 4°C

Specific Heat Capacity

- The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by it, is characterized by a quantity called the heat capacity of that substance.

Mathematically – $S = \Delta Q/\Delta T$;

here, S = heat capacity; ΔQ = amount of heat supplied to the substance;

ΔT = change in temperature

- Every substance has a unique value for the amount of heat absorbed or given off to change the temperature of unit mass of it by one unit. This quantity is referred to as the specific heat capacity of the substance.

- The specific heat capacity is the property of the substance which determines the change in the temperature of the substance (undergoing no phase change) when a given quantity of heat is absorbed (or given off) by it.
- It is defined as the amount of heat per unit mass absorbed or given off by the substance to change its temperature by one unit. It depends on the nature of the substance and its temperature.
- The SI unit of specific heat capacity is J kg^{-1} K^{-1}

Mathematically – $s = S/m = 1/m\ (\Delta Q/\Delta T)$; s = specific heat capacity

- If the amount of substance is specified in terms of moles μ (1 mole = 6.022×10^{23} units), instead of mass m in kg, we can define heat capacity per mole of the substance.

Mathematically – $C = S/\mu = 1/\mu\ (\Delta Q/\Delta T)$; C = molar specific heat capacity

- The SI unit of molar specific heat capacity is J mol^{-1} K^{-1}.
- Now in case of gases, certain conditions are needed; If the gas is held under constant pressure during the heat transfer, then it is called the molar specific heat capacity at constant pressure and is denoted by C_p .
- And, if the volume of the gas is maintained during the heat transfer, then the corresponding molar specific heat capacity is called molar specific heat capacity at constant volume and is denoted by C_v .

Calorimetry

- Calorimetry means measurement of heat.
- A device in which heat measurement can be done is called a calorimeter.

q: Calculate the heat required to raise 0.6 Kg of sand from 30°C to 90°C? (Specific Heat of sand = 830 J/Kg°C)

q: A sphere of 0.047 kg aluminium is placed for sufficient time in a vessel containing boiling water, so that the sphere is at 100 °C. It is then immediately transfered to 0.14 kg copper calorimeter containing 0.25 kg water at 20 °C. The temperature of water rises and attains a steady state at 23 °C. Calculate the specific heat capacity of aluminium.

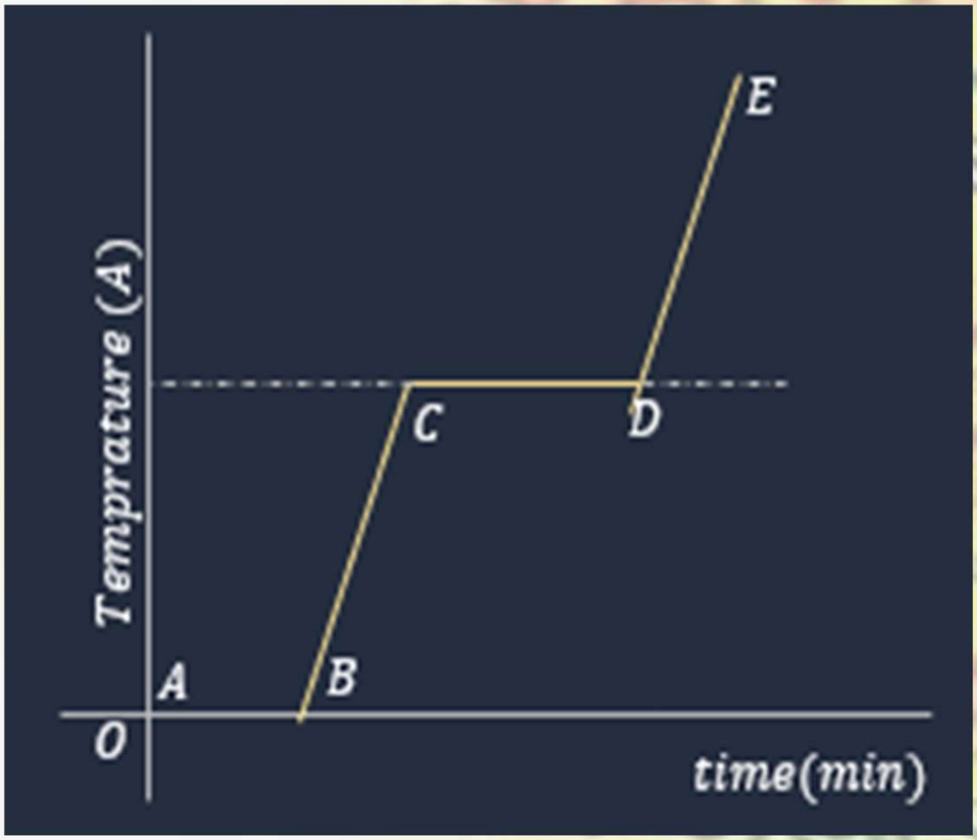
Change of State

- As we know, there are three states of matter – Solid, Liquid and Gas.
- The change of state from solid to liquid is called melting or fusion.
- The change of state from liquid to solid is called freezing.
- The change of liquid to gas is called evaporation or vaporization.
- It is observed that the temperature remains constant until the entire amount of the solid substance melts. That is, both the solid and the liquid states of the substance coexist in thermal equilibrium during the change of states from solid to liquid.

- The temperature at which the solid and the liquid states of the substance is in thermal equilibrium with each other is called its melting point.
- Pressure also plays a vital role is changing state and the best phenomenon to explain it is the phenomenon of regelation.
- Regelation is a phenomenon observed in certain materials, particularly ice, where melting occurs under pressure and then refreezing happens when the pressure is released. This process allows ice to melt at a temperature lower than its normal melting point when subjected to pressure and then refreeze when the pressure is reduced.

- In case of vaporisation, we also see that the temperature remains constant until the entire amount of the liquid is converted into vapour. That is, both the liquid and vapour states of the substance coexist in thermal equilibrium, during the change of state from liquid to vapour.
- The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point.
- With the increase or decrease in pressure, the boiling point also increases and decreases respectively.

- However, all substances do not pass through the three states: solid-liquid-gas.
- The change from solid state to vapour state without passing through the liquid state is called sublimation, and the substance is said to sublime.
- During the sublimation process both the solid and vapour states of a substance coexist in thermal equilibrium.



A plot of temperature versus time showing the changes in the state of ice on heating

Latent Heat

- The amount of heat per unit mass transferred during change of state of the substance is called latent heat of the substance for the process.
- The heat required during a change of state depends upon the heat of transformation and the mass of the substance undergoing a change of state.
- If mass 'm' of a substance undergoes a change from one state to the other, then the quantity of heat required is given by –

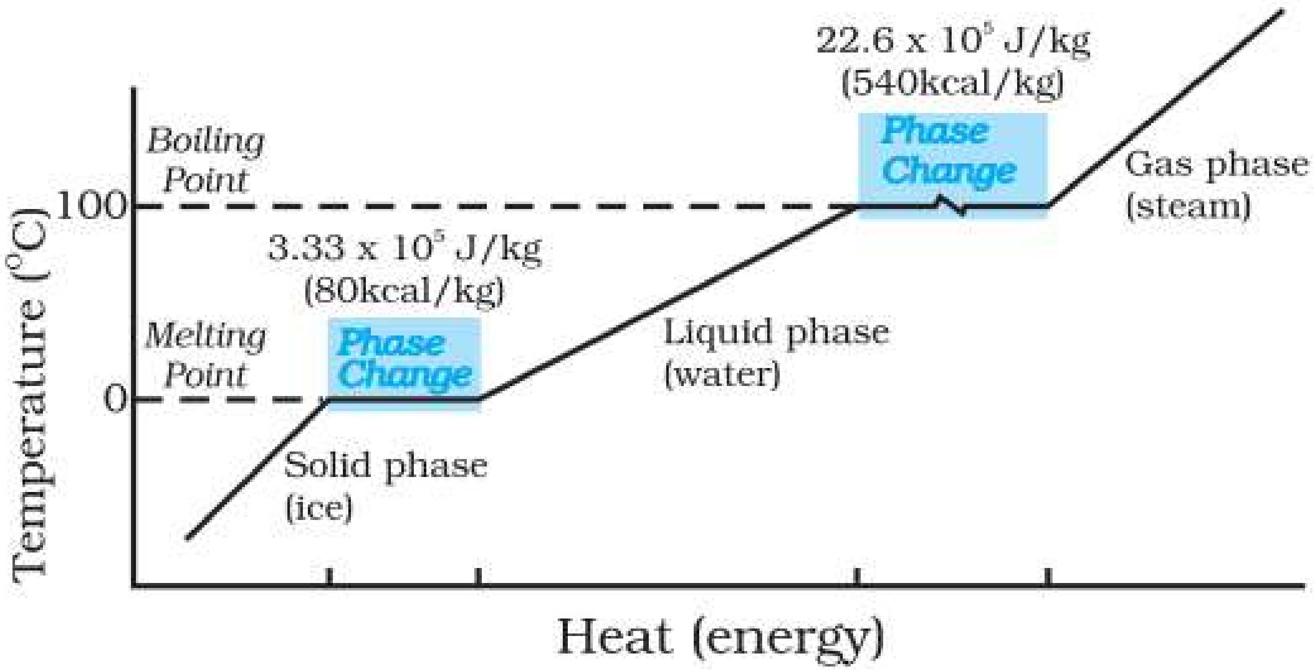
$$Q = mL$$

$$\text{or, } L = Q/m \text{ ; } L = \text{latent heat.}$$

- Its SI unit is J kg^{-1} .
- The value of 'L' also depends on the pressure.
- The latent heat for a solid-liquid state change is called latent heat of fusion (L_f).
- The latent heat for a liquid-gas state change is called the latent heat of vaporisation (L_v).

q: When 0.15 kg of ice at 0 °C is mixed with 0.30 kg of water at 50 °C in a container, the resulting temperature is 6.7 °C. Calculate the heat of fusion of ice. (s_{water} = 4186 J kg–1 K–1)

q: Calculate the heat required to convert 3 kg of ice at –12 °C kept in a calorimeter to steam at 100 °C at atmospheric pressure. Given specific heat capacity of ice = 2100 J kg–1 K–1, specific heat capacity of water = 4186 J kg– 1 K–1, latent heat of fusion of ice = 3.35 × 105 J kg–1 and latent heat of steam = 2.256 ×106 J kg–1.



Temperature versus heat for water at 1 atm pressure (not to scale).

Modes of Transfer of Heat

- Conduction –
  - Conduction is the mechanism of transfer of heat between two adjacent parts of a body because of their temperature difference.
  - Heat conduction can also be described quantitatively as the time rate of heat flow in a material for a given temperature difference.
  - The rate of heat flow is given as –

$$H = KA\,(T_c - T_D)/L\ ,$$

here, T_C and T_D are temperature differences at two ends of a material

K = thermal conductivity

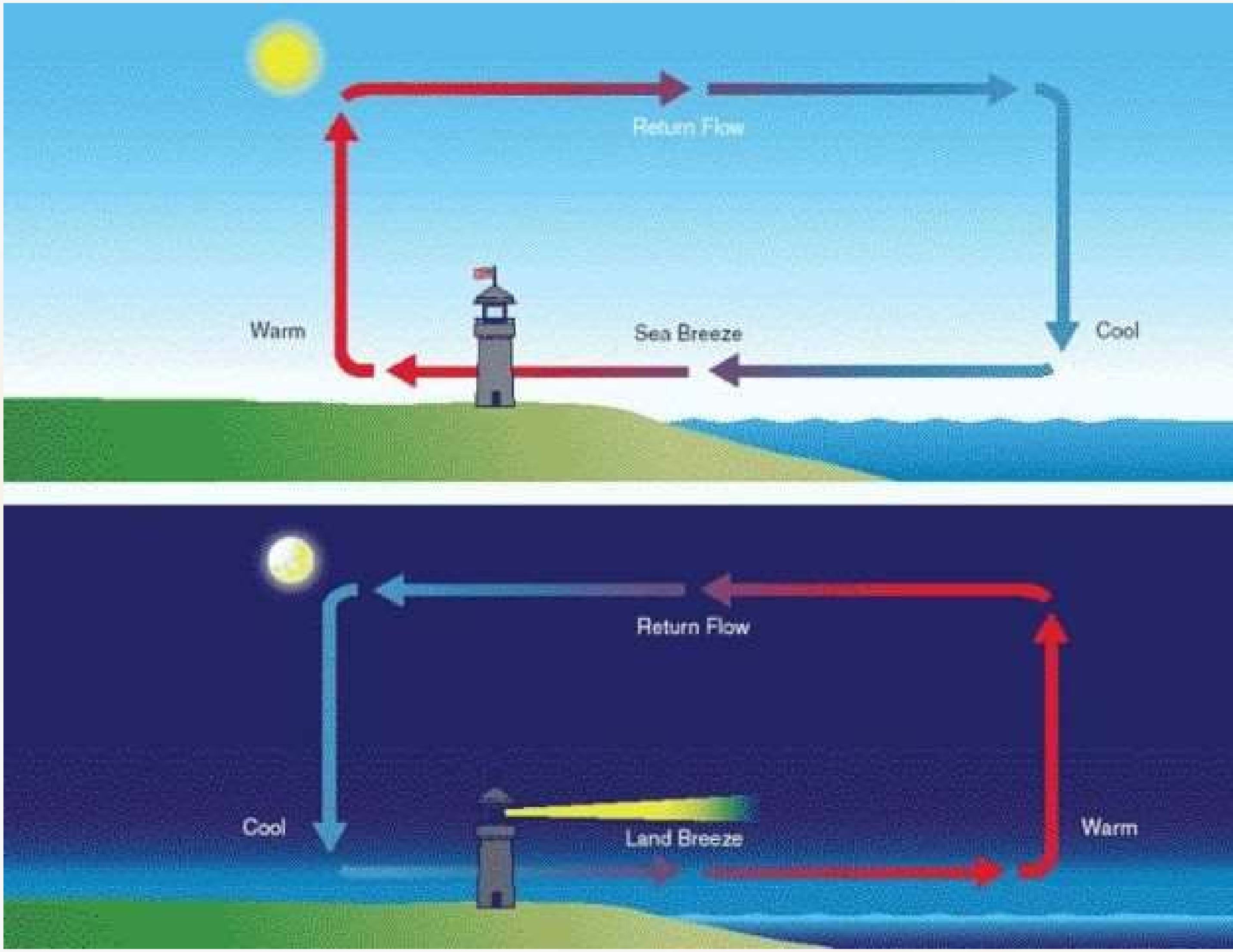
L= length of the material

A = cross section area of the material

- The greater the value of K for a material, the more rapidly will it conduct heat.
- The SI unit of K is J s–1 m–1 K–1 or W m–1 K–1.
- Houses made of concrete roofs get very hot during summer days because thermal conductivity of concrete (though much smaller than that of a metal) is still not small enough. Therefore, people, usually, prefer to give a layer of earth or foam insulation on the ceiling so that heat transfer is prohibited and keeps the room cooler.
- In some situations, heat transfer is critical. In a nuclear reactor, for example, elaborate heat transfer systems need to be installed so that the enormous energy produced by nuclear fission in the core transits out sufficiently fast, thus preventing the core from overheating.

- Convection –
    - Convection is a mode of heat transfer by actual motion of matter. It is possible only in fluids.
    - When a fluid is heated from below, the hot part expands and, therefore, becomes less dense. Because of buoyancy, it rises and the upper colder part replaces it. This again gets heated, rises up and is replaced by the relatively colder part of the fluid. The process goes on. This mode of heat transfer is evidently different from conduction. This is natural convection in which gravity also plays its part.

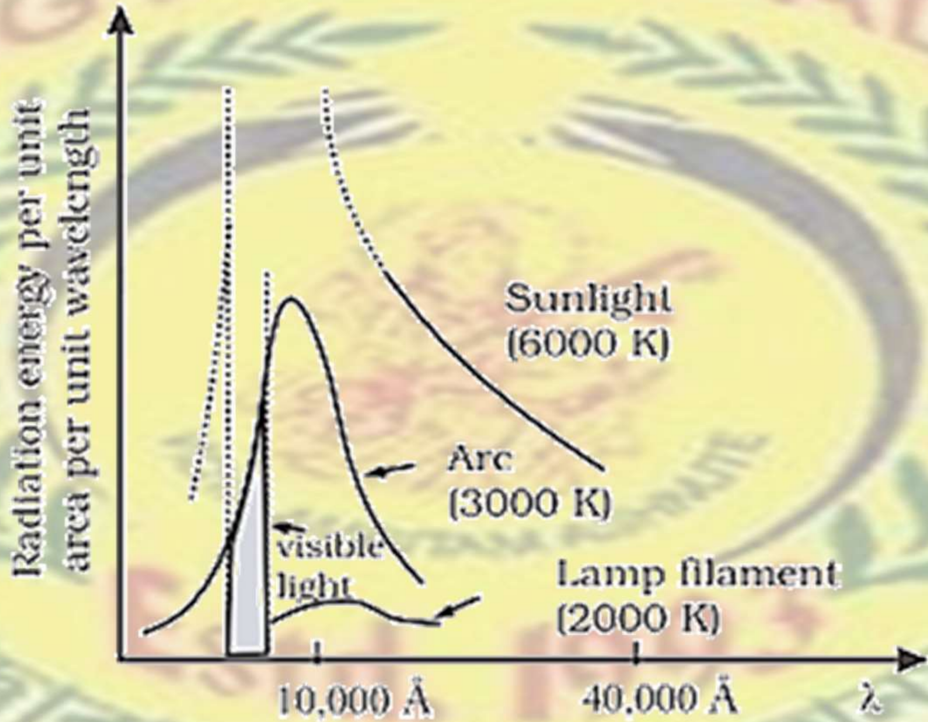
- In forced convection, material is forced to move by a pump or by some other physical means. The common examples of forced convection systems are forced-air heating systems in home, the human circulatory system, and the cooling system of an automobile engine.
- Natural convection is responsible for many familiar phenomena. During the day, the ground heats up more quickly than large bodies of water do. This occurs both because water has a greater specific heat capacity and because mixing currents disperse the absorbed heat throughout the great volume of water. The air in contact with the warm ground is heated by conduction. It expands, becoming less dense than the surrounding cooler air. As a result, the warm air rises (air currents) and the other air moves (winds) to fill the space-creating a sea breeze near a large body of water. Cooler air descends, and a thermal convection cycle is set up, which transfers heat away from the land. At night, the ground loses its heat more quickly, and the water surface is warmer than the land. As a result, the cycle is reveresed


Return Flow
Warm
Sea Breeze
Cool
Return Flow
Cool
Land Breeze
Warm

- Radiation –
    - This type of mechanism for heat transfer needs no medium; it is called radiation and the energy so transferred by electromagnetic waves is called radiant energy.
    - All bodies emit radiant energy, whether they are solid, liquid or gas. The electromagnetic radiation emitted by a body by virtue of its temperature, like radiation by a red hot iron or light from a filament lamp is called thermal radiation. When this thermal radiation falls on other bodies, it is partly reflected and partly absorbed. The amount of heat that a body can absorb by radiation depends on the color of the body.

- Black bodies absorb and emit radiant energy better than bodies of lighter colors.

- **Black Body Radiation -** The important thing about thermal radiation at any temperature is that it is not of one (or a few) wavelength(s) but has a continuous spectrum from the small to the long wavelengths. The energy content of radiation, however, varies for different wavelengths.



Radiation energy per unit area per unit wavelength
Sunlight
(6000 K)
Arc
(3000 K)
visible light
Lamp filament
(2000 K)
10,000 Å
40,000 Å
λ

- λ_m for which energy is the maximum decreases with increasing temperature. The relation between λ_m and T is given by what is known as Wien's Displacement Law:

$$\Lambda_m T = constant$$

The value of the constant (Wien's constant) is 2.9 × 10–3 m K.

- This law explains why the colour of a piece of iron heated in a hot flame first becomes dull red, then reddish yellow, and finally white hot.
- Wien's law is useful for estimating the surface temperatures of celestial bodies like, the moon, Sun and other stars. Light from the moon is found to have a maximum intensity near the wavelength 14 μm.
- The total electromagnetic energy radiated by a body at absolute temperature T is proportional to its size, its ability to radiate (called emissivity) and most importantly to its temperature.

- For a body, which is a perfect radiator, the energy emitted per unit time (H) is given by

$$H = A\sigma T^4$$

This relation obtained experimentally by Stefan and later proved theoretically by Boltzmann is known as Stefan-Boltzmann law and the constant σ is called Stefan-Boltzmann constant.

Its value in SI units is 5.67 × 10–8 W m–2 K–4.