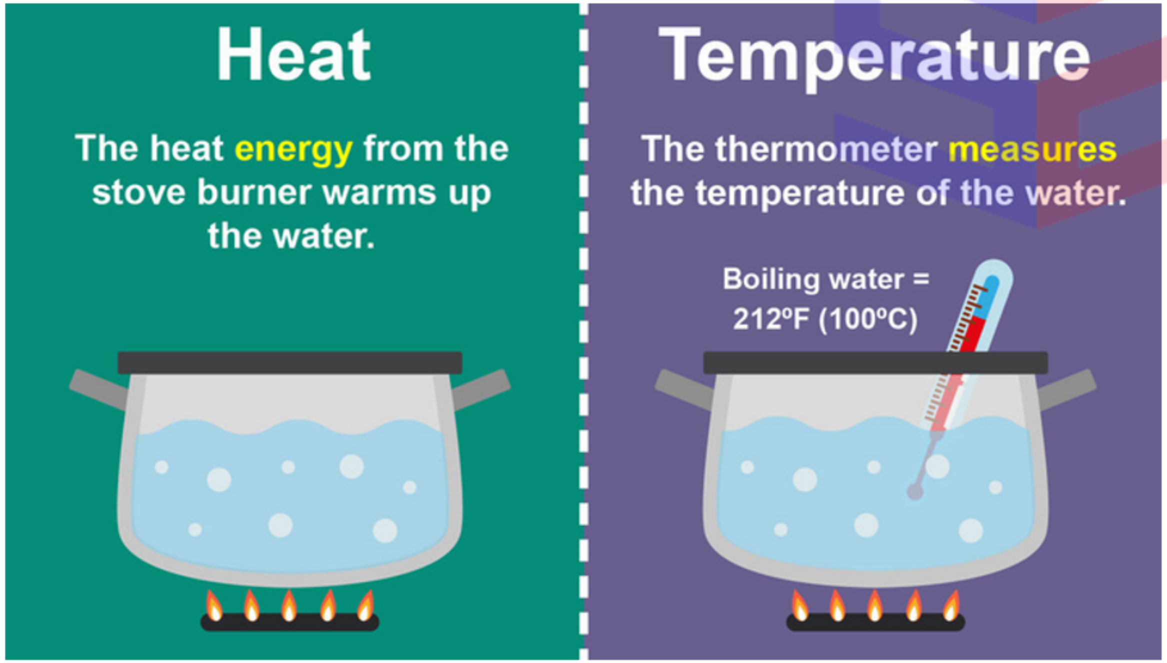
Engineering Physics

Thermal Physics

- Temperature & Heat
- Thermal expansion
- Thermal stress
- Expansion joints
- Bimetallic strips
- Specific Heat Capacity
- Heat Transfer
- Thermal conductivity
- Heat conductions in solids
- Flow of heat through compound media

Temperature & Heat

- Temperature is a relative measure, or indication of hotness or coldness.
- Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference.



Measure of temperature

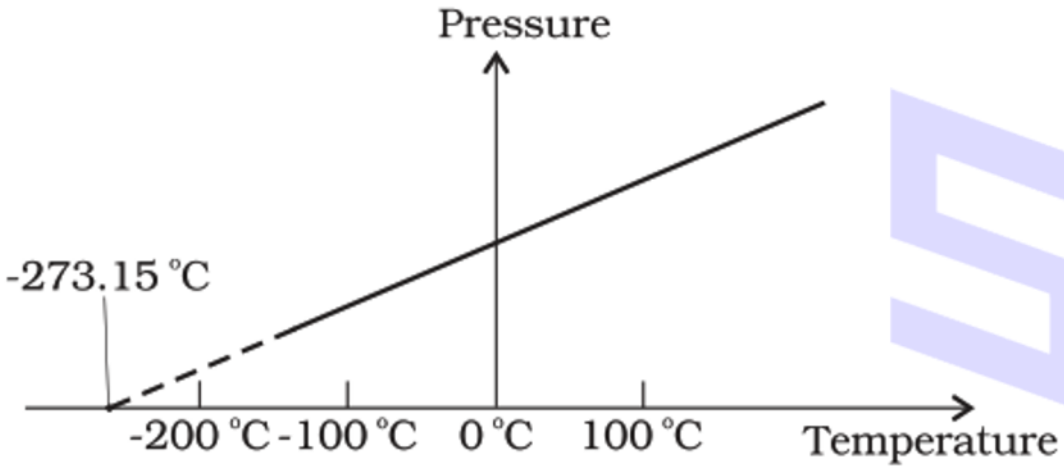
- Obtained using a thermometer
- Unit : Celsius (˚C) or Fahrenheit (˚F)

$$\frac{t_F - 32}{180} = \frac{t_C}{100}$$

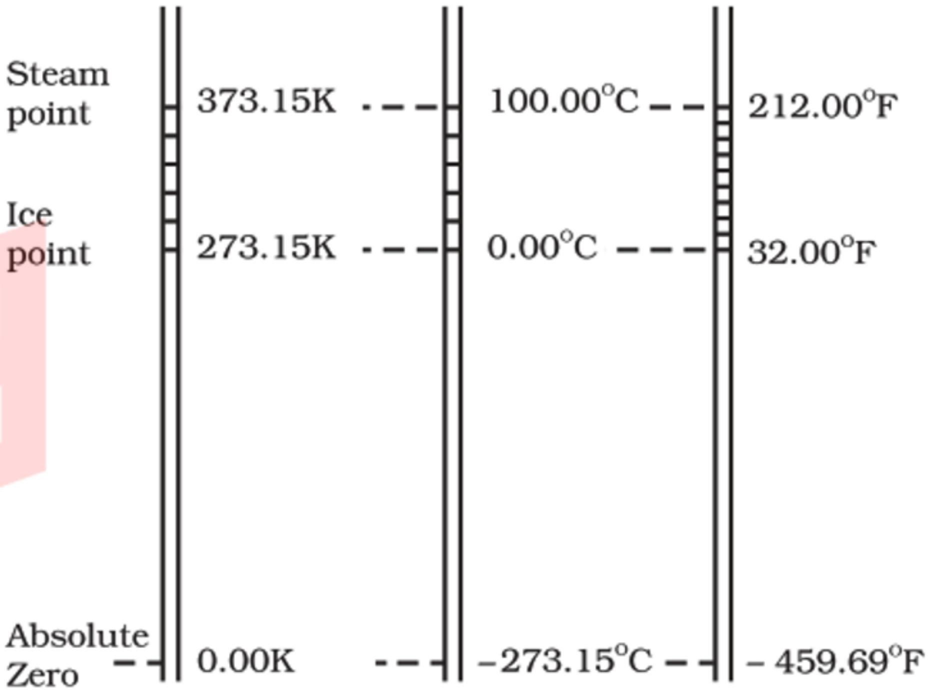
- The Celsius and Fahrenheit scales are equal at - 40˚C and - 40˚F.

Temperature & Heat

- **Absolute Zero Temperature: -273.15˚C**



Pressure versus temperature of a low density gas kept at constant volume



Comparision of the Kelvin, Celsius and Fahrenheit temperature scales.

Temp in Kelvin K = ˚C + 273

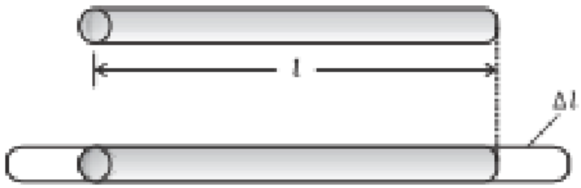
Thermal Expansion

- A change in the temperature of a body causes change in its dimensions.
- The increase in the dimensions of a body due to the increase in its temperature is called **thermal expansion**.
- The expansion in length is called **linear expansion**. The expansion in area is called **area expansion**. The expansion in volume is called **volume expansion.**
- For small change in temperature, ΔT, the fractional change in length, Δl/l, is directly proportional to ΔT.

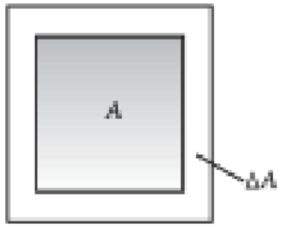
$$\frac{\Delta l}{l} = \alpha_1 \, \Delta T$$

α_1 = coefficient of linear expansion

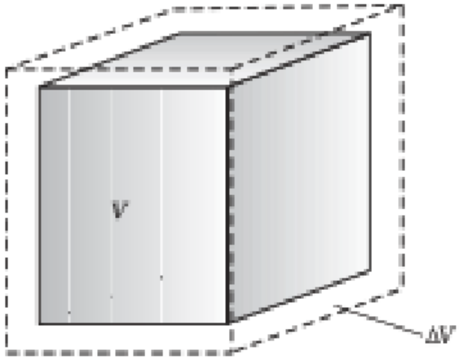
Linear expansion $\Delta l = \alpha_1 \, l \, \Delta T$



Linear Expansion



Area Expansion



Volume Expansion

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Thermal Expansion

- **Coefficient of linear expansion, α_l**

Materials	α_l (10^{-5} K^{-1})
Aluminium	2.5
Brass	1.8
Iron	1.2
Copper	1.7
Silver	1.9
Gold	1.4
Glass (pyrex)	0.32
Lead	0.29

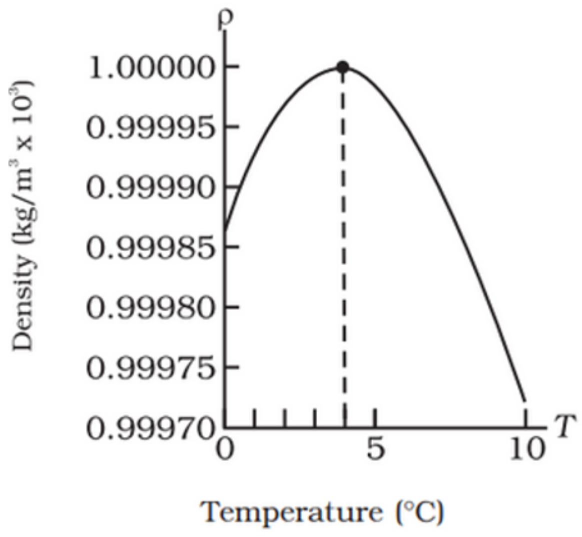
Coefficient of superficial expansion $\alpha_a = 2\,\alpha_l$

Coefficient of cubical expansion $\alpha_v = 3\,\alpha_l$

- **Coefficient of volume expansion,** $\alpha_V = \left(\frac{\Delta V}{V}\right)\frac{1}{\Delta T}$

Materials	α_v (K^{-1})
Aluminium	7×10^{-5}
Brass	6×10^{-5}
Iron	3.55×10^{-5}
Paraffin	58.8×10^{-5}
Glass (ordinary)	2.5×10^{-5}
Glass (pyrex)	1×10^{-5}
Hard rubber	2.4×10^{-4}
Invar	2×10^{-6}
Mercury	18.2×10^{-5}
Water	20.7×10^{-5}
Alcohol (ethyl)	110×10^{-5}

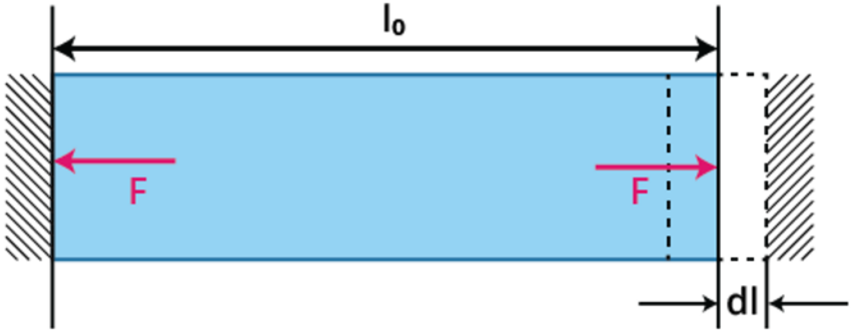
Thermal expansion of water



Water has a maximum density at 4 °C

Thermal Stress

- When preventing the thermal expansion of a rod by fixing its ends rigidly, the rod acquires a compressive strain due to the external forces provided by the rigid support at the ends.
- The corresponding stress set up in the rod is called thermal stress.
- The Thermal Stress developed $\frac{\Delta F}{A} = Y_{steel}\left(\frac{\Delta l}{l}\right)$
- Corresponding external force $\Delta F = AY_{\text{steel}}\left(\frac{\Delta l}{l}\right)$



Expansion Joint

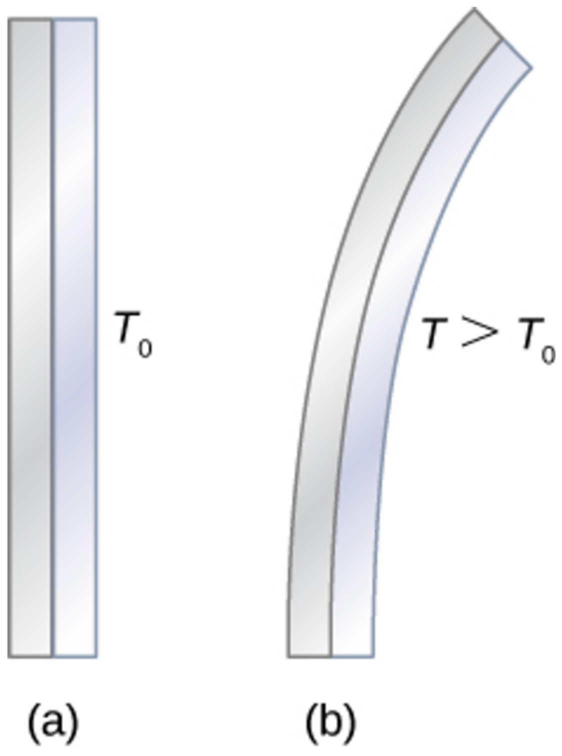
- Solids also undergo thermal expansion when temperature raises.
- A expansion joint, or movement joint, is an assembly designed to hold parts together while safely absorbing temperature-induced expansion and contraction of building materials.
- If the expansion is prevented thermal stress will be produced, it can damage the material.
- They are commonly found between sections of buildings, bridges, sidewalks, railway tracks, piping systems, ships, and other structures.

Bridge expansion joint

Pipe expansion joint

Bimetallic Strip

- A bimetallic strip is used to convert a temperature change into mechanical displacement.
- The strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper, or in some cases steel and brass



- The curvature of a bimetallic strip depends on temperature.
- (a) The strip is straight at the starting temperature, where its two components have the same length.
- (b) At a higher temperature, this strip bends to the right, because the metal on the left has expanded more than the metal on the right. At a lower temperature, the strip would bend to the left.

Specific heat capacity

- **Heat capacity** is defined as the amount of heat energy required to raise the temperature of a given quantity of matter by one degree Celsius.
- **Specific heat capacity:** The amount of heat per unit mass absorbed or rejected by the substance to change its temperature by one unit.
- Unit: J /(kg K)

Mass (g)

Temperature change (°C)

Heat (J) → $q = m \times C_s \times \Delta T$

Specific heat capacity (J/g · °C)

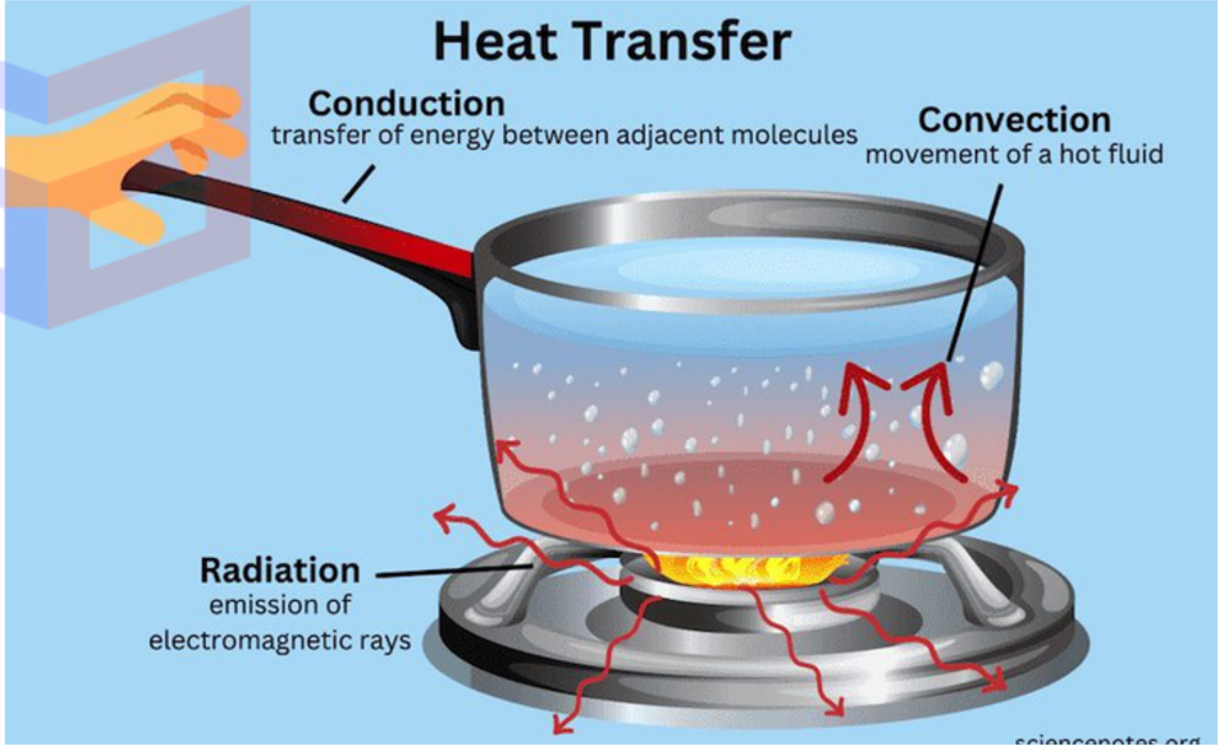
Substance	Specific heat capacity (J kg^{-1} K^{-1})
Aluminium	900.0
Carbon	506.5
Copper	386.4
Lead	127.7
Silver	236.1
Tungesten	134.4
Water	4186.0
Ice	2060
Glass	840
Iron	450
Kerosene	2118
Edible oil	1965
Mercury	140

Heat Transfer

- **Heat is energy transfer from one system to another or from one part of a system to another part, arising due to temperature difference.**

- Modes of Heat Transfer

1. **Conduction** - Medium required
2. **Convection** - Medium required
3. **Radiation** - No Medium required



Conduction

- Conduction is the process by which heat energy is transmitted through collisions between neighboring atoms or molecules. Conduction occurs more readily in solids and liquids, where the particles are closer together in gases.

- Fourier's Law of Heat Conduction

Heat flux is directly proportional to the magnitude of the temperature gradient.

$$q = -k\frac{\Delta T}{\Delta x}$$

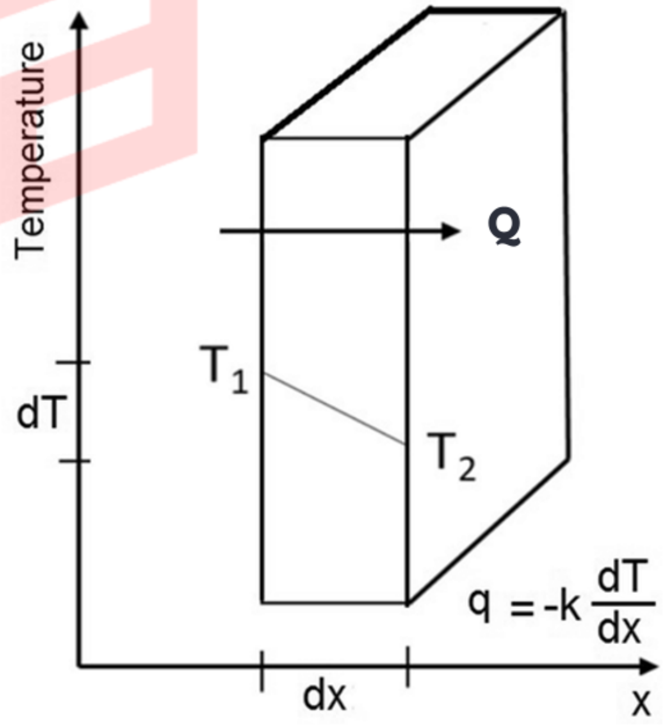
ΔT - Temperature difference, K

Δx - Distance, m

k - Thermal conductivity, W/(m.K)

ΔT/Δx - Temperature gradient

q - Heat flux = Q/A, W/m²



Heat Transfer Rate (Q)

$$\dot{Q}_{wall} = -kA\frac{T_2 - T_1}{L} = -\frac{T_2 - T_1}{R_t}$$

Thermal resistance (R)

$$R_t = \frac{L}{kA}$$

Heat Flux (q)

Heat flux is rate of heat transfer per unit area

$$q = Q/A$$

Thermal Conductivity, k

- The constant of proportionality K is called the thermal conductivity of the material.
- The greater the value of K for a material, the more rapidly will it conduct heat.
- Unit: W/(m K)
- Diamond has highest thermal conductivity, 2000-2200 W/(mK)

Materials	Thermal conductivity ($J\ s^{-1}\ m^{-1}\ K^{-1}$)
Metals	
Silver	406
Copper	385
Aluminium	205
Brass	109
Steel	50.2
Lead	34.7
Mercury	8.3

Materials	Thermal conductivity ($J\ s^{-1}\ m^{-1}\ K^{-1}$)
Non-metals	
Insulating brick	0.15
Concrete	0.8
Body fat	0.20
Felt	0.04
Glass	0.8
Ice	1.6
Glass wool	0.04
Wood	0.12
Water	0.8

Thermal Conductivity, k

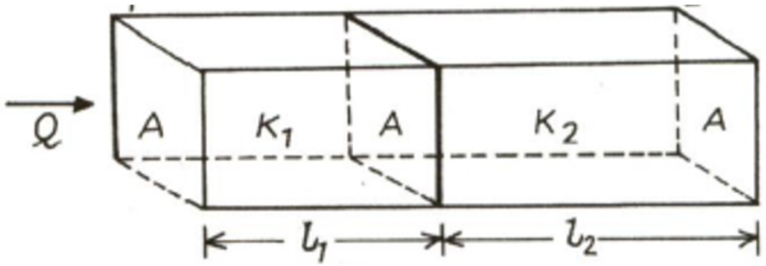
Gases	Thermal conductivity of gases increases with temperature as the molecules move fast.
Liquids	Thermal conductivity of liquids decreases with increasing temperature as the liquid expands and the molecules move apart
Metals	In the case of solids, because of lattice distortions, higher temperatures make it difficult for electrons to flow, hence the thermal conductivity of metals decreases.
Non-Metals	Electronic conductivity is practically non- existent and due to increase in phonon conduction, the thermal conductivity increases.

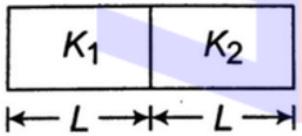
- Unlike other liquids, thermal conductivity of water (k) increases as the temperature increases, but this happens only up to 130˚C. Beyond 130˚C, k values decreases with temperature.

Heat conduction through compound media

- Heat Conduction through two or more materials having different thermal conductivities.

Series





$$R_{eq} = R_1 + R_2$$

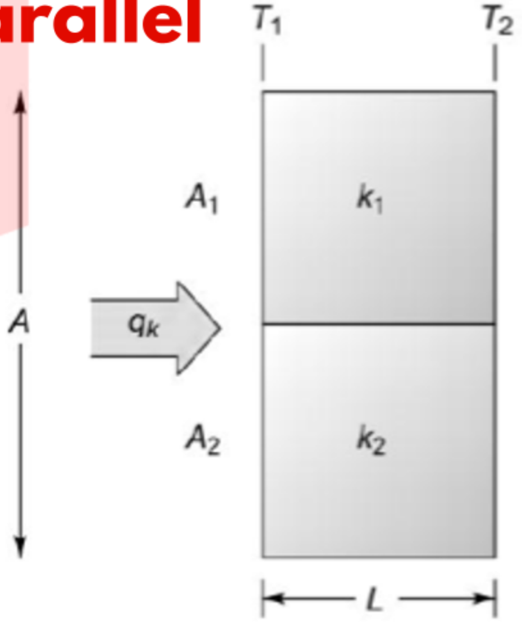
$$\frac{2L}{K_{eq}A} = \frac{L}{K_1 A} + \frac{L}{K_2 A}$$

$$K_{eq} = \frac{2K_1K_2}{K_1 + K_2}$$

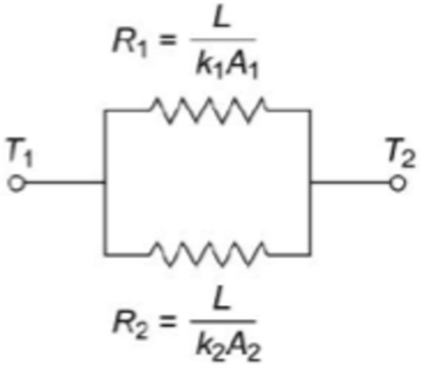
Equivalent Thermal Resistance

$$R = R_1 + R_2 = \frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2}$$

Parallel



Physical system



Thermal circuit

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}.$$

#1 A Bimetallic strip is example for the following:

(A) Temperature

(B) Thermal expansion

(C) Thermal gradient

(D) Thermal strain

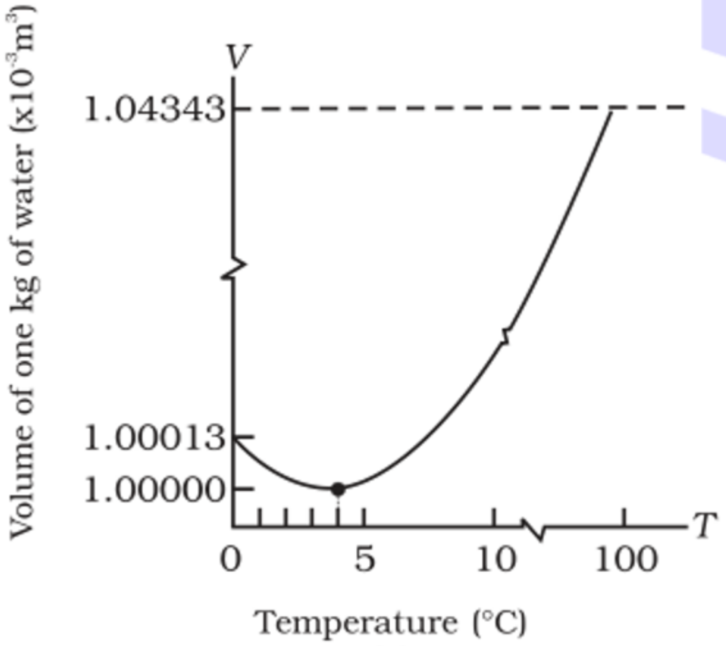
#2 Water has the density maximum at the temperature equal to

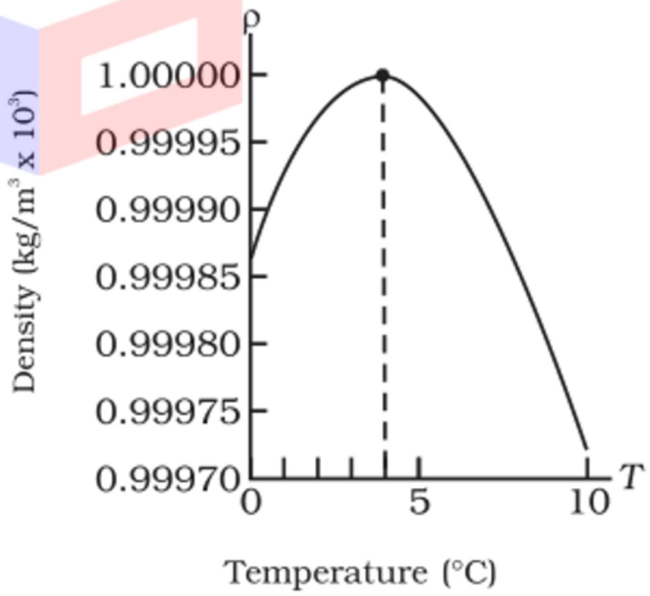
(A) – 4°C

(B) 0°C

(C) 4K

(D) 4°C





#3 As temperature increases, the thermal conductivity of water will

(A) Decrease

(B) Increase

(C) No change

(D) Either decrease or increase

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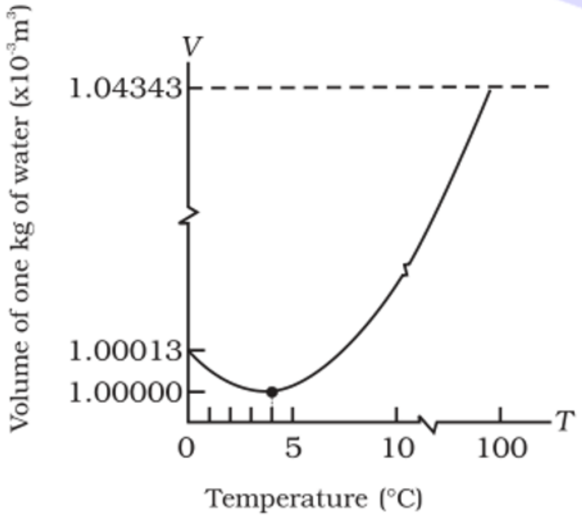
#4 When water is heated from 0°C to 10°C, its volume

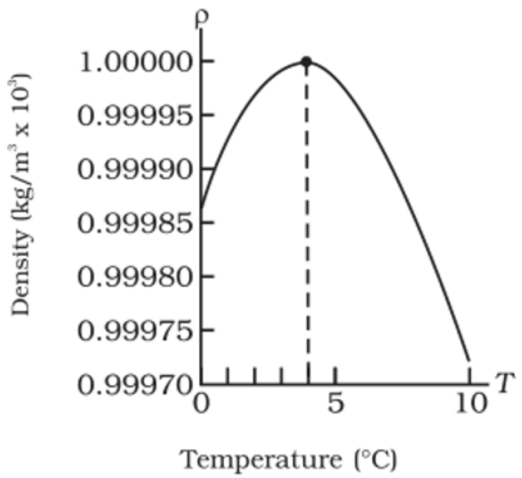
(A) Increases

(B) Decreases

(C) First increases and then decreases

(D) First decreases and then increases





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#5 In which of the following mode, heat is carried by the moving particle

(A) Conduction

(B) Convection

(C) Radiation

(D) Wave motion

#6 The specific heat capacity of brass is ___ J/kg/K.

(A) 272

(B) 370

(C) 730

(D) 186

Table of specific heat capacities in J/kg K

Aluminium	900	Lead	130
Brass	380	Mercury	140
Copper	400	Methylated spirit	2400
Glass (ordinary)	670	Sea-water	3900
Ice	2100	Water	4200
Iron	460	Zinc	380