1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 02 (Physics Part 2, Class XI)
Module Name/Title	Unit 7, Module 16, Heat Transfer Chapter 11, Thermal Properties of Matter
Module Id	keph_201105_eContent
Pre-requisites	Heat as energy, temperature, thermometer, influence of heat addition and removal of heat energy
Objectives	After going through this module, the students will be able to: • Understand the meaning of Heat Transfer • Distinguish between the three modes of heat transfer conduction, convection, radiation • Express coefficient of thermal conductivity
Keywords	Bulk properties of matter, intermolecular forces, conduction, convection, radiation

2. Development Team

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	Central Institute of Educational Technology, NCERT, New Delhi
Programme Coordinator	Dr. Mohd. Mamur Ali	Central Institute of Educational Technology, NCERT, New Delhi
Course Coordinator / PI	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Subject Matter Expert (SME)	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Review Team	Prof. V. B. Bhatia (Retd.) Associate Prof. N.K. Sehgal (Retd.) Prof. B. K. Sharma (Retd.)	Delhi University Delhi University DESM, NCERT, New Delhi

TABLE OF CONTENTS

1. UNIT SYLLABUS

UNIT 7: PROPERTIES OF BULK MATTER:

Chapter–9: Mechanical Properties of Solids:

Elastic behaviour, Stress-strain relationship, Hooke's law, Young's modulus, bulk modulus, shear, modulus of rigidity, Poisson's ratio, elastic energy.

Chapter–10: Mechanical Properties of Fluids:

Pressure due to a fluid column; Pascal's law and its applications (hydraulic lift and hydraulic brakes). Effect of gravity on fluid pressure. Viscosity, Stokes' law, terminal velocity, streamline and turbulent flow, critical velocity, Bernoulli's theorem and its applications. Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, application of surface tension ideas to drops, bubbles and capillary rise

Chapter–11: Thermal Properties of Matter:

Heat, temperature, thermal expansion; thermal expansion of solids, liquids and gases, anomalous expansion of water; specific heat capacity; Cp, Cv - calorimetry; change of state - latent heat capacity. Heat transfer-conduction, convection and radiation, thermal conductivity, qualitative ideas of Blackbody radiation, Wien's displacement Law, Stefan's law, Greenhouse effect

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 17 MODULES

Module 1	• **Forces between atoms and molecules making up the bulk matter** • **Reasons to believe that intermolecular and interatomic forces exist**

	• Overview of unit • State of matter • Study of a few selected properties of matter • Study of elastic behaviour of solids • Stationary fluid property: pressure and viscosity • Stationary liquid property: surface tension • Properties of Flowing fluids • Effect of heat on matter
Module 2	• Idea of deformation by external force • Elastic nature of materials • Elastic behaviour • Plastic behaviour • Tensile stress • Longitudinal Stress and longitudinal strain • Relation between stress and strain • Hooke's law • Young's modulus of elasticity 'Y'
Module 3	• Searle's apparatus • Experiment to determine Young's modulus of the material of a wire in the laboratory • What do we learn from the experiment?
Module 4	• Volumetric strain • Volumetric stress • Hydraulic stress • Bulk modulus K • Fish ,aquatic life on seabed ,deep sea diver suits and submarines
Module 5	• Shear strain • Shear stress • Modulus of Rigidity G • Poisson's ratio • Elastic energy • To study the effect of load on depression of a suitably clamped meter scale loaded at i)its ends ii)in the middle • Height of sand heaps , height of mountains
Module 6	• Fluids-liquids and gases • Stationary and flowing fluids • Pressure due to a fluid column • Pressure exerted by solids , liquids and gases • Direction of Pressure exerted by solids , liquids and gases
Module 7	• Viscosity- coefficient of viscosity

	• Stokes' Law • Terminal velocity • Examples • Determine the coefficient of viscosity of a given viscous liquid by measuring terminal velocity of a given spherical body in the laboratory
Module 8	• Streamline and turbulent flow • Critical velocity • Reynolds number • Obtaining the Reynolds number formula using method of dimensions • Need for Reynolds number and factors effecting its value • Equation of continuity for fluid flow • Examples
Module 9	• Bernoulli's theorem • To observe the decrease in pressure with increase in velocity of a fluid • Magnus effect • Applications of Bernoulli's theorem • Examples • Doppler test for blockage in arteries
Module 10	• Liquid surface • Surface energy • Surface tension defined through force and through energy • Angle of contact • Measuring surface tension
Module 11	• Effects of surface tension in daily life • Excess pressure across a curved liquid surface • Application of surface tension to drops, bubbles • Capillarity • Determination of surface tension of water by capillary rise method in the laboratory • To study the effect of detergent on surface tension of water through observations on capillary rise.
Module 12	• Thermal properties of matter • Heat • Temperature • Thermometers
Module 13	• Thermal expansion • To observe and explain the effect of heating on a bi-metallic strip • Practical applications of bimetallic strips

	• Expansion of solids, liquids and gases • To note the change in the level of liquid in a container on heating and to interpret the results • Anomalous expansion of water
Module 14	• Rise in temperature • Heat capacity of a body • Specific heat capacity of a material • Calorimetry • To determine specific heat capacity of a given solid material by the method of mixtures • Heat capacities of a gas have a large range • Specific heat at constant volume C_V • Specific heat capacity at constant pressure C_P
Module 15	• Change of state • To observe change of state and plot a cooling curve for molten wax. • Melting point, Regelation, Evaporation, boiling point, sublimation • Triple point of water • Latent heat of fusion • Latent heat of vaporisation • Calorimetry and determination of specific latent heat capacity
Module 16	• Heat Transfer • Conduction, convection, radiation • Coefficient of thermal conductivity • Convection
Module 17	• Black body • Black body radiation • Wien's displacement law • Stefan's law • Newton's law of cooling, • To study the temperature, time relation for a hot body by plotting its cooling curve • To study the factors affecting the rate of loss of heat of a liquid • Greenhouse effect

Module 16

3. WORDS YOU MUST KNOW

Heat energy: **Heat energy** (or thermal **energy** or simply **heat**) is a form of **energy** transfer among particles in a substance (or system) by means of kinetic **energy** of those particles. In other words, under kinetic theory, the **heat** is transferred by particles bouncing into each other.

Temperature: a measure of the warmth or coldness of an object or substance with reference to some standard/reference value.

Thermometer: a device to measure temperature.

Hot body: which have higher temperature as compared to the surroundings

System: A collection of physical bodies in a space where heat transfer can take place and is under study for heat exchange

Environment: anything outside the system under consideration

Cold body: which have lower temperature as compared to its environment

Heat exchange: heat transfer from one system to another or between system and its surroundings

Electromagnetic radiation: a kind of radiation including visible light, radio waves, gamma rays, and X-rays, in which electric and magnetic fields vary simultaneously.

Infrared radiations: **is electromagnetic radiation (EMR) with longer wavelengths than those of visible light, and is therefore invisible to the human eye. It is sometimes called infrared light.**

Ultraviolet radiations: Radiation in the part of the electromagnetic spectrum where wavelengths are just shorter than those of ordinary, visible violet light but longer than those of x-*rays*.

Wavelength: is the distance from one crest to another, or from one trough to another, of a wave (which may be an electromagnetic wave, a sound wave, or any).

Specific Latent heat: It takes a certain amount of energy to change the state of 1kg of water from solid to liquid. This amount of energy is called the **Specific Latent Heat** of water. "The amount of energy per kg (unit mass) required to change ice to water without change in temperature."

Specific heat capacity: The **specific heat** is the amount of **heat** per unit mass required to raise the temperature by one degree Celsius.

4. INTRODUCTION

Heat is an electromagnetic radiation. The 'sensation', that infrared waves create when they fall on surfaces, is that of heat. This energy increases the activity of molecules within the system and the temperature rises. In earlier modules, we have already considered some effects of heat on bodies and systems: viz; rise in temperature, change of state and expansion.

Once the body or system has a temperature higher than its environment it gives out more heat than it absorbs. Which means the heat leaving the system is greater than what is being absorbed by it.

We have seen that heat is the energy that gets transferred from one system to another (or from one part of a system to another part,) due to a temperature difference between them. What are the different ways by which this energy transfer takes place?

We notice, from our experience, that to heat a metal plate we could put it on a flame, hang it above a bonfire or just leave it in the sun.

In the first case there was contact with the hot flame, in the second hot air above the flame was in contact with the flame; in the third case, there is no contact between the sun and the metal plate, yet it still gets heated.

These three methods of heating up the metal plate corresponds to three distinct modes of heat transfer; they are known as:

- **CONDUCTION,**
- **CONVECTION**
- **RADIATION**

The three methods are quite distinct. When a metallic vessel, containing water is placed on a stove, heat from the stove goes to the metallic conductor, to heat water. This transfer is through the process of conduction and convection. For any one standing near the stove, feeling the heat, the transfer of heat is due to convection and radiation.

We will now study the salient features of these three modes of transfer of heat

5. CONDUCTION

Conduction is the mechanism of transfer of heat between two adjacent parts of a body because of a temperature difference between them.

Suppose one end of a metallic rod is put in a flame, the other end of the rod will soon be so hot that you cannot hold it by your bare hands. Here heat transfer takes place by conduction from the hot end of the rod, through its different parts, to the other end.

THINK ABOUT THIS

- **In winter a metallic handle feels colder than a wooden door**
- **The end of the rod in an arc flame can be very hot while its other end may be held by bare hands.**

How does conduction of heat take place?

The molecular mechanism of thermal conduction is not difficult to understand.

We know that temperature is a measure of average kinetic energy of atoms and molecules.

When one end of the rod is heated the molecules at that end have greater average kinetic energy. Energy exchange takes place through **collision** with molecules in the adjoining layers, without the molecules leaving their average location. (keep the interatomic separation graph and internal structure of crystalline solids in mind).

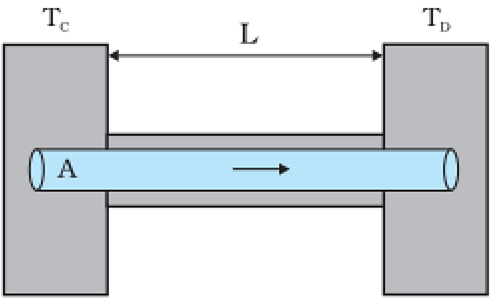
The energy transfer takes place from one layer to another. Eventually all parts of the metal rod have equal average kinetic energy of the molecules. That is, the temperature becomes uniform throughout and there is no further heat flow between the adjacent parts.

In metals, free electrons are also responsible for thermal conduction as they carry the thermal energy from the hotter to the colder parts.

Gases are poor thermal conductors while liquids have conductivities intermediate between solids and gases.

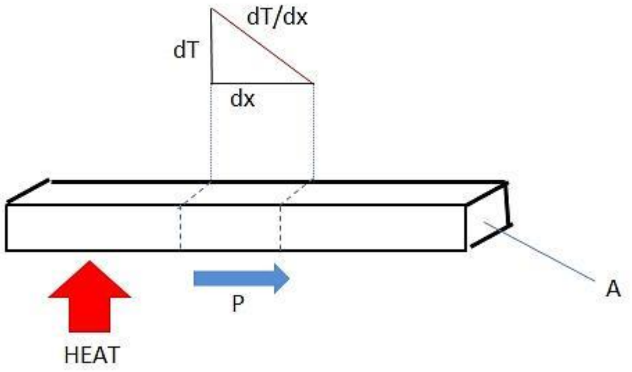
6. THERMAL CONDUCTIVITY K

Heat conduction may be described quantitatively as **the time rate of heat flow in a material for a given temperature difference**.



Consider a metallic bar of length L and uniform cross section A with its two ends maintained at different temperatures. (Note the length inside the chambers is ignored). This can be done, for example, by putting the ends in thermal contact with large reservoirs at temperatures, say, T_C and T_D respectively

Steady state heat flow by conduction in a bar with its two ends maintained at temperatures T_C and T_D; ($T_C > T_D$).



Let us assume **the ideal condition** that the sides of the bar are fully insulated so that no heat is exchanged between the sides and the surroundings.

The fig shows the temperature gradient in such a lagged metallic rod,

when heat is supplied at its one end of a constant rate. Here, temperature gradient means drop in temperature per unit length.

After sometime, **a steady state** is reached; the temperature of the bar decreases uniformly with distance from T_C to T_D; ($T_C > T_D$).

The reservoir at C supplies heat at a constant rate, which transfers through the bar and is given out at the same rate to the reservoir at D.

Steady state does not mean that the entire rod comes to the same temperature; it simply means that there is a uniform steady flow of heat throughout the bar.

It is found experimentally that in this steady state, **the rate of flow of heat (or heat current), H, is proportional to the temperature difference ($T_C - T_D$) and the area of cross section A; also it is inversely proportional to the length L. Hence,**

$$H = \mathbf{K}A\frac{T_C - T_D}{L}$$

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**.

From

$$H = \mathbf{K}A\frac{T_C - T_D}{L}$$

$$\mathbf{K} = \frac{HL}{A(T_C - T_D)}$$

And if A =1 m^2

$\frac{T_C - T_D}{L}$ = unity ^{0}C or K per m

H is the amount of heat energy flow per s

So thermal conductivity of a material is the rate of flow of heat across a conductor of area of cross section one m^2, at a temperature gradient of unity

The SI unit of K is J s^{-1} m^{-1} K^{-1} or W m^{-1} K^{-1}.

The thermal conductivities of some common substances are listed below:

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
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
Gases	
Air	0.024
Argon	0.016
Hydrogen	0.14

These values vary slightly with temperature, but can be considered to be constant over a normal temperature range.

Observe that the thermal conductivities of the good thermal conductor, the metals are quite large in comparison to the relatively small thermal conductivities of good thermal insulators, such as wood and glass wool.

You may have noticed that some cooking pots have copper coating on the bottom. Being a good conductor of heat, copper promotes the distribution of heat over the bottom of a pot for uniform cooking. Plastic foams, on the other hand, are good insulators, mainly because they contain pockets of air. Recall that gases are poor conductors; and note the low thermal conductivity of air in the Table.

Heat retention and transfer are important in many other applications. 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 gets slow down; this helps to keep the room cooler.

http://naturalhomes.org/img/basotho.jpg.

Using mud/ wood /earthen pots embedded in the roof to keep cool during summer.

In some situations, heat transfer is critical.

In automobiles coolants are used to maintain the engine temperature. 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.

EXAMPLE

A metal rod of length 15cm has a temperature difference of 32°C between its ends. It transmits 200 kcal h^{-1} through an area of 5 cm^2 . Calculate the thermal conductivity of the material of the rod.

Sometimes heat energy is expressed as calorie, this is not an SI unit

1 Calorie = 4.18 joule approximately =4.2J

SOLUTION:

Given: H= 200 kcal h^{-1} = $\frac{200\times10^3\times4.2}{3,600}$

= 233.3 Js^{-1}

T_1-T_2=32°C, L= 15cm, A=5cm^2

$$K=\frac{HL}{A(T_1-T_2)} = \frac{200\times10^3\times4.2\times15}{3,600\times5\times32} = \mathbf{21.87\ J\ s^{-1} m^{-1}\ K^{-1}}$$

EXAMPLE

One end of brass rod 2m long and 1 cm radius is maintained at 250°C. When a steady state is reached, the rate of heat flow across any cross section is 0.5$cals^{-1}$. What is the temperature of the other end? K= 0.26 $cals^{-1}cm^{-1}$°C^{-1}.

SOLUTION:

Given: length of rod, L= 2m = 200cm, r =1cm

$$Area A = \pi r^2 = 3.142 \times (1)^2 = 3.142 cm^2$$

T_1=250°C, T_2 =?

As we know, $H = KA\frac{T_1 - T_2}{L}$

$$0.5 = 0.26 \times 3.142 \times \frac{250 - T_2}{200}$$

$$\frac{0.5 \times 200}{0.26 \times 3.142} = 250 - T_2$$

$$122.41 = 250 - T_2$$

$$T_2 = 250 - 122.41 = 127.588\ °C$$

EXAMPLE

Calculate the rate of loss of heat through a glass window of area 1000cm^2 and thickness 0.4 cm when temperature inside is 37°C and outside is -5°C. Coefficient of thermal conductivity of glass is 2.2 × 10^{-3} cal s^{-1}cm^{-1} K^{-1}.

SOLUTION:

Given: Area, A= 1000cm^2, thickness, L= 0.4cm

T_1= 273 + 37 = 310 K

T_2= 273 - 5 = 268 K

K= 2.2 ×10^{-3}cal s^{-1}cm^{-1}K^{-1}

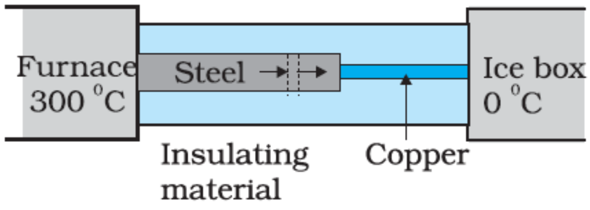
As we know, $H = KA\frac{T_1 - T_2}{L}$

$$H = 2.2 \times 10^{-3} \times 1000 \times \frac{310 - 268}{0.4} = \frac{2.2 \times 42}{0.4} = 231 \text{ cal s}^{-1}$$

Or $231 cals^{-1} \times 4.12 = 951.72\, Js^{-1}$

EXAMPLE

What is the temperature of the steel-copper junction in the steady state of the system shown in the Figure



Length of the steel rod = 15.0 cm, length of the copper rod = 10.0 cm, temperature of the furnace = 300 °C, temperature of the other end = 0 °C. The area of cross section of the steel rod is twice that of the copper rod. (Thermal conductivity of steel = 50.2 J s^{-1} m^{-1}K^{-1}; and of copper = 385 J s^{-1} m^{-1}K^{-1}).

SOLUTION

The insulating material around the rods reduces heat loss from the sides of the rods.
Therefore, heat flows only along the length of the rods.
Consider any cross section of the rod.

In the steady state, heat flowing into the element must equal the heat flowing out of it; otherwise
there would be a net gain or loss of heat by the element and its temperature would not be steady.

Thus in the steady state, rate of heat flowing across a cross section of the rod is the same at every point along the length of the combined steel-copper rod.

Let *T* be the temperature of the steel-copper junction in the steady state.
Then,

$$\frac{\mathbf{K_1A_1(300-T)}}{\mathbf{L_1}} = \frac{\mathbf{K_2A_2(T-0)}}{\mathbf{L_2}}$$

Where 1 and 2 refer to the steel and copper rod respectively
For $A_1 = 2\,A_2$
$L_1 = 15.0$ cm
$L_2 = 10.0$ cm
$K_1 = 50.2$ $\mathbf{J\ s^{-1}\ m^{-1}K^{-1}}$
$K_2 = 385$ $\mathbf{J\ s^{-1}\ m^{-1}K^{-1}}$

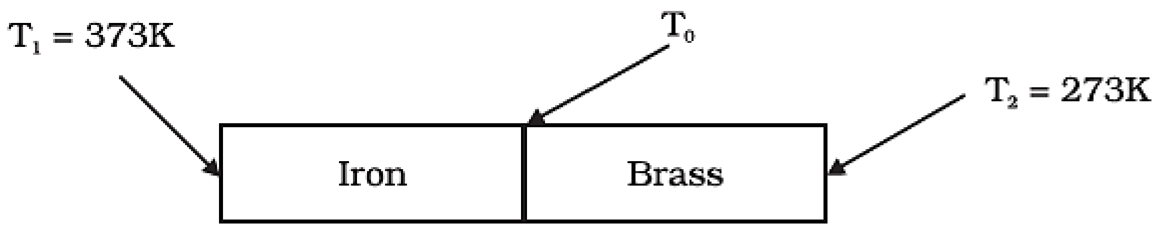
We have

$$\frac{50.2 \times 2(300-T)}{15} = \frac{385T}{10}$$

Which gives T = 44.4 ^{0}C

EXAMPLE

An iron bar (L_1 = 0.1 m, A_1 = 0.02 m^2, K_1 = 79 W m^{-1} K^{-1}) and a brass bar (L_2 = 0.1 m, A_2 = 0.02 m^2,
K_2 = 109 W m^{-1}K^{-1}) are soldered end to end as shown in Figure



The free ends of the iron bar and brass bar are maintained at 373 K and 273 K respectively. Obtain expressions for and hence
Compute
(i) the temperature of the junction of the two bars,
(ii) the equivalent thermal conductivity of the compound bar, and
(iii) the heat current through the compound bar.

SOLUTION

$L_1 = L_2 = L = 0.1$ m,
$A_1 = A_2 = A = 0.02\ m^2$
$K_1 = 79\ Wm^{-1}K^{-1}$,
$K_2 = 109\ Wm^{-1}K^{-1}$
$T_1 = 373$ K, and
$T_2 = 273$ K.

Under steady state condition,

the heat flow (H_1) through iron bar = heat flow (H_2) through brass bar.

So, $H = H_1 = H_2$

$$\frac{\mathbf{K_1A_1}(T_1 - T_0)}{\mathbf{L_1}} = \frac{\mathbf{K_2A_2}(T_0 - T_2)}{\mathbf{L_2}}$$

substituting

$$K_1(T_1 - T_0) = K_2(T_0 - T_2)$$

The junction temperature T_0 is given by

$$T_0 = \frac{K_1T_1 + K_2T_2}{(K_1 + K_2)}$$

Using this equation, the heat flow H through either bar is

$$H = \frac{\mathbf{K_1A}(T_1 - T_0)}{\mathbf{L}} = \frac{\mathbf{K_2A}(T_0 - T_2)}{\mathbf{L}}$$

$$= \left(\frac{K_1K_2}{K_1 + K_2}\right)\frac{\mathbf{A}(T_1 - T_0)}{\mathbf{L}} = \frac{A(T_1 - T_2)}{L\left(\frac{1}{K_1} + \frac{1}{K_2}\right)}$$

Using these equations, the heat current H′ through the compound bar of length $L_1 + L_2 = 2L$ and the equivalent thermal conductivity K′, of the compound bar are given by

$$H' = \frac{K'\mathbf{A}(T_1 - T_2)}{\mathbf{2L}}$$

$$K' = \frac{2\,K_1K_2}{K_1 + K_2}$$

i)

$$T_0 = \frac{K_1T_1 + K_2T_2}{(K_1 + K_2)} = \frac{79Wm^{-1}K^{-1}(373K) + (109Wm^{-1}K^{-1})(273K)}{79Wm^{-1}K^{-1} + 100Wm^{-1}K^{-1}}$$

=315K

ii) $K' = \frac{2\,K_1K_2}{K_1+K_2}$

$$\frac{2 \times 79Wm^{-1}K^{-1}(373K) + (109Wm^{-1}K^{-1})(273K)}{79Wm^{-1}K^{-1} + 100Wm^{-1}K^{-1}}$$

=91.6 $Wm^{-1}K^{-1}$

iii) $H' = H = \frac{K' \;\; A \;\; (T_1 - T_2)}{2L}$

$$= \frac{(91.6Wm^{-1}K^{-1}) \times \left(0.02m^2 \times (373K - 273K)\right)}{2 \times (0.1m)}$$

=916.1W

EXAMPLE

A 'thermocole' icebox is a cheap and efficient method for storing small quantities of cooked food in summer in particular. A cubical icebox of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice is put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is 45 °C, and co-efficient of thermal conductivity of thermocole is 0.01 J $s^{-1}m^{-1}K^{-1}$. [Heat of fusion of water = 335 × 103 J kg^{-1}]

SOLUTION:

https://www.bing.com/images/search?view=detailV2&ccid=E6O9FB6z&id=EA5D85E1D6FB6F2EBA83B6BA97C96C3FCC7A96C2&thid=OIP.E6O9FB6zUP7hx8xB3IEjMAHaFj&mediaurl=http%3a%2f%2fimg1.exportersindia.com%2fproduct_images%2fbc-full%2fdir_50%2f1497851%2fthermocol-boxes-425275.jpg&exph=600&expw=800&q=in+thermocole+box&simid=607992519057346174&selectedIndex=18

Here, A = 6 × $(30 \times 30) = 5{,}400\ cm^2 = 0.54m^2$

$(\because the\ box\ has\ six\ faces)$

$d = 5.0\ cm = 5 \times 10^{-2} m;\ t = 6\ h = 6 \times 60 \times 60\ s;$

$$T_1 - T_2 = 45 - 0 = 45°C$$

$$K = 0.01\ Js^{-1}m^{-1}\ °C^{-1}$$

Therefore, total heat entering the box in 6 h,

$Q = \frac{KA(T_1 - T_2)t}{d} = \frac{0.01 \times 0.54 \times 45 \times 6 \times 60 \times 60}{5 \times 10^{-2}}$ (i)

Or Q = 104976 J

Also, $L = 335 \times 10^3 Jkg^{-1}$

Let M (in kg) be the mass of the ice, which melts in 6 h. Then,

Q = M L = M$\times$ $335 \times 10^3 J$ (ii)

By the above equation (i) and (ii), we have

$M \times 335 \times 10^3 = 104976$

Or M = $\frac{104976}{335 \times 10^3} = 0.313\ kg$

Total ice present in the box in the beginning = 4.0 kg

Therefore, ice left in the box after 6 h = 4.0 - 0.313 = **3.687 kg**

EXAMPLE

A brass boiler has a base area of 0.15 m^2 and thickness 1.0 cm. It boils water at the rate of 6.0 kg/min when placed on a gas stove. Estimate the temperature of the part of the flame in contact with the boiler. Thermal conductivity of brass = 109 J $s^{-1}m^{-1}K^{-1}$; Heat of vaporisation of water = 2256 × 103 J kg^{-1}.

Solution:

Here, $K = 109 J\ s^{-1}m^{-1}°C^{-1}$

A = $0.15 m^2$

d = 1.0 cm = $10^{-2} m;\ T_2 = 100\ °C$

Let T_1 be the temperature of the part of the boiler in contact with the stove. Therefore, amount of heat flowing per second through the base of the boiler,

$Q = \frac{KA(T_1 - T_2)}{d} = \frac{109 \times 0.15 \times (T_1 - 100)}{10^{-2}}$

$Q = 1635\ (T_1 - 100) J\ s^{-1}$ (i)

Also, heat of vaporisation of water,

$$L = 2256\ Jg^{-1} = 2256 \times 10^3 Jkg^{-1}$$

Rate of boiling of water in the boiler,

$$M = 6.0\ kg\ min^{-1} = \frac{6.0}{60} = 0.1\ kg\ s^{-1}$$

Therefore, heat received by water per second,

$Q = ML = 0.1 \times 2256 \times 10^3 Js^{-1}$ (ii)

By the above equations (i) and (ii), we get

$1635(T_1 - 100) = 0.1 \times 2256 \times 10^3$

Or $T_1 = \frac{0.1 \times 2256 \times 10^3}{1635} + 100 = 138 + 100 = \mathbf{238\ °C}$

THINK ABOUT THESE

- **If one end of a metal wire is at higher temperature and other end is at lower temperature, will the rate at which heat flows from one end to another remain constant till end?**
- **Does the rate of heat flow change with the change in temperature gradient?**
- **Some metal like iron take time to heat as well as to cool while in some metals like tin, temperature changes can be very rapid. Why?**
- **From the table, which metal has the highest thermal conductivity? Can we explain it from atomic size?**
- **What is the thermal conductivity of a perfect heat conductor and of a perfect heat insulator?**
- **How do we feel the warmth of the body of a person when he is suffering from fever? name the process**
- **The bulb of one thermometer is spherical while that of other is cylindrical. Both have equal amounts of mercury. Which one will respond quicker to temperature changes?**
- **Why do most cooking vessels have a flat bottom?**
- **What should we do to reduce the heat transmission from a body?**
- **Snow is better heat insulator than ice, why?**
- **A brass tumbler feels much colder than a wooden tray on a chilly day .why?**

7. CONVECTION

When you look at the flame of a fire or a candle or a match, you are watching thermal energy being transported upward by convection.

Such energy transfer occurs when a fluid, such as air or water, water vapour comes in contact with an object whose temperature is higher than that of the fluid.

The temperature of the part of the fluid, that is in contact with the hot object, increases and (in most cases) that fluid expands and becomes less dense.

Because this expanded fluid is now lighter than the surrounding cooler fluid, buoyant (upward) forces cause it to rise.

Some of the surrounding cooler fluid then flows so as to take the place of the rising fluid; the process continues.

Convection is part of many natural processes. Atmospheric convection plays a fundamental role in determining global climate patterns and daily weather variations. Glider pilots and birds alike seek rising thermals (convection currents of warm air) that keep them aloft. Huge energy transfers take place within the oceans by the same process.

Convection is a mode of **heat transfer** by **actual motion of matter**.

It is therefore possible only in fluids.

Convection can be natural or forced.

In natural convection, **gravity** plays an important part.

When air is heated from below, (this may be due to hot ground, fire, stove or even incense stick(agarbatti),

the air that comes in contact expands and, therefore, becomes less dense. It rises and the upper colder air replaces it. This again gets heated, rises up and is replaced by the colder part of the fluid. The process goes on.

This mode of heat transfer is evidently different from conduction. The effect is easily visible in case of agarbatti.

https://upload.wikimedia.org/wikipedia/commons/b/be/Incense_sticks_%285109967068%29.jpg

Convection involves bulk transport of different parts of the fluid.

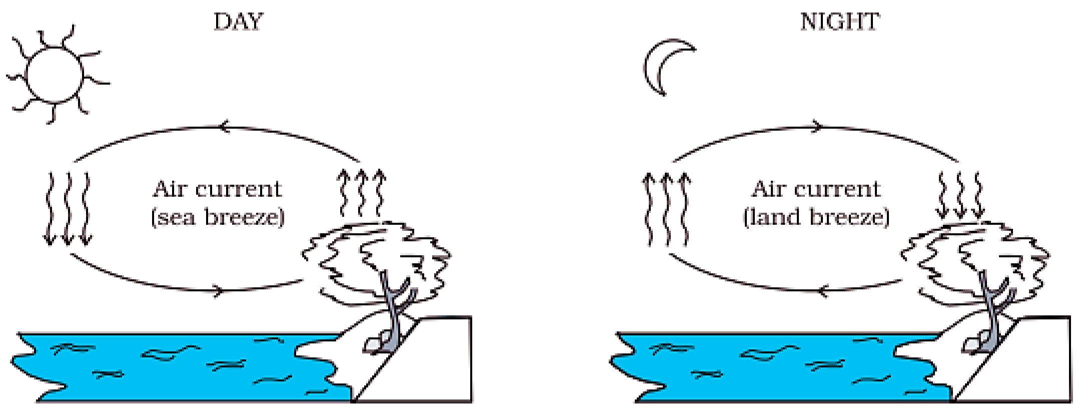
In forced convection, material is forced to move by a pump or by some other physical means.

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.

In the human body, the heart acts as the pump that circulates blood through different parts of the body, transferring heat by forced convection and maintaining the whole body at a uniform temperature.

Natural convection is responsible for many familiar phenomena.



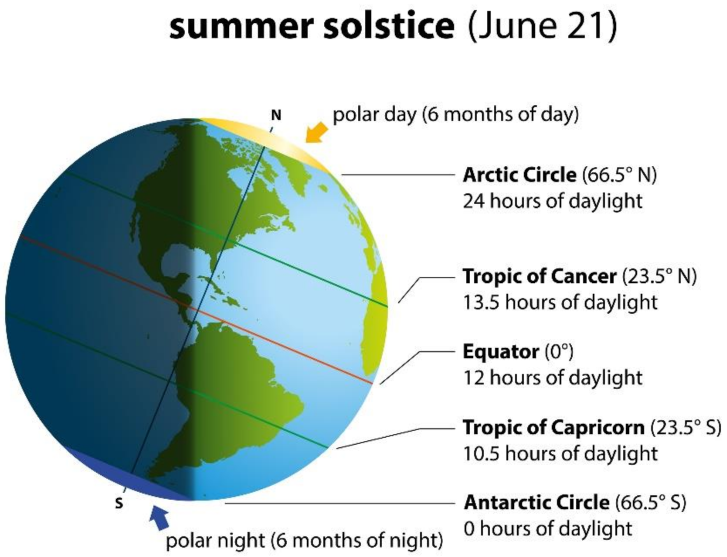
Land warmer than water

Water warmer than land

During the day, the ground heats up more quickly than large bodies of water do. This occurs because the 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 other air (winds) moves to fill the space; this creates 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 reversed.

The other example of natural convection is the steady surface winds on the earth blowing in from north-east towards the equator, the so called trade winds.

A reasonable explanation is as follows:



The equatorial and polar regions of the earth receive unequal solar heat. Air at the earth's surface near the equator, is hot while the air in the upper atmosphere of the poles is cool. In the absence of any other factor, a convection current would be set up, with the air at the equatorial surface rising and moving out towards the poles, then descending and streaming in towards the equator.

The rotation of the earth, however, modifies this convection current. Because of this, air close to the equator has an eastward speed of 1600 km/h, while it is zero close to the poles. As a result, the air descends not at the poles but at 30° N (North) latitude and returns to the equator. **This is called trade wind.**

- **Why are the coolant coils fitted on the ceiling of refrigerator?**
- **Why is a split ac more effective as compared to window ac.?**

8. SUMMARY

In this module we have learnt

- Heat is electromagnetic radiation; with wavelengths corresponding to ultraviolet, visible, and near-infrared regions.
- Electromagnetic radiation, with longer wavelengths than those of visible light, is invisible light. Most of the thermal radiation, emitted by objects near room temperature, is infrared radiation.
- Heat transfers from a hot body to a colder body by three ways:

  Conduction
  Convection
  Radiation

- The process of conduction involves heat transfer through the material. The molecular agitation or movement of high energy electrons in metals is responsible for heat transfer.
- Conduction is the prominent mode of heat transfer in solids, especially metals
- The rate of transfer of heat depends upon the material , area of cross-section of the solid (in case it is shaped like a bar),temperature gradient and lagging
- Thermal conductivity of a material is defined as **the rate of flow of heat across a conductor of area of cross section one m^2, at a temperature gradient of unity**

- Thermal conductivity is important while making homes, temperature-controlled chambers.
- Convection is the mode of transfer in fluids. The flow depends upon the variation in density created by hot fluid. The hot fluid with respect to cold fluid.
- Convection results in predictable patterns of flow.
- Convection can be natural as in occurrence of land and sea breeze , trade winds
- Convection can be forced as in cooling or heating systems in homes , restaurants or a theatre