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 17, Radiation Chapter 11, Thermal Properties of Matter
Module Id	keph_201106_eContent
Pre-requisites	Heat is a form of energy, temperature is an indicator of extent of heat in a body, thermometers measure temperature, transfer of heat takes place.
Objectives	After going through the module ,the students will be able to: • Understand the concept of Black body • Know laws of Black body radiation vis Wien's displacement law and Stefan's law • Deduce Newton's law of cooling • Learn a method to determine the factors affecting the rate of loss of heat of a liquid • Understand Greenhouse effect
Keywords	Bulk properties of matter, intermolecular forces, conduction, convection, radiation, Newton's law of cooling, Stefan's law, Wien's displacement law, black body, greenhouse effect .

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

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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.

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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 17

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.

System: is a part of the universe being studied**.**

Hot system if a collection of bodies making up a system has a temperature greater than its surroundings, it is said to be a hoy system**.**

Environment: the system may be contained in another system. The system outside the one which is being considered is said to be the environment.

Cold body: a body or system**, which** has a lower temperature than its environment

Heat exchange: heat transfer from one system with another with or without direct contact

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

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 waves, 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.

Conduction: Mode of heat transfer by increased molecular motion and in metal by movement of electrons

Convection: This mode of heat transfer involves motion of heated fluid. Convection can be natural or forced

4. INTRODUCTION

You will recall our consideration of hot bodies and heat emission from them to their surroundings. 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.

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 correspond 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.

Kettles of water being heated on a stove to make tea. The heat from the burner can be felt by bystanders as well.

We will now study the salient features of transfer of heat, the mode being radiation

5. RADIATION

Conduction and convection require some material as a transport medium. These modes of heat transfer cannot operate between bodies separated by a distance in vacuum. But the earth does receive heat from the sun across a huge distance and we quickly feel the warmth of the fire nearby even though air conducts poorly and even before convection can set in. The third mechanism for heat transfer needs no medium; it is called **radiation**, and the energy so transferred through electromagnetic waves is called **radiant energy.**

In an electromagnetic wave electric and magnetic fields undergo oscillations in space and time. Like any wave, electromagnetic waves can have different wavelengths. However, electromagnetic waves, of different wavelength, all propagate in vacuum with the same speed, namely the speed of light i.e., 3×10^8 m s^{-1}.

The electromagnetic heat waves (infrared waves) ranges in wavelength from the long wavelength infrared rays through the visible-light spectrum to the short wavelength ultraviolet rays.

The third method by which an object and its environment can exchange energy as heat is via electromagnetic waves (visible light is one kind of electromagnetic wave). Energy transferred in this way is called **thermal radiation** to distinguish it from **electromagnetic signals used in television broadcasts and from nuclear radiation** (energy and particles emitted by nuclei).

('To radiate' generally means 'to emit')

When you stand in front of a big fire, you are warmed by absorbing thermal radiation from the fire; that is, your thermal energy increases as the fire's thermal energy decreases.

Radiation does not involve movement of atoms, (as in conduction), or mass movement of molecules (as in convection).

Radiant energy is in the form of electromagnetic waves and behaves quite like visible light.

For example, it can be reflected and refracted. Observation indicates that thermal radiation is quite like light and that the process of heat transfer by radiation is similar to the passage of light through space.

When the Sun sets, or is temporarily obscured by a dense cloud, for example, both the light and the heat, received from it, diminish simultaneously.

6. BEHAVIOR OF BODIES DURING HEAT RADIATION:

In this section we will discuss some important rules /laws related to radiation. We will logically deduce some results without going into their detailed quantitative derivations.

When radiant energy falls on a body,

a part of the energy is absorbed,

a part is reflected and

remaining part is transmitted.

If we denote by a, r, and t the fractions absorbed, reflected and transmitted, respectively, then:

$$a + r + t = 1$$

We can use the parameters a, r and to classify substances in terms of their behavior toward radiant energy.

For a good absorber, $a > (r + t)$ and for a near perfect absorber, $a >> (r + t)$,

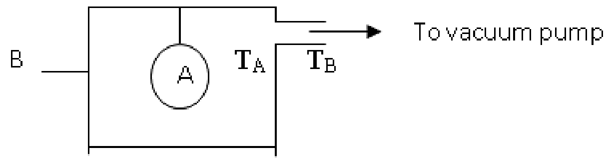
For a good reflector, $r > (a + t)$ and for a near perfect reflector, $r >> (a + t)$,

For a good transmitter, $t > (a + r)$ and for a near perfect transmitter, $t >> (a + r)$

The nature of surfaces of bodies decides the behavior of bodies toward radiation. It turns out that shiny surfaces are good reflectors, while black surfaces are good absorbers of heat. Surfaces which are transparent to light are (generally) also transparent to heat; they are hence good transmitters of heat.

PREVOST'S THEORY OF EXCHANGES:

Let's imagine a small body A, at temperature T_A, suspended by a non-conducting thread inside the evacuated box B whose walls are maintained at a constant, different temperature T_B as shown in the fig.



It is very clear that energy exchanges between A and B can occur only by radiation. It is clear that if $T_A > T_B$, A's temperature falls until it is equal to T_B, but if $T_A < T_B$, it rises to T_B. Thus, finally, in any case A acquires B's temperature and it may appear that energy exchange may have stopped then.

This is like saying if a cup of hot tea is placed on a table in a room, the cup of tea cools to the room temperature. We cannot say that the cup of tea should further cool below room temperature by radiating more heat to the colder room.

Imagine (during winters, before sunrise) a hot cup of tea is placed in a cold room. The tea gets cold, comes to room temperature, it takes some time in doing so, as the day proceeds and room temperature increases, the cold tea becomes warmer and may continue to get warmer; it then cools as the night falls. **Amazing tea!!!**

Prevost suggested that, actually, when a body is at the same temperature as its surroundings its rate of emission of radiation to the surroundings equals its rate of absorption of radiation from the surroundings. (Kind of two-way traffic, at constant temperature)

Heat energy (radiated) out of the body = Heat energy (absorbed) into the body

That is, there is dynamic equilibrium and energy exchange continues, at a rate that depends on the temperature.

Thus, a body which is a **good absorber** of radiation must also be a **good emitter** of radiation otherwise its temperature would rise above that of its surroundings. Conversely, a good emitter must be a good absorber.

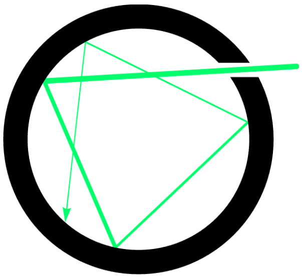
Experiments confirm these conclusions and indicate that a dull, black surface is the best absorber and also the best emitter.

So we can say; all bodies, whether they are solid, liquid or gases emit radiant energy all the time. The electromagnetic radiation emitted by a body by virtue of its temperature (like the 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.

7. BLACK BODY

A body which is a good radiator (or emitter) is also a good absorber. Imagine that radiation of all possible wavelengths is incident on a body, and it absorbs all of them. Such a body would also be capable of emitting all the wavelengths under suitable conditions.

Such a perfect absorber is called a **black body**. The notion of black body is an idealization; in reality no object behaves like a perfect body.



A practical approximation, to a perfect black body, is having an a hollow enclosure, maintained at a uniform temperature, opening that is very small compared to its size. It is designed in such a way that any radiation falling on the aperture is internally reflected and absorbed; and has negligible chance of coming out of the enclosure.

https://upload.wikimedia.org/wikipedia/commons/e/ef/Hole_in_Cavity_as_Blackbody.png

Kirchhoff's law says that a good absorber is a good emitter; it is a poor reflector .So a black body is a perfect absorber and a perfect emitter. Since it is capable of absorbing all the wavelengths of the entire electromagnetic spectrum it is also capable of emitting the same. The ratio of emission to absorption is, therefore, unity for a perfect body.

Interesting outcomes

Thermal radiations, inside a hollow enclosure behave, like a black body. So individual objects, inside the hollow enclosure, lose their identity.

The amount of radiant heat energy, that a body can absorb, depends on the colour of the body. We find that black bodies absorb and emit radiant energy better than bodies of lighter colours.

This fact finds many applications in our daily life.

We wear white or light coloured clothes in summer so that they absorb the least heat from the sun.

However, during winter, we use dark coloured clothes which absorb heat from the sun and keep our body warm.

The bottoms of the utensils for cooking food are blackened so that they absorb maximum heat from the fire and give it to the vegetables to be cooked.

A Dewar flask, or thermos bottle, is a device to minimise heat transfer between the contents of the bottle and outside. It consists of a double-walled glass vessel with the inner and outer walls coated with silver. Radiation, from the inner wall, is reflected back into the contents of the bottle. The outer wall similarly reflects back any incoming radiation. The space between the walls is evacuated to reduce conduction and convection losses and the flask is supported on an insulator like cork. The device is, therefore, useful for preventing hot contents (like milk) from getting cold. It can alternatively be used to store cold contents (like ice).

We will now take up a few laws related to radiation.

They are

- **Wien's displacement Law: This relates the temperature of a body (or system) and the preferred wavelengths radiated by the body at that temperature.**
- **Stefan's Law: This relates the total energy radiated per unit area per second to the absolute temperature of the body (or the system).**

- **Newton's law of cooling**: **The rate of fall in temperature of a hot body (or system) depends upon the temperature difference between the hot body and its surroundings**

8. WIEN'S DISPLACEMENT LAW

The heat radiation emitted by a body consists of different wavelengths. These wavelengths are distributed continuously over a range.

However, some wavelengths contribute much more than the others in total radiation energy.

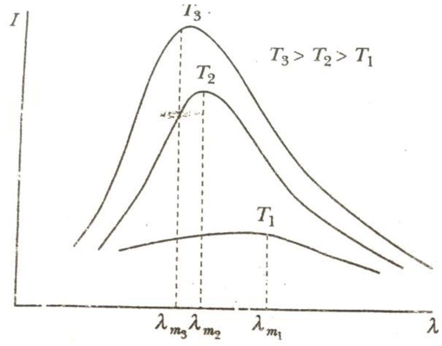
In fig. (a) graph of intensity versus wavelengths has been plotted using experimental data for a body at three different temperatures.

We can see that intensity is not same for all wavelengths. These graphs, at a given temperature, are same for all black bodies.

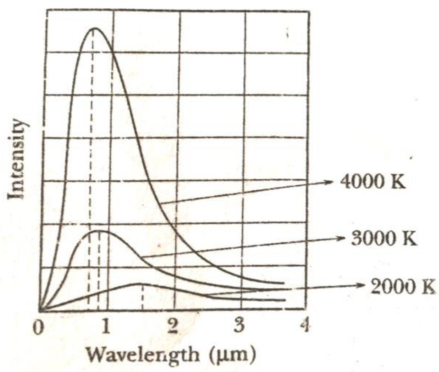
As the temperature of the body increases, the wavelength of dominant region decreases.

At around 100 K, the radiation has a good contribution from red region of wavelength and the object appears red.

At temperature around 3000K, the radiation contains enough shorter wavelengths and the object appears white.



(a)



(b)

Figure (a) General variation of intensity with wavelength at different temperatures. (b) Variation of intensity with wavelength at different temperatures for black body.

The peak of the wavelength distribution shifts to shorter wavelengths as the temperature increases.

This behavior is described by the following relationship, called Wien's displacement law:

$$\lambda_{max}T = b = 2.88 \times 10^{-3} mK$$

Here λ_{max} is the wavelength at which the curve peaks, T is the absolute temperature of the surface of the object emitting the radiation and b is constant or we can say **Wein's constant**.

The wavelength, at the curve's peak is inversely proportional to the absolute temperature that is, as the temperature increases, the peak is "displaced" towards shorter wavelengths as in fig. (b).

At room temperature the object does not appear to glow because the peak is in the infrared region of the electromagnetic spectrum. At higher temperatures it glows red because the peak is in the near infrared with some radiation at the red end of the visible spectrum. At still higher temperatures, it glows white because the peak is in the visible region and all colors are getting emitted.

You can heat a platinum wire in the chemistry lab

THUS WE CAN SUMMARIZE:

a. **For all black bodies, radiation spectrum, at a given temperature, is same.**
b. **Black body emits all wavelengths from 0 to ∞.**
c. **Area, bounded by the E_λ-λ curve, and λ axis gives the emissive power.**
d. **With increase in temperature, energy associated with each wavelength increases.**
e. **Wavelength, that corresponds to maximum spectral emissive power (λ_{max}), decreases with increase in temperature. This decrease is according to Wien's law.**

$$\lambda_{max} \propto \frac{1}{T}$$

We may assume the sun to be a blackbody. Then its wavelength of maximum emission and its surface temperature are related by Wien's law.

9. STEFAN'S LAW OF BLACK BODY RADIATION

The rate P_{rad} at which an object emits energy via electromagnetic radiation depends on the object's surface area A and the temperature T in kelvin of that area. It is given by:

$$P_{rad} = \sigma\varepsilon A T^4$$

Here $\sigma = 5.6704 \times 10^{-8} W/m^2K^4$ is called the **Stefan-Boltzmann constant** after Josef Stefan and Ludwig Boltzmann.

Suppose an object with surface area A and temperature T is exposed to thermal radiation coming from its surroundings in all directions that are at a uniform temperature T_{env}. Then the net rate of heat flow due to thermal radiation is (T in kelvin):

$$P_{net} = \sigma\varepsilon A T^4 - \sigma\varepsilon A\, T^4{}_{env} = \sigma\varepsilon A(T^4 - T^4{}_{env})$$

HENCE WE CAN SAY

- A body emits energy even if it is at the same temperature as its surroundings; it just emits at the same rate at which it absorbs. In such a case,

  $P_{net} = 0$.

- If $T > T_{env}$, the object emits more thermal radiation than it absorbs.
- If $T < T_{env}$, the object absorbs more thermal radiation than it emits.
- The rate of absorption is proportional to the emissivity because a good emitter is also a good absorber.

- The emissivity ε measures not only how much the object emits compared to a black body but it also measures how much the object absorbs compared to a blackbody.
- A blackbody, at the same temperature as its surroundings, would have to absorb radiation at the rate $P_{abs} = \sigma \varepsilon A {T^4}_{env}$ to exactly balance its rate of emission.

THIS MIGHT INTEREST YOU

Thermogram and its application

A thermogram reveals the rate at which energy is radiated. White and red indicating the greatest radiation rate and the nose is cool.

https://cdn.pixabay.com/photo/2013/03/01/17/57/heat-87276_960_720.jpg

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The rate, P_{abs}, at which an object **absorbs energy via thermal radiation** from its environment, which we take to be at uniform temperature T_{env} (in kelvin), is:

$$P_{abs} = \sigma \varepsilon A {T^4}_{env}$$

An idealized black body radiator, with ε =1, will absorb all the radiated energy it intercepts rather than sending a portion back away from itself through reflection or scattering.

Because an object will radiate energy to the environment while it absorbs energy from the environment, the object's net rate P_{net} of energy exchange due to thermal radiation is:

$$P_{net} = P_{abs} - P_{rad} = \sigma\varepsilon A(T^4_{env} - T^4)$$

P_{net} is positive if net energy is being absorbed via radiation and negative if the net energy is being lost via radiation.

Let's now return to the story about the ability of a **Melanophila beetle** to detect a fairly large fire from a distance of 12 km without seeing or smelling it. A pair of organs along each side of the beetle's body can detect even low-level thermal radiation. Each organ contains about 70 small knob-like sensors that expand very slightly when they absorb thermal radiation from the fire; the expansion causes them to press down on sensory cells. Thus, the detector is a mechanism that transfers energy from the thermal radiation to the energy of a mechanical device. The beetle can locate the fire by orienting itself so that all four infrared-detecting organs are affected, and then it flies toward the fire so that the response of the organs increases.

https://baynature.org/wp-content/uploads/2014/02/Melanophila_Alameda-County.jpg

Thermal radiation is also involved in the numerous medical cases of a seemingly **dead rattle snake** striking a hand reaching toward it. Pits, between each eye and nostril of a rattlesnake, serve as sensors of thermal radiation. When, say, a mouse moves close to a rattlesnake's head, the thermal radiation from mouse triggers these sensors, causing a reflex action in which the snake strikes the mouse with its fangs and injects its venom.

The thermal radiation, from a reaching hand can cause the same reflex action even if the snake has been dead for as long as half an hour. This is because the snake's nervous system continues to function. As one snake expert advised, if you must remove a recently killed rattlesnake, use a long stick rather than your hand.

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EXAMPLE

A thermograph is a device that measures the amount of radiation each small portion of a person's skin emits and presents information in pictorial form by different shades of colour called a thermogram

The skin over a tumour is warmer than elsewhere may be because of increased blood flow or a higher rate of metabolism, thus a thermogram is a useful diagnostic method for detecting breast and thyroid cancer to verify that a small difference in temperature leads to a significant difference in radiation rate. Calculate the percentage difference between the radiation from skin at 34^{0}C and 35^{0}C.

SOLUTION

Absolute temperature of the two patches of skin

$$T_1 = 34 + 273 = 307K$$

$$T_2 = 35 + 273 = 308K$$

Since rate of emission of heat from patch 1 R_1 is proportional to T_1^4

And rate of emission of heat from patch 2 R_2 is proportional to T_2^4

$$\frac{R_2 - R_1}{R_1} = \frac{T_2^4 - T_2^4}{T_1^4} = \frac{(308)^4 - (307)^4}{(307)^4} = 0.013$$

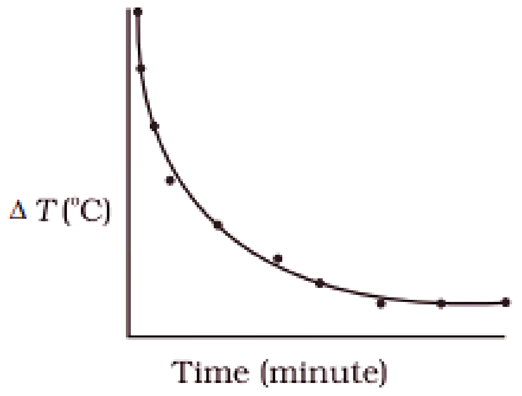
Or **1.3 %**

10. NEWTON'S LAW OF COOLING

We all know that hot water or milk when left on a table begins to cool gradually. Ultimately it attains the temperature of the surroundings.

To study how a given body cools, on exchanging heat with its surroundings, let us perform an activity.

Take some water, say 300 ml, in a calorimeter with a stirrer and cover it with two holed lid. Fix a thermometer through a hole in the lid and make sure that the bulb of thermometer is immersed in the water. Note the reading of the thermometer. This reading T_1 is the temperature of the surroundings. Heat the water, kept in the calorimeter, till it attains a temperature, say, 40 °C above room temperature (i.e., temperature of the surroundings). Then stop heating the water by removing the heat source. Start the stopwatch and note the reading of the thermometer after fixed interval of time, say after every one minute; keep stirring the water gently with the stirrer. Continue to note the temperature (T_2) of water till it attains a temperature about 5 °C above that of the surroundings. Plot a graph by taking each value of temperature excess $\Delta T = (T_2 - T_1)$ along y axis and the corresponding value of t along x-axis



From the graph we see

Rate of cooling of hot water depends on the difference of its temperature from that of the surroundings.

- Initially the rate of cooling is higher; it decreases as the temperature of the body falls.
- A hot body loses heat to its surroundings in the form of heat radiation.
- The rate of loss of heat depends on the difference in temperature between the body and its surroundings.

Newton was the first to study, in a systematic manner, the relation between the rate of heat lost by a body in a given enclosure and its temperature.

According to Newton's law of cooling,

The rate of loss of heat, dQ/dt, of the body is directly proportional to the difference of temperature ΔT (= (T_2–T_1)) of the body and the surroundings.

The law holds good

- **Only for small differences of temperature.**
- **Also, the rate of loss of heat depends upon the nature of the surface of the body and**
- **The area of the exposed surface**.

We can write Newton's law of cooling as

$$-\frac{dQ}{dt} = k(T_2 - T_1)$$

where k is a positive constant depending upon the area and nature of the surface of the body.

Suppose a body of mass m, and specific heat capacity s, is at temperature T_2.

Let T_1 be the temperature of the surroundings. If the temperature falls by a small amount dT_2

in time dt,

then the amount of heat lost is

$dQ = msdT_2$

∴ Rate of loss of heat is given by

$$\mathbf{\frac{dQ}{dt} = ms\frac{dT_2}{dt}}$$

From equations

$$-\frac{dQ}{dt} = k(T_2 - T_1) \quad \text{and} \quad \frac{dQ}{dt} = ms\frac{dT_2}{dt}$$

we have

$$-ms\frac{dT_2}{dt} = k(T_2 - T_1)$$

$$\mathbf{\frac{dT_2}{T_2 - T_1} = -\frac{k}{ms}dt = -Kdt}$$

Where K= k/m s

On integrating,

$$\mathbf{\log_e (T_2 - T_1) = -Kt + c}$$

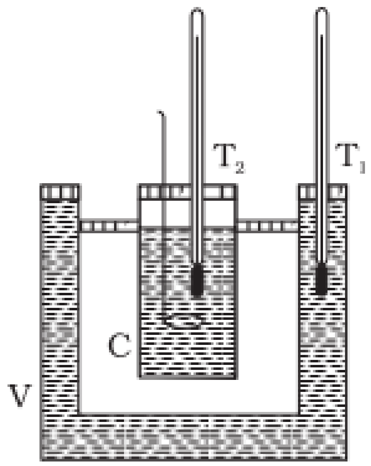
Or $T_2 = T_1 + C' e^{-kt}$; where $C' = e^c$

This equation enables us to **calculate the time of cooling of a body through a particular range of temperature.**

For small temperature differences, the rate of cooling, due to conduction, convection, and radiation combined, is proportional to the difference in temperature.

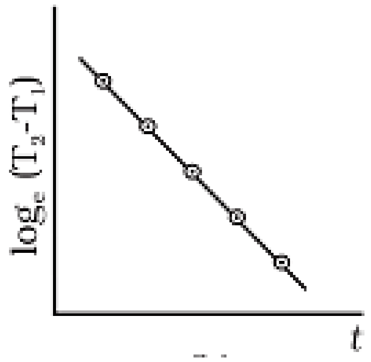
It is a valid approximation in the transfer of heat from a radiator to a room, the loss of heat through the wall of a room, or the cooling of a cup of tea on the table

Newton's law of cooling can be verified with the help of the experimental set-up shown in Fig.



The set-up consists of a double walled vessel (V) containing water in between the two walls. A copper calorimeter (C) containing hot water is placed inside the double walled vessel. Two thermometers through the corks, are used to note the temperatures T_2 of water in calorimeter and T_1 of water in between the double walls respectively. Temperature of water, in the calorimeter, is noted after equal intervals of time. A graph is plotted between $\log_e (T_2 - T_1)$ and time (t).

The nature of the graph is observed to be a straight line having a negative slope as shown in Fig. This is as per Newton's law of cooling.



EXAMPLE

A pan, filled with hot food cools from 94 °C to 86 °C in 2 minutes when the room temperature is at 20 °C. How long will it take to cool from 71 °C to 69 °C?

SOLUTION

The average temperature of 94 °C and 86 °C is 90 °C, which is 70 °C above the room temperature. Under these conditions the pan cools 8 °C in 2 minutes.

$$\frac{Change\ in\ temperature}{Time} = K\Delta T$$

$$\frac{8°C}{2\ min} = K(70°C)$$

The average of 69 °C and 71 °C is 70 °C, which is 50 °C above room temperature. K is the same for this situation as for the original.

$$\frac{2°C}{Time} = K(50°C)$$

When we divide above two equations, we have

Time ≃ 0.7 minutes = 42 s

11. TO STUDY THE FACTORS AFFECTING THE RATE OF LOSS OF HEAT OF A LIQUID.

APPARATUS AND MATERIAL REQUIRED

- Two copper calorimeters of different sizes (one small and another big);
- two copper calorimeters of same size (one painted black and the other highly polished),
- two tumblers of same size (one metallic and another plastic);
- two thermometers having a range of - 10° C to 110° C and least count 0.5 °C,
- stop watch/clock,
- cardboard lids for calorimeters,
- two laboratory stands,

- a pan to heat water;
- a measuring cylinder,
- a plastic mug.

PRINCIPLE

Hot bodies cool whenever placed in a cooler surrounding.

Rate of loss of heat is given by

$$\frac{dQ}{dt} = \frac{d}{dt}(\text{mass} \times \text{specific heat capacity(s)} \times \text{temperature } (\theta)) = ms\frac{d\theta}{dt}.$$

Hence rate of loss of heat is proportional to rate of change of temperature.

The rate of loss of heat of a body depends upon

(a) the difference in temperature of the hot body and its surroundings,

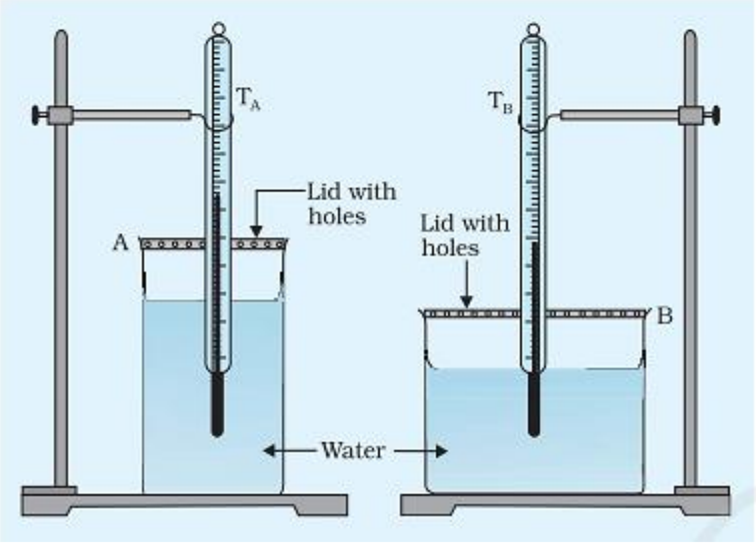
(b) area of the surface losing heat,

(c) nature of the surface losing heat and

(d) material of the container.

PROCEDURE

(A) EFFECT OF AREA OF SURFACE ON RATE OF LOSS OF HEAT.



Experimental setup for studying the effect of surface area on cooling

i) Note the room temperature and the least counts of the two thermometers (T_A and T_B).

ii) Take the big (A) and small (B) calorimeters.

iii). Heat water in the pan up to nearly 80°C (no need to boil the water).

iv) Pour 100 mL of hot water in calorimeter (A) and also in calorimeter (B).

This should be done carefully and with least time loss. One can use a plastic mug to pour 100 mL of hot water in a measuring cylinder.

v) Insert a thermometer in each of the two calorimeters.

Use stands to keep the thermometers vertical. Also ensure that the thermometer bulb is well inside the hot water in the calorimeters.

vi) Note the temperature of the water in the two calorimeters initially at an interval of 1 minute (till the temperature of water in the calorimeter is about 40–30°C above the room temperature) and thereafter at intervals of 2 minutes (when the temperature of hot water is about 20–10°C above room temperature).

The temperature falls more rapidly initially because the difference between the temperature of water in the calorimeter and the room temperature is large

vii) Record your observation in table

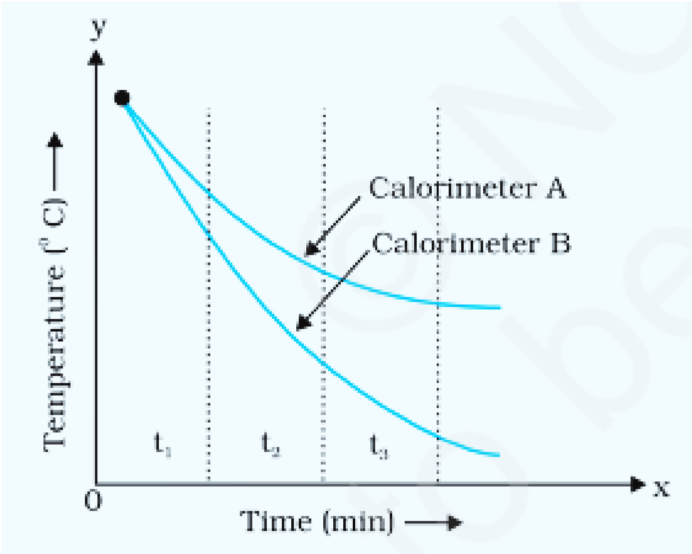
Effect of area of surface on rate of cooling

	Calorimeter A (Big)			Calorimeter B (Small)	
S. No.	Time	Temp θ_A	S. No.	Time	Temp θ_B

viii) Plot graphs between θ_A versus time and θ_B versus time for both the calorimeters on the same graph paper

This should be done with different colours if possible a visible comparison will amaze you

ix). Determine the slope of θ versus t graph after 5-minute interval.



Cooling curve for water cooled in calorimeter A and B. Surface area of water is more for calorimeter B than for the calorimeter A

OBSERVATIONS

Least count of thermometer = ... °C

Room temperature = ... °C

The water is observed to cool faster in calorimeter B which has a larger surface area.

B. EFFECT OF NATURE OF SURFACE OF CONTAINER ON RATE OF COOLING OF A LIQUID

- Use the two identical small calorimeters; one with black (A) and the other (B) with a highly polished surface.
  You can paint the calorimeter with black and silver paint , alternately take two small identical steel glasses , paint one of them black and leave the other shiny
- Repeat Steps 3 to 8 as in part A

Effect of nature of surface on rate of cooling

	Calorimeter Black (A)			Calorimeter White (B)	
S. No.	Time	Temp θ_A	S. No.	Time	Temp θ_B

It is observed that the black calorimeter cools down faster than the polished one.

C. EFFECT OF MATERIAL OF CONTAINER ON RATE OF COOLING OF A LIQUID

- Use the metallic tumbler (A) and the plastic tumbler (B) instead of calorimeters. Choose from Plastic glass, paper cup , steel glass , glass , kulhar * terracotta glass .the challenge is to keep the exposed surface area same
- Repeat Steps 3 to 8 as in part A. Record your observations in a table similar to Table A 12.1.

It is observed that the rate of cooling is faster for the metallic tumbler as compared to the plastic tumbler.

RESULT

From the six graphs, plotted on 3 graph sheets, complete the following:

i. **The rate of cooling is ... °C/min in the larger calorimeter as compared to the smaller calorimeter.**
ii. **Least rate of cooling is ... °C/min observed in ... part A/B/C.**
iii. **Black surfaces radiate ... heat as compared to white or polished surface in the same time when heated to the same temperature.**
iv. **Plastic mugs are preferred for drinking tea, as the rate of cooling of a liquid in them is ...**

PRECAUTIONS

1. θ_A, θ_B and time recordings are to be done simultaneously so a set up that allows both thermometers to be read quickly and at the same time, should be planned.

2. The lid of the calorimeter should be covered with insulating material to make sure that the heat is lost (cooling takes place) only from the calorimeter surface.

3. All three activities should be performed under similar conditions of wind and temperature of the surrounding (to maintain their effect on the rate of cooling) at the same level.

May be done in the same corner of the laboratory. Remember you need to draw smooth average curves for each case, after all you are studying the general effect in the three different comparative cases

THINK ABOUT THESE

- **The rate of cooling in summers is lower than in winters. Give a reason for your answer.**
- **Surface of metallic kettles are often polished to keep the tea warm for a long time.**
- **Why does the rate of cooling decrease when the temperature of liquid is closer to the room temperature?**

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

- **Compare the effectiveness of disposable tumblers, with that of glass, for taking tea.**

- **Study the rate of cooling of tea contained in a stainless steel (metallic) teapot and a ceramic teapot.**
- **Compare the rate of cooling of tea in a cup and in a saucer.**

12. GREENHOUSE EFFECT

The "greenhouse effect" of the atmosphere is named by analogy to green houses, which become warmer in sunlight.

However, a greenhouse may not be primarily warmed by the "greenhouse effect".

"Greenhouse effect" is actually a misnomer since heating in the usual greenhouse is due to the reduction of convection.

The "greenhouse effect" works by preventing absorbed heat from leaving the structure through radiative transfer.

WORKING OF GREENHOUSE

A greenhouse is built of any material usually glass, or plastic that lets sunlight pass through it.

The sun warms the ground and the contents inside the greenhouse (just like the outside). This then warms the air.

Outside, the warm air near the surface rises and mixes with cooler air on top.

This makes the outside temperature lower than inside, where the air continues to heat up because it is confined within the greenhouse.

(This can be demonstrated by opening a small window near the roof of a greenhouse: the temperature will drop considerably. It was demonstrated experimentally by R. W. Wood in 1909).

https://upload.wikimedia.org/wikipedia/commons/8/8a/Greenhouse_at_Wilson_Farm%2C_East_Lexington_MA.jpg

The **greenhouse effect** is the process by which radiation coming through a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere.

If a planet's atmosphere contains greenhouse gases, they will radiate energy in all directions. Part of this radiation is directed towards the surface of the earth, thus warming it.

The intensity of the downward radiation – that is, the strength of the greenhouse effect – will depend on the atmospheric temperature and on the amount of greenhouse gases that the atmosphere contains.

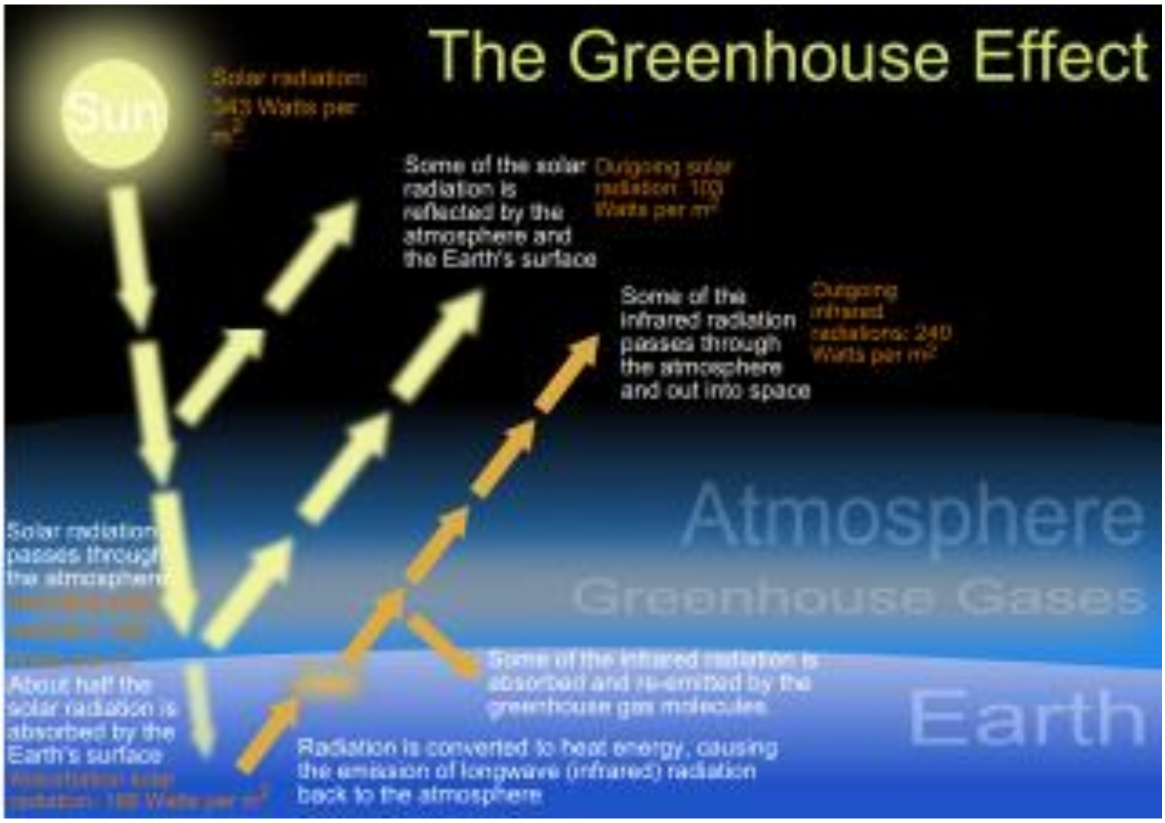
Earth's natural greenhouse effect is critical to supporting life. Human activities, primarily the burning of fossil fuels and clearing of forests, have intensified the natural greenhouse effect, causing **global warming.**

The mechanism is named after a faulty analogy with the effect of solar radiation, passing through glass and warming a **greenhouse.**

The way a greenhouse retains heat is fundamentally different, as a greenhouse works mostly by reducing airflow and thus retaining warm air inside the structure.

The Energy flow between the sun, the atmosphere and earth's surface.

The ability of the atmosphere, to capture and recycle energy emitted by Earth's surface, is the defining characteristic of the greenhouse effect



https://upload.wikimedia.org/wikipedia/commons/thumb/d/d5/The_green_house_effect.svg/320px-The_green_house_effect.svg.png

Earth receives energy from the Sun in the form of ultraviolet, visible, and near-infrared radiation.

Of the total amount of solar energy available at the top of the atmosphere, about **26%** is reflected to space by the atmosphere and clouds and **19%** is absorbed by the atmosphere and clouds. Most of the remaining energy is absorbed by the surface of Earth.

Because the Earth's surface is colder than the photosphere of the Sun, it radiates at **wavelengths that are much longer** than the wavelengths that were absorbed. Most of this thermal radiation is absorbed by the atmosphere, thereby warming it. In addition to the absorption of solar and thermal radiation, the atmosphere gains heat by sensible and latent heat fluxes from the surface.

The atmosphere radiates energy both upwards and downwards; the part radiated downwards is absorbed by the surface of Earth. This leads to a higher equilibrium temperature than if the atmosphere were absent.

An ideal thermally conductive **blackbody,** at the same distance from the Sun as Earth, would have a temperature of about 5.3 °C. However, because Earth reflects about **30%** of the incoming sunlight, this idealized planet's **effective temperature** (the temperature of a blackbody that would emit the same amount of radiation) would be about −18 °C. The surface temperature of this hypothetical planet is 33 °C below Earth's actual surface temperature of approximately 14 °C.

Warmed earth's surface, radiates long-wavelength, infrared heat in the range of 4–100 μm. At these wavelengths, greenhouse gases, that were largely transparent to incoming solar radiation, are more absorbent. Each layer of atmosphere, with greenhouses gases, absorbs some of the heat being radiated upwards from lower layers. It reradiates in all directions, both upwards and downwards; in equilibrium (by definition) the same amount as it has absorbed. This results in more warmth below. Increasing the concentration of the gases increases the amount of absorption and reradiation, and thereby further warms the layers and ultimately the surface below.

Greenhouse gases—including most diatomic gases with two different atoms (such as carbon monoxide, CO) and all gases with three or more atoms—are able to absorb and emit infrared radiation.

Though more than 99% of the dry atmosphere is transparent (because the main constituents —N_2, O_2, and Ar—are not able to directly absorb or emit infrared radiation), intermolecular collisions cause the energy absorbed and emitted by the greenhouse gases to be shared with the other, active, (greenhouse) gases.

The major non-gas contributor to Earth's greenhouse effect, clouds, also absorb and emit infrared radiation and thus have an effect on the radiative properties of the atmosphere

ROLE IN CLIMATE CHANGE

Human activity has increased atmospheric concentrations of carbon dioxide, methane and nitrous oxide. An unprecedented amount of CO_2 is now being produced by fossil fuel burning.

The effect of combustion-produced carbon dioxide on the global climate, is a special case of the greenhouse effect.

OZONE LAYER AND HOW IT IS GETTING DEPLETED

Ozone (O_3) is a molecule formed by three atoms of oxygen. While O_2, which we normally refer to as oxygen, is essential for all aerobic forms of life. Ozone, is a deadly poison. However, at the higher levels of the atmosphere, ozone performs an essential function. It shields the surface of the earth from ultraviolet (UV) radiation from the Sun. This radiation is highly damaging to organisms; for example, it is known to cause skin cancer in human beings. Ozone, at the higher levels of the atmosphere, is a product of UV radiation acting on oxygen (O_2) molecule. The higher energy UV radiations split apart some molecular oxygen (O_2) into free oxygen (O) atoms. These atoms then combine with the molecular oxygen to form ozone. The amount of ozone in the atmosphere began to drop sharply in the 1980s. This decrease has been linked to synthetic chemicals like chlorofluorocarbons (CFCs) which are used as refrigerants and in fire extinguishers.

13. 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
- Bodies radiate and absorb heat according to certain well defined laws
- Stefan's law : The heat radiation emitted from a body is proportional to the fourth power of its absolute temperature
- Wien's displacement law: All heat wavelengths are not emitted to the same extent at all temperatures The peak of the wavelength distribution shifts to shorter wavelengths as the temperature increases
- Newton's law of cooling : The rate of cooling of a hot boy depends upon its excess temperature with respect to its environment
- Newton's law of cooling can be verified in the laboratory
- Greenhouse effect is due to trapped radiations in a limited space. Earth receives energy from the Sun mostly in the form of ultraviolet, visible, and near-infrared radiation.

- Increase in the amount of greenhouse gases is resulting in global warming
- Depletion of ozone layer causes extra ultraviolet radiations to reach the earth