THE REPUBLIC OF UGANDA

Ministry of Education and Sports

HOME-STUDY LEARNING

SENIOR 5

PHYSICS

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This material has been developed as a home-study intervention for schools during the lockdown caused by the COVID-19 pandemic to support continuity of learning.

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FOREWORD

Following the outbreak of the COVID-19 pandemic, government of Uganda closed all schools and other educational institutions to minimize the spread of the coronavirus. This has affected more than 36,314 primary schools, 3129 secondary schools, 430,778 teachers and 12,777,390 learners.

The COVID-19 outbreak and subsequent closure of all has had drastically impacted on learning especially curriculum coverage, loss of interest in education and learner readiness in case schools open. This could result in massive rates of learner dropouts due to unwanted pregnancies and lack of school fees among others.

To mitigate the impact of the pandemic on the education system in Uganda, the Ministry of Education and Sports (MoES) constituted a Sector Response Taskforce (SRT) to strengthen the sector's preparedness and response measures. The SRT and National Curriculum Development Centre developed print home-study materials, radio and television scripts for some selected subjects for all learners from Pre-Primary to Advanced Level. The materials will enhance continued learning and learning for progression during this period of the lockdown, and will still be relevant when schools resume.

The materials focused on critical competences in all subjects in the curricula to enable the learners to achieve without the teachers' guidance. Therefore effort should be made for all learners to access and use these materials during the lockdown. Similarly, teachers are advised to get these materials in order to plan appropriately for further learning when schools resume, while parents/guardians need to ensure that their children access copies of these materials and use them appropriately.
I recognise the effort of National Curriculum Development Centre in responding to this emergency through appropriate guidance and the timely development of these home study materials. I recommend them for use by all learners during the lockdown.

Alex Kakooza
Permanent Secretary
Ministry of Education and Sports

ACKNOWLEDGEMENTS

National Curriculum Development Centre (NCDC) would like to express its appreciation to all those who worked tirelessly towards the production of home–study materials for Pre-Primary, Primary and Secondary Levels of Education during the COVID-19 lockdown in Uganda.

The Centre appreciates the contribution from all those who guided the development of these materials to make sure they are of quality; Development partners - SESIL, Save the Children and UNICEF; all the Panel members of the various subjects; sister institutions - UNEB and DES for their valuable contributions.

NCDC takes the responsibility for any shortcomings that might be identified in this publication and welcomes suggestions for improvement. The comments and suggestions may be communicated to NCDC through P.O. Box 7002 Kampala or email admin@ncdc.go.ug or by visiting our website at http://ncdc.go.ug/node/13.

Grace K. Baguma
Director,
National Curriculum Development Centre

ABOUT THIS BOOKLET

Dear learner, you are welcome to this home-study package. This content focuses on critical competences in the syllabus.

The content is organised into lesson units. Each unit has lesson activities, summary notes and assessment activities. Some lessons have projects that you need to carry out at home during this period. You are free to use other reference materials to get more information for specific topics.

Seek guidance from people at home who are knowledgeable to clarify in case of a challenge. The knowledge you can acquire from this content can be supplemented with other learning options that may be offered on radio, television, newspaper learning programmes. More learning materials can also be accessed by visiting our website at www.ncdc.go.ug or ncdc-go-ug.digital/. You can access the website using an internet enabled computer or mobile phone.

We encourage you to present your work to your class teacher when schools resume so that your teacher is able to know what you learned during the time you have been away from school. This will form part of your assessment. Your teacher will also assess the assignments you will have done and do corrections where you might not have done it right.

The content has been developed with full awareness of the home learning environment without direct supervision of the teacher. The methods, examples and activities used in the materials have been carefully selected to facilitate continuity of learning.

You are therefore in charge of your own learning. You need to give yourself favourable time for learning. This material can as well be used beyond the home-study situation. Keep it for reference anytime.

Develop your learning timetable to ca ter for continuity of learning and other responsibilities given to you at home.

Enjoy learning

HEAT

TOPIC: THERMOMETRY

OBJECTIVE: By the end of this topic, you should be able to describe different types of thermometers used in the measurement of temperature.

LESSON 1

SUBTOPIC: TEMPERATURE AND THE SCALE OF TEMPERATURE

OBJECTIVES: By the end of this unit, you should describe how temperature scales are established and solve related numerical problems

INTRODUCTION

Our interest in **heat** is because it is the most common form of energy and because changes of **temperature** have great effects on our comfort and on the properties of substances that we use every day.

- Heat is energy transferred due to temperature difference
- Temperature is the degree of hotness of a body or a place

We measure temperature using thermometers on which there are suitable scales.
Thermometers use physical properties of substances called thermometric properties to measure temperature.

ASSIGNMENT: List some properties of physical quantities you think change with temperature and are constant at constant temperature.

NOTE: A good thermometric property should vary linearly and continuously with temperature and each value of thermometric property should correspond to a unique value of temperature.

SCALE OF TEMPERATURE

A scale of temperature is one that is used to measure the degree of hotness of a body by taking a thermometric property of a substance.

THE CENTIGRADE SCALE

This is a type of temperature scale which has the lower fixed point at ice point (0^0C) and upper fixed point at steam point (100^0C).

ESTABLISHMENT OF CENTIGRADE or CELSIUS TEMPERATURE SCALE

- A thermometric property, ***x*** of a substance is selected.
- The property is measured at steam point and ice point and its values $x_{100}$and x_0 respectively are noted.
- The property is measured at an unknown temperature, Θ and its value be x_Θ, is noted.

Property, X	X_0	X_Θ	X_{100}
Temperature	Ice point (0^0C)	Unknown (θ)	Steam point (100^0C)

The property varies linearly and continuously with temperature. The gradient of the line is the same for any two points on the line and the unknown temperature on this scale is given by the equation below.

$$\theta = \left(\frac{x_\theta - x_0}{x_{100} - x_0} \right) \times 100^0\,C$$

LESSON 2

SUBTOPIC: THERMOMETERS

OBJECTIVES: By the end of this lesson, you should

- describe how different types of thermometers are used to measure temperature
- Solve related numerical problems

Temperature is measured using both analog and digital thermometers. Some of the thermometers are shown in the figure below.

Examples are discussed there under.

(a) **Liquid-in-glass thermometer**. The thermometric property, **x**, in this case is the length, *l* of the liquid column.

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0} \right) \times 100^0 \mathrm{C}$$

This is the most common type of thermometer used.

(b) **Thermocouple Thermometer**. The thermometric property is the e.m.f, E of the thermocouple.

$$\theta = \left(\frac{E_\theta - E_0}{E_{100} - E_0} \right) \times 100^0 \mathrm{C}$$

(c) **Platinum resistance Thermometer**. The thermometric property is the resistance R of platinum.

$$\theta = \left(\frac{R_\theta - R_0}{R_{100} - R0} \right) \times 100^0 \mathrm{C}$$

(d) **Constant volume gas Thermometer**. The thermometric property is the pressure of a fixed mass of a gas

$$\theta = \left(\frac{P_\theta - P_0}{P_{100} - P_0} \right) \times 100^0 \mathrm{C}$$

THE THERMODYNAMIC OR KELVIN TEMPERATURE SCALE

This is a standard temperature scale which uses a fixed point called the **triple point** of water.

Note: Triple point is the temperature at which pure water, pure ice and pure vapor co-exist in equilibrium. Triple point of water = 273.16 K.

Note: θ = T - 273.16

θ is the Celsius temperature, T is the Kelvin or absolute temperature?

ESTABLISHING A THERMODYNAMIC TEMPERATURE SCALE

- The thermometric property, **x** of a substance is selected.
- The property is measured at the triple point of water and its value x_{tr} is noted.
- The property is measured at unknown temperature, θ and its value be x_θ is noted
- The unknown temperature is given as,

$$\theta = \left(\frac{x_\theta}{x_{tr}} \right) \times 273.16 \text{ K}$$

NOTE: Two different thermometers usually give different values of temperature except at the fixed points where they must agree and this is due to the difference in variation of the thermometric properties with temperature.

EXAMPLES

1. If the resistance of the platinum wire on a resistance thermometer is measured at ice point, steam point and unknown temperature θ as 2.00Ω, 2.760Ω and 2.480Ω respectively. Determine the unknown temperature θ.

Solution:

$$R_\theta = 2.00\Omega,\ R_{100} = 2.760,\ R_\theta = 2.480\Omega$$

$$\text{Using; } \theta = \left(\frac{R_\theta - R_0}{R_{100} - R_0}\right) \times 100^0\mathrm{C}$$

$$\theta = \left(\frac{2.48 - 2.00}{2.76 - 2.00}\right) \times 100^0\mathrm{C}$$

$$\theta = 63.2^0\mathrm{C}$$

2. The resistance R_θ of platinum varies with temperature $\theta^0\mathrm{C}$ as measured by a constant volume gas thermometer according to the equation $R_\theta = R_0(1 + 800\alpha\theta - \alpha\theta^2)$ where R_0 the resistance at 0^0 C and α is a constant. Calculate the temperature on the platinum scale corresponding to 400^0 C on this gas scale.

Solution

$$R_\theta = R_0(1 + 800\alpha\theta - \alpha\theta^2)$$

For $\theta = 100^0$ C

$$R_{100} = R_0(1 + 800(100)\alpha - (100)^2\alpha)$$

$$R_{100} = R_0(1 + 80000\alpha - 10000\alpha)$$

$$R_{100} = R_0(1 + 70000\alpha) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

For $\theta = 400^0$ C

$$R_{400} = R_0(1 + 800(400)\alpha - (400)^2\alpha)$$

$$R_{400} = R_0(1 + 320000\alpha - 160000\alpha) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

On the resistance thermometer,

$$\theta = \left(\frac{R_{400} - R_0}{R_{100} - R_0}\right) \times 100^0\,\text{C}$$

$$\theta = \left(\frac{R_0(1 + 160000\alpha) - R_0}{R_0(1 + 70000\alpha) - R_0}\right) \times 100^0\,\text{C}$$

$$\theta = \frac{R_0}{R_0}\left(\frac{1 + 160000\alpha - 1}{1 + 70000\alpha - 1}\right) \times 100^0\,\text{C}$$

$$\theta = \left(\frac{160000\alpha}{70000\alpha}\right) \times 100^0\,\text{C}$$

$$\theta = \frac{1600}{7}\ {}^0\text{C} \quad ; \quad \theta = 228.57\ {}^0\text{C}$$

ASSIGNMENT

One junction of a thermocouple is placed in melting ice while the other is inserted into a bath whose temperature as measured by a high temperature mercury in glass thermometer is T. The following readings were obtained

T(°C)	emf, E(mv)
0	0
100	0.64
200	1.44
300	2.32
400	3.25
500	4.32

By graphical method, find

(i) The temperature on the thermocouple scale corresponding to 380° on the Hg- in glass scale

(ii) The temperature on the mercury -in glass thermometer corresponding to

250°C on the temperature scale

LESSON 3

TOPIC: CALORIMETRY

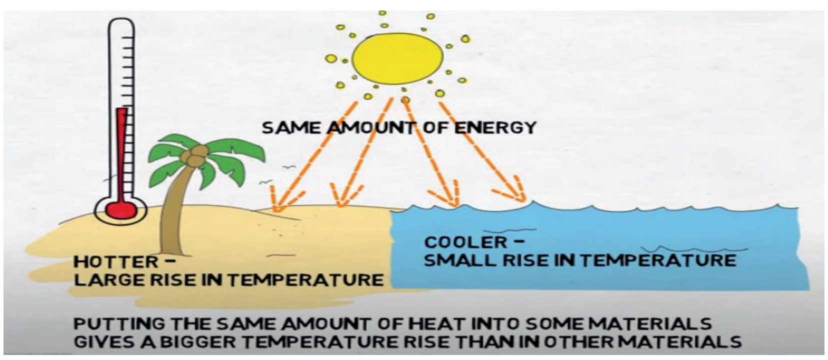
SUBTOPIC: HEAT CAPACITY AND SPECIFIC HEAT CAPACITY

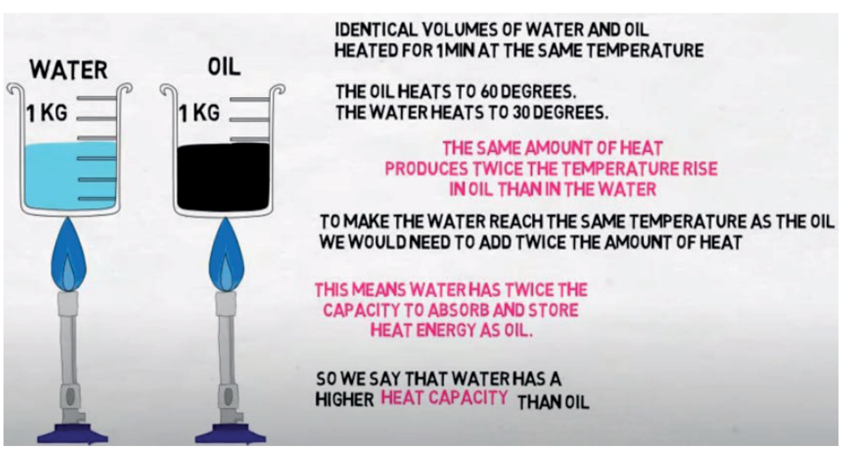
OBJECTIVE:

- Explain heat capacity and specific heat capacity.
- Measure specific heat capacity using different methods.

INTRODUCTION

Materials differ from one another in the quantity of heat needed to produce a certain rise of temperature in a given mass.





- **Heat capacity or thermal capacity** is the amount or quantity of heat required to raise the temperature of a substance by one kelvin.
  Heat Capacity = mc
  m = mass of the substance, c = specific heat capacity of the substance.
- **Specific heat capacity** is the amount of heat required to raise the temperature of one kilogram (1kg) mass of a substance by one kelvin.

Note: The amount of heat, H required change the temperature of a body is obtained from:

$$H = mc\theta \quad \text{................(i)}$$

Where,

m - mass of the body

c - specific heat capacity

θ - change in temperature

From .....**(i)**

$$c = \frac{H}{m\theta}$$

This means that the specific heat capacity depends on:

- The nature of the substance,
- The mass of the substance and,
- The change in temperature of the substance

Thus, if the temperature of a body of mass 0.5 kg and specific heat capacity 400 J $kg^{-1}K^{-1}$ rises from 150C to 200C (288 K to 293 K) the heat taken in is:

$H = 0.5\ kg \times 400\ J\ kg^{-1}K^{-1} \times 5\ K$

$H = (0.5 \times 400 \times 5)\ kg\ J\ kg^{-1}K^{-1}K$

$H = 1000\ J$

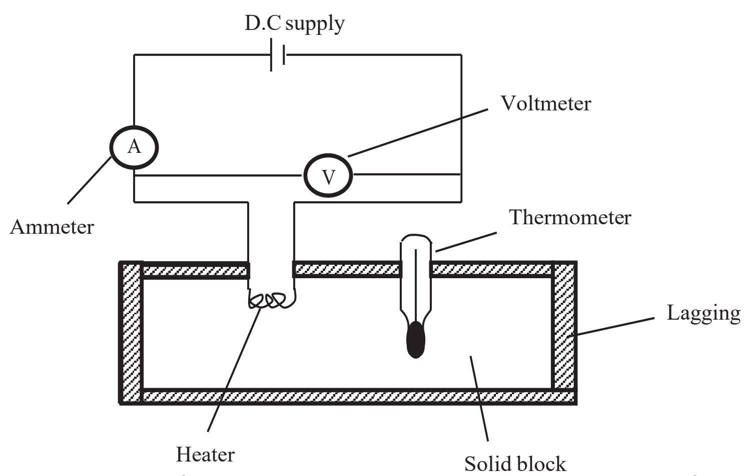
MEASURING SPECIFIC HEAT CAPACITY OF A SUBSTANCE

a) ELECTRICAL MATHOD

(i) SOLIDS: This method is suitable for metals when used as solids.

- ➢ Two holes are drilled into the metal whose specific heat capacity, c is required.
- ➢ The mass, m of the metal is measured and initial temperature, θ_1 determined.
- ➢ The metal is carefully lagged to minimize heat losses.

- A thermometer is inserted in one of the holes and a heater connected to source of electrical energy is inserted in the other hole as shown in the figure below.

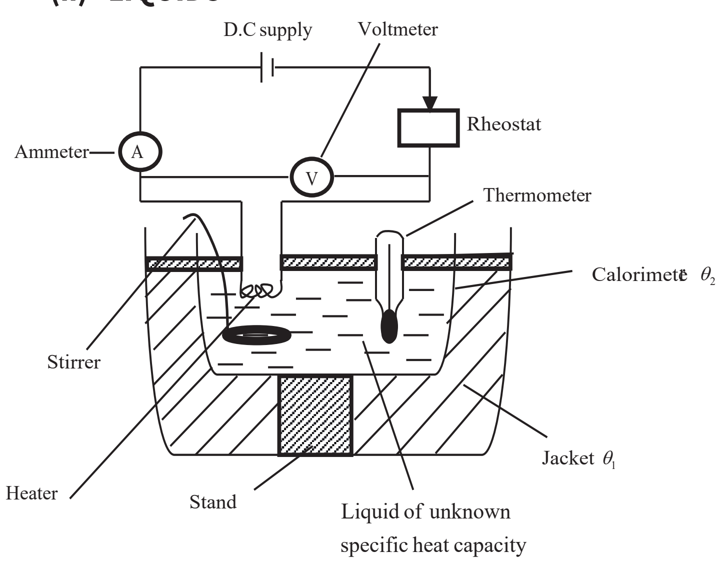


- The heater is switched on for a time t during which temperature of the metal rises to θ_2.
- The potential difference, V and current, I during the time, t are determined from the voltmeter and ammeter respectively.
- Assuming negligible heat losses,
- Electrical energy supplied through the heater = heat energy gained by the metal.

$$IVt = mc(\theta_2 - \theta_1)$$

$$c = \frac{IVt}{m(\theta 2 - \theta 1)}$$

(ii) LIQUIDS

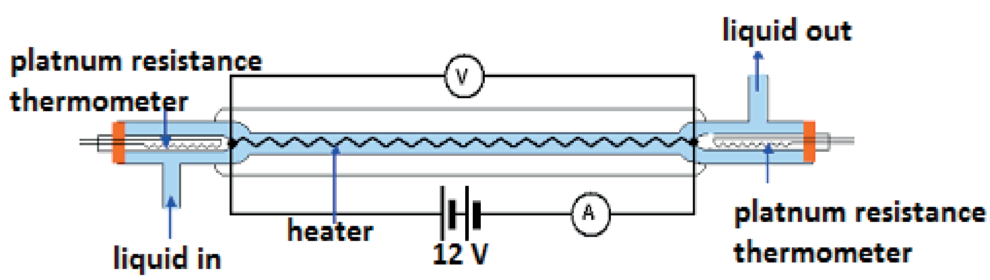


- In the arrangement shown in the figure above, a d.c supply is switched on for a time **t**, until the temperature of the liquid and calorimeter changes from θ_1 and θ_2 .
- The rheostat is adjusted to get suitable values of I and **V** and the mixture is stirred to get uniform values of the temperature.
- Assuming that there is no heat gained by the stirrer and thermometer and no heat lost to the surroundings then, heat energy supplied by the heater is equal to heat energy gained by the calorimeter and the liquid.

$$IVt = m_c c_c(\theta_2 - \theta_1) + m_l c_l(\theta_2 - \theta_1)$$

The mass m_c of the calorimeter and its specific heat capacity, c_c are known. The mass m_l of the liquid is determined, temperatures θ_1 and θ_2 are measured, then c_l can be determined.

DETERMINATION OF SPECIFIC HEAT CAPACITY OF A LIQUID BY CONTINUOUS FLOW METHOD (CALLENDAR AND BARNES METHOD)



- A spiral resistance wire carrying a steady current, I heats the liquid until a steady state is attained.
- At a steady state the inlet temperature, θ_1 and outlet temperature, θ_2 are recorded by thermometers, T_1 andT_2 respectively and the mass rate of flow, m is also measured.
- The current I and the voltage V are measured by ammeter, A and voltmeter, V.
- At steady state, all the heat is used to heat the liquid and upset heat losses.

$$IV = mc(\theta_2 - \theta_1) \text{ ....(i)}$$

- The mass collected per second is changed to m^1 the current and voltage are adjusted to I^1 and V^1 to bring back θ_1 and θ_2 to the original values such that,

$$I^1V^1 = m^1c(\theta_2 - \theta_1) \text{ .... (ii)}$$

Combining (i) and (ii) gives $C = \frac{IV - I1V1}{(\theta 2 - \theta 1)(M - M1)}$

ADVANTAGES OF CONTINUOUS FLOW METHOD

- Temperatures θ_1 and θ_2 to be measured are steady and therefore can be determined accurately by using platinum resistance thermometers.
- The specific heat capacity of the apparatus is not required since at a steady state the apparatus absorbs no more heat.
- Heat losses by conduction and radiation are accounted for by repeating the experiment and heat losses by convection is prevented by vacuum.

  However it cannot be used to determine specific heat capacity of solid and volatile liquids.

LESSON 4

TOPIC: COOLING LAWS AND TEMPERATURE FALL

OBJECTIVE: By the end of this unit, you should state the cooling laws and describe how to verify Newton's laws of cooling.

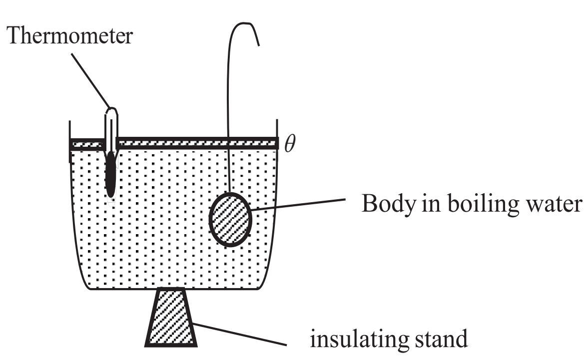
NEWTON'S LAW OF COOLING

It states that under conditions of forced convection e.g. in a steady draught the rate of heat loss of a body is proportional to the excess temperature over the surrounding.

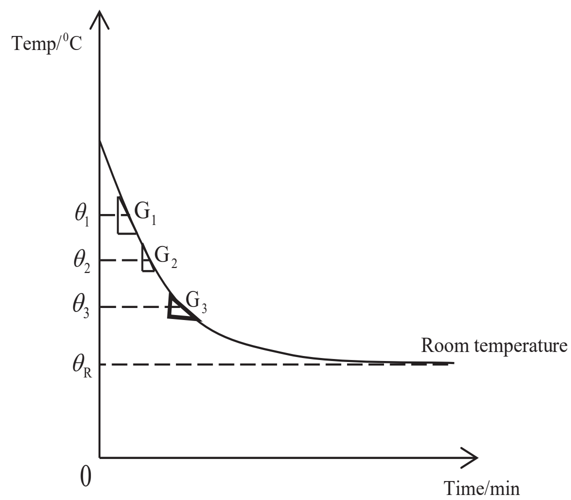
i.e. $\frac{\partial Q}{\partial t} \alpha (\theta - \theta_R)$, Where, θ_R - Room temperature
θ - temperature of the body

Note: When a body losses heat, its temperature falls and this means that also rate of fall is directly proportional to $(\theta - \theta_R)$, **i.e** $\frac{\partial Q}{\partial t} \alpha (\theta - \theta_R)$

VERIFICATION OF NEWTON'S LAW OF COOLING



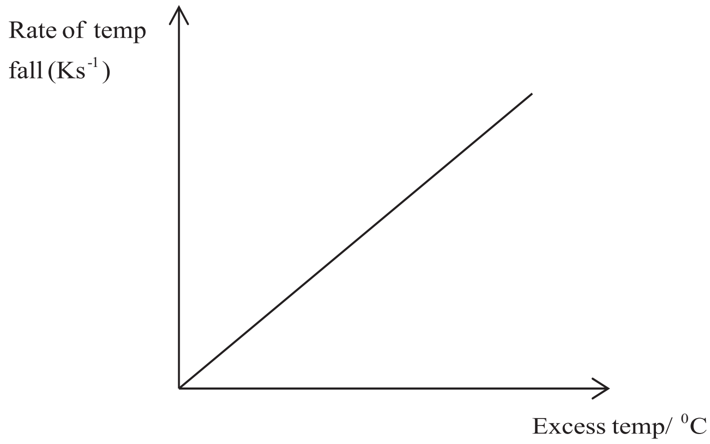
- A body is heated in boiling water up to a temperature θ.
- It is then transferred to the environment whose room temperature is θ_R.
- Different values of temperature θ at corresponding time intervals t are tabulated
- The cooling curve (temperature against time) plotted as shown below.



$$G = \frac{d\theta}{dt}.$$

- Different rates of the temperature fall, G_1, G_2 and G_3 at different temperatures θ_1, θ_2 and θ_3 respectively are determined and tabulated.
- A graph of rate of temperature fall against excess temperature is plotted a
- A straight line is obtained implying that the rate of fall of temperature is proportional to excess temperature over the surrounding and this verifies Newton's law of cooling.

Rate of temperature fall	Excess temperature
G_1	$\theta_1 - \theta_R$
G_2	$\theta_2 - \theta_R$
G_3	$\theta_3 - \theta_R$



HEAT LOSS AND TEMPERATURE FALL

Apart from excess temperature $(\theta - \theta_R)$, the rate of heat loss depends on the surface area **S** of the body and the nature of the surface of the body. For example; a dull surface loses heat faster than a shiny one. Hence, for a body having uniform surface area S and uniform temperature distribution, Newton's law becomes

$$\frac{dQ}{dt} \alpha (\theta - \theta_R) \quad \text{But;} \quad \frac{dQ}{dt} \alpha \, \mathrm{S}$$

$$\frac{dQ}{dt} \alpha \, \mathrm{S} (\theta - \theta_R)$$

$$\frac{dQ}{dt} = -\mathrm{k}\,\mathrm{S} (\theta - \theta_R)$$

Where k is a constant of proportionality and depends on the nature of the body's surface. But $Q = \mathrm{mc}\theta$, Where m – mass and c – Specific heat capacity.

$$\frac{d}{dt}(\mathrm{mc}\theta) = -\mathrm{kS}(\theta - \theta_\mathrm{R})$$

$$\mathrm{mc}\frac{d\theta}{dt} = -\mathrm{kS}(\theta - \theta_\mathrm{R})$$ Where the negative sign implies temperature fall

$$\frac{d\theta}{dt} = \frac{\mathrm{kS}}{\mathrm{mc}}(\theta - \theta_\mathrm{R}),$$ But $\mathrm{m} = \rho \times \mathrm{V}$, Where $\rho - \text{density}$, V - volume $\frac{d\theta}{dt} = \frac{\mathrm{k}}{\rho \mathrm{c}} \frac{\mathrm{S}}{\mathrm{V}} (\theta - \theta_R)$,

$$\frac{d\theta}{dt} = \frac{\lambda \mathrm{S}}{\mathrm{V}}, \quad \lambda = \frac{\mathrm{k}}{\rho \mathrm{c}}(\theta - \theta_R)$$

$$\frac{d\theta}{dt} \alpha \frac{\mathrm{S}}{\mathrm{V}}$$

$$\frac{d\theta}{dt}\alpha\frac{1}{\text{any linear dimension}}$$

This means that a smaller body cools faster than a large one i.e. a temperature of a small body falls faster.

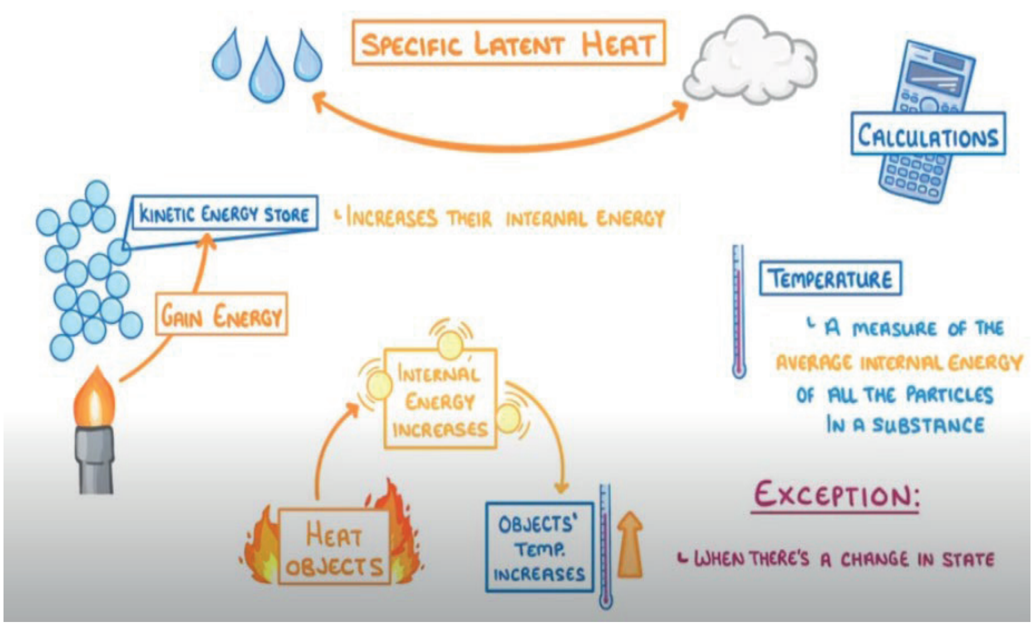
Note In laboratory experiment the use of large apparatus minimizes errors due to heat losses in a given time.

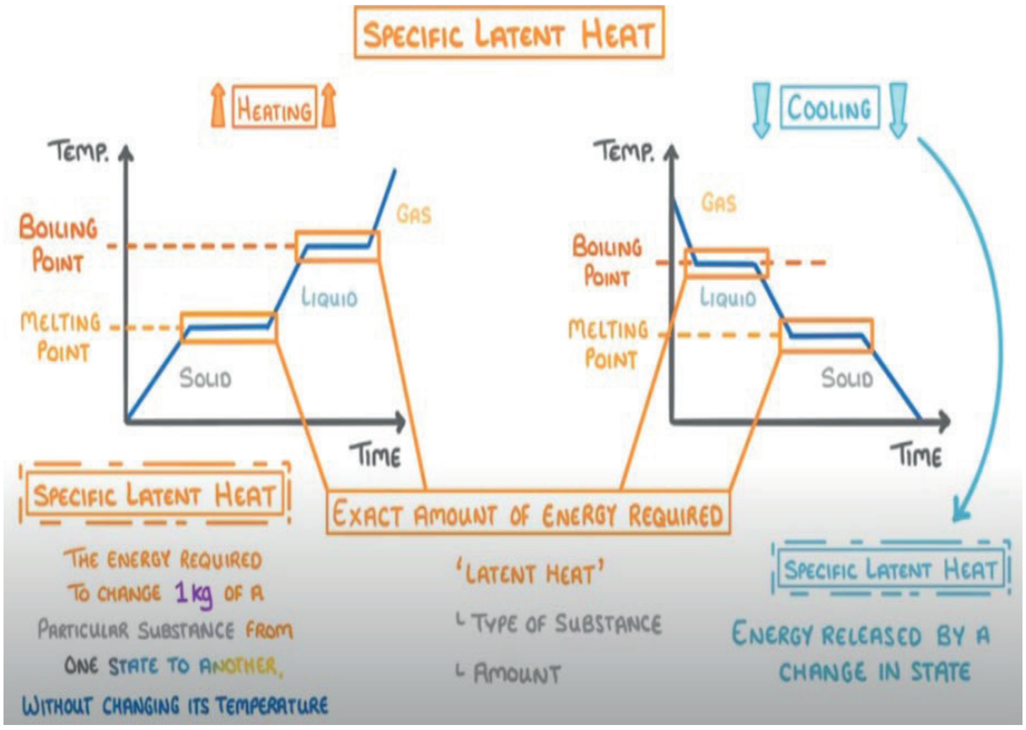
LESSON 5

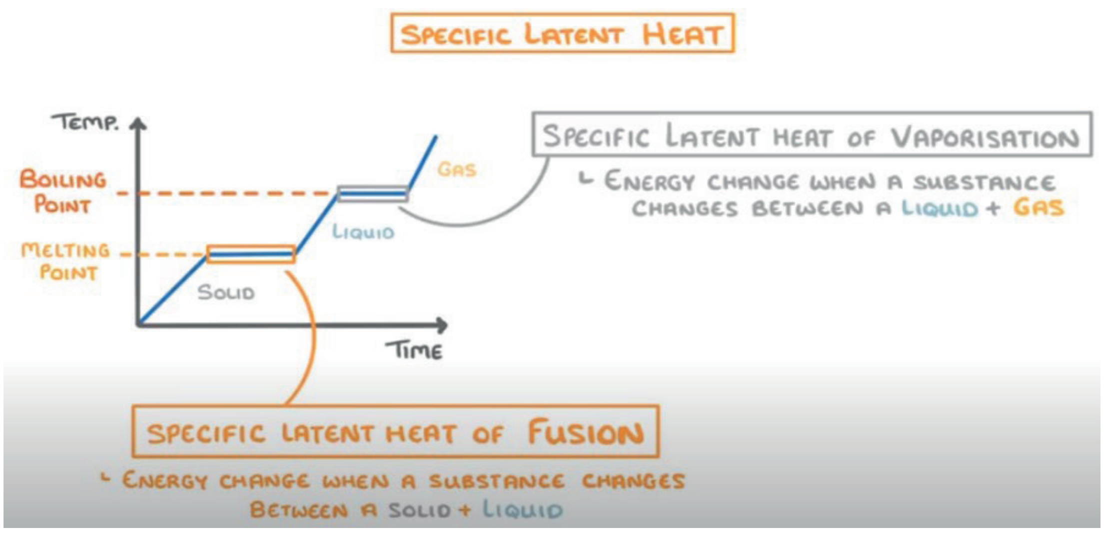
TOPIC: LATENT HEAT

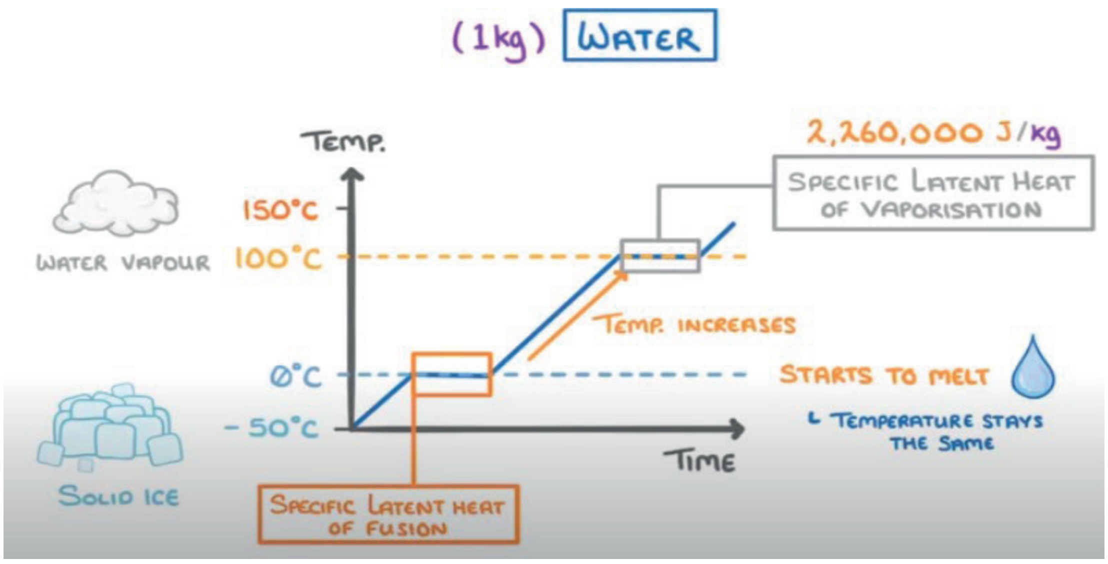
OBJECTIVE: By the end of this unit, you should describe simple experiments to determine latent heat of fusion and vaporization.

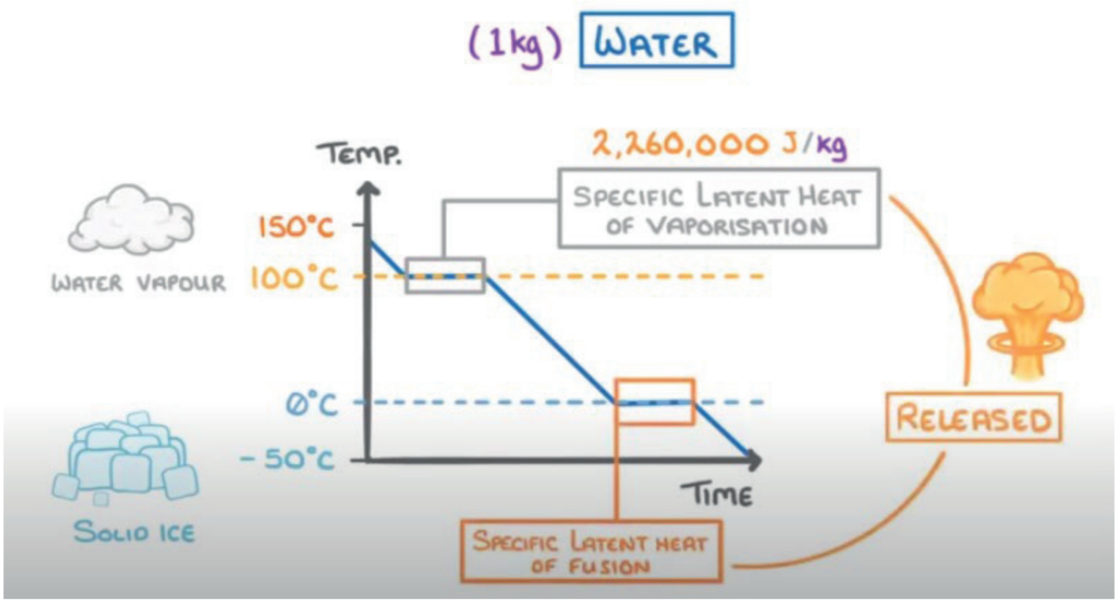
Consider the illustrations below:

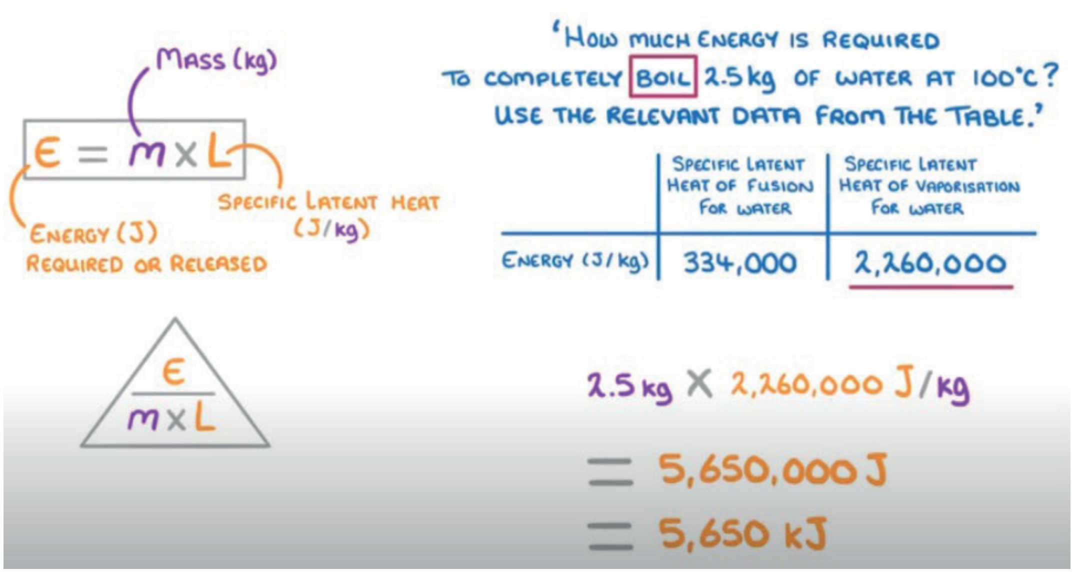



Specific Latent Heat
Heating
Cooling
Temp.
Boiling Point
Melting Point
Gas
Liquid
Solid
Time
Specific Latent Heat
The energy required to change 1 kg of a particular substance from one state to another, without changing its temperature
Exact amount of energy required
'Latent Heat'
Type of substance
Amount
Specific Latent Heat
Energy released by a change in state


Specific Latent Heat
Temp.
Boiling Point
Melting Point
Gas
Liquid
Solid
Time
Specific Latent Heat of Vaporisation
Energy change when a substance changes between a liquid + gas
Specific Latent Heat of Fusion
Energy change when a substance changes between a solid + liquid


(1kg) WATER
TEMP.
2,260,000 J/kg
SPECIFIC LATENT HEAT OF VAPORISATION
150°C
WATER VAPOUR
100°C
TEMP. INCREASES
0°C
STARTS TO MELT
- 50°C
TEMPERATURE STAYS THE SAME
TIME
SOLID ICE
SPECIFIC LATENT HEAT OF FUSION


(1kg) WATER
TEMP.
2,260,000 J/kg
SPECIFIC LATENT HEAT OF VAPORISATION
150°C
WATER VAPOUR
100°C
0°C
RELEASED
- 50°C
TIME
SOLID ICE
SPECIFIC LATENT HEAT OF FUSION


MASS (kg)
E = m x L
ENERGY (J) REQUIRED OR RELEASED
SPECIFIC LATENT HEAT (J/kg)
'HOW MUCH ENERGY IS REQUIRED
TO COMPLETELY BOIL 2.5kg OF WATER AT 100°C?
USE THE RELEVANT DATA FROM THE TABLE.'
SPECIFIC LATENT HEAT OF FUSION FOR WATER
SPECIFIC LATENT HEAT OF VAPORISATION FOR WATER
ENERGY (J/kg)
334,000
2,260,000
E
m x L
2.5 kg X 2,260,000 J/kg
= 5,650,000 J
= 5,650 kJ

Latent heat is the hidden heat which when supplied to the body causes its change of state or phase at constant temperature i.e.

$$\text{Solid} \underset{\substack{\text{absorbed} \\ \text{(latent heat of fusion)}}}{\overset{\text{heat}}{\rightleftharpoons}} \text{Liquid} \underset{\substack{\text{given out} \\ \text{(latent heat of vaporization)}}}{\overset{\text{heat}}{\rightleftharpoons}} \text{Vapour}$$

When melting a solid latent heat of fusion is absorbed to break the intermolecular forces between the solid molecules and to raise their potential energy since it allows molecules to move apart. When evaporating a liquid latent heat of vaporization is absorbed to break the intermolecular forces between liquid molecules and to raise their potential energy by high amounts since the molecules become widely spaced when they are in vapour state.

SPECIFIC LATENT HEAT OF FUSION (L_F)

It is the amount of heat required to change one kilogram of a solid into a liquid at the same temperature. SI unit is Jkg-1.
surroundings.

SPECIFIC LATENT HEAT OF VAPORIZATION (L_V)

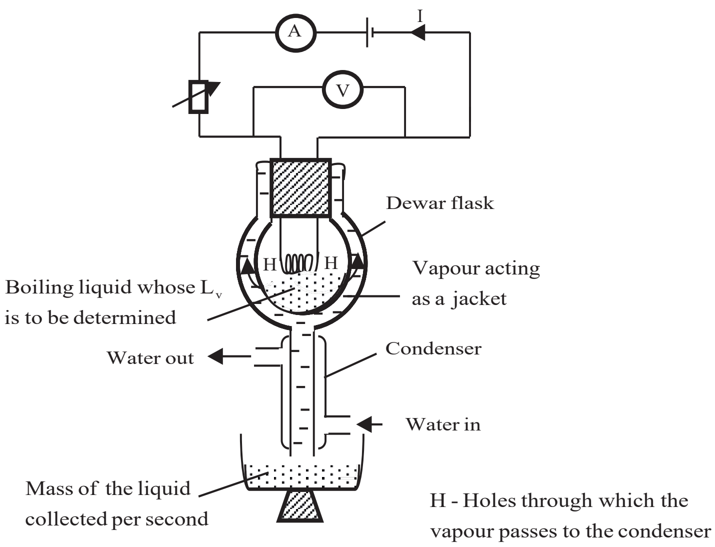
This is the amount of heat required to change one kilogram of a substance from liquid state to vapour state at the same temperature. SI unit is also Jkg^{-1}.

ASSIGNMENT: Which of the specific latent heat of fusion and specific latent heat of vaporization is greater? Explain why?

DETERMINATIONOF LATENT HEAT OF VAPORIZATION OF A LIQUID BY ELECTRICAL METHOD (CONTINUOUS FLOW METHOD, DEWAR FLASK METHOD)

- A liquid is heated in a Dewar flask up to its boiling point.

- After the liquid has been boiling for some time it becomes surrounded by a jacket of vapour and eventually a new state is attained meaning that the heat supplied by the heater is used in evaporating the liquid and offsetting the heat losses and in this case the rate of evaporation is equal to the rate of condensation.
- At a steady state values of current I, and voltage V and mass collected per second, m, are measured.



$$IV = mL_v + h \text{ ....(1)}$$

h - heat lost per second

With a different rate of evaporation,

$$I'V' = m'L_v + h \text{ ....(2)}$$

These are measured in the same time as in part one, then

$$IV - I'V' = (m - m')L_v$$

$$L_v = \frac{IV - I'V'}{m - m'} \text{ ....} \otimes$$

$$\text{Note : Mass rate of flow} = \frac{\text{mass}}{\text{time}}$$

EXAMPLE: When electrical energy is supplied at a rate of 12.0 watts to a boiling liquid, 1 x 10^{-2} kg of the liquid evaporates in 30 min. On reducing the power to 7.0 watts, 5×10^{-3} kg **of liquid evaporates in same time. Calculate:**

(a) The latent heat of vaporization.

(b) The power loss to the surroundings.

$$\text{Power IV} = 12, \qquad \text{Mass} = 1.0\times10^{-2}\,\text{kg}$$

$$m = \frac{1\times10^{-2}}{1800}$$

$$m = 5.56\times10^{-6}\ \text{kgs}^{-1}$$

$$\text{Using IV} = mL_v + h$$

$$12 = (5.6\times10^{-6})L_v + h$$

Case II

$$I'V' = 7.0\text{w}, \qquad \text{mass} = 5.6\times10^{-2}\ \text{kg} \qquad \text{time} = 1800\,\text{s}$$

$$m' = \frac{5\times10^{-3}}{1800}$$

$$m' = 2.78\times10^{-6}\,\text{kgs}^{-1}$$

$$\text{Using } V'I' = m'L_v + h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$7 = (2.7\times10^{6})L_v + h$$

(i) - (ii)

$$5 = (5.56 - 2.78)\times10^{-6}L_v$$

$$L_V = \frac{5}{2.78\times10^{-6}}$$

$$L_v = 1.799\times10^{6}\ \text{J/kg}$$

(iii) using (1)

$$12 = 5.56\times10^{-6}\times7.99\times10^{6} + h$$

$$h = 2\ \text{Js}^{-1}$$

ASSIGNMENT: In an experiment to determine the specific latent heat of vaporization by electrical method the following results were obtained.

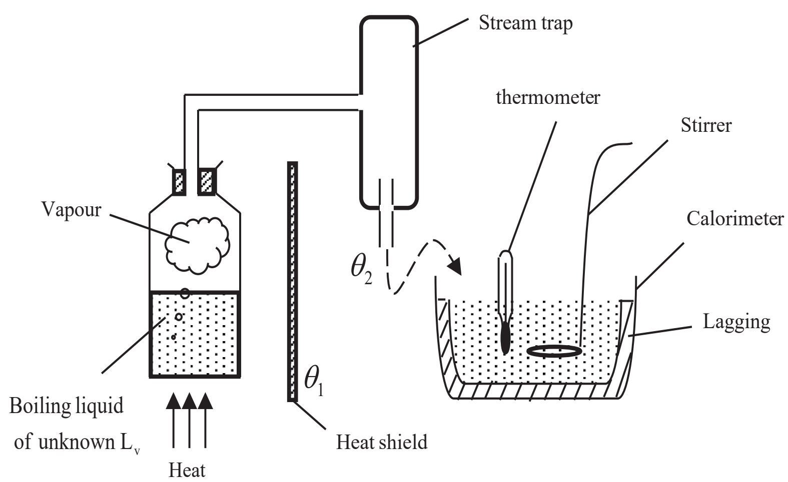
Ammeter reading (A)	Voltmeter reading (V)	Mass of a liquid in vapour at 100 ^{0}C/g
1.00	5.0	0.8
2.00	5.4	3.6
3.00	7.0	6.0
2.63	8.0	8.4

Plot a suitable graph and use it to determine;

(a) The specific latent heat of vaporization.

(b) The rate of loss of heat

DETERMINATION OF LATENT HEAT OF VAPORIZATION OF A LIQUID BY THE METHOD OF MIXTURES



- A calorimeter of known mass m_c is half-filled with water.
- The mass m_w of water is determined.
- The temperature θ_i of water is measured, after thorough stirring.
- The calorimeter is placed in a constant temperature jacket as shown above. The temperature θ_s of the steam is recorded.
- Steam is blown onto the surface of the water in the calorimeter until a temperature rise of about 30^0C is obtained.

- The temperature θ_f of the water is measured after thorough stirring. The calorimeter and the contents are weighed again to determine the mass of steam condensed.

Heat lost by steam in condensing and cooling to a temperature θ_f is $= m_s L_v + m_s c_w(\theta_b - \theta_f)$, where θ_b the boiling point of water is.

Heat gained by the calorimeter and water is $= (m_c c_c + m_w c_w)(\theta_f - \theta_i)$

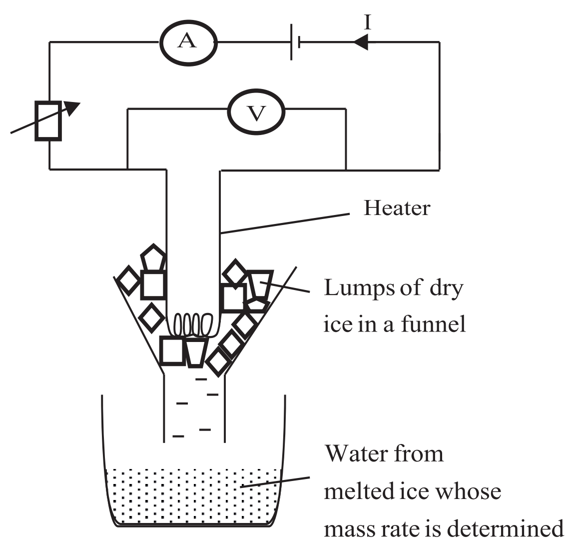
Where c_c, c_w are the specific heat capacities of the calorimeter and water respectively?

Assuming no heat losses to the surroundings,

$$(m_c c_c + m_w c_w)(\theta_f - \theta_i) = m_s L_v + m_s c_w(\theta_b - \theta_f)$$

$$\Rightarrow L_v = \frac{(m_c c_c + m_w c_w)(\theta_f - \theta_i) - m_s c_w(\theta_b - \theta_f)}{m_s}$$

DETERMINATION OF LATENT HEAT OF FUSION OF ICE BY ELECTRICAL METHOD



- A rheostat R is adjusted until suitable values of I and V are obtained
- Water from melted ice is collected and its mass rate m is determined.
- This means that heat supplied by the heater per second (power) plus heat absorbed by ice from the surrounding per second is equal to latent heat absorbed in melting ice.

$$IV + h = mL_f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where h - heat absorbed by ice from the surroundings per second.

- The experiment is repeated with values I' and V' and mass rate m' determined in the same time.

$$I'V' + h = m'L_F \text{ ....}(2)$$

$$(1) - (2)$$

$$IV - I'V' = (m - m')L_f$$

$$L_f = \frac{IV - I'V'}{(m - m')}$$

Hence, L_f is determined from the above equation.

LESSON 6

TOPIC: GAS LAWS

OBJECTIVE: By the end of this lesson, you should be able to describe and verify gas laws and solve related numerical problems.

INTRODUCTION

Like other forms of matter, gases change in volume when heated. The change in volume occurs either at constant temperature or at constant pressure.

BOYLE'S LAW

This states that the pressure of a fixed mass of a gas at constant temperature is inversely proportional to its volume.

$$P \alpha \frac{1}{V}$$

$$P = \frac{k}{V}$$

Where k – constant of proportionality

$$PV = k \text{ - constant}$$

CHARLES' LAW

It states that the volume of a fixed mass of a gas at constant pressure is directly proportional to its absolute temperature

$$V \alpha T$$
$$V = kT$$
$$\frac{V}{T} = k$$

THE PRESSURE LAW

It states that the pressure of a fixed mass of a gas at constant volume is directly proportional to absolute temperature.

$$P \alpha T, \quad P = kT = \text{Constant}$$

SUMMARY

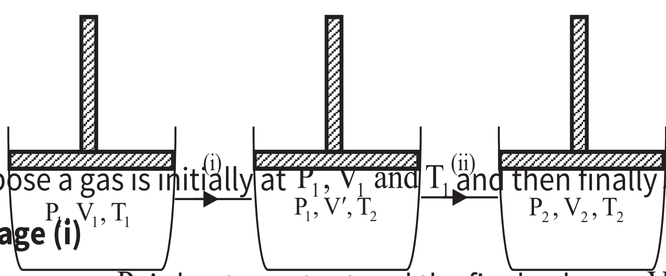
$$PV = \text{Constant - Boyle's Law}$$
$$\frac{V}{T} = \text{Constant - Charles' Law}$$
$$\frac{P}{T} = \text{Constant - Pressure Law}$$

Combining all the three laws, we obtain;

$$\frac{PV}{T} = \text{Constant} = nR \text{ ....} \otimes$$

Where n is the number of moles of the gas and R is the molar gas constant ($R = 8.314 \text{ Jmol}^{-1}$)
Equation $\otimes$ is called the ideal gas equation or the equation of state.

EQUATION OF STATE



Suppose a gas is initially at P_1, V_1 and T_1 and then finally P_2, V_2 and T_2.

In stage (i)

The pressure P_1 is kept constant and the final volume V' can be got by Charles' law,

$$\frac{V}{T} = \text{Constant}$$

$$\frac{V_1}{T_1} = \frac{V'}{T_2}$$

$$V' = \frac{V_1T_2}{T_1} \quad \text{...E}$$

In stage (ii)

T_2 is kept constant and the pressure changed. This means that the final volume can be got by Boyle's law,

$$PV = \text{Constant}$$

$$P_1V' = P_2V_2$$

$$V' = \frac{P_2V_2}{P_1} \quad \text{..S}$$

Equation E = S

$$\frac{V_1T_2}{T_1} = \frac{P_2V_2}{P_1}$$

$$\frac{V_1P_1T_2}{T_1} = \frac{P_2V_2}{P_1} \times P_1$$

$$\frac{V_1P_1T_2}{T_1} = P_2V_2$$

$$\frac{V_1P_1}{T_1} = \frac{P_2V_2}{T_1}$$

$$\frac{PV}{T} = \text{Constant} = nR$$

$$PV = nRT \quad \text{...}\oplus$$

Where n – moles of a gas

R – Molar gas constant ($R = 8.314\ Jmol^{-1}K^{-1}$)

Equation $\oplus$ is called the equation of state or ideal gas equation.

The molar gas constant R depends on:

(a) The nature of the gas

(b) The number of moles or mass of the gas.

For 1 mole of the gas, n = 1

Equation $\oplus$ becomes;

$$PV = RT$$

Note

$$n = \frac{m}{M_R}$$

Where m is the given mass and M_R is the relative molecular mass.

Note

An ideal gas is that gas with no intermolecular forces.

Example: Helium gas occupies a volume of 0.04 m³ at a pressure of $2\times10^5\ Nm^{-2}$ and temperature of 300 K. Determination the mass of helium. (R = 8.314 $Jmol^{-1}K^{-1}$)

Solution

$$\text{Using, } PV = nRT$$

$$(2\times10^5)(0.04) = n\times8.314\times300$$

$$n = \frac{(2\times10^5)(0.04)}{(8\times3.14)(300)}$$

$$n = 3.21\text{ moles}$$

$$\text{But } n = \frac{m}{M_R}$$

$$3.21 = \frac{m}{4}$$

$$m = 12.84\text{ g}$$

or

$$m = 12.84\times10^{-3}\text{ kg}$$

LESSON 7

TOPIC: KINETIC THEORY OF GASES

OBJECTIVE: By the end of this lesson, you should derive expression for pressure exerted by a gas in a container.

NTRODUCTION

Gases are composed of molecules. If we could see the molecules in a gas, we would see that they are separated from one another by distances which are large compared with their actual sizes. Their speeds differ and they move about in random directions. They continually collide with one another and with the container walls.

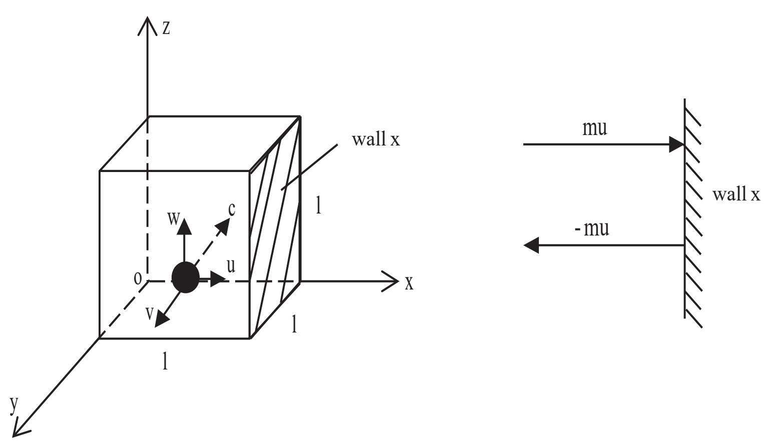
We make assumptions in the simple kinetic theory when deriving pressure of a gas.

- The intermolecular forces between the molecules are negligible except during a collision.
- The volume of molecules is negligible compared to the volume occupied by the gas.
- The molecules are perfectly elastic spheres so that after collision with the walls of the container, there is no energy lost that is; kinetic energy is conserved.
- The duration of a collision is negligible compared to the time between collisions.

DERIVATION OF THE PRESSURE EXERTED BY A GAS

We consider a cube of side, l, containing n molecules of a gas each of mass m. Suppose, c is the velocity of a molecule at any instant such the u, v and w are components of c in ox, oy and oz respectively as shown below;

i.e. $c^2 = u^2 + v^2 + w^2$



Considering a molecule colliding with wall x, with a velocity u.

Change in momentum = mu – (-mu) = 2 mu.

Time taken for the molecule to move to the opposite face and back to x = $\frac{2l}{u}$.

Rate of change of momentum = $2\,mu \div \frac{2l}{u} = \frac{mu^2}{l}$

$\therefore$ Force exerted $= \frac{mu^2}{l}$,

From Newton's 2nd law of motion, rate of change of momentum = Force applied.

From Pressure $= \frac{\text{Force}}{\text{Area}}$,

$\Rightarrow$ Pressure $P = \frac{mu^2}{l} \div l^2$

$$\text{Pressure } P = \frac{mu^2}{l^3}$$

For N molecules moving with different speeds; $u_1, u_2, ..., u_N$ the total pressure is;

$$P = \frac{mu_1{}^2}{l^3} + \frac{mu_2{}^2}{l^3} + ... + \frac{mu_N{}^2}{l^3}$$

$$P = \frac{m}{l^3}(u_1{}^2 + u_2{}^2 + ... + u_N{}^2) \text{ .... } \otimes$$

Suppose $\overline{u}^2$ is the mean value of all the squares of velocities along the ox direction, then;

$$\overline{u}^2 = \frac{u_1{}^2 + u_2{}^2 + ... + u_N{}^2}{N}$$

$$\Rightarrow u_1{}^2 + u_2{}^2 + ... + u_N{}^2 = \overline{u}^2 N$$

Substituting in equation $\otimes$

$$P = \frac{m}{l^3} N\overline{u}^2$$

$$P = \frac{mN\overline{u}^2}{l^3} \text{ .... } 1$$

For molecules in random motion and with no preferred direction, then;

$$u^2 = v^2 = w^2$$

$$\text{but } c^2 = u^2 + v^2 + w^2$$

$$\Rightarrow \overline{c}^2 = \overline{u}^2 + \overline{v}^2 + \overline{w}^2$$

$$\text{But for } u^2 = v^2 = w^2$$

$$\Rightarrow \overline{u}^2 = \overline{v}^2 = \overline{w}^2$$

$$\Rightarrow \overline{c}^2 = \overline{u}^2 + \overline{u}^2 + \overline{u}^2$$

$$\Rightarrow \overline{c}^2 = 3\overline{u}^2$$

$$\Rightarrow \overline{u}^2 = \tfrac{1}{3}\overline{c}^2$$

Substituting this in equation 1 above, we obtain;

$P = \frac{1}{3}\frac{Nm}{l^3}\overline{c}^2$; Where N is the number of molecules and m is the mass of a molecule.

l^3 – is the volume v of the cube or gas.

$\Rightarrow P = \frac{1}{3}\frac{Nm}{v}\overline{c}^2$; Where Nm is Total mass.

$$\frac{Nm}{v} - \text{density} = \rho$$

$$\Rightarrow P = \tfrac{1}{3}\rho\overline{c}^2 \text{ .... } \otimes$$

LESSON 8

OBJECTIVE: By the end of this lesson, you should derive the relationship between kinetic energy (mean kinetic energy) of molecules of an ideal gas and temperature using kinetic theory.

From the kinetic theory;

$$P = \tfrac{1}{3}\rho \bar{c}^2$$

$$\rho = \frac{Nm}{v}$$

$$P = \frac{1}{3}\left(\frac{Nm}{v}\right)\bar{c}^2$$

$$Pv = \frac{1}{3}Nm\bar{c}^2$$

$$Pv = \frac{2}{3}(\frac{1}{2}Nm\bar{c}^2) \quad \text{.....................................}2$$

From the equation of state;

$$Pv = nRT \text{ ....}3$$

Where n is the number of molecules of a gas.

From 2 and 3;

$$Pv = \frac{2}{3}(\frac{1}{2}Nm\bar{c}^2) = nRT$$

$$\frac{1}{2}Nm\bar{c}^2 = \frac{3}{2}nRT \text{ ....} \oplus$$

Where $\frac{1}{2}Nm\bar{c}^2 = \frac{3}{2}nRT$ is the mean translational kinetic energy of molecules for n moles of a gas.

Using equation $\oplus$ we can get the mean kinetic energy of a molecule by dividing through by N.

From $\frac{1}{2}Nm\bar{c}^2 = \frac{3}{2}nRT$, dividing through by N gives;

$$\frac{1}{2}m\bar{c}^2 = \frac{3}{2}\frac{n}{N}RT \text{ ....} w$$

Where $\frac{1}{2}m\bar{c}^2$ is the mean kinetic energy of a molecule.

$\frac{N}{n}$ – is the number of molecules per mole

$\frac{N}{n} = N_A$ is called the Avogadro's number and it is a constant.

$$\Rightarrow \frac{n}{N} = \frac{1}{N_A}$$

Equation *w* becomes;

$$\frac{1}{2}m\bar{c}^2 = \frac{3}{2}\frac{1}{N_A}RT \;\therefore \text{Mean kinetic energy of a molecule is } \frac{1}{2}m\bar{c}^2 = \frac{3}{2}\frac{R}{N_A}T \text{ ....z}$$

$$\text{But } \frac{R}{N_A} \text{ is a constant} = K_B$$

K_B is called Boltzmann's constant

Equation z becomes;

$$\frac{1}{2}m\bar{c}^2 = \frac{3}{2}K_BT \text{ ....s}$$

$$\text{Where } K_B = \frac{R}{N_A} = \frac{8.31}{6.02\times10^{23}}$$

$$K_B = 1.38\times10^{-13}\,JK^{-1}$$

$$\Rightarrow \frac{3}{2}K_B \text{ is a constant}$$

$$\Rightarrow \text{Mean translational kinetic energy} = \left(\frac{1}{2}m\bar{c}^2\right) \alpha \text{ absolute temperature}$$

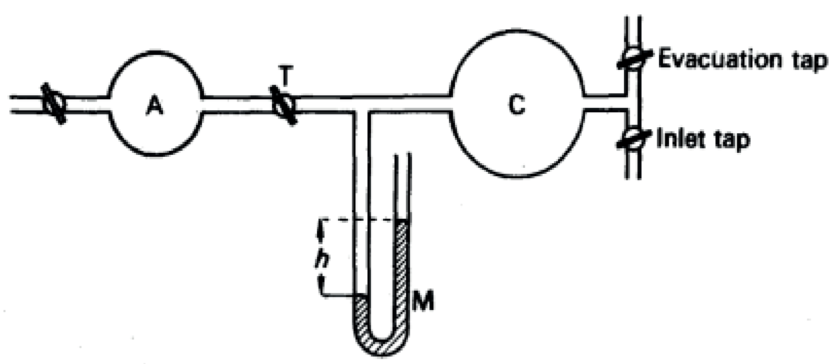
LESSON 9

SUBTOPIC: DALTON’S LAW OF PARTIAL PRESSURE.

OBJECTIVE: By end of this lesson you should derive the expression for relating pressure of a mixture of gases and state Dalton’s law of partial pressure.

INTRODUCTION

The figure below shows an apparatus with which we can study the pressure of a mixture of gases. A is a bulb of volume V, containing air at atmospheric pressure, P_1. C is another bulb of volume V_2, containing carbon dioxide at a pressure P_2. The pressure P_2 is measured on the manometer M.



When the bulbs are connected by opening the tap T, the gases mix, and reach the same pressure, p; this pressure is given by the new height of the manometer. Its value is found to be given by

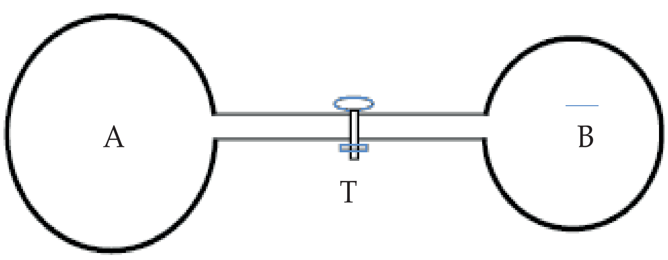
$$p = p_1\frac{V_1}{V_1+V_2}+p_2\frac{V_2}{V_1+V_2}.$$

Dalton's law of partial pressure states that the pressure of a mixture of gases is the sum of the partial pressures of the individual gases.

Partial pressure of a gas is the pressure the gas would have if it occupied the whole volume of the mixture alone.

EXAMPLE

Two bulbs A of volume 100 cm^3 and B of volume 50 cm^3 are connected to a tap, T which enables them to be connected with each other after being filled with gas or evacuated.



Initially bulb A is filled with an ideal gas at 10^0 C to a pressure of **3.0×10^5** Pa and bulb B is filled with an ideal gas at 100^0 C to a pressure of **1.0×10^5** Pa. The two bulbs are connected with A maintained at 10^0 C and B at 100^0 C until equilibrium is established. The volume of the tubes is negligible. Calculate the pressure at equilibrium.

$$n_A = \frac{3 \times 10^5 \times 100}{283R} = \frac{3 \times 10^7}{283R}$$

$$n_B = \frac{1 \times 10^5 \times 50}{373R} = \frac{5 \times 10^6}{373R}$$

Total number of moles, n initially = $n_A + n_B$

$$n = \frac{3 \times 10^7}{283R} + \frac{5 \times 10^6}{373R}$$

Finally

$$n_A = \frac{P \times 100}{283R} = \frac{100P}{283R}$$

$$n_B = \frac{P \times 50}{373R} = \frac{50P}{373R}$$

Total number of moles, n finally = $n_A + n_B$

$$n = \frac{100P}{283R} + \frac{50P}{373R}$$

$$\frac{3 \times 10^7}{283R} + \frac{5 \times 10^6}{373R} = \frac{100P}{283R} + \frac{50P}{373R}$$

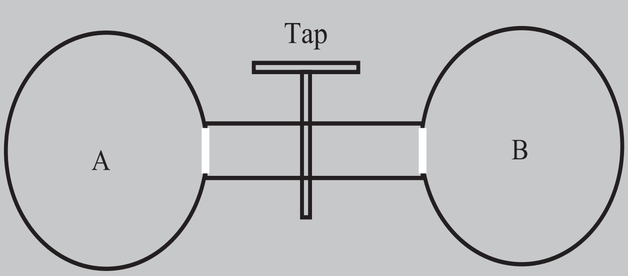
Simplifying gives,

$0.48741P = 119411.893$

$P = 244995.14$ Pa

ASSIGNMENT

1. Two cylinders A and B of volumes v and 3v respectively are separated and filled with a gas. They are then connected as shown in the figure below with the tap closed



The pressures of the gas in A and B are P and 4P respectively. When the tap is opened, the common pressure becomes 60 Pa. Assuming isothermal conditions, find the value of P. (P = 18.46 Pa)

LESSON 10

TOPIC: THERMODYNAMICS

OBJECTIVES: By the end of this lesson, you

- **should state the laws of thermodynamics**
- **Derive the expression for the work done when a gas expands**

INTRODUCTION

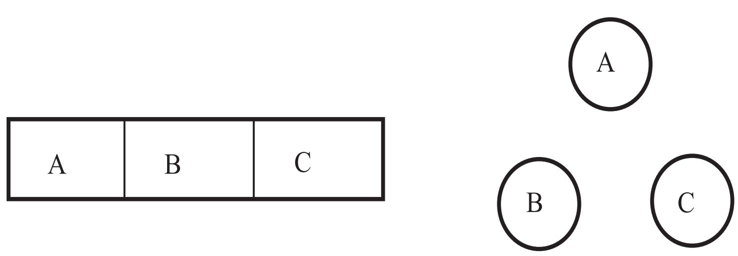
Let us now deal with the relation between work and heat energy. This branch of Physics, called thermodynamics, is widely used by engineers in their researches and studies into engines. The word 'thermodynamics' is composed of two words, namely 'Thermo' and 'dynamics'. 'Thermo' stands for heat while 'dynamics' is used in connection with mechanical motion which involves 'work' done. Thus, thermodynamics is the branch of physics which deals with process involving heat, work and internal energy.

FIRST LAW

It states that heat supplied to a system is equal to the increase in internal energy plus the external work done by the system to the surrounding. i.e.

$$\Delta Q = \Delta U + \Delta W$$

For any three bodies A, B and C arranged as shown below,



If A is in thermodynamic equilibrium with B and B is in thermodynamic equilibrium with C, it implies that A is in thermodynamic equilibrium with C. **This is the zeroth law of thermodynamics.**

Note

- The internal energy of the system is the sum of the kinetic energy and potential energy of the molecules of the system.
- From the first law of thermodynamics; $\Delta Q = \Delta U + \Delta W$, If ΔQ is positive, the system gains heat and if ΔQ is negative, the system loses heat.

- If ΔU is positive, there is increase in internal energy. If it is negative then there is a decrease in internal energy.
- If ΔW is positive, the system does work against the surroundings (i.e. it expands).
- If ΔW is negative, work is done on the system (i.e. compressed).

For real gases, the internal energy consists of kinetic energy due to the motion of its molecules and potential energy due to the intermolecular forces.

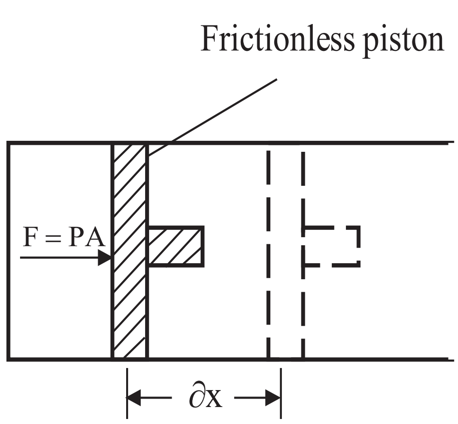
For ideal gases the internal energy consists of only the kinetic energy of its molecules and there is no potential energy since there are no intermolecular forces, i.e. for an ideal gas;

$\Delta U = \text{transitional (mean) kinetic energy}$

$$\Delta U = \frac{3}{2}nRT$$

WORK DONE BY A GAS, ΔW WHEN EXPANDING

Consider a mass of a gas at a pressure, P and volume, v enclosed in a cylinder by a frictionless piston of cross-sectional area A, under a force F on the piston.



Suppose the gas expands and pushes the piston through a distance ∂x such that the volume increases by ∂v , then,

$$\partial A = A\partial x$$

Since ∂x is so small, then the pressure is considered to remain constant.

Therefore, work done by the gas is;

$$\partial W = F\partial x$$

$$\Rightarrow \partial W = PA\partial x$$

$$\partial W = P\partial v, \qquad \text{since } A\partial x = \partial v$$

The total work done, W in changing the volume of the gas from v_1 to v_2 is given by,

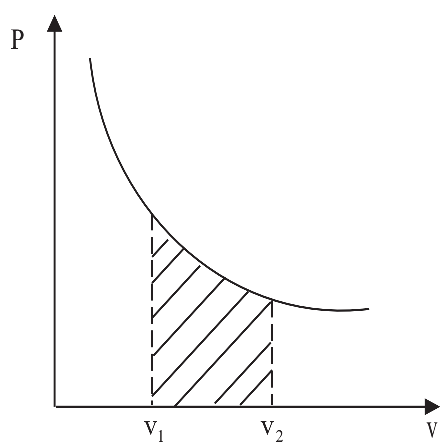
$$\int dW = \int_{v_1}^{v_2} Pdv$$

$$W = P\int_{v_1}^{v_2} dv$$

$$W = P[v_2 - v_1] \text{ ....} \oplus$$

Equation $\oplus$ is the expression of work done by the gas if P is constant.

Work done W is the same as the area under a P-v curve from v_1 to v_2. i.e.



If the pressure P is not constant, then we use the equation of state, $Pv = nRT$

$$\Rightarrow P = \frac{nRT}{v}$$

$$\text{From; } W = \int_{V_1}^{V_2} P\,dv$$

$$\Rightarrow W = \int_{V_1}^{V_2} \frac{nRT}{v}\,dv$$

$$W = nRT\int_{V_1}^{V_2} \frac{1}{v}\,dv$$

$$W = nRT\left[\ln v\right]_{V_1}^{V_2}$$

$$W = nRT\left[\ln v_2 - \ln v_1\right]$$

$$W = nRT\ln\left(\frac{v_2}{v_1}\right)\text{.........................}\otimes$$

Equation $\otimes$ is the external work done by the gas if P is not constant.

LESSON 11

SUBTOPIC: MOLAR HEAT CAPACITIES OF GASES

OBJECTIVE

By end of this lesson, you should define molar heat capacities derive a relation between the molar heat capacities

Molar heat capacity at constant volume (C_V)

It is heat energy required to change the temperature of one mole of a gas by one kelvin at constant volume.

Molar heat capacity at constant pressure (C_P)

It is heat energy required to change the temperature of one mole of a gas by one kelvin at constant pressure.

Note

For one kilogram of a gas, the heat capacities at constant pressure and constant volume are called **specific heat capacities.** i.e.

Specific heat capacity at constant volume $c_V = \frac{C_V}{m}$,

Specific heat capacity at constant pressure, $c_P = \frac{C_p}{m}$, where m is the mass of 1 mole.

RELATIONSHIP BETWEEN C_P AND C_V

Consider one mole of an ideal gas in a cylinder. Let a quantity of heat, δQ be supplied to the gas which is allowed to expand reversibly at constant pressure, p.

Suppose the volume of the gas increases from v to $v + \delta v$ and the temperature from T to $T + \delta T$.

From the first law of thermodynamics, $\delta Q = \delta U + \delta W$ ....(i)

At constant pressure, $\delta Q = C_p \delta T$ ....(ii)

The increase of internal energy, δU for an ideal gas at constant volume by a temperature, δT is given by $\delta U = C_v \delta T$ ....(iii)

The external work done by the gas is given by $\delta W = p\,\delta v$ ....(iv)

Combining equations (i), (ii), (iii), (iv) gives

$C_p \delta T = C_v \delta T + p\,\delta v$ ......(m)

For one mole of an ideal gas, $pv = RT$ ....(v)

And $p(v + \delta v) = R(T + \delta T)$

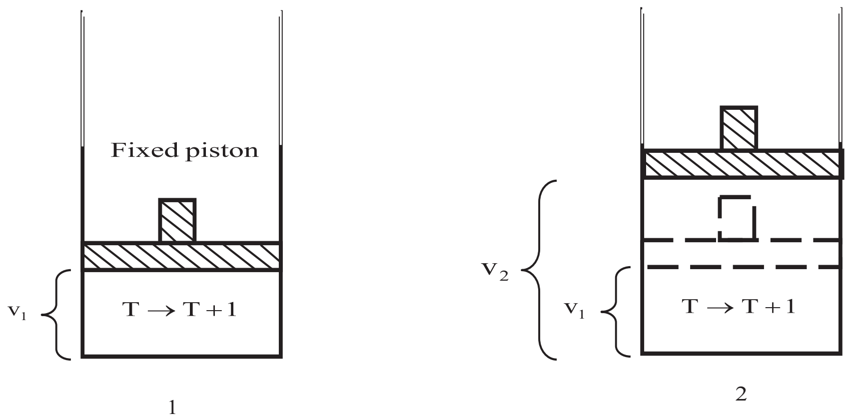
$pv + p\,\delta v = RT + R\,\delta T$ .....(vi)

Combining (v) and (vi) gives $p\,\delta v = R\,\delta T$........(viii)

Combining (viii) and (m) gives $C_P \delta T = C_v \delta T + R\,\delta T$

Which gives $CP - C_v = R$

Alternatively;



1 mole of a gas warmed at 1 mole of a gas warmed at
Constant volume by 1 K (C_v) constant pressure by 1 K (C_p)
In the first case, we consider 1 mole of a gas warmed at a constant volume through 1K such that the heat required is $C_v$which is used only to increase the internal energy ∂U of the gas. (No external work done since volume is constant i.e. $\partial W = 0$)

$$\Rightarrow C_V = \partial U \text{.............................}1$$

Secondly, we consider one mole of a gas warmed at a constant pressure through 1 K such that its volume increases from v_1 to v_2 and the heat supplied is C_P which is used to increase the internal energy ∂U and also do external work, ∂W .

$$\Rightarrow C_P = \partial U + \partial W, \text{ for } P = \text{constant}$$

$$\partial W = P[v_2 - v_1]$$

$$C_P = \partial U + P[v_2 - v_1]$$

From equation 1;

$$C_V = \partial U$$

$$\Rightarrow C_p = C_V + Pv_2 - Pv_1 \text{...............................}2$$

Using the equation of state for one mole, n = 1

$$\Rightarrow Pv = RT$$

Suppose v_1 and T_1 are the values of volume and temperature before warming and v_2 and T_2 being the values after warming.

$$\Rightarrow T_1 = T_2$$

Equation of state becomes

$$Pv_1 = RT_1 \text{.....................................} \otimes$$

And,

$$Pv_2 = RT_2 \text{.....................................} \#$$

But $T_2 = T_1 + 1$

$$\Rightarrow Pv_2 = R(T_1 + 1)$$

$$\Rightarrow Pv_2 = RT_1 + R$$

$$Pv_2 = RT_1 + R \text{..............................} \otimes\otimes$$

Substituting $\otimes$ and $\otimes\otimes$ in 2, we obtain;

$$C_P = C_V + RT_1 + R - RT_1$$

$$C_P = C_V + R$$

$$C_P - C_V = R$$

C_P is greater than C_V. This is because when the gas is at constant volume, the heat required C_V is used to increase the internal energy only but when the gas is heated at a constant pressure, the heat supplied C_P is used to increase the internal energy and do external work since there is an increase in volume.

LESSON 12

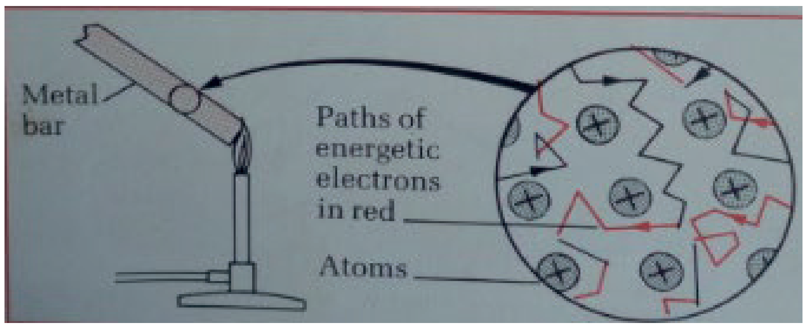
TOPIC: HEAT TRANSFER (THERMAL CONDUCTION)

OBJECTIVES: By the end of this lesson, you should:

- **Describe the mechanism of conduction in solids.**
- **Describe experiments to determine the coefficient of thermal conductivity of a material.**

INTRODUCTION

METALS are good conductors of heat and electricity. The reason is the presence of electrons inside the metal. At absolute zero, these electrons are attached to individual atoms in the outer shells. When the metal is supplied with energy to raise its temperature above absolute zero, the outer electrons of each atom break free as the atoms vibrate. Therefore, any metal above absolute zero contains lots of free electrons moving about inside the metal in a haphazard way. Free electrons collide with one another and with the atoms of the metal as they move about. Therefore energy is transmitted through the metal by movement of free electrons even though the electrons only travel short distances.



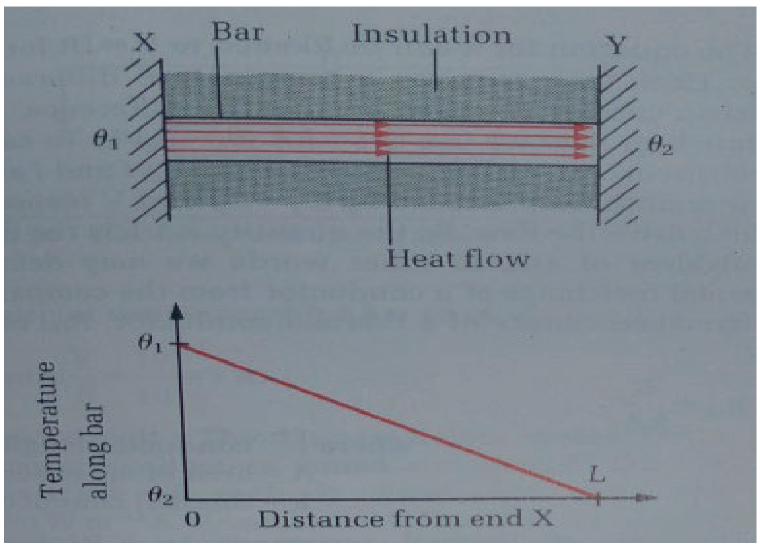
Insulators are poor thermal conductors because they have no free electrons. All the electrons are firmly attached to individual atoms, even at high temperatures. So insulators cannot conduct electricity at all. Yet they do conduct thermally, even if very poorly. Insulation to prevent heat loss from houses does not cut out heat losses altogether. The reason is that the vibrations of the atoms transmit energy through the material. When part of the material is heated, the atoms in that part vibrate more. The increased vibrations make neighbouring atoms vibrate more which in turn make other atoms further away vibrate more. So energy passes to other parts of the material. This mechanism is present in metals but energy transfer due to electrons is much greater than that due to atomic vibrations.

Gases and liquids conduct heat energy. When heated, molecules gain extra kinetic energy which is transferred to other molecules as a result of collisions between molecules. The mechanism is not unlike what happens in metals due to free electrons, but here the molecules, rather than free electrons, carry the energy. Gases and liquids are poor thermal conductors, in general, compared with metals. The reason is that molecules in a gas or liquid move much more slowly than the free electrons in a metal. So energy transfer in a liquid or gas is much slower. One type of liquid, though, is an excellent thermal conductor: liquid metals such as mercury. The reason is the presence of free electrons.

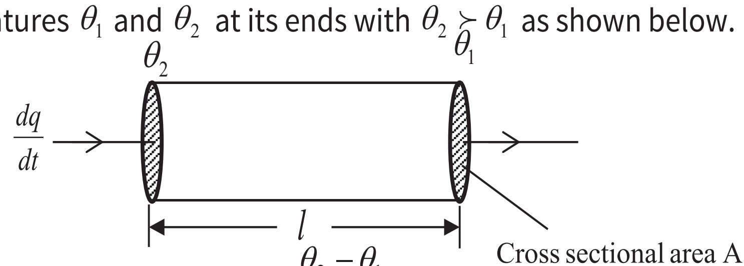
THE COEFFICIENT OF THERMAL CONDUCTIVITY

Consider a uniform bar which is insulated along its sides. Suppose one end is at a constant temperature θ_1 and the other end at a lower constant temperature θ_2. Heat is conducted from the hotter end to the other end at a steady rate. Because the sides are perfectly insulated, the heat energy per second reaching the cold end is equal to the heat energy per second from the hot end. Therefore, the heat energy per second passing any position along the bar is the same.

The temperature varies along the bar as shown below. The temperature fall per unit length along the bar is the same from one end to the other.



The temperature gradient at any position along the bar is defined as the change of temperature per unit distance along the bar. Considering a conductor of length, *l* and cross sectional area *A*, having temperatures θ_1 and θ_2 at its ends with $\theta_2 \succ \theta_1$ as shown below.



The temperature gradient is given by $(\frac{\theta_2 - \theta_1}{l})$

The rate of heat flow $\frac{dq}{dt}$ along the bar depends on:

- The cross sectional area, A,
- The temperature gradient, $(\frac{\theta_2 - \theta_1}{l})$

- The nature of the material.

Therefore, $\frac{dq}{dt} \alpha$ A ....*(i)* And $\frac{dq}{dt} \alpha \left(\frac{\theta_2 - \theta_1}{l}\right)$ ......*(ii)*

Combining *(i)* and *(ii)* $\frac{dq}{dt} = kA\left(\frac{\theta_2 - \theta_1}{l}\right)..(iii)$

Where k is a constant of a given material, which depends on the nature of the material and it is called thermal conductivity or coefficient of thermal conductivity.

Definition of k (thermal conductivity)

From equation ***(iii)***

$$k = \frac{\frac{dq}{dt}}{A\left(\frac{\theta_2 - \theta_1}{l}\right)}$$

Where $\frac{dq}{dt}$ - rate of heat flow per second

A – unit cross sectional area

$\left(\frac{\theta_2 - \theta_1}{l}\right)$ - unit temperature gradient.

Units of *k*

$$\text{k} = \frac{\frac{dq}{dt}}{\text{A}\left(\frac{\theta_2 - \theta_1}{l}\right)} = \frac{\text{Js}^{-1}}{\text{m}^2\frac{\text{k}}{\text{m}}} = \frac{\text{Js}^{-1}}{\text{mk}} = \text{Js}^{-1}\text{m}^{-1}\text{k}^{-1}$$

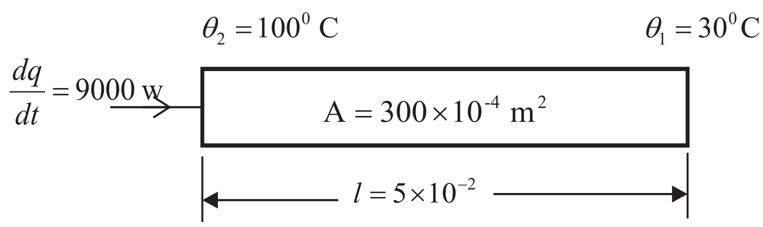
$$\text{k} = \frac{\text{Js}^{-1}}{\text{mk}}\text{Js}^{-1}\text{m}^{-1}\text{k}^{-1}\text{, but Js}^{-1} = \text{watts}$$

$$\text{k} = \text{wm}^{-1}\text{k}^{-1}$$

EXAMPLE

An aluminum plate of area 300 cm^2 and thickness 5.0 cm has one side maintained at 100^0C by steam and another side at 30^0C. Energy passes through the plate at a rate of 9 kw. Calculate the coefficient of thermal conductivity of aluminum.

Solution



$$9000 = k(3 \times 10^{-2})(\frac{100 - 30}{5 \times 10^{-2}})$$

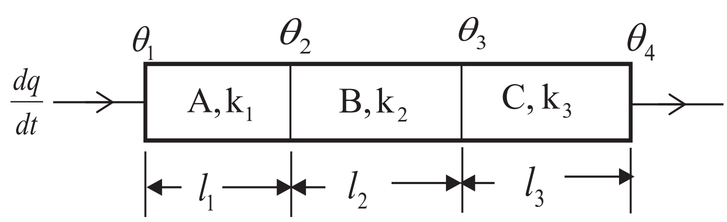
Using $\frac{dq}{dt} = kA(\theta_2 - \theta_1)$, $450 = k(3 \times 10^{-2})(70)$

$$k = 214.3\ Js^{-1}m^{-1}k^{-1}$$

HEAT FLOW THROUGH SEVERAL PLATES

(a) Plates in series

Consider three plates A, B and C of thermal conduct ivies, k_1, k_2 and k_3 respectively whose ends are maintained at temperatures $\theta_{1,}\ \theta_2, \theta_3$ and θ_4 as shown below:



Note:

$$\theta_1 > \theta_2 > \theta_3 > \theta_4 .$$

In this case we assume that the cross sectional area, A is constant and the rate of heat flow through the plates is the same.

$$\frac{dq}{dt} \text{ for A,} \quad \frac{dq}{dt} = k_1A(\frac{\theta_1 - \theta_2}{l_1})$$

$$\frac{dq}{dt} \text{ for B,} \quad \frac{dq}{dt} = k_2B(\frac{\theta_2 - \theta_3}{l_2})$$

$$\frac{dq}{dt} \text{ for C,} \quad \frac{dq}{dt} = kC(\frac{\theta_3 - \theta_4}{l_3})$$

Since $\frac{dq}{dt}$ is the same throughout

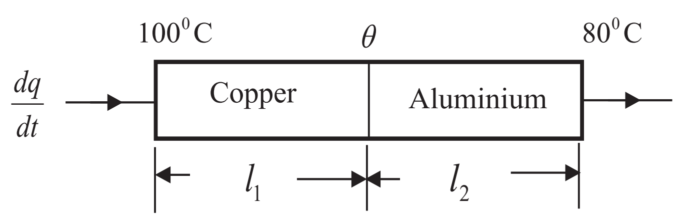
$$k_1A(\frac{\theta_1 - \theta_2}{l_1}) = k_2B(\frac{\theta_2 - \theta_3}{l_2}) = k_3C(\frac{\theta_3 - \theta_4}{l_3})$$

EXAMPLE

Heat is conducted through a wall consisting 5 mm thickness of copper and 10 mm thickness of aluminium. The temperature of 100^0 C and 80^0 C are maintained on the outside of copper and aluminium respectively.

(a) Determine the temperature between the copper and aluminium junction.
(b) Determine the rate of heat flow through the wall if it's cross sectional area is 20 cm^2.
(Thermal conductivities of copper and aluminium are 100 $wm^{-1}k^{-1}$ and 200 $wm^{-1}k^{-1}$ respectively.)

SOLUTION



Let the temperature of the junction be θ

$$l_1 = 5\times10^{-3}\,\text{m}$$

For copper; $\frac{dq}{dt} = k_{cu}A(\frac{100 - \theta}{l_1})$

$$l_2 = 10\times10^{-3}\,\text{m}$$

For Aluminium, $\frac{dq}{dt} = k_{Al}A(\frac{\theta - 80^0}{l_2})$

$$\left(\frac{dq}{dt}\right)_{cu} = \left(\frac{dq}{dt}\right)_{Al}$$, since Copper and Aluminium are in series.

$$k_{cu}A\left(\frac{100-\theta}{l_1}\right) = k_{Al}A\left(\frac{\theta-80}{l_2}\right)$$

$$100\left(\frac{100-\theta}{5\times10^{-3}}\right) = 200\left(\frac{\theta-80}{10\times10^{-3}}\right)$$

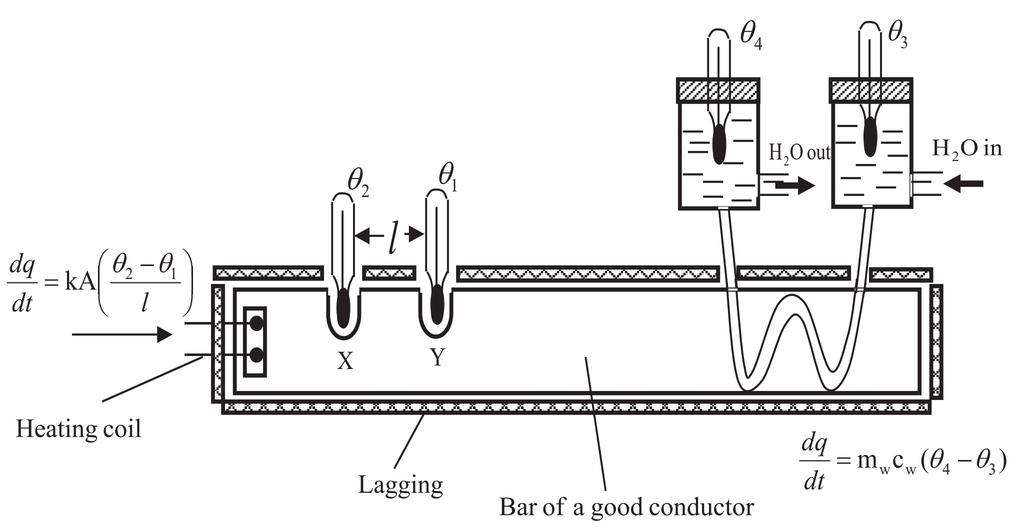
$$\theta = 90^0\,C$$

(b) For plates in parallel

For plates in parallel the rates of heat flow are different and the total heat flowing per second is equal to the sum of the individual rates of heat.

DETERMINING COEFFICIENT OF THERMAL CONDUCTIVITY OF A GOOD CONDUCTOR

Experiment for determining thermal conductivity of a metal of a good conductor using Searle's apparatus



- The conductor is heated by steam or heating coil H and cooled by circulating water.
- It is also heavily lagged to prevent heat losses to the surroundings.
- When the apparatus has been running for some time, a steady state is attained where temperatures $\theta_1, \theta_2, \theta_3$ and θ_4 become steady and they are recorded.
- A distance between X and Y is measured and the mass rate of flow m_w is determined.
- If A is the cross sectional area of the bar, then the rate of heat flow throughout is given by;

$$\frac{dq}{dt} = \text{kA}\left(\frac{\theta_2 - \theta_1}{l}\right) \text{.......................................(1)}$$

- The heat in equation (1) is carried away by the cooling water per second.
- If c_w is the specific heat capacity of water then the heat carried away by water per second is;

$$\frac{dq}{dt} = \text{m}_\text{w}\text{c}_\text{w}(\theta_4 - \theta_3) \text{.......................................(2)}$$

Therefore,

$$\text{kA}\left(\frac{\theta_2 - \theta_1}{l}\right) = \text{m}_\text{w}\text{c}_\text{w}(\theta_4 - \theta_3) \text{..} \otimes$$

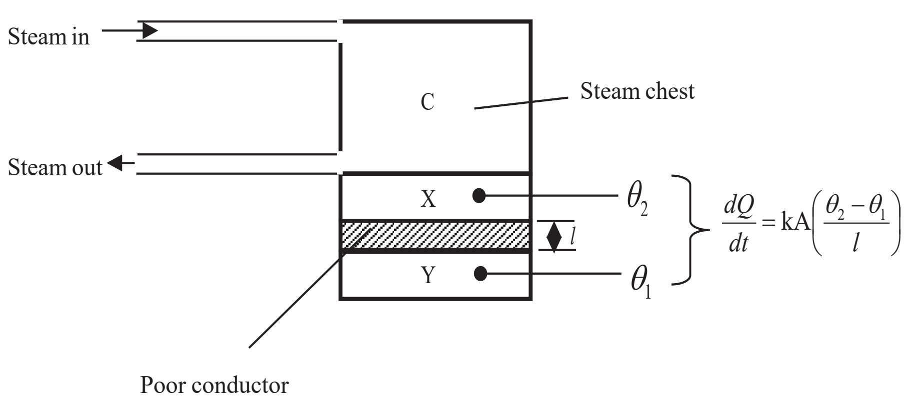
And thermal conductivity, k, can be determined from equation $\otimes$.

Note. When determining the thermal conductivity of a metal by this method the following conditions are necessary:

(a) Heat flow through the conductor should be steady.
(b) The temperature gradient should be steep.
A steady heat flow can be obtained by lagging the conductor and the problem of getting a steep temperature gradient can be solved by using a bar which is long compared to its diameter.

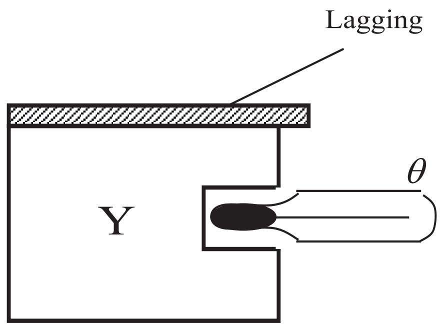
DETERMINATION OF THERMAL CONDUCTIVITY OF A POOR CONDUCTOR E.G. GLASS

Let X and Y be brass slabs.

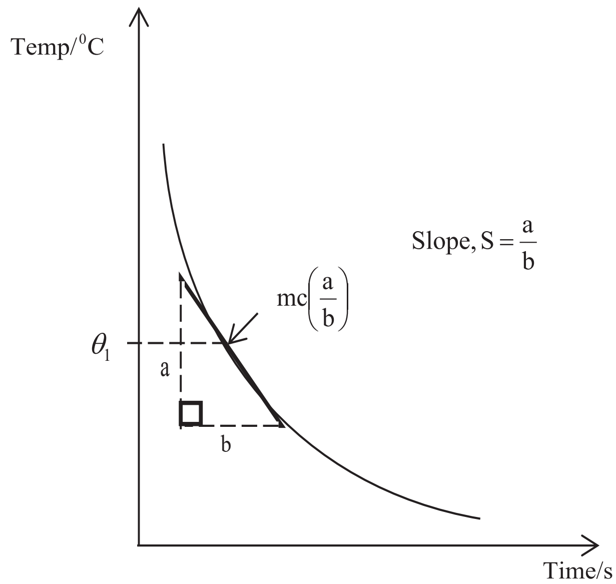


- X and Y are brass slabs.
- A thin sample of known diameter, d_1 and thickness *l* is placed between two brass slabs X and Y

- Steam is passed through the chest C until the temperature θ_1 and θ_2 are steady. θ_1 and θ_2 are recorded.
- A poor conductor is removed and Y is heated directly by steam chest until temperature rises by about 10^0C above θ_1.
- A lagging is put on top of Y and a temperature of Y is recorded every after suitable time interval until it falls by about 10^0C below θ_1.



- A cooling curve is plotted and its gradient, S of the tangent to the curve at θ_1 is formed.



Then thermal conductivity k can be determined from;

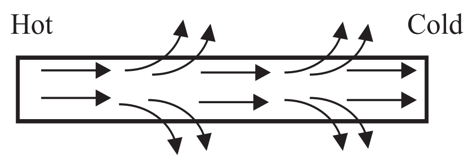
$$kA\left(\frac{\theta_2 - \theta_1}{l}\right) = mc\left(\frac{a}{b}\right)$$

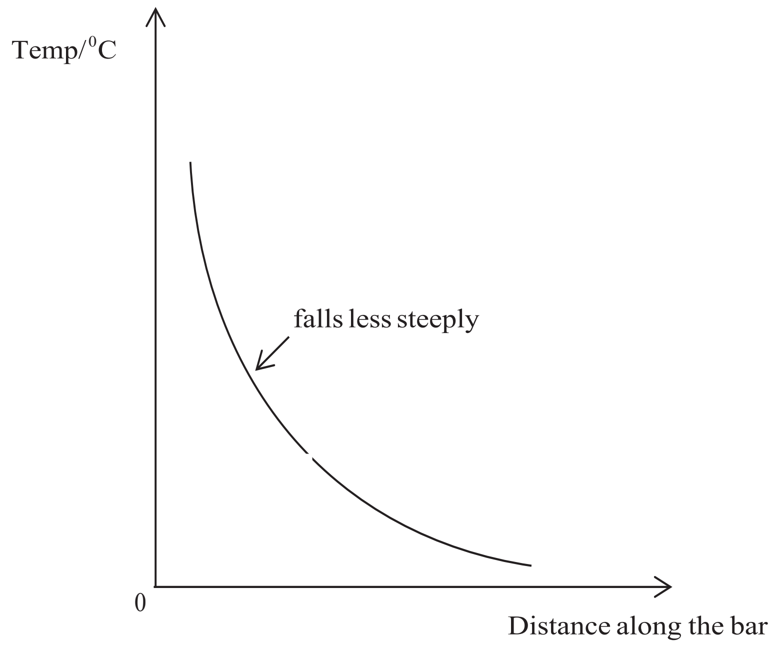
Where,

m - mass of Y
c - specific heat capacity of Y
A - cross sectional area of Y

Temperature distribution along an unlagged bar

For an unlagged bar temperature falls less and less steeply from the hot end to the cold end as shown in the figure below. This is because if the bar is unlagge , heat escapes from sides to the surroundings.





ASSIGNMENT

A sheet of rubber and a sheet of cardboard each 2 mm thick are pressed together and their outer faces are maintained respectively at 0^0 C and 25^0 C. If the thermal conductivities of rubber and the cardboard are respectively0.13 and 0.05 $Wm^{-1}k^{-1}$, find the quantity of heat which flows in one hour across the composite sheet of area 100 cm^2.

LESSON 13

TOPIC: THERMAL RADIATION

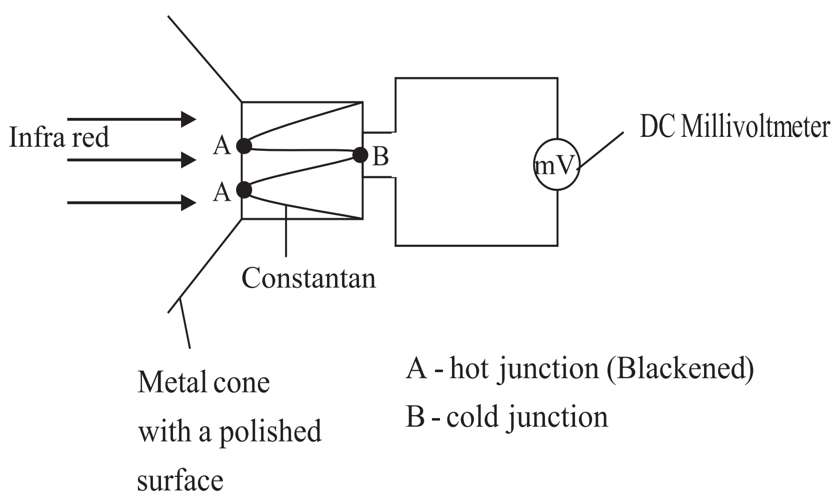
OBJECTIVES: By end of this lesson, you should describe radiation as a means of heat transfer and solve related numerical problems.

INTRODUCTION

All objects emit thermal radiation. The hotter an object is, the more energy per second is carried away from it by thermal radiation. Thermal radiation consists of electromagnetic waves with a range of wave length covering the infra-red and visible regions of the electromagnetic spectrum. When thermal radiation is directed at a surface, some of the radiation is absorbed by the surface and some is reflected. Some of the radiation may pass through the surface and be transmitted through the material to pass out through the side. Shiny silvered surfaces are the best reflectors, whereas dull black surfaces are very good absorbers. Surfaces which appear black daylight do not reflect any light. They absorb all the light which falls on them. Such surfaces are good absorbers of radiation.

Detection of infra-red

This can be done by using a thermopile as shown below;

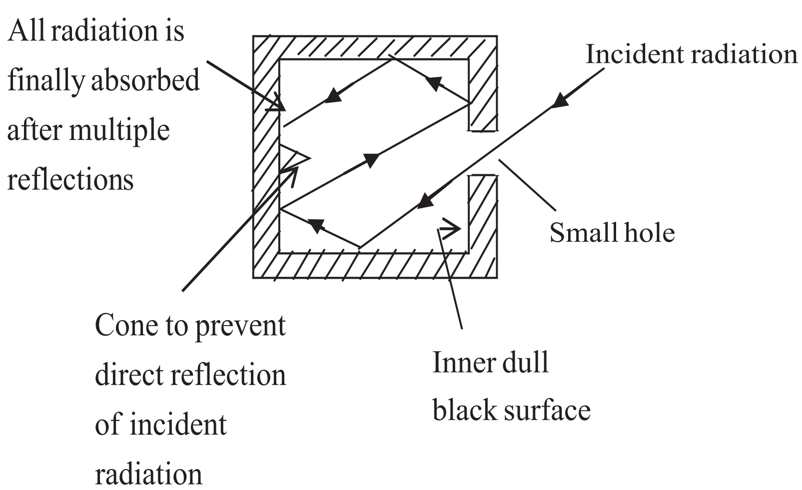


A metal cone concentrates the infra-red radiation onto the blackened metal junctions, A which get warmed up. As a result an e.m.f is set up between the hot and cold junctions and can be measured by a mill voltmeter. The magnitude of e.m.f depends on the intensity of incident radiation.

BLACK BODY RADIATION

An object with surfaces which absorb thermal radiation of all wave lengths is called a **black body** because it reflects no light. **A black body is defined as a body which absorbs all incident radiation falling on it and reflects none.**

APPROXIMATION OF A BLACK BODY



The absorber which approximates to a black body is made by punching a very small hole in an enclosure e.g. a tin whose inside walls are rough and blackened. All the radiation is finally absorbed and none is reflected after undergoing multiple reflections.

STEFAN'S LAW

This states that the total energy E, radiated per unit surface area per unit time is directly proportional to the fourth power of the absolute temperature T of the black body.

i.e. $E \, \alpha T^4$. Hence $E = \sigma T^4$

Were,σ is Stefan's constant,

$$E = \sigma T^4 \quad \sigma = 5.7 \times 10^{-8}\, Wm^{-2}K^{-4}$$

$$But\ E = \frac{energy}{Area\ x\ time} = \sigma T^4$$

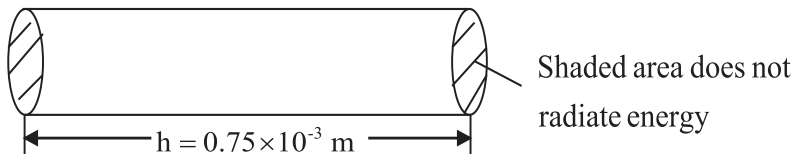
Power radiated by the black body = $A\sigma T^4$

Where; A is the surface area of the body.

Note. For a non-black body, we consider; $E = \varepsilon\sigma T^4$ where; ε is the emissivity of the non- black body.

EXAMPLE. A cylinder has a radius of 10^{-2} m and a height of 0.75 mm. Calculate the temperature of the cylinder if it's assumed to be a lamp of power 1 KW and acting as a black body. (Stefan's constant $\sigma = 5.7\times10^{-8}\,Wm^{-2}K^{-4}$)

Solution



Surface area $A = \pi$ rh

For two surfaces; $A = 2\pi\, r\, h$

Power radiated by the black body $= A\sigma T^4$

$$(1\times10^3) = (2\pi\ rh)\sigma T^4$$

$$T^4 = \frac{1000}{2\pi\ rh\sigma} = \frac{1000}{2\times3.14\times10^{-2}\times0.75\times10^{-3}}$$

$$T^4 = 3.7248\times10^{14}$$

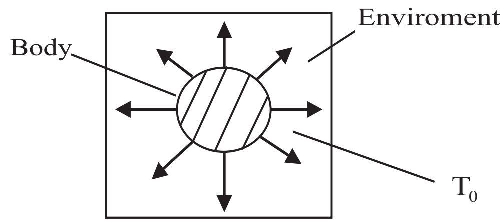
$$T = 4393.2\ K$$

PREVOST'S THEORY OF HEAT EXCHANGE

Prevost's theory of heat exchange states that a body emits radiation at a rate which depends on the nature of its surface and its temperature and absorbs heat at a rate which is determined by the nature of its surface and the temperature of the surrounding. Hence a body at the same temperature as that of the surroundings is in the state of thermodynamic equilibrium with its surroundings.

Note: From the above theory we deduce that a good absorber of radiation must also be a good emitter of radiation. Experiments show that a dull black surface is a good absorber and emitter of radiation while a shiny surface is a poor absorber and emitter of radiation.

If a black body of surface area A is at absolute temperature, T in an environment which is at a lower temperature T_0, then the body emits heat to the surrounding environment.



T - temperature of the body

T_0 - temperature of the enviroment

$T \succ T_0$

Using, Power radiated by the black body $= A\sigma T^4$

Net power radiated $= A\sigma(T^4 - T_0{}^4)$

EXAMPLE. A solid copper sphere of diameter 10 mm is cooled to a temperature of 150 K and then placed in an enclosure maintained at 290 K. Assuming that all interchange of heat is by radiation, calculate the initial rate of rise of temperature of the sphere. The sphere may be assumed as a black body. (Density of copper $= 8.9 \times 10^3$ kg/m^3, specific heat capacity of copper $= 3.7 \times 10^2$ J/kg/K, Stefan's constant $\sigma = 5.7 \times 10^{-8}$ W/m^2/K)

SOLUTION

Net power radiated $= A\sigma(T^4 - T_0{}^4)$, Surface area of a sphere $A = 4\pi r^2$

Net power radiated $= 4\pi r^2 (T^4 - T_0{}^4)\sigma$, Net power radiated 0.1176 W

But heat energy $= mc\theta$, Power absorbed $= mc\left(\frac{\theta}{t}\right)$

$$\text{Power absorbed} = (\text{density} \times \text{volume}) \times c \times \left(\frac{\theta}{t}\right)$$

$$\text{Power absorbed} = \rho \times \frac{4\pi r^3}{3} \times c \times \left(\frac{\theta}{t}\right)$$

$$\text{Power absorbed} = 0.1176 = (8.9 \times 10^3 \times \frac{4\pi}{3} \times 3.7 \times 10^2) \times \frac{\theta}{t}$$

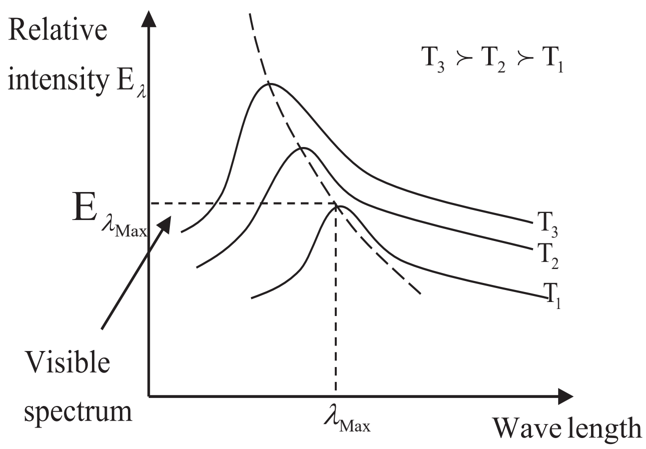
$$\frac{\theta}{t} = \frac{3 \times 0.1176}{4 \times 4\pi \times 8.9 \times 10^3 \times (\frac{10}{2} \times 10^{-3})^3 (3.7 \times 10^2)}$$

$$\frac{\theta}{t} = 0.068\ \mathrm{Ks^{-1}}$$

ASSIGNMENT. A metal sphere of diameter 1×10^{-2} m at a temperature of 240 K is placed in an enclosure at a temperature of 100 K. Assuming that all interchange of heat is by radiation. Calculate the initial rate of temperature rise of the sphere if it is assumed to behave like a black body.
(Density of the sphere $=7.2\times10^{3}$ kg/m^{3}, specific heat capacity of the sphere = 3.5×10^{2} J/kg/K, Stefan's constant $\sigma = 5.7\times10^{-8}$ Wm^{-2}K^{-1})

ENERGY DISTRIBUTION IN A SPECTRUM OF A BLACK BODY

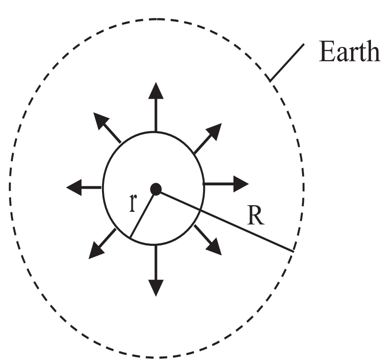
The spectral curves show the variation of relative intensity (energy distribution) emitted by a black body with wave length as temperature rises.



As the temperature rises the intensity of every wavelength increases. At a particular temperature there is a wavelength which is more intensely emitted than all the others.
As the temperature rises, the intensity of shorter wavelengths increases more rapidly. This is why when the temperature of the source is progressively raised, the radiation is first red, becomes less red, tending to white.

SOLAR CONSTANT

Solar constant is the energy per unit area per second incident on the earth's surface from the sun i.e.



Total energy per second (power) radiated by the sun $= A_S \sigma T_S^{\,4}$

Where, A_S – Surface area of the sun $= 4\pi r^2$

T_S = Surface temperature of the sun

Solar energy $= 4\pi r^2 \sigma T_S^{\,4}$

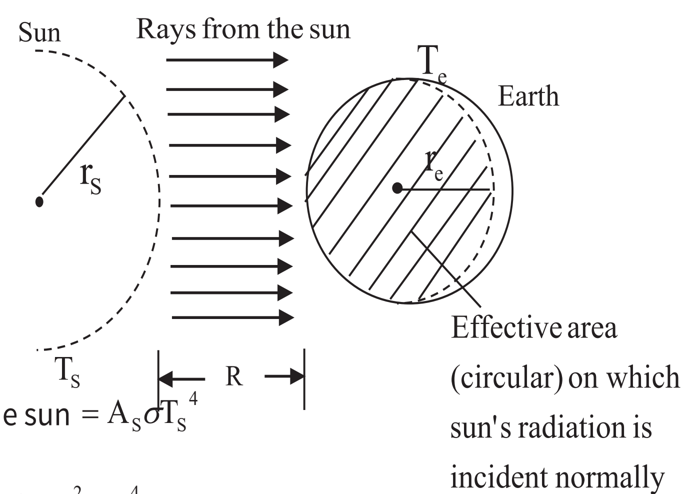
Energy arriving per square metre per second on the earth (solar constant) = $\dfrac{4\pi r^2 \sigma T_S^{\,4}}{4\pi R^2}$

Energy constant $= \dfrac{r\,\sigma T_S^{\,4}}{R^2}$.

Where, r – radius of the sun

R – Radius of the Earth.

RADIATIVE EQUILIBRIUM OF THE SUN AND THE EARTH



Power radiated from the sun $= A_S \sigma T_S^{\,4}$

$= 4\pi r_S^{\,2} \sigma T_S^{\,4}$

Power received by the Earth $= \dfrac{\pi r_e^{\,2}}{4\pi R^2} \times$ power radiated by the Sun

Where, $4\pi R^2$ is the total area available over which the sun radiates at a distance R from the earth.

Power radiated by the Earth $= A_e \sigma T_e^{\,4}$, Where, A_e is the surface area of the effective part of the Earth that radiates.

$$A_e = 4\pi r_e^2$$

Power radiated by the Earth $= 4\pi r_e^2 \sigma T_e^4$

Assuming radiative equilibrium;

Power radiated by the Earth = Power recieved by the Earth

$$4\pi r_e^2 \sigma T_e^4 = \frac{\pi r_e^2}{4\pi R^2} \times (4\pi r_S^2 \sigma T_S^4)$$

$$T_e^4 = T_S^4 \times \left(\frac{r_S^2}{4R^2} \right)$$

Note. We assumed that the sun and Earth are black bodies.

ASSIGNMENT

(a) Explain the mechanism of heat conduction in solids.

(b) Describe a method of determining the thermal conductivity of cork in the form of a thin sheet.

(c) A window of height 1.0m and width 1.5m contains a double glazed unit consisting of two single glass panes, each of thickness 4.0mm separated by an air gap of 2.0 mm. Calculate the rate at which heat is conducted through the window if the temperatures of the external surfaces of glass are 200C and 300C respectively. [Thermal conductivities of glass and air are 0.72 $Wm^{-1}K^{-1}$ and 0.025$Wm^{-1}K^{-1}$ respectively]

OPTICS AND WAVES

TOPIC: LIGHT

SUB-TOPIC: REFLECTION OF LIGHT AT PLANE SURFACES

LESSON 1

AIM: *By the end of the lesson, you should be able to:*

- ✓ *Show that light moves in a straight line*
- ✓ *State the laws of reflection of light.*

Introduction

Look around you and identify any five objects. How were you able to tell that this is a cup, tree, hen, basin, etc.? Now, close your eyes. Can you still identify any object(s)? Why is it so?

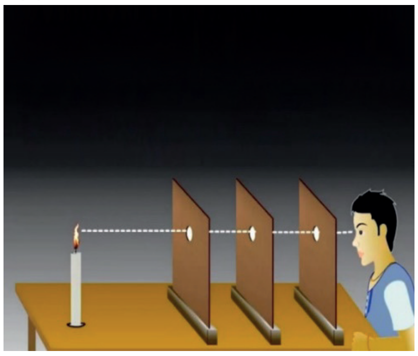
Activity one

Materials you need

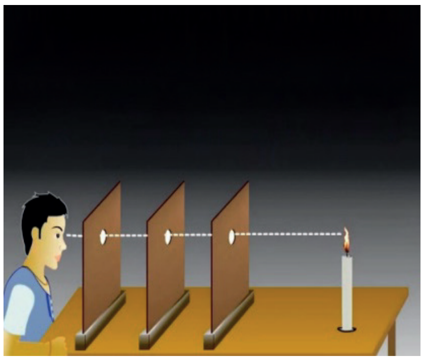
- Box
- Candle/torch
- Razor blade/ knife
- Thread
- Mathematical set

Procedures

1. Cut out three rectangular pieces, the size of half a foolscap, from the box. Fold one end of each piece so that it can stand without support.
2. Cut a tiny hole in each of the pieces, about 4cm from the top. The hole should be at the same position in each of the pieces.
3. Place the pieces in a straight line. Pass a thread through the holes to ensure they are in the same line.
4. Place a burning candle, torch or any other source of light on one side and observe from the opposite side.

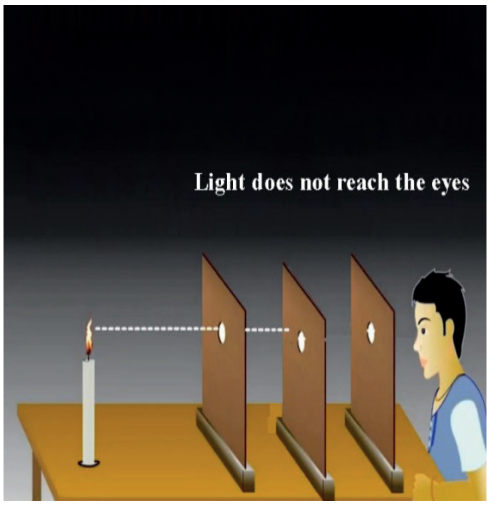


5. Change the position of the candle to where you are and observe from the side where the candle was initially. What do you notice?



6. Displace one of the cutouts so that its hole is no longer in the same line with the rest of the holes. Do you still see the light?

Light is a form of energy which travels in a straight line. This is evidenced by the straight edges of a shadow. The direction along which this energy travels is *a ray*. A ray is illustrated with a straight line bearing an arrow pointing in the direction of travel of light. A collection of light rays is a *beam*. **If the direction is reversed, light travels along its original path** (as seen in procedure 5 above). This is the *principle of reversibility of light.*



Activity two

Materials needed

- Plane mirror
- Cello tape
- Mathematical set
- box
- White sheet of paper
- Torch
- Razor blade/ knife

Procedures

1. Draw a line AB on the white piece of paper. Place the plane mirror vertically on the line.
2. Cut a piece from the box, just enough to cover the front of the torch. Make a tiny hole from a piece of box and use it to cover the torch using cellotape. (do this with care lest you cut yourself)

3. Switch on the torch and direct the light ray at an angle towards the mirror as shown in figure 1.

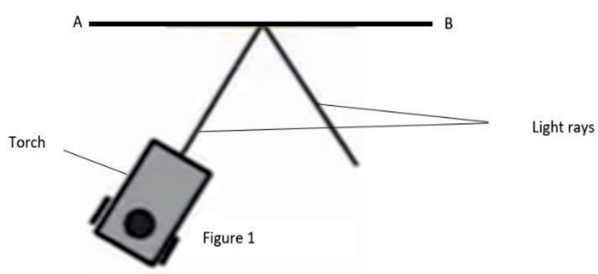
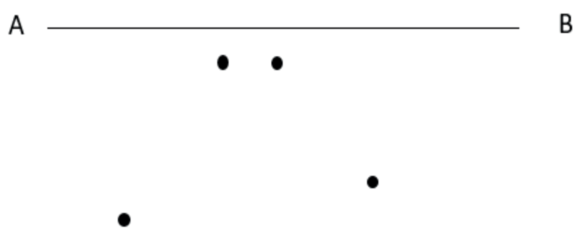
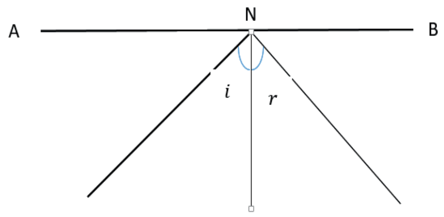


Figure 1

4. Using a pencil or pen, draw two small dots along each light ray.



5. Remove the mirror and the torch. Using a ruler, connect the dots with straight lines to meet line AB at N.
6. Draw a normal at N and measure the angle of incidence,i and the angle of reflection, r. What is the relationship between i and r?

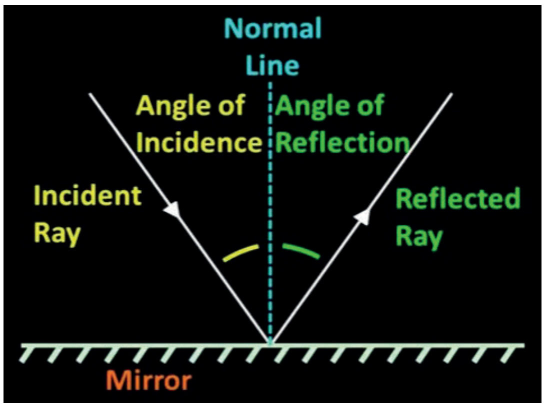


Try out the above procedures by directing the light from the torch to the mirror at different angles.

What conclusions do you draw from the measurements above?

When light is incident on a surface, it is reflected in accordance with the laws of reflection of light. These are:

1. **The incident ray, the reflected ray and the normal, at the point of incidence, all lie in the same plane.**
2. **The angle of incidence is equal to the angle of reflection.**



LESSON 2

AIM**:** *By the end of the lesson, you should be able to:*

- ✓ *Describe formation of an image by a plane mirror.*
- ✓ *Distinguish between regular and diffuse reflection.*

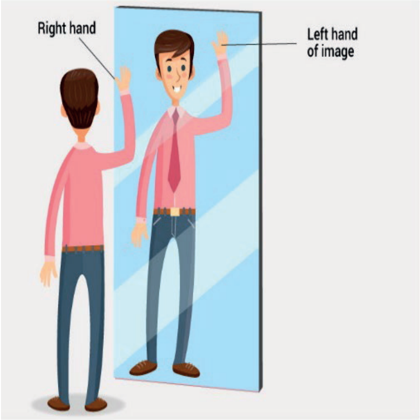
Activity

Materials needed

- ➢ Plane mirror
- ➢ Tape measure/ meter rule
- ➢ Piece of charcoal/ chalk
- ➢ Object e.g. cup, stone, bottle, etc.

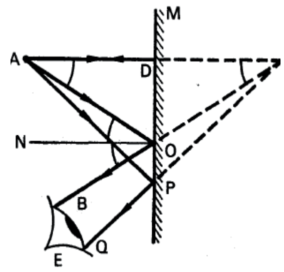
Procedures

1. Place a plane mirror vertically on the floor or on the table. You can lean the mirror on the wall.
2. Using a piece of chalk, make two lines in front of the mirror, one at 30 cm and the other at 50 cm from the mirror. Label them A and B respectively.
3. Get any object for example cup, stone or bottle. Place the object on line A and observe its image in the mirror. Thereafter, shift the object to line B and observe the shift in the image. Now, take back the object to line A.
   What conclusion can you make about the distance of the object and the distance of the image from the mirror?
4. Face the mirror and touch your left ear as you look at your image. Is your image also touching the left ear? What else can you say about the nature of the image formed?



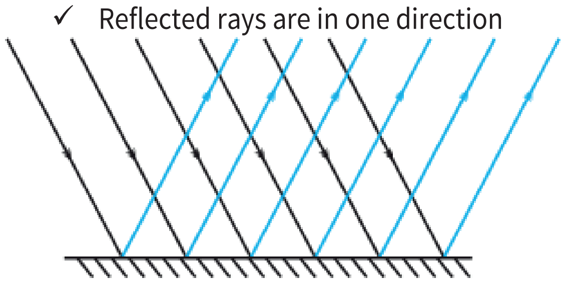
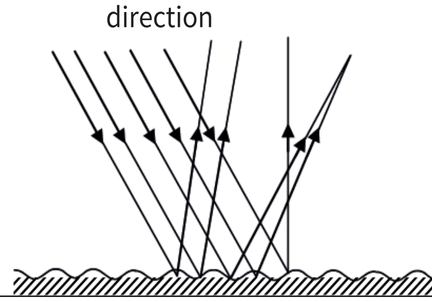
When an object is placed in front of a plane mirror, light from it is reflected off the mirror to the eyes of the observer. Since light moves in a straight line, the reflected rays appear to be coming from some point, I inside the mirror. It is that point that the image is formed. The image has the following characteristics.

- **It is virtual**
- **It is laterally inverted**
- **It is upright**
- **It is of the same size as the object**
- **It is the same distance from the mirror as the object.**



When you look around you, you see objects of varying shapes and size. There are flat objects, curved ones and those whose shape you may not tell. When light falls on those objects, it is reflected. Light reflected from these objects enables us to tell their shape, size and what type of objects they are. There are two forms of reflection: **regular reflection** and **irregular/diffuse reflection**.

Regular reflection is the type of reflection where a parallel beam of light incident on a smooth reflecting surface is reflected as a parallel beam. **On the other hand,** *diffuse reflection is the type of reflection where a parallel beam of light incident on a rough reflecting surface is scattered in different directions after reflection.*

Regular reflection	Irregular/ diffuse reflection
✓ It takes place on a smooth surface ✓ It has all the reflected rays in parallel ✓ Reflected rays are in one direction 	✓ It takes place on a rough surface ✓ Reflected rays are not parallel ✓ Reflected rays are scattered in different direction 

Can you tell the difference between regular and diffuse reflection?

LESSON 3

AIM: *By the end of the lesson, you should be able to:*

- ✓ *Derive the relationship between the angle of deviation and the glancing angle for a plane mirror.*
- ✓ *Derive the relationship between the angle of rotation of plane mirror and angle of rotation of reflected ray.*

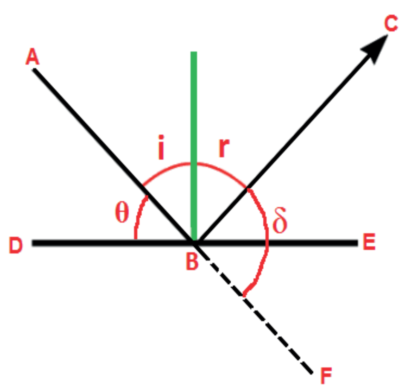


Figure 3.1

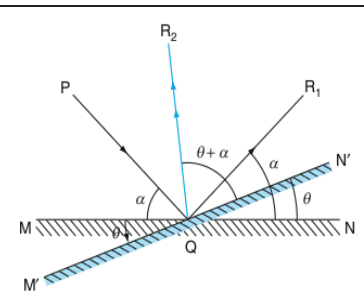
Consider the figure 3.1. If the mirror DE were not there, the ray would have taken the path ABF. However, light is reflected off the mirror. So, the ray takes the path BC. This means that the direction of the ray is changed through an angle δ. This is the angle of deviation. The angle $\theta$is the glancing angle. Since the angle of incidence i, is equal to the angle of reflection r, angle EBC is equal to the glancing angle θ. But angle ABD is equal to angle FBE (vertically opposite angles). Therefore,

$$\delta = angle\ FBE + angle\ EBC = \theta + \theta = 2\theta$$

This implies that when light is reflected in a plane mirror, ***the angle of deviation of a ray is twice the glancing angle.***

From figure 3.2, when a ray PQ is incident on a plane mirror MN, it is reflected in the direction QR_1. The ray is deviated through an angleδ which is twice the glancing angleα. i.e. $\delta = 2\alpha$.

If the direction of the incident ray is not changed and the mirror is rotated through an angle θ to a new position M'N', the reflected ray changes position to QR_2. The glancing angle is now



$(\alpha + \theta)$. This means that the angle of deviationδ_1,is $2(\alpha + \theta)$. The reflected ray is rotated through an angle R_1QR_2. This angle is the difference between δ_1 and δ. Therefore, the angle of

rotation of the reflected ray is given by $\delta_1 - \delta = 2(\alpha + \theta) - 2\alpha = 2\theta$.

This shows that *when a plane mirror is rotated through an angle keeping the direction of the incident ray unchanged, the reflected ray is rotated through twice that angle*. **This has an application in** *a sextant* **and an** *optical lever mirror galvanometer.*

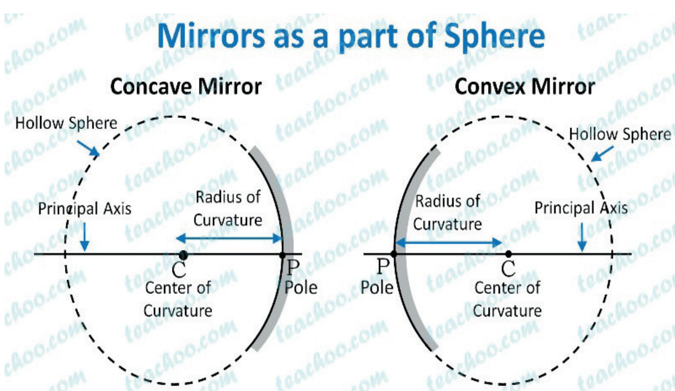
SUB-TOPIC: REFLECTION OF LIGHT AT A CURVED SURFACE

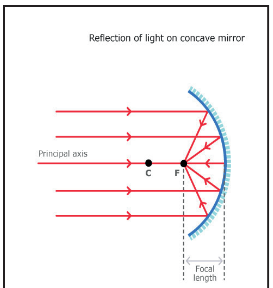
LESSON 1

AIM: *By the end of the lesson, you should be able:*

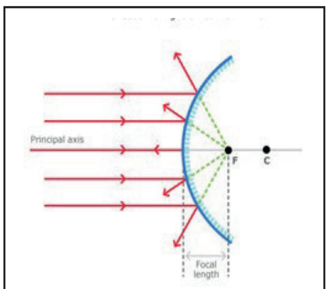
- ✓ *identify the types of curved mirrors*
- ✓ *describe how images are **formed in curved mirrors***

A spoon has two curved surfaces. If light is reflected from the inner surface, it is a concave mirror. In case the light is reflected from the outer surface, it is a convex mirror. So, there are two types of curved mirrors: ***a concave mirror*** and ***a convex mirror***. A concave mirror reflects light to the same point. A convex mirror reflects light in such a way that the reflected rays appear to originate from the same point.





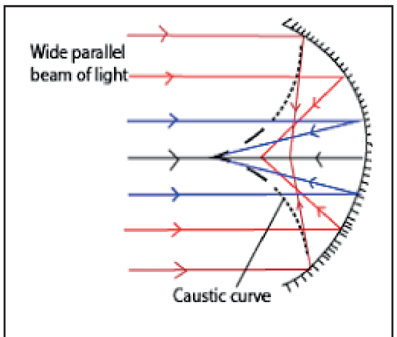
Concave mirror



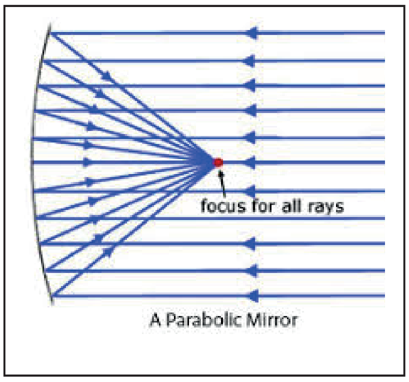
Convex mirror

The size of the reflecting surface of a curved mirror is its *aperture*. If a concave mirror has a wide aperture, all rays parallel to the principal focus are not brought to the same focus. Only rays close to the principal axis (paraxial rays) are reflected through the principal focus. This leads to formation of a bright surface known as a *caustic surface* is formed. The image formed from such reflection is not clear (blurred).

This condition is referred to as *spherical aberration*. This problem is overcome by using *a parabolic mirror*. Such a mirror has a property that all rays parallel to the principal axis are reflected through the principal focus. If a source of light is placed at the principal focus of a parabolic mirror, all rays are reflected parallel to the principal axis. Such mirrors are used as reflectors in flashlights and car head lamps.



Formation of caustic curve



Activity

Materials needed

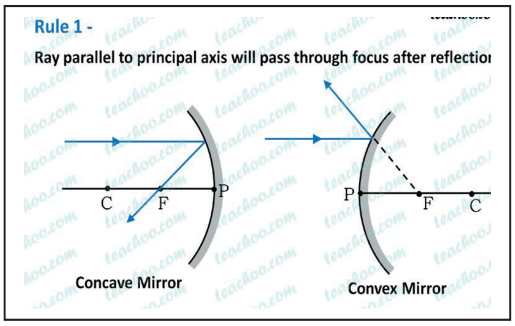
- Paper
- Pencil
- Ruler
- Pair of compasses
- Eraser

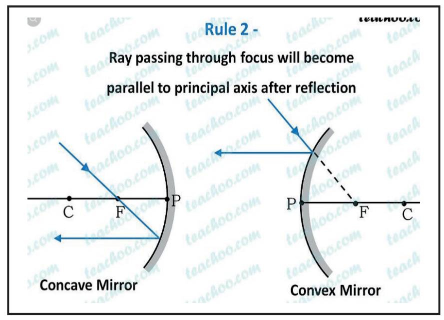
Procedures

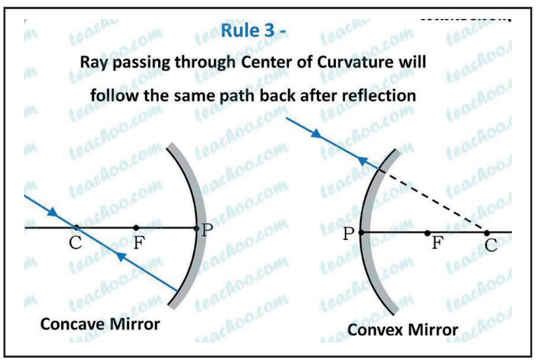
1. Draw a circle and mark its center as C.
2. Draw a line through the center of the circle and mark a point P, where the line touches the circle.
3. Cut off some section of the circle to remain with part that represents the curved mirror.
4. Obtain the midpoint of the line PC and label it F.
5. Measure length PC and call it r.
6. Measure the length FP and call it f.
7. Establish the relationship between r and f.

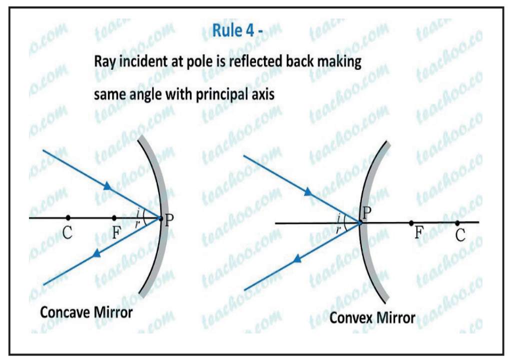
Formation of images in curved mirrors

While locating images formed in curved mirrors, the following rules are considered.

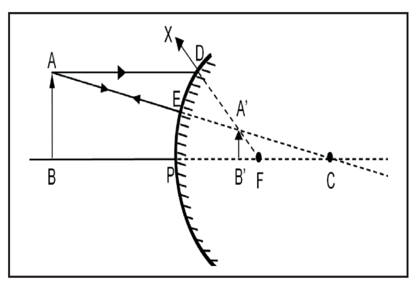


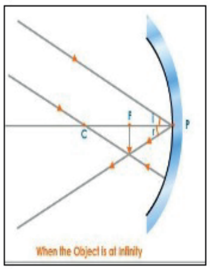




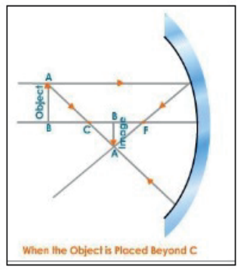


When an object is placed in front of a curved mirror, it will form an image. In a concave mirror, the image formed depends on the position of the object on the principal axis. For a convex mirror, no matter the position of the object, the image will always have the same characteristics.

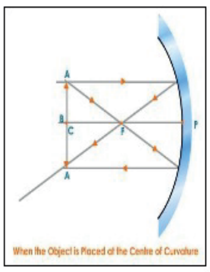




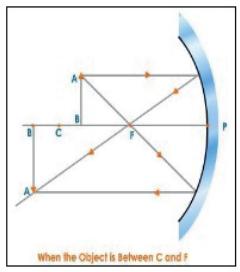
When object is at infinity.



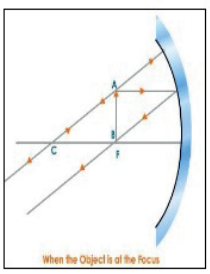
When object is beyond centre of curvature('C').



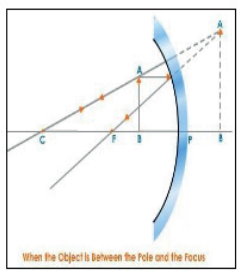
When object is at centre of curvature ('C').



When object is between 'C' and 'F'.



When object is at focus 'F'.



When object is between 'P' and 'F'.

Practice on formation of images in curved mirrors using guidance of the pictures shown and in each, state the characteristics of the image formed.

Assignment

You will look around for a boda boda motorcycle and check the words written on the side mirror. Are they similar to those in the photo? Do the words make any sense to you? Ask any motorcyclist if the words make sense to them. Why do you think they were written?

LESSON 2

AIM: *By the end of this lesson, you should be able to:*

- ✓ *State and use the mirror formula in solving numerical problems.*
- ✓ *Explain the applications of curved mirrors*

In the previous lesson, we looked at how curved mirrors form images. The distance of the object from the mirror is the *object distance*. This we shall represent with letter, u. The distance of the image from the mirror, *image distance,* we shall represent by letter v. These two distances have a relationship with the *focal length*, f of the mirror. This relationship is the equation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$.

The mirror formula can be used to find any of the unknowns$u$, v and f. However, this should be done with care. *Distances of real objects and images are positive. Distances of virtual objects and images are negative. A concave mirror has a real principal focus hence a positive focal length. A convex mirror has a virtual principal focus hence a negative focal length.* Let us look at some examples.

Example 1: An object is placed 10cm in front of a concave mirror of focal length 15cm. Find the image position. What is the nature of the image formed?

SOLUTION

u=+10 cm (real object)

f=+15cm (a concave mirror has a real principal focus hence positive focal length)

v=?

Substituting in$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$

$\frac{1}{10}+\frac{1}{v}=\frac{1}{15}$, $\qquad \frac{1}{v}=\frac{1}{15}-\frac{1}{10}=-\frac{1}{30}$

$$\therefore v=-30$$

Activity

Discuss with fellow students on the derivation of the mirror formula for both concave and convex mirror. Make use of available physics textbooks.

Since v is negative, the image is virtual (formed 30cm behind the mirror)

The image formed in a mirror may be smaller than the object, bigger than the object or even the same size as the object.

Magnification is the ratio of the image height to the object height. It can also be defined as the ratio of image distance to object distance.

$$magnification, m=\frac{image\ height}{object\ height}=\frac{image\ distance}{object\ distance}=\frac{v}{u}$$

In example 1, the magnification is,$m=\frac{v}{u}=\frac{30}{10}=3$

This means that the image is three times the size of the object i.e. it is magnified

Example2. The image of an object in a convex mirror is 4cm from the mirror. If the focal length of the mirror is 12cm. find the object position and the magnification of the image.

Solution

v=-4 cm (image in convex mirror is always virtual), f=-12 cm (convex mirror has a virtual focal point)

u=?

Try out!

The image of an object in a convex mirror is 4 cm from the mirror. If the mirror has a radius of curvature of 24 cm, find the object position and the magnification. $(u = 6\ cm, m = \frac{2}{3})$

Substituting these in $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$,

$$\frac{1}{u} = \frac{1}{-12} - \frac{1}{-4} = \frac{1}{6}$$

$\therefore u = 6cm$(real object)

$m = \frac{v}{u} = \frac{4}{6} = \frac{2}{3}$ What conclusion can you draw from the value of the magnification?

Applications for curved mirrors

Curved mirrors find numerous applications in the life of mankind. Use the pictures below to identify and describe these applications.

Are there any other applications not shown in the pictures? Mention them!

SUB-TOPIC: REFRACTION OF LIGHT AT PLANE SURFACES

LESSON 1

Aim: ***The learner should be able to:***

- ✓ ***demonstrate refraction***
- ✓ ***state the laws of refraction***

When a stick or pencil is placed in a glass of water, it appears bent. This and many other phenomena are used to explain another property of light: **refraction**. The next activity will help us to demonstrate refraction of light.

Activity

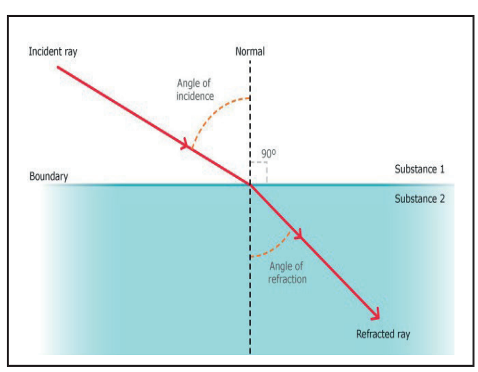
Materials needed

- Water
- Glass
- Pencil/stick
- White sheet of paper
- Pen/marker

Instructions

1. Make an arrow, big enough, on a white sheet of paper using a pen or a marker
2. Pour water in a glass. Look at the arrow through the glass of water as shown in the figure below.

You will notice that when you look at the arrow through the glass, it changes direction. What makes the arrow change direction?



When light travels from one optical medium to another, it suffers a change of direction at the surface of separation of the two media. This is referred to as ***refraction of light.***

The laws of refraction are:

1. *The incident ray, the refracted ray and the normal, at the point of incidence, all lie in the same plane.*
2. *The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for a pair of media.*

Care has to be taken when spelling the words 'reflection' and 'refraction' as they seem to look and sound alike. The same care should be taken when stating the laws of reflection and refraction as the first law is almost similar.

LESSON 2

AIM: the learner should be able to derive the relation between the refractive indicies of different media.

Think of different transparent materials: water, kerosene, glass, etc. As light moves from one medium to another, its direction changes. Consequently, the speed of light changes.

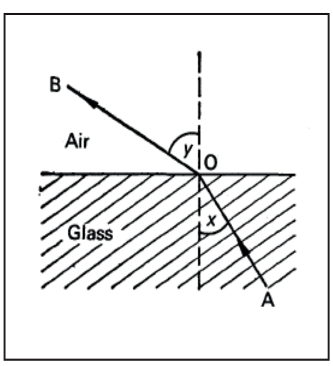
From the second law of refraction, the constant ratio $\frac{\sin i}{\sin r}$ is known as the *refractive index* for the two media. For example, if light is travelling from water to glass, the refractive index is denoted as

$_{water}\cap_{glass}$

If the first medium is a vacuum, the refractive index is known as the the *absolute refractive index, ∩.* Alternatively, the absolute refractive index is given by

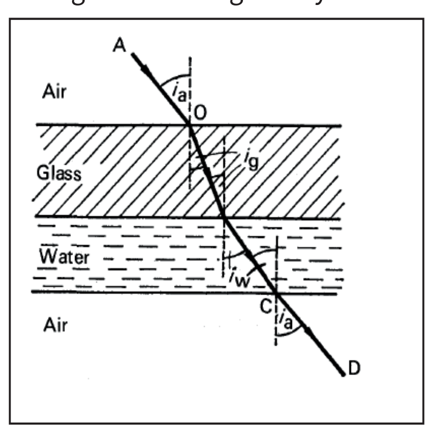
$$\cap = \frac{velocity\ of\ light\ in\ vacuum}{velocity\ of\ light\ in\ medium}$$

Consider a ray of light travelling from glass to air. The refractive index from glass to air is given by



$_g\cap_a = \frac{\sin x}{\sin y}$. From the principle of reversibility of light discussed earlier, if the ray is reversed to move from from air to glass, it will take the same path. In that case, the refractive index from air to glass is given by $_a\cap_g = \frac{\sin y}{\sin x}$. Therefore,

$$_g\cap_a = \frac{1}{_a\cap_g}$$



Let us now consider light travelling between parallel media. If i_g, i_w are the angles made with the normals by the respective rays in the glass and water media, ${}_g\cap_w = \frac{\sin i_g}{\sin i_w} = \frac{\sin i_g}{\sin i_a} \times \frac{\sin i_a}{\sin i_w}$. But $\frac{\sin i_g}{\sin i_w} = {}_g\cap_w$ and $\frac{\sin i_a}{\sin i_w} = {}_a\cap_w$.

$\therefore\ {}_g\cap_w = {}_g\cap_a \times {}_a\cap_w$

Thus, ${}_1\cap_3 = {}_1\cap_2 \times {}_2\cap_3$

From $\frac{\sin i_a}{\sin i_g} = {}_a\cap_{g,}$

$\rightarrow \sin i_a = {}_a\cap_g \sin i_a$

Also, $\frac{\sin i_w}{\sin i_a} = {}_w\cap_a = \frac{1}{{}_a\cap_w}$

$\rightarrow \sin i_a = {}_a\cap_w \sin i_a$

$\therefore \sin i_a = {}_a\cap_g \sin i_g = {}_a\cap_w \sin i_w$

If the equation is written in terms of of the absolute refractive indicies of air($\cap_a$), glass($\cap_g$) and water($\cap_w$). Then , $\cap_a \sin i_a = \cap_g \sin i_g = \cap_w \sin i_w$. This relation shows that when a ray is refracted from one medium to another, the boundaries being parallel,

$$\cap \sin \boldsymbol{i} = \boldsymbol{a\ constant}$$

where $\cap$is the absolute refractive index of the medium and i is the angle made by the ray with the normal in that medium.

LESSON 3

AIM: *By the end of this lesson, you should be able to:*

- ✓ *demonstrate real and apparent depth*
- ✓ *describe the occurrence of total internal reflection and state its applications*

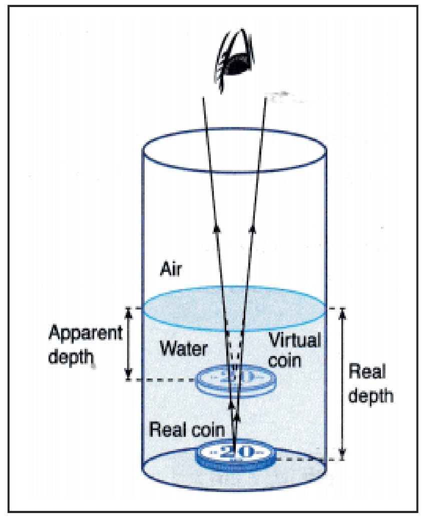
Activity

Materials needed

- Glass
- Water
- Ruler
- Coin

Procedures

1. Place a coin in a glass and pour water to half way the glass
2. Using a ruler, measure and record the depth of water. This is the real depth.
3. Looking from directly above the glass, measure and record the depth of the coin from the surface of water. This is the apparent depth.



The refractive index of water(and any other material) is related to the real and apparent depth by the equation

$$refractive\ index, \cap = \frac{real\ depth}{apparent\ depth}$$

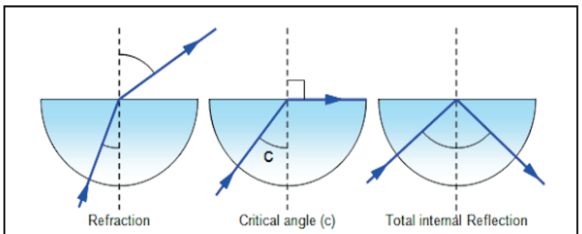
Total internal reflection

When light travels from an optically denser medium to a less optically dense medium (for example from water to air), the refracted ray bends away from the normal. At some angle of incidence known as the *critical angle*, the refracted ray grazes the boundary between the two media. Beyond this angle, the ray is reflected back to the denser medium. This is referred to as ***total internal reflection.***

Critical angle is defined as the angle of incidence in the denser medium for which the angle of refraction in the less dense medium is ninety degrees.

The refractive index, ∩ of a material is related to its critical angle, C by the equation $\sin c = \frac{1}{\cap}$

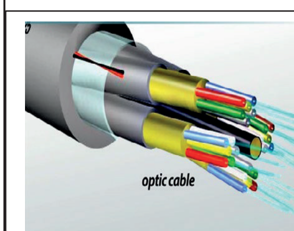
Total internal reflectionhas a number of applications. Some of them are shown in the pictures below. Can you identify any? Is there any other you

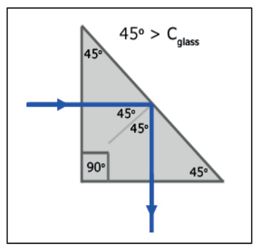


Demonstrating total internal reflection

know that has not been indicated in the picture

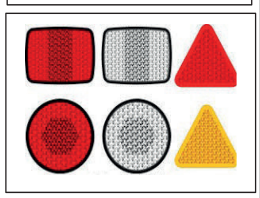
Do you know any other applications for total internal reflection that have not been included in the picture?





Applications

1. Optical fiber
2. Refracting prism
3. Rear reflectors



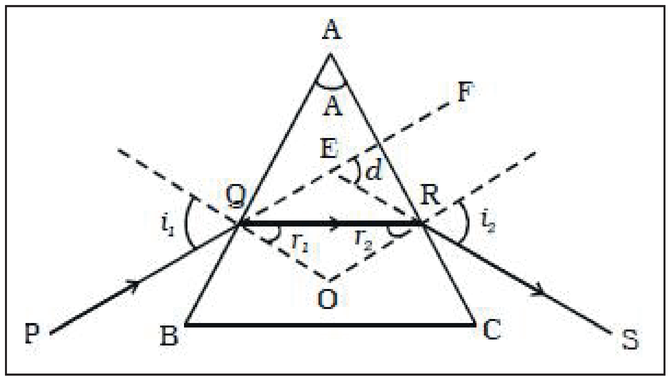
Effects for refraction include the fish's view, mirage and atmospheric refraction of radio waves. Research about them!

SUB-TOPIC: REFRACTION OF LIGHT THROUGH TRIANGULAR PRISMS

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Derive the expression for the angle of deviation of a prism*
- ✓ *Explain dispersion of white light*
- ✓ *Describe the applications of glass prisms*

When a ray of light is incident at Q on a triangular prism, at an angle $i_1$it is refracted at an angler_1.At R, the angle of incidence is r_2 and the ray emerges out of the prism at an angle i_2. If A is the refracting angle of the prism(angle at which the refracting edges AB and AC are inclined), then $A = r_1 + r_2$.



The angle of deviation at Q is the angle FQR and it is equal to $i_1 - r_1$. The angle of deviation at R is the angle ERQ and it is equal to $i_2 - r_2$. The total deviation is the angle d(FER) and it is equal to the sum of the deviation at Q and the deviation at R.

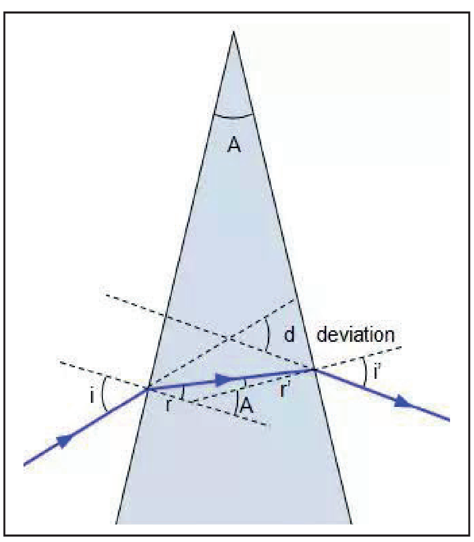
$$\therefore d = (i_1 - r_1) + (i_2 - r_2)$$

$$d = (i_1 + i_2) - (r_1 + r_2)$$

$$d = (i_1 + i_2) - A$$

If the ray passes symmetrically through the prism, the angle of deviation is

$D = (i + i) - (r + r) = 2i - A$ (since i_1=i_2=i and r_1=r_2=r)



From $D = 2i - A, i = \frac{A+D}{2}$. From $A = r + r, r = \frac{A}{2}$. Therefore, the refractive index of the material of the prism can be obtained from $\cap = \frac{\sin i}{\sin r} = \frac{sin\frac{A+D}{2}}{sin\frac{A}{2}}$

Deviation by small angle prism

Consider a small-angled prism shown in the figure. The deviation $d = (i - r) + (i' - r')$

$$d = i + i' - (r + r').$$

But $A = r + r'$

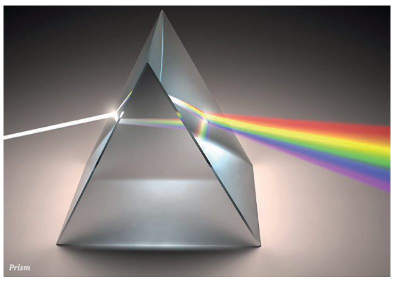
$\therefore d = i + i' - A$

Since the refracting angle is very small, i, i', r andr' are also small. For small angles, $\sin i = i$ and $sin\, r = r$. So, $i = nr$ and $i' = nr'$.

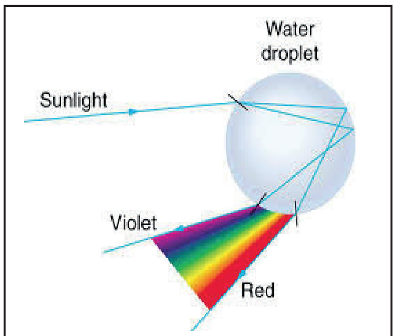
$\therefore d = nr + nr' - A$

$$= n(r + r') - A = nA - A = (n - 1)A$$

Dispersion of white light



White light is a mixture of a number of colors. A glass prism can separate white light into its constituent colors. This is due to the fact that light is refracted depending on the wavelength of the light. The shorter the wavelength, the more it bends. Different colors have different wavelengths. So, each color is refracted by different amounts. Dispersion of light by tiny water drops in the atmosphere leads to formation of the rainbow.



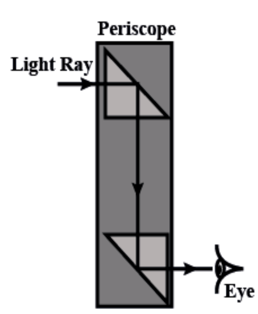
Applications of triangular prisms

Triangular prisms find numerous applications. One of the many is the *spectrometer*, an instrument used to study light from different sources. The spectrometer can be used to measure the refracting angle of a prism. It can also be used in the measurement of the Minimum Deviation of a prism.

The other applications for triangular prisms are prism periscopes and prism binoculars.

Fig: *Spectrometer*

Can you identify the prism?



SUB-TOPIC: REFRACTION OF LIGHT THROUGH THIN LENS

LESSON ONE

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Identify the types of lenses*
- ✓ *Define the terms principal focus, principal axis, optical center, focal length and power of a lens.*

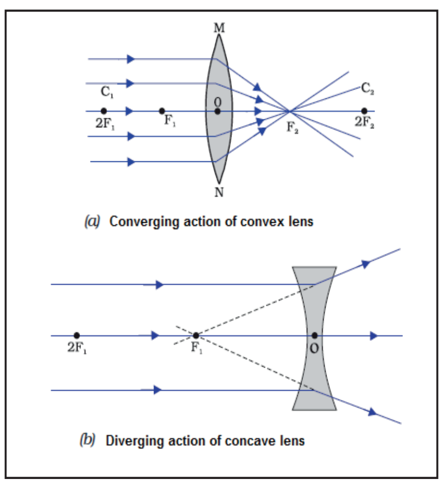
Have you wondered why some people wear spectacles and others don't? Do you wear spectacles? Do you know anyone in your class/ family who wears them?

Activity

Identify an individual at home or in the neighborhood wearing glasses. Kindly, request them to have a look at them (**take care not to break them**). Can you tell what type they are? Look at any object by trying to bring the glasses close to your eyes. Is there a difference when you look at the same object with a naked eye?

A lens is a piece of glass with one or two spherical surfaces. If a lens is thicker in the middle than the edges, it is a convex lens. One that is thinner in the middle than the edges is a concave lens.

When light is incident on a convex lens, it is refracted so that it converges at a point, F_2. This point is the ***principal focus***. This point is real. A convex lens is therefore ***a converging lens***.



(a) Converging action of convex lens

(b) Diverging action of concave lens

When a parallel beam of light is incident on a concave lens, light rays are refracted so that they appear to be coming from the same point, F_1. This point is the principal focus for the lens. Since light rays appear to be coming from this point, it is a virtual point. A concave lens is ***a diverging lens***.

Point O, is the ***optical center***. Rays through this point are not refracted. The distance OF_1 and OF_2 is the ***focal length*** for the concave and convex lens respectively. The line through O, F_1 and F_2 is the ***principal axis***.

Activity

Materials needed

- Convex lens
- Ordinary glass
- Pieces of paper/ dry grass

Procedures

1. Make a small heap of papers or dry grass.
2. Using a convex lens, focus sunlight onto the papers/ dry grass until it burns.
3. Try the same procedure with ordinary glass. Do you achieve the same result? Why or Why not?

Power of a lens

The power of a lens is defined as the reciprocal of the focal length (in meters) of the lens. It is measured in diopters (D).

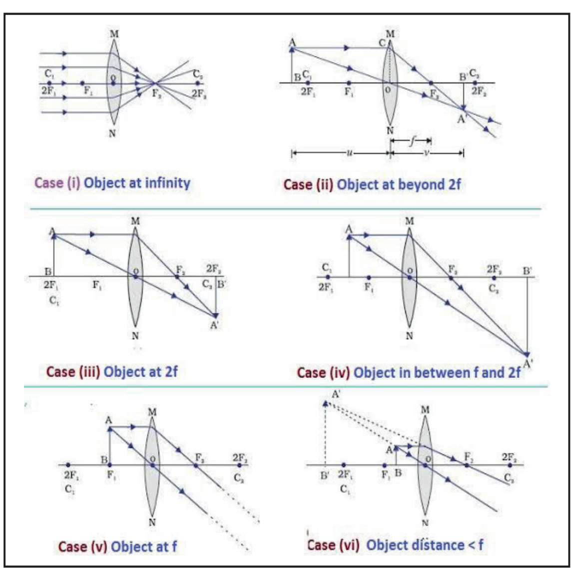
Try out!
Calculate the power of a lens of focal length 10 cm.

$$power\ of\ a\ lens = \frac{1}{f\,(in\ meters)}$$

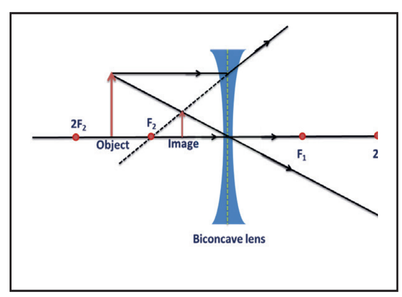
LESSON TWO

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Describe the formation of images by lenses*
- ✓ *Apply the thin lens formula.*



Light from an object is refracted by a lens leading to formation of an image by the lens. These images can be located by constructing ray diagrams. Here, we consider two main rays.

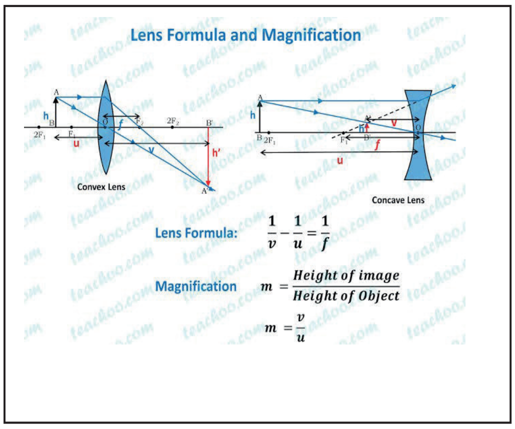


A ray parallel to the principal axis is refracted through the principal focus.
A ray through the optical center is not refracted.

Use the pictures to guide you in practicing the construction of ray diagrams. State the characteristics of the image formed in each case.

Thin lens formula

Earlier on, we looked at the mirror formula. Do you recall what the letters u, v and f stand for? The same formula applies for thin lenses. The same sign convention applies. That is, *distances of real objects and images are positive while distances of virtual objects and images are negative*.



The magnification can also be expressed as $m = \frac{v}{f} - 1$ or $\frac{1}{m} + 1 = \frac{u}{f}$

Try this out!

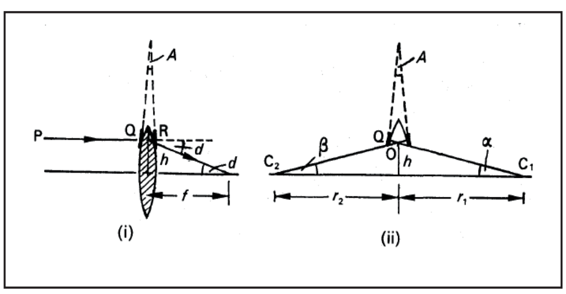
1. An object is placed 12 cm from a converging lens of focal length 18 cm. Find the position of the image and the magnification.

LESSON THREE

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Derive the expression for the focal length of a thin lens using the small angle prism method.*
- ✓ *Derive the expression for the combined focal length of two thin lenses in contact.*

An alternative way of deriving the expression for the focal length of a thin lens is using the small angle prism method.



Consider a ray parallel and close to the principal axis shown in figure(i). After refraction, the ray is deviated through an angle d. From $tan\ d = \frac{h}{f}$, $d = \frac{h}{f}$. ($\tan d = d$ for small angles). Since the angle of incidence is small and the ray is close to the principal axis, $d = (\cap - 1)A$. (deviation for small angle prism). This implies that $\frac{h}{f} = (\cap - 1)A$.

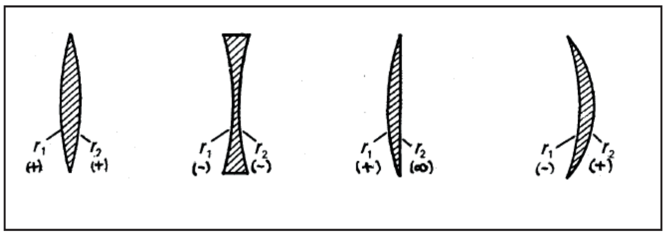
$\therefore \frac{1}{f} = (\cap - 1)\frac{A}{h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$. From figure (ii), $A = \alpha + \beta = \frac{h}{r_1} + \frac{h}{r_2}$.

$\therefore \frac{A}{h} = \frac{1}{r_1} + \frac{1}{r_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$. Substituting (ii) in (i), $\frac{1}{f} = (\cap - 1)(\frac{1}{r_1} + \frac{1}{r_2})$.

The focal length of a thin lens can be obtained from the expression $\frac{1}{f} = (\cap - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$ where $\cap$ is the refractive index of the material of the lens and r_1 and r_2 are the radii of curvature of the lens surfaces.

TRY OUT!

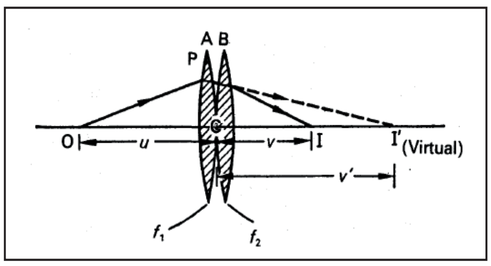
A biconvex lens has radii of curvaturer_1 and r_2, each 10cm. If the refractive index of the material of the lens is 1.5. Find the focal length of the lens.



The sign for the radius of curvature of the lens surface can be positive or negative. The picture on the left shows the sign for the radius of curvature of the different lens surfaces.

Combined focal length of two thin lenses in contact

If two lenses of focal lengthf_1 and $f_2$are combined as shown in the figure, the effective focal length, F of the combined lenses is given by $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$.



Example: A thin converging lens of 8cm focal length is placed in contact with a diverging lens of 12cm focal length. Find the combined focal length.

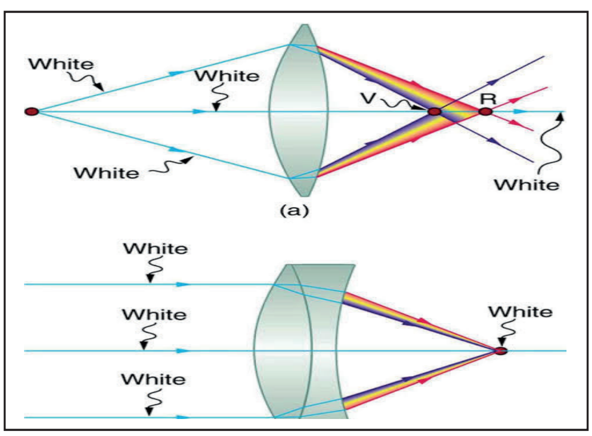
Solution

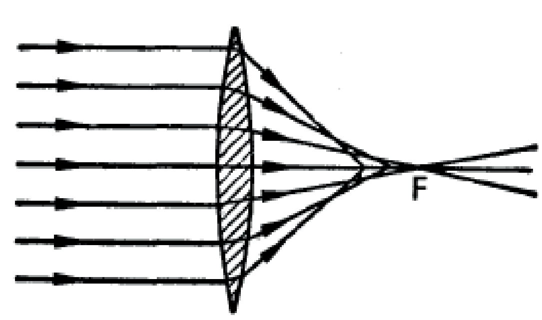
f_1=8cm, f_2=-12cm, F=?

$\frac{1}{F} = \frac{1}{8} + \frac{1}{-12} = \frac{1}{24}$ therefore, $F = 24\ cm$

Since F is positive, the combination acts like a converging lens.

Chromatic aberration





Spherical aberration

When white light is incident on a prism, different colors of light are refracted differently. White light incident on a convex lens lens is refracted so that thedifferent colors are brought to different focus. This effect is ***chromatic aberration*** (a). It is corrected using an achromatic doublet (b).

If a wide beam of light is incident on a lens, not all rays are brought to the same focus. The image is therefore distorted. This defect is known as ***spherical aberration***.

SUB-TOPIC: OPTICAL INSTRUMENTS

LESSON 1

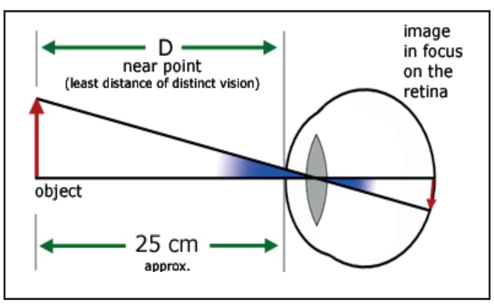
AIM: *By the end of this lesson, you should be able to:*

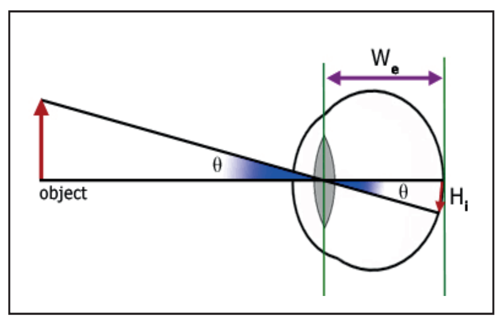
- ✓ *Define the terms visual angle, near point, far point and accommodation.*
- ✓ *Explain the relationship between visual angle and apparent size of objects.*
- ✓ *Define magnifying power of an optical instrument.*

Introduction

Get out of the house and look around you. What is the farthest thing you can see? How far do think is this object from you? Now, put your finger at about 2 cm from your eye. Can you distinctively see the finger? Move the finger to away from the eye until you can distinctively see it. How far do you think is your finger from your eye?

Our eyes can see close and far objects. The eye can see an object in greatest detail when it is placed at a certain distance from the eye. The point at this distance is known as the near point. An object is not clearly seen if it is brought closer to the eye than the near point. A normal eye can also focus far objects (objects at infinity).



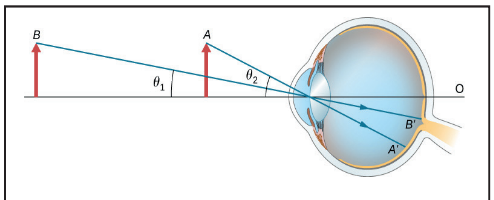


This is the far point of the normal eye.

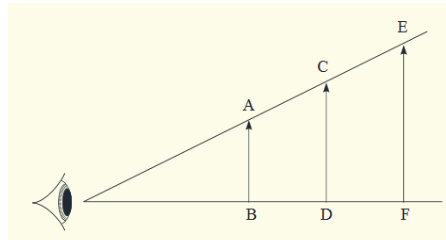
Consider an object placed at some distance from the eye, and suppose θ is the angle in radians subtended by the object at the eye. Since vertically opposite angles are equal, the length of the image on the retina is given by $H_i = W_e\theta$. Since the distance W_e is fixed, H_i is proportional to θ. We conclude that the length of the image formed by the eye is proportional to the angle subtended at the eye by the object. This angle, θ is known as the ***visual angle***.

If two or more objects of different sizes subtend the same visual angle at the eye, they appear to be of the same size. If the same object is viewed at different visual angles, it appears to be of different size.

Accommodation is the ability of the eye to change its focus from distant to near objects.



Same object at different visual angle



Objects of different size at same visual angle

If a microscope or telescope is used, the visual angle is increased such that the object viewed appears larger. If the object subtends an angle α at the eye without the instrument and an angle α' when the instrument is used, the ratio $M = \frac{\alpha}{\alpha'}$ is known as the ***angular magnification*** of the instrument. It is also referred to as the ***magnifying power*** of the instrument.

LESSON 2

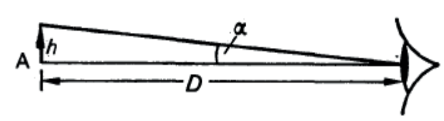
AIM: *By the end of this lesson, you should be able to:*

- ✓ *Describe the structure and action of a simple microscope.*
- ✓ *Describe the structure and action of a compound microscope.*

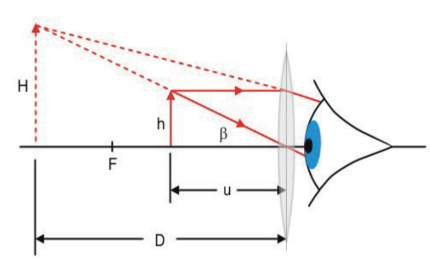
The simple microscope

A microscope is an instrument used to see near objects. They are used for viewing tiny micro-organisms like malaria parasites. An example of a simple microscope is the magnifying glass.


Children observing with magnifying glass



(a) Unaided eye

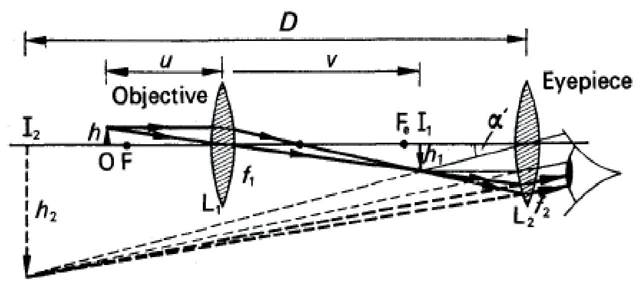


(b) Simple microscope

An object subtends an angle α at the unaided eye and is located at a distance, D from the eye (a). Therefore, $\alpha = \frac{h}{D}$. With the microscope (b), the image subtends an angle β at the eye and is also a distance, D from the eye (since a microscope forms image at near point). Therefore, $\beta = \frac{H}{D}$. the magnifying power is given by $M = \frac{\beta}{\alpha} = \frac{H}{D} \div \frac{h}{D} = \frac{H}{h}$. But for a lens, $M = \frac{v}{u}$ where v is the image distance and u is the object distance.Multiplying through the lens formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ by v, $1+\frac{v}{u}=\frac{v}{f}$. Therefore, $\frac{v}{u}=\frac{v}{f}-1$. But $v=D$. So, $\frac{v}{u}=\frac{H}{h}=\frac{D}{f}-1$. Hence, $\boldsymbol{M}=\frac{\boldsymbol{D}}{\boldsymbol{f}}-\mathbf{1}$.

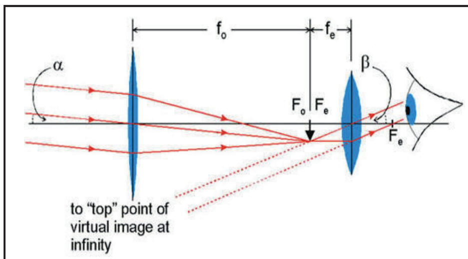
Compound microscope

A compound microscope has two separated lenses. The lens nearer the object is called ***the objective***. The lens through which the final image is viewed is called ***the eye-piece.*** Both the objective and eye-piece have a small focal length.



Compound microscope in normal adjustment

In normal adjustment, the image is formed at near point. The object is placed at a distance slightly beyond the focal length of the objective. An inverted real image is formed at I_1. The eye-piece is adjusted until a virtual image is formed at I_2(the eye –piece acts as a simple magnifying glass for viewing the image formed at $I_1$by the objective). The angular magnification, $M=\frac{\alpha'}{\alpha}=\frac{h_2}{D}\div\frac{h}{D}=\frac{h_2}{h}$. The image subtends an angle α'at the eye and it is formed at the least distance of distinct vision, D. But $\frac{h_2}{h}=\frac{h_2}{h_1}\times\frac{h_1}{h}$. Therefore, $\frac{h_2}{h_1}=\frac{v}{f_2}-1$. Since$v=D$, it implies that $\frac{h_2}{h_1}=\frac{D}{f_2}-1$. But $\frac{h_1}{h}=\frac{v}{f_1}-1$. Hence, the angular magnification is given by $\boldsymbol{M}=\left(\frac{\boldsymbol{D}}{\boldsymbol{f_2}}-\mathbf{1}\right)\left(\frac{\boldsymbol{v}}{\boldsymbol{f_1}}-\mathbf{1}\right)$.

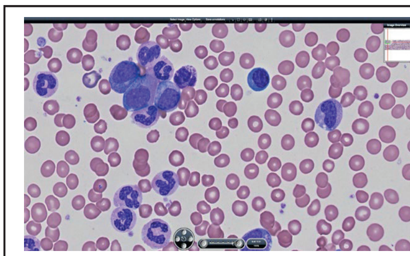


Compound microscope with final image at infinity

Compound microscope with final image at infinity

For the image to be formed at infinity, the image of the object in the objective must be formed at the focus, F_e, of the eye-piece. The visual angle, β, subtended at the eye by the final image at infinity is $\frac{h_1}{f_e}$. So, the angular magnification,

$M=\frac{\beta}{\alpha}=\frac{h_1}{f_e}\div\frac{h}{D}=\frac{h_1}{h}\times\frac{D}{f_e}$. But $\frac{h_1}{h}=\frac{v}{f_o}-1$, where$f_o$ and $f_e$are the focal lengths for the objective and eye-piece respectively. Therefore, $\boldsymbol{M}=\left(\frac{\boldsymbol{v}}{\boldsymbol{f_o}}-\mathbf{1}\right)\frac{\boldsymbol{D}}{\boldsymbol{f_e}}$



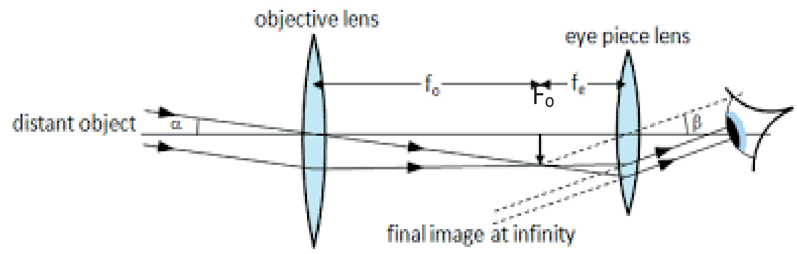
Malaria parasites (purple) seen under a microscope

LESSON 3

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Describe the structure and action of astronomical and Galileo's telescopes in normal adjustment and with the final image at near point.*

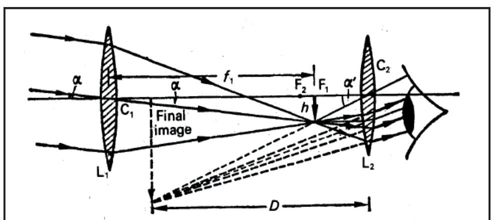
Telescope



Astronomical telescope in normal adjustment

Telescopes are used to view distant objects like stars. In normal adjustment, an astronomical telescope forms the final image at infinity. The image of a distant object is formed at the focus, F_o, of the objective. Since the final image is formed at infinity, the focus of the eye-piece must also be at F_o. The angular magnification, $M = \frac{\beta}{\alpha}$ where $\beta$is the angle subtended at the eye when the telescope is used and $\alpha$is the angle subtended at the unaided eye by a distant object. Assuming the eye is so close to the eye-piece, the length between the objective and the eye-piece is very small compared with the distance of the object from either lens. We can take the angle αsubtended at the unaided eye by the object as that subtended at the objective lens.$\beta = \frac{h}{fe}$ where h is the length of the image at $F_o$and $f_e$is the focal length of the eye-piece.$\alpha = \frac{h}{fo}$ since theimage is at distance $f_o$from the objective. The angular magnification $M = \frac{\beta}{\alpha} = \frac{h}{fe} \div \frac{h}{fo} = \frac{fo}{fe}$. The angular magnification is the ratio of the focal length of the objective to that of the eye-piece.

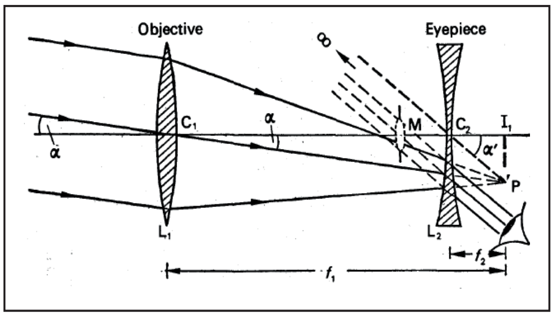
Astronomical telescope with image at near point



The image in a telescope can be formed at near point. The objective forms an image of a distant object at its focus F_1. The eye-piece is moved so that the image is near to it than its focus F_2, thus acting as a magnifying glass. The angle α subtended at the unaided eye is the same as that subtended at the objective. Therefore $\alpha = \frac{h}{fo}$ where h is the height of the image in the objective and $f_o$its focal length. The angle subtended at the eye by the final image is $\alpha' = \frac{h}{u}$ where u is distance of the image from the eye-piece. Therefore, $M = \frac{\alpha'}{\alpha} = \frac{h}{u} \div$

$\frac{h}{f_o} = \frac{f_o}{u}$. Since the image is formed at near point, $v = D$ when $f = +f_e$. From $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$, $\frac{1}{-D} + \frac{1}{u} = \frac{1}{fe}$. This implies that $u = \frac{f_e D}{f_e + D}$. Therefore, $M = \frac{f_o}{fe}\left(\frac{f_e + D}{D}\right) = \frac{f_o}{fe}\left(1 + \frac{fe}{D}\right)$.

Galileo's telescope



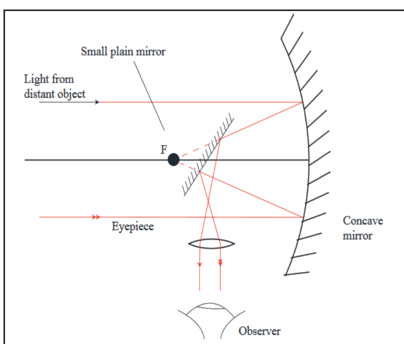
This telescope consists an objective which is a convex lens of long focal length and an eye-piece which is a concave lens of short focal length. In the absence of the diverging lens, an image of a distant object in the objective would be formed at I. since the eye-piece is at a distance f_2 from I, rays falling on it are refracted so they emerge parallel. The angle subtended by the final image at the eye-piece is $\alpha' = \frac{h}{f_2}$ where h,is the height of the image and $f_2$is the focal length of the eye-piece. The angle subtended by the object at the unaided eye is the same as that subtended by the object at the objective and is given by $\alpha = \frac{h}{f_1}$ where $f_1$is the focal length of the objective. Therefore, the angular magnification is given by $M = \frac{\alpha'}{\alpha} = \frac{h}{f_2} \div \frac{h}{f_1} = \frac{f_1}{f_2}$.

LESSON 4

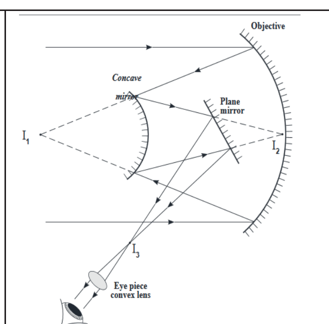
AIM: By the end of this lesson, you should be able to:

- ✓ *Describe the structure and action of reflecting telescopes*
- ✓ *Compare the use of refracting and reflecting telescopes.*
- ✓ *Describe the action of projection lantern, lens camera and prism binoculars.*

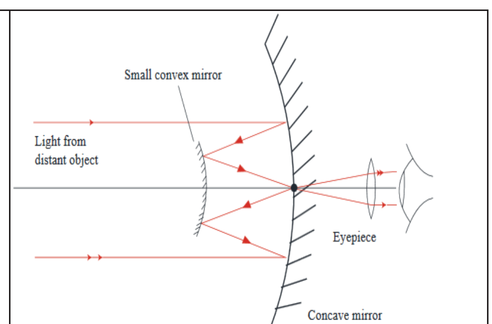
Reflecting telescopes



Newton reflecting telescope



Coude reflecting telescope



Cassegrain reflecting telescope

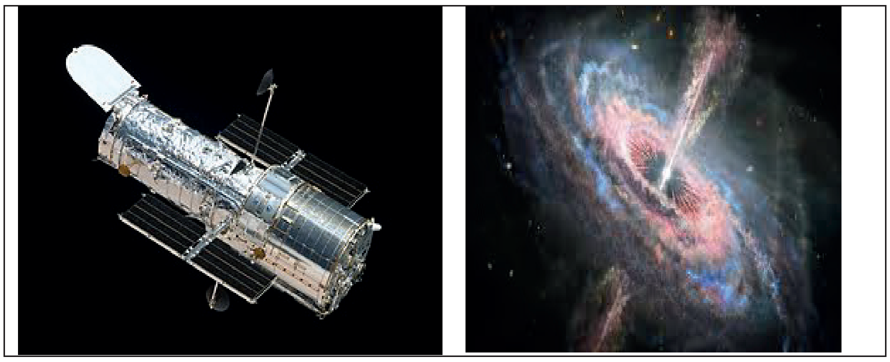
Reflecting telescopes employ a large concave mirror that is used to collect light rays from a distant object and focus them on a reflecting mirror. Thereafter, the rays are reflected to the eye-piece. There are three such telescopes: Newton, Cassegrain and Coude reflecting telescopes.

Advantages of reflecting telescopes over refracting telescopes

- ➢ Not subject to chromatic aberration.

- Spherical aberration can be overcome by using a parabolic mirror.
- Telescope tube is shorter making it more economical.

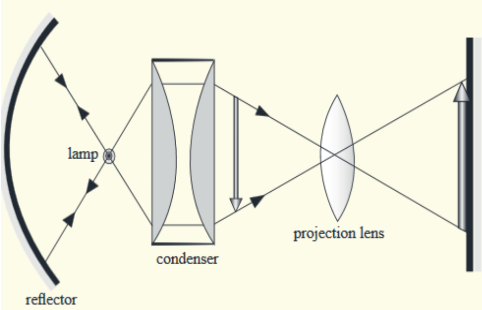
The Hubble Space telescope



This is a telescope that was launched in 1990 and orbits at about 547km above the earth's surface. It has a primary mirror of width 2.4m. It is powered by two 25-foot solar panels. It has six Nickel-Hydrogen batteries with a storage capacity equal to 20 car batteries.

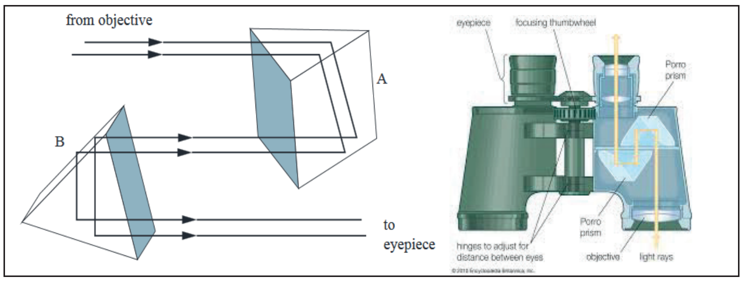
For a period of 30 years the telescope has been used to study the universe.

The projection lantern



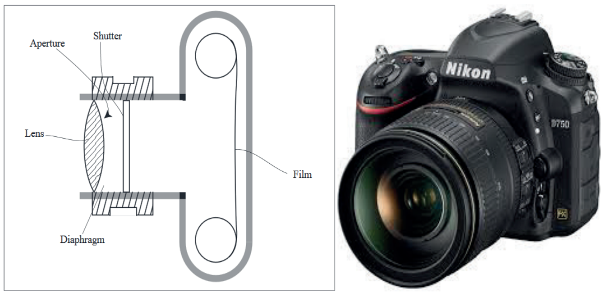
A projection lantern is commonly known as a projector and is used for throwing on a screen a magnified image of a slide. Light from a lamp s reflected off a concave mirror and focused by the condenser onto the film. The projection lens is mounted in the sliding tube so that it is moved to and fro to focus a sharp image on the screen.

Prism binoculars



Binoculars are used by tourists, scientists and soldiers to see distant objects. They consist of a pair of refracting astronomical telescopes with two totally reflecting prisms between each objective and eye-piece. The prisms use total internal reflection to invert rays of light so that the final image is seen the correct way.

Lens camera



Lens camera

A lens camera is used to take photographs. The lens focuses light from the object onto a light sensitive film. It is moved to and fro so that a sharp image is formed on the film.

TOPIC: WAVES

SUB-TOPIC: BASIC PROPERTIES OF WAVES

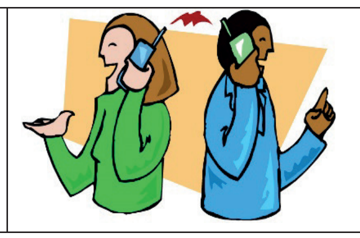
LESSON 1

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Define the terms: wave, amplitude, wavelength, frequency and phase.*
- ✓ *Distinguish between transverse and longitudinal waves.*
- ✓ *State the characteristics of a progressive wave.*

Introduction

The government of Uganda is planning to give out radios to every household so that students can continue learning from home during the lockdown. Do you have a favorite radio station? How are the signals able to move from the broadcasting center to reach you at home? Radio broadcasting, mobile phone communication, X-ray and ultrasound imaging, and remote control of devices is all possible because of waves. So, what is **a wave**?




Activity

Material needed

- ➢ Rope
- ➢ Basin
- ➢ Water

Get a rope and tie on end on a tree or any other fixed support. Swing the rope so that it makes continuous up and down movements. What do you notice? Thereafter, pour water in a basin and wait for it to settle. Gently, touch the surface of the water from the middle of the basin. Observe the waves as they spread from the center to the end**. (You do not have to necessarily carry out the activities at the same time)**

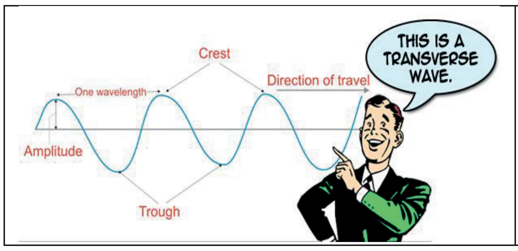
Waves are produced when a vibrating source causes a disturbance in a medium. When you touch the water surface, energy is transferred to the water particles and this energy is carried away from that point to the end. Therefore, *a wave is a disturbance which travels through a medium, transforms energy from one point to another without transferring medium.*

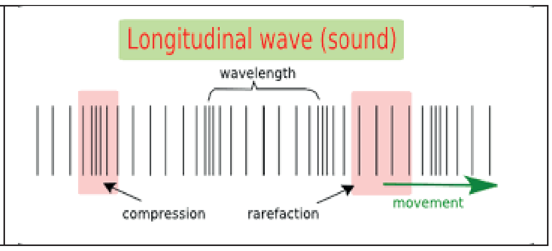
Waves are categorized as mechanical or electromagnetic.
Electromagnetic waves are waves which do not require a medium for their propagation. Electromagnetic waves travel in a vacuum. Examples of such waves include radio waves, infrared, visible light, Ultraviolet, X-rays and Gamma rays.
Mechanical waves are waves which require a material medium for their propagation. These include water waves, sound waves and waves on stretched strings.

Waves can also be classified as transverse and longitudinal waves.

A transverse wave is one in which the direction of propagation of the wave is perpendicular to the direction of vibration of the particles. Examples of transverse waves include all electromagnetic waves, water waves and waves on a string.

A Longitudinal wave is a mechanical wave in which the vibrations of the particles takes place in the same direction as that direction of the travel of the wave. An example is sound waves.





Terms used

Amplitude: This is the greatest displacement of a particle from the rest position.
Wavelength *(λ)*: This is the distance between two successive crests or troughs. Or, it is the distance between two consecutive wave particles in phase.
Period (T): The time taken for one cycle. T=$\frac{time}{number\ of\ cycles} = \frac{t}{n}$ where t is the time and n is the number of cycles. It is measured in seconds.
Frequency (f): The number of cycles per second. It is measured in hertz (Hz)

Velocity of a wave (v): This is the distance covered by a wave particle per second.

Relationship between f and T
If a wave completes n cycles in time t, then frequency, f is given by $f = \frac{n}{t}$. But $T = \frac{t}{n}$.

Therefore, $f = \frac{1}{T}$.

Relationship between v, f and λ

If a wave of wavelength λ completes n cycles in time t, then total distance covered = $n\lambda$

$Speed, v = \frac{distance}{time} = \frac{n\lambda}{t} = \frac{n}{t}\lambda = f\lambda$. Therefore, $v = f\lambda$.

LESSON 2

AIM: *By the end of this lesson, you should be able to:*

- ✓ *Define a progressive wave.*
- ✓ *Explain phases of vibration.*
- ✓ *Derive the progressive wave equation.*

Progressive wave

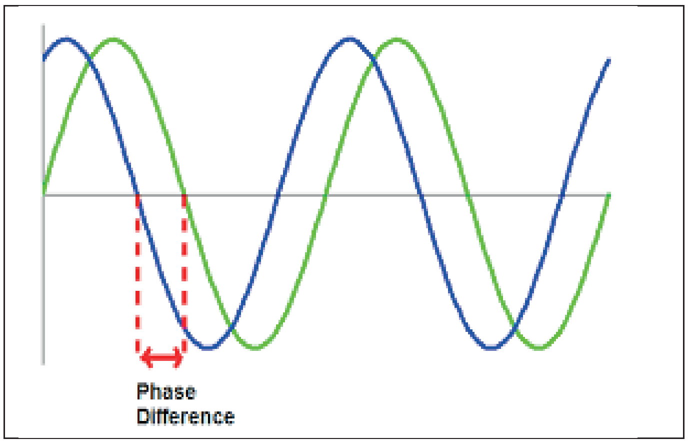
A wave which travels continuously in a medium in the same direction without a change in its amplitude is **a progressive wave.** In a progressive wave, there is continuous transmission of energy from one particle to another. Electromagnetic waves and mechanical waves are examples of progressive waves.

A tsunami is an example of a progressive wave. A large volume of water is displaced by a disturbance resulting in a huge wave. The energy propagated by the wave is so much that it destroys property.

Characteristics of a progressive wave

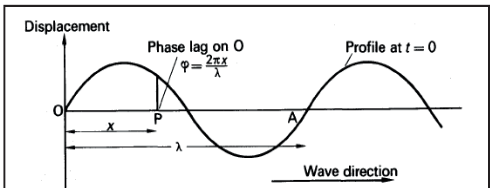
- Each particle of the medium vibrates at its mean position.
- Particles vibrate with the same amplitude.
- There is transfer of energy across the medium in the direction of propagation of the wave.

Phase of vibrations



When you tie a rope at one end and swing it, it makes up and down movements similar to a sine wave. Any oscillation of this form is represented by the equation $y = a \sin \omega t$.

Consider an oscillation given by $y_1 = a \sin \omega t$ (blue). Suppose a second oscillation (green) has the same amplitude, a, and angular frequency, ω but reaches the end of its oscillation a fraction, β, of the period T later than the first one. The second oscillation thus ***lags behind*** the first by a time, βT and so, its displacement is given by $y_2 = a \sin(\omega t - \beta T) = a \sin(\omega t - \varphi)$ where $\varphi = \omega\beta T$. If the second oscillation leads the first by a time βT, the displacement is given by $y_2 = a \sin(\omega t + \varphi)$. φ is the phase angle of the oscillation.



Progressive wave

The progressive wave equation

The figure shows a progressive wave represented by a sine wave. Suppose the wave moves from left to right. A particle at the origin vibrates according to the equation $y = a \sin \omega t$(equation of a sine wave) where a, is the amplitude, t is the time and ω is the angular frequency (**angular displacement per unit time**).

$\omega = 2\pi f$ where f if the frequency. Since $f = \frac{1}{T}$, it implies that $\omega = \frac{2\pi}{T}$. A particle at P a distance x from O to the right has a phase of vibration different from that at O. the phase difference at P is $\varphi = \frac{2\pi x}{\lambda}$ (a distance λ form O corresponds to a phase difference of 2π). The displacement of any particle at a distance x from the origin is given by $y = a \sin(\omega t - \varphi)$. But $\omega = 2\pi f$ and $\varphi = \frac{2\pi x}{\lambda}$.

Therefore $y = a\sin(2\pi ft - \frac{2\pi x}{\lambda}) = a\sin\left(\frac{2\pi vt}{\lambda} - \frac{2\pi x}{\lambda}\right) = a\sin\frac{2\pi}{\lambda}(vt - x)$. Since $f = \frac{1}{T}$, the equation can be written as $y = a\sin 2\pi(\frac{t}{T} - \frac{x}{\lambda})$. A wave travelling from right to left arrives at P before O. thus, the vibration at P leads that at O. so, a wave travelling in the opposite direction (right to left) is given by $y = a\sin 2\pi(\frac{t}{T} - \frac{x}{\lambda})$.

Example

Suppose a wave is represented by $y = a\sin(2000\pi t - \frac{\pi x}{17})$. Find the velocity and frequency of the wave.

Solution

From $y = a\sin\frac{2\pi}{\lambda}(vt - x)$, $\frac{2\pi v}{\lambda} = 2000\pi$. This implies that $v = 1000\lambda$. Also, $\frac{2\pi}{\lambda} = \frac{\pi}{17}$.

$\therefore\ \lambda = 2 \times 17 = 34\ cm$. Hence,

$v = 1000 \times 34 = 34000cms^{-1}$.

$$\therefore f = \frac{v}{\lambda} = \frac{34000}{34} = 1000Hz$$

Try out!

A transverse progressive wave is given by $y = 3\sin 2\pi(\frac{t}{0.04} - \frac{x}{40})$where the length is in cm and the time in seconds. Calculate the wavelength, frequency, amplitude and the speed of the wave.

SUB-TOPIC: STATIONARY WAVES

LESSON 1

AIM: *By the end of this lesson, you should be able to:*

- ✓ *State the principle of superposition.*
- ✓ *Explain how a stationary wave is formed*
- ✓ *State characteristics of a stationary wave*

When two waves travel in the same medium at the same time, their resultant displacement when they combine is obtained from the principle of superposition.

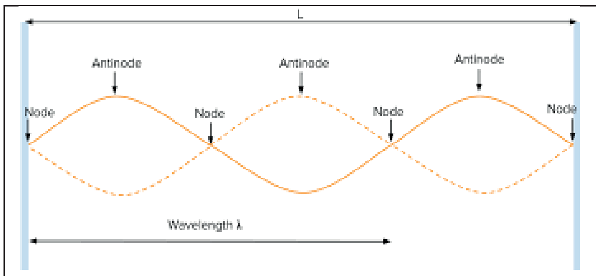
The principle of superposition states that ***the resultant displacement at any point is the sum of the separate displacements due to the two waves.***

Stationary waves

Stationary waves are produced by superposition of two progressive waves of equal amplitude and frequency traveling with the same speed in opposite direction.

Consider two waves $y_1 = a\sin(\omega t - kx)$ and $y_2 = a\sin(\omega t + kx)$. If the two waves combine, from the principle of superposition, their resultant displacement y is given by

$y = y_1 + y_2 = a\sin(\omega t - kx) + a\sin(\omega t + kx)$. From trigonometry, $\sin A + \sin B = 2\sin\left(\frac{A+B}{2}\right)\cos\left(\frac{A-B}{2}\right)$. Therefore $y = 2a\sin\omega t\cos kx = A\sin\omega t$ where A is the amplitude of the resulting wave.



Stationary wave

The amplitude is maximum and equal to $2a$ at $x = 0, x = \frac{\lambda}{4}, x = \frac{3\lambda}{4}$ and so on. These points are the antinodes and the separation between consecutive antinodes is $\frac{\lambda}{2}$. (x is the displacement of the particle)

The displacement is zero when $x = 0,\ x = \frac{\lambda}{2}, x = \lambda$ and so on. These points are called nodes and they are midway between consecutive antinodes.

Properties of stationary waves

- Energy is not transferred from one point to another.
- Particles at the node do not vibrate at all. So, their amplitude is zero. Particles at the antinode vibrate with maximum amplitude.
- All particles within one vibrating loop (e.g. between two adjacent nodes) are in phase.

LESSON 2

AIM: By the end of this lesson, you should be able to describe the modes of vibration of a stretched string.

Activity

Materials needed

- Three strings of different size(thickness)
- A piece of stick that can bend

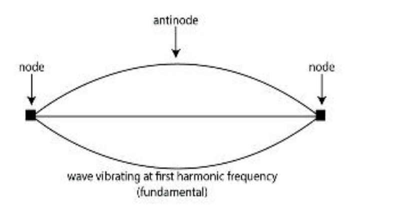
Bow

Procedures

1. Bend the stick and tie the string at either end to form a bow.
2. Pluck the string at half-way, a quarter-way and a three-quarter way. In each case, keenly take a note of the sound produced.

3. Repeat the above procedures using different strings. (it is better if you can get strings from different materials say, cotton, sisal, nylon and banana fiber)

Is the sound produced in each case the same? If not, what causes the difference?

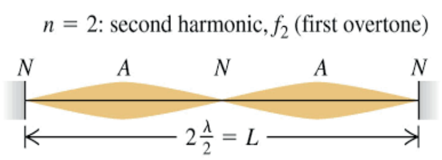


Fundamental frequency of stretched string

When a stretched string is made to vibrate, it produces stationary waves. Consider a string of length l plucked to produce the wave shown in the picture. The length from node to node is $\frac{\lambda}{2}$. This means that $l = \frac{\lambda}{2}$. $\therefore \lambda = 2l$.

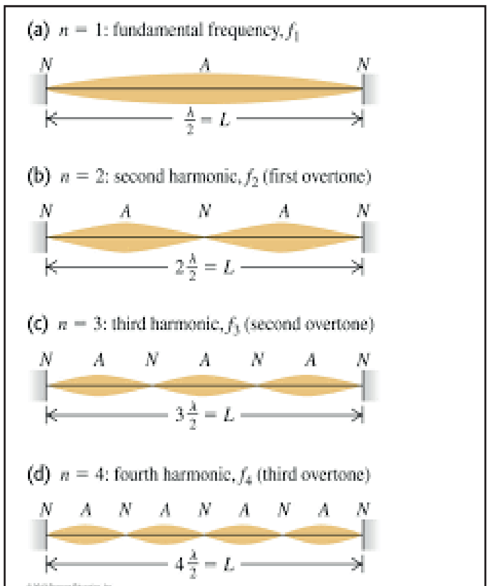
From $v = f\lambda$, it implies that $v = 2lf$. Hence, $f = \frac{v}{2l}$. This can be written as $f_1 = \frac{v}{2l}$ and it is the frequency of the first harmonic or the fundamental frequency (lowest frequency that can be produced by the string).

The velocity of sound in a string is given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the string and is the mass per unit length of the string. Therefore $f_1 = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$. This shows that the frequency of a note produced by a vibrating string depends on the ***length of the string***, ***tension in the string*** and the ***mass per unit length of the string***.



First overtone (second harmonic)

A stretched string can produce a number of frequencies which are multiples of the fundamental frequency. These are called overtones. For the first overtone (second harmonic), $l = \lambda$. This means that $f_2 = \frac{v}{\lambda} = \frac{v}{l}$. Therefore, $f_2 = 2f_1 = \frac{1}{l}\sqrt{\frac{T}{\mu}}$.



Assignment

1. Derive the expression for the third harmonic, fifth harmonic and nth harmonic of a vibrating string.
2. List all the musical instruments you know that use the above principle.

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