RTB | RWANDA TVET BOARD

RQF LEVEL 4

TRADE:

MODULE CODE: GENAP402

TEACHER'S GUIDE

Module name: MECHANICS AND PROPERTIES OF MATTER

MODULE NAME:GENAP402 MECHANICS AND PROPERTIES OF MATTER

2022

Table of Contents

Introduction

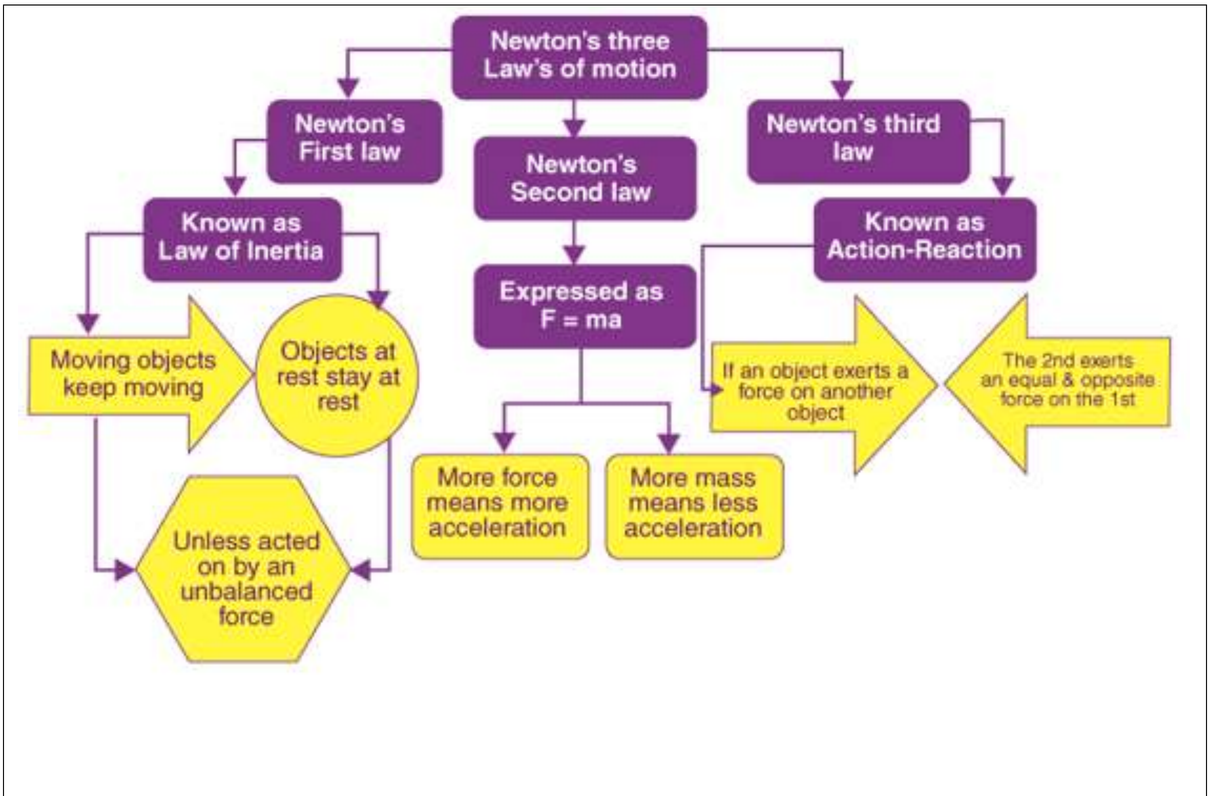
The current module describes skills, knowledge and attitudes required to apply concepts of mechanics and properties of matter. At the end of the module the trainee should be able to apply static equilibrium and elasticity, thermodynamics, analyze fluid mechanics, describe laws of motion and their applications, describe optical instrument and examine effects of electric current flow in dc electric circuit. It will help trainee to carry out his/her specialized tasks that are useful in analyzing data, solving real life problems encountered in related fields.

GENAP402: MECHANICS AND PROPARTIES OF MATTER

Learning Units:

1: Describe laws of motion and their applications
2: Apply static equilibrium and elasticity
3: Analyze fluid mechanics
4: Apply thermodynamics
5: Examine effects of electric current flow in DC electric circuit
6: Apply Geometric instruments

Learning Unit 1: Describe laws of motion and their applications



STRUCTURE OF LEARNING UNIT 1

Learning outcomes: 1.1: Interpret the concept of the force 1.2: Interpret Newton laws 1.3: Describe the free body diagram

Learning outcome 1.1: Interpret the concept of the force

Duration: 2 hrs

Learning outcome 1.1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. List correctly fundamental forces and their characteristics
2. Differentiate clearly Contact force and field forces
3. Differentiate clearly internal and external forces

Resources

Equipment	Tools	Materials
PPE, Whiteboard and chalkboard	Computer, Projector, Various measuring instruments, Textbooks, Scientific calculator	Chalks, Markers, Flipchart

Advance preparation:

- Definition of a force
- Characteristics of a force
- Effects of a force

CONTENT

1.1 Contact forces and Field forces.

1.1.1 Contact force

Contact force is **a force that is applied by objects in contact with each other**. The contact force acts on a point of direct contact between the two objects. This force can either be continuous as a continuous force or can be momentary in the form of an impulse. Contact force is governed by Newton's Laws.

Types of contact forces are: **Frictional force; Tension force; Normal Force; Air Resistance Force, Applied Force, Spring Force**

1. Applied Force

An applied force is a force that is applied to an object by a person or another object. If a person is pushing a table across the room, then there an applied force acting upon the object. The applied force is the force exerted on the table by the person.

Fif.1.1 Pushing a table

2. Normal Force

The normal force is the support force exerted upon an object that is in contact with another stable object. For example, if a book is resting upon a surface, then the surface is exerting an upward force upon the book in order to support the weight of the book. On occasions, a normal force is exerted horizontally between two objects that are in contact with each other. For instance, if a person leans against a wall, the wall pushes horizontally on the person.

3. Friction Force

The friction force is the force exerted by a surface as an object moves across it or makes an effort to move across it. There are at least two types of friction force - sliding and static friction. Though it is not always the case, the friction force often opposes the motion of an object. For example, if a book slides across the surface of a desk, then the desk exerts a friction force in the opposite direction of its motion. Friction results from the two surfaces being pressed together closely, causing intermolecular attractive forces between molecules of different surfaces. As such, friction depends upon the nature of the two surfaces and upon the degree to which they are pressed together.

4. Air Resistance Force

The tension force is the force that is transmitted through a string, rope, cable or wire when it is pulled tight by forces acting from opposite ends. The tension force is directed along the length of the wire and pulls equally on the objects on the opposite ends of the wire.

5. Tension Force

The tension force is the force that is transmitted through a string, rope, cable or wire when it is pulled tight by forces acting from opposite ends. The tension force is directed along the length of the wire and pulls equally on the objects on the opposite ends of the wire.

6. Spring Force

The spring force is the force exerted by a compressed or stretched spring upon any object that is attached to it. An object that compresses or stretches a spring is always acted upon by a force that restores the object to its rest or equilibrium position. For most springs (specifically, for those that are said to obey "Hooke's Law"), the magnitude of the force is directly proportional to the amount of stretch or compression of the spring.

1.1.2 Non-contact force or Field force

A non-contact force(Field force) is **a force which acts on an object without coming physically in contact with it**.

The most familiar non-contact force is gravity, which confers weight. In contrast a contact force is a force which acts on an object coming physically in contact with it.
Examples of field forces: Gravitational force. Magnetic force. Electrostatic force. The nuclear force .

1.1.3 Fundamental forces and their characteristics
There are four fundamental forces at work in the universe. The four fundamental forces of nature are, in order of strength: strong nuclear, electromagnetic, weak nuclear, and gravitational. They work over different ranges and have different strengths. Gravity is the weakest but it has an infinite range.

1.Gravity

Gravity is the attraction between two objects that have mass or energy, whether this is seen in dropping a rock from a bridge, a planet orbiting a star or the moon causing ocean tides. Gravity is probably the most intuitive and familiar of the fundamental forces, but it's also been one of the most challenging to explain.
Isaac Newton was the first to propose the idea of gravity, supposedly inspired by an apple falling from a tree. He described gravity as a literal attraction between two objects. Centuries later, Albert Einstein suggested, through his theory of general relativity, that gravity is not an attraction or a force. Instead, it's a consequence of objects bending space-time. A large object works on space-time a bit like how a large ball placed in the middle of a sheet affects that material, deforming it and causing other, smaller objects on the sheet to fall toward the middle.

Though gravity holds planets, stars, solar systems and even galaxies together, it turns out to be the weakest of the fundamental forces, especially at the molecular and atomic scales. Think of it this way: How hard is it to lift a ball off the ground? Or to lift your foot? Or to jump? All of those actions are counteracting the gravity of the entire Earth. And at the molecular and atomic levels, gravity has almost no effect relative to the other fundamental forces.

2.The weak force

The weak force, also called the weak nuclear interaction, is responsible for particle decay. This is the literal change of one type of subatomic particle into another. So, for example, strays close to a neutron can turn the neutron into a proton while the neutrino becomes an electron. Physicists describe this interaction through the exchange of force-carrying particles called bosons. Specific kinds of bosons are responsible for the weak force, electromagnetic force and strong force. In the weak force, the bosons are charged particles called W and Z bosons. When subatomic particles such as protons, neutrons and electrons come within 10^-18 meters, or 0.1% of the diameter of a proton, of one another, they can exchange these bosons. As a result, the subatomic particles decay into new particles, according to Georgia State University's Hyper Physics website.

The weak force is critical for the nuclear fusion reactions that power the sun and produce the energy needed for most life forms here on Earth. It's also why archaeologists can use carbon-14 to date ancient bone, wood and other formerly living artifacts. Carbon-14 has six protons and eight neutrons; one of those neutrons decays into a proton to make nitrogen-14, which has seven protons and seven neutrons. This decay happens at a predictable rate, allowing scientists to determine how old such artifacts are.

3.Electromagnetic force

The electromagnetic force, also called the Lorentz force, acts between charged particles, like negatively charged electrons and positively charged protons. Opposite charges attract one another, while like charges repel. The greater the charge, the greater the force. And much like gravity, this force can be felt from an infinite distance (albeit the force would be very, very small at that distance).

As its name indicates, the electromagnetic force consists of two parts: the electric force and the magnetic force. At first, physicists described these forces as separate from one another, but researchers later realized that the two are components of the same force.

The electric component acts between charged particles whether they're moving or stationary, creating a field by which the charges can influence each other. But once set into motion, those charged particles begin to display the second

component, the magnetic force. The particles create a magnetic field around them as they move. So when electrons zoom through a wire to charge your computer or phone or turn on your TV, for example, the wire becomes magnetic.

4.The strong nuclear force

The strong nuclear force, also called the strong nuclear interaction, is the strongest of the four fundamental forces of nature. It's 6 thousand trillion trillion trillion (that’s 39 zeroes after 6!) times stronger than the force of gravity, according to the HyperPhysics website(opens in new tab). And that's because it binds the fundamental particles of matter(opens in new tab) together to form larger particles. It holds together the quarks that make up protons and neutrons, and part of the strong force also keeps the protons and neutrons of an atom's nucleus together.

Much like the weak force, the strong force operates only when subatomic particles are extremely close to one another. They have to be somewhere within 10^-15 meters from each other, or roughly within the diameter of a proton.

The strong force is odd, though, because unlike any of the other fundamental forces, it gets weaker as subatomic particles move closer together. It actually reaches maximum strength when the particles are farthest away from each other, according to Fermilab(opens in new tab). Once within range, massless charged bosons called gluons transmit the strong force between quarks and keep them "glued" together. A tiny fraction of the strong force called the residual strong force acts between protons and neutrons. Protons in the nucleus repel one another because of their similar charge, but the residual strong force can overcome this repulsion, so the particles stay bound in an atom's nucleus(opens in new tab)

1.1.4 : Internal and external forces

1.External force

An external force occurs as a result of interaction between a system and the surroundings. External forces cause motion in an object.

Examples of external forces are applied force, normal force, tension force, air resistance

2. Internal force

An internal force is an interaction that exists within a system. Internal fore resists the motion. Gravitational force, Magnetic force, electric force, Spring force are examples of internal forces.

Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ Contact force is a force that is applied by objects in contact with each other.
- ✓ A non-contact force is a force which acts on an object without coming physically in contact with it.
- ✓ Four fundamental forces: the strong force, the weak force, the electromagnetic force, and the gravitational force.
- ✓ An external force occurs as a result of interaction between a system and the surroundings
- ✓ An internal force is an interaction that exists within a system. Internal fore resists the motion.


Theoretical learning Activity

- ✓ In small groups, discuss the relationship between motion and its cause
- ✓ Group discussion on the examples of contact forces & field forces
- ✓ Discussion on the four fundamental forces and their characteristics
- ✓ Group discussion on the internal and external forces on a system


Practical learning Activity

…………………………………… (Example: Trainees in pair perform

Points to Remember (Take home message)

Learning outcome 1.2: Interpret Newton laws

- ✓ Definition of Contact force and non-contact
- ✓ Four fundamental forces
- ✓ External and internal force

Duration: 2 hrs

Learning outcome 1.2 objectives:

By the end of the learning outcome, the trainees will be able to:

1. State and apply First law of Newton
2. State and apply Second law of Newton
3. State and Apply Third law of Newton

Resources

Equipment	Tools	Materials
PPE, Whiteboard and chalkboard	Computer, Projector, Various measuring instruments, Textbooks, Scientific calculator	Chalks, Markers, Flipchart

Advance preparation:

- Acceleration
- Momentum
- Rest and motion

CONTENT

1.2 Newton's laws of motion

Newton has formulated three laws of motion, which are the basic postulates or assumptions on which the whole system of dynamics is based. Like other scientific laws, these are also justified as the results, so obtained, agree with the actual observations. Following are the three laws of motion:

1.2.1 Newton's First Law of Motion.

It states, "Everybody continues in its state of rest or of uniform motion in a straight line, unless acted upon by some external force". This is also known as Law of Inertia.

Inertia

It is that property of a matter, by virtue of which a body cannot move of itself nor change the motion imparted to it.

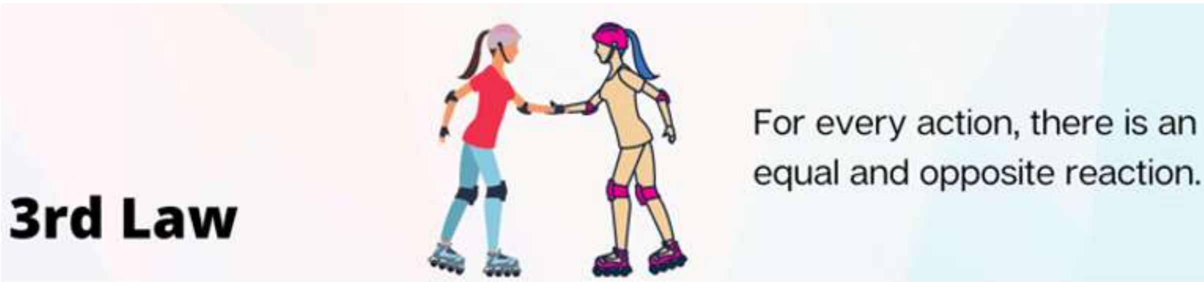
1.2.2 Newton's Second Law of Motion.

It states, "The rate of change of momentum is directly proportional to the impressed force and takes place in the same direction in which the force acts".

$$\sum \vec{F} = \frac{d\vec{P}}{dt} = \frac{d(m\vec{v})}{dt} = m\frac{d\vec{v}}{dt} = m\vec{a}$$

1.2.3 Newton's s third law of motion:

The force of action and reaction between interacting bodies are equal in magnitude, opposite in direction and have the same line of action



Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ They are three Newton's laws of motion
- ✓ A body is not able to change its by its self
- ✓ Force is equal to the product of mass and acceleration
- ✓ Action and reaction forces add to zero

Theoretical learning Activity

- ✓ Brainstorming on the principle of inertia
- ✓ Discussion on the equilibrium at rest and constant velocity
- ✓ Discussion on application of second law statement
- ✓ Group discussion on the net external forces and vectors
- ✓ Group work on using the mathematical expression of the second law
- ✓ Group discussion on application of Third law statement
- ✓ Group discussion on the action and reaction pairs

Practical learning Activity

- ✓ **……………………………….** (Example: Trainees in pair perform ……………….)

Points to Remember (Take home message)

Newton's laws of motion

1.3 Describe the free body diagram

Duration: 2 hrs		
Learning outcome 1.3 objectives: By the end of the learning outcome, the trainees will be able to: 1. Analyse Motion on a plane 2. Analyse Motion of suspended object 3. Analyse Rocket motion		
Resources		
Equipment	Tools	Materials
PPE, Whiteboard and chalkboard	Computer, Projector, Various measuring instruments, Textbooks, Scientific calculator	Chalks, Markers, Flipchart
Advance preparation: .Friction force		

1.3.1: Motion on a plane

1.static friction

Static friction is friction that occurs between two bodies in contact with one another while they are at rest. It's friction which prevents an object from moving while it is still.

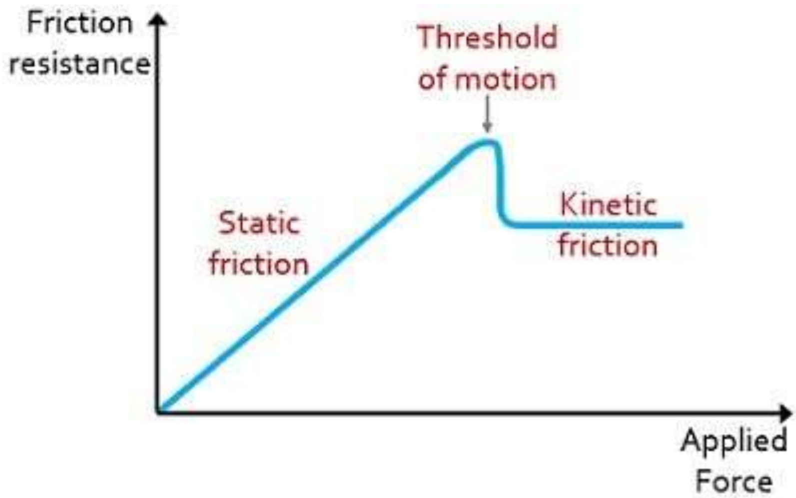
2. Dynamic friction

Dynamic (or kinetic) friction is friction that opposes the movement of a body which is already in motion.

3. Differences Between Static and Dynamic Friction

a. The key factor of differentiation between static and kinetic friction is that the static friction acts on a body that is **at rest**. On the contrary, kinetic friction acts when there is a **relative motion** of two surfaces. We can make it more clear by understanding that an object when is stationary does not automatically glide over the surface, so the frictional force that keeps the object stable is the static friction. While, whenever, there is a movement of an object over a surface then the surface also applies some frictional force to it so as to retard the movement, this force of friction is kinetic friction.

b. The static friction shows a **linear rise** up to a maximum value when some external force is applied. While kinetic friction shows invariable nature and remains **constant** irrespective of the force applied.



c. The magnitude of the coefficient of static friction is comparatively more than that of kinetic friction. Thus, the force of friction that is required to keep the object stable is obviously more than the frictional force which opposes the motion of the object.

d. Static friction is dependent on the magnitude of the force applied while kinetic friction is independent of the magnitude of the force which is applied.

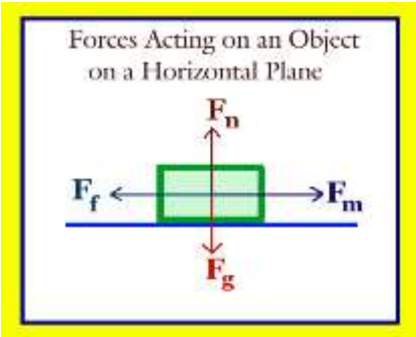
e. Static friction corresponds to the opposition to start a motion whereas kinetic friction is the opposition offered to something which is already in motion.

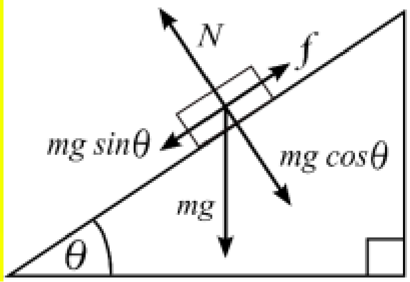
f. The value of static friction can be **zero** but the value of kinetic friction can never be zero.

g. The various **examples** of static friction are a pen placed on the tabletop, a chair on a floor, a stationary vehicle on the road, etc. However, some examples of kinetic friction are sliding the box on the floor, movement of the vehicle on road, writing anything on the blackboard with chalk.

4. Free Body Diagram (FBD)

Free body diagrams (otherwise known as FBD's) are **simplified representations in a problem of an object (the body), and the force vectors acting on it**. This body is free because the diagram will show it without its surroundings; i.e. the body is 'free' of its environment.





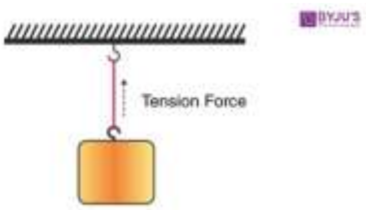
FBD of Horizontal plane FBD of inclined plane

1.3.2 Motion of suspended object

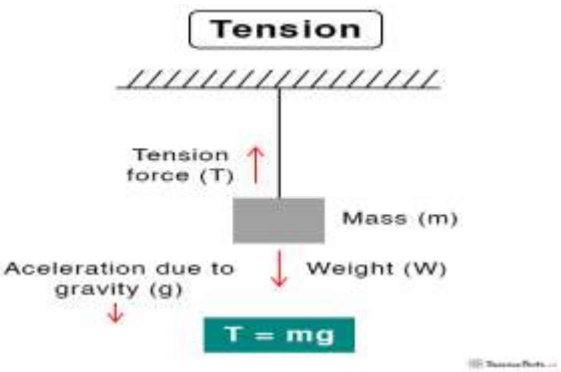
1.Weight of suspended object

The weight It is the force with which the body is attracted towards the centre of earth.Weight is equal to the product of mass and acceleration due to gravity. $\vec{W} = m\vec{g}$

2.Tension force

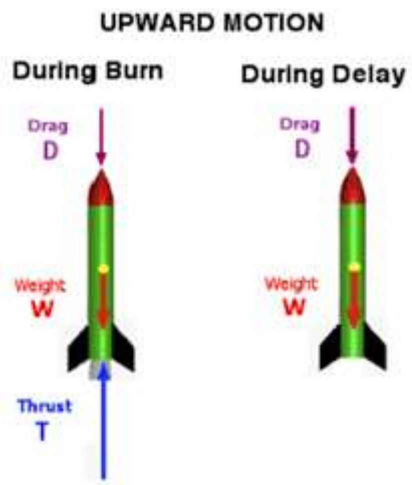


3. Free body diagram on suspended objects



1.3.3 Rocket motion

Rocket motion is based on Newton's third law, which states that "**for every action there is an equal and opposite reaction**". Hot gases are exhausted through a nozzle of the rocket and produce the action force. The reaction force acting in the opposite direction is called the thrust force.



⚠ Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ In the first law, an object will not change its motion unless a force acts on it.
- ✓ In the second law, the force on an object is equal to its mass times its acceleration.
- ✓ In the third law, when two objects interact, they apply forces to each other of equal magnitude and opposite direction.
- ✓ Free body diagrams are simplified representations in a problem of an object (the body), and the force vectors acting on it.

Theoretical learning Activity

- ✓ Individually, perform Experimental demonstration on the static friction and dynamic friction
- ✓ Group discussion about simulation on types of friction
- ✓ Group work on solving problems related to the plane
- ✓ Group work on solving problems related to the on suspended object
- ✓ Group work on solving problems related to the rocket motion

Practical learning Activity

A book is at rest on a table top. Draw a diagram the forces acting on the book

Points to Remember (Take home message)

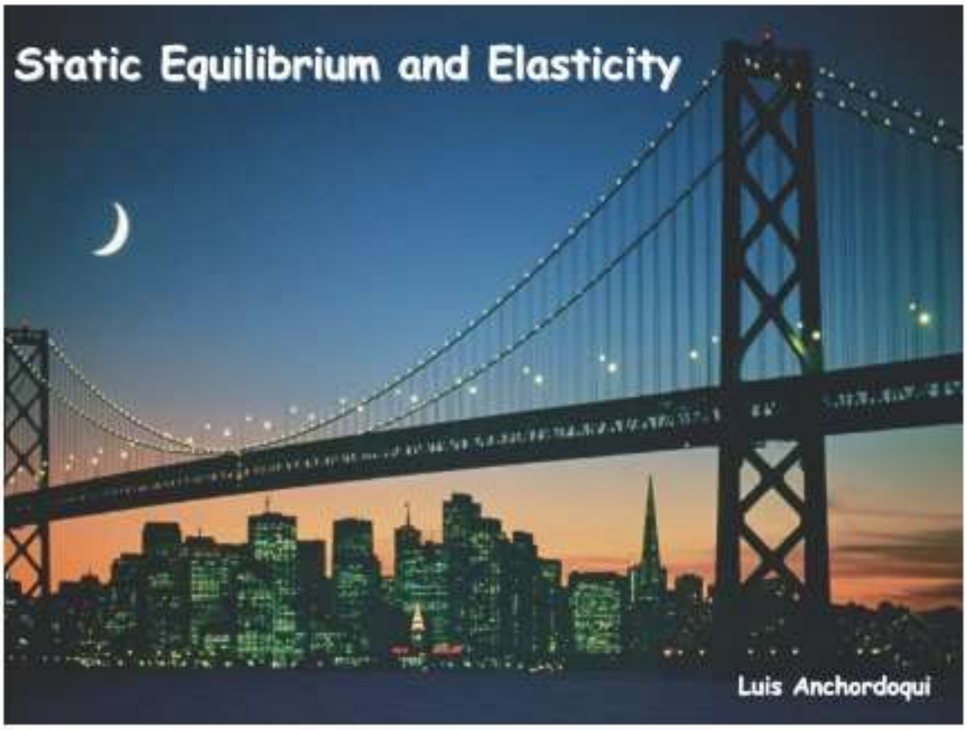
Newton's laws of motion

Learning outcome 1.1 : formative assessment

Written assessment

Practical assessment

Learning Unit 2: Apply static equilibrium and elasticity



STRUCTURE OF LEARNING UNIT

Learning outcomes:
2.1: Explanation of equilibrium conditions
2.2: Application of static equilibrium
3.3: Application of elastic properties

Learning outcome 2.1: Explanation of equilibrium conditions

Duration: 4 hrs

Learning outcome 2.1 objectives: By the end of the learning outcome, the trainees will be able to: 1.Define clearly Moment of the force 2.State and apply clearly Necessary conditions for equilibrium of an object 3. Apply properly the Centre of gravity

Resources

Equipment	Tools	Materials
PPE, whiteboard and chalkboard	Compute, projector, textbooks, scientific calculator, meter ruler, compass	Chalks, Markers

Advance preparation:

- Moment of the force
- conditions for equilibrium of an object
- Centre of gravity

CONTENT

2.1.1 Moment of the force or torque

When an external force acting on a body has a tendency to rotate the body about an axis, then the force is said to exert a 'torque' upon the body about that axis. The moment of a force, or the torque, about an axis of rotation is equal to the product of the magnitude of the force and the perpendicular distance of the line of action of the force from the axis of rotation.

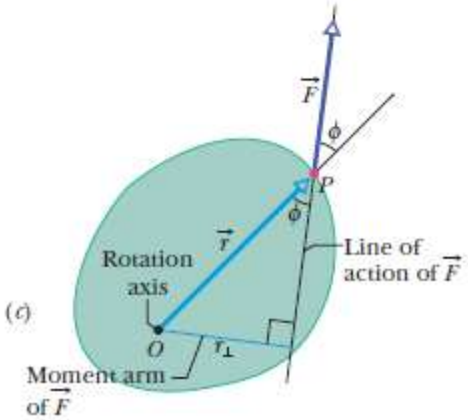


Fig.2.1 : moment arm

1.Calculation of moment

$\vec{\tau} = \vec{r} \times \vec{F}$

Magnitude of torque : $\tau = r\,F\sin\phi$

2.CLOCKWISE AND ANTI-CLOCKWISE MOMENTS

If a force *P* is applied to a body in such a way that it tends to rotate the body in the clockwise sense as, shown in Fig. 2.2 (*a*), then the moment is said to be *clockwise*. If, on the other hand, the force *P* tends to rotate the body in the anti-clockwise sense, as shown in Fig. 2.2 (*b*), the moment is said to be anti-clockwise.

Clockwise is negative and anti-clockwise moment is positive

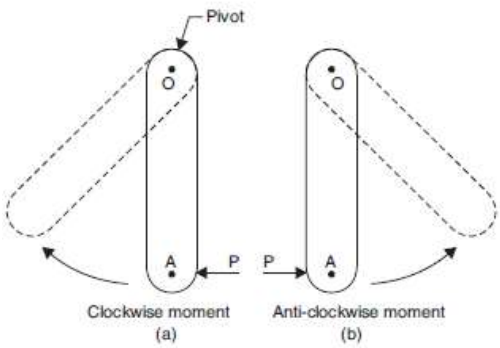


Fig.2.2 Clockwise and anticlockwise moments

2.1.2 conditions for equilibrium of an object

Rotational equilibrium: A state in which net torque is equal to zero.

static equilibrium: The state in which a system is stable and at rest. To achieve complete static equilibrium, a system must have both rotational equilibrium (have a net torque of zero) and translational equilibrium (have a net force of zero).

The first condition necessary to achieve equilibrium is the one already mentioned: **the net external force on the system must be zero**. Expressed as an equation, this is simply. net F=0. Note that if net F is zero, then the net external force in any direction is zero.

Two conditions of equilibrium must be satisfied to ensure that an object remains in static equilibrium. Firstly, the net force acting upon the object must be zero. Secondly, **the net torque acting upon the object must also be zero**.

1. **The net external force on the object must equal zero:**

$$\sum \vec{\mathbf{F}}_{\text{ext}} = 0$$

2. **The net external torque on the object about *any* axis must be zero:**

$$\sum \vec{\tau}_{\text{ext}} = 0$$

2.1.3 Centre of gravity

The centre of gravity of an object is the point of application of its weight.

Summary for the trainer related to the content (key notes using bullets such as ticks etc)

Theoretical learning Activity

- ✓ Brainstorming on moment of force
- ✓ Brainstorming on:
- ✓ Torque associated with the force
- ✓ Rotational equilibrium and static equilibrium
- ✓ In groups, trainee discuss on equilibrium condition
- ✓ Individually, trainee determine centre of gravity

- ✓ What is the effect of a torque on rigid body?
- ✓ State the First condition for equilibrium
- ✓ State the First condition for equilibrium
- ✓ State the second condition for equilibrium
- ✓ Define the centre of gravity of a body.

Practical learning Activity

- ✓ Draw a rectangle and show the position of its centre of gravity.

Learning outcome 2.2 : Application of static equilibrium

Duration: 3 hrs
Learning outcome 2.2 objectives: By the end of the learning outcome, the trainees will be able to: 1. Apply clearly the Standing on horizontal beam 2. Apply clearly the Standing on a slope

2.2.1: Standing on horizontal beam

A horizontal beam is always horizontal and has a constant cross-section. In addition to common beam parameters, beam has the following properties: Direction. A horizontal beam may be oriented either along the global X-axis or global Y-axis

1.Upward forces

Upward forces are positive

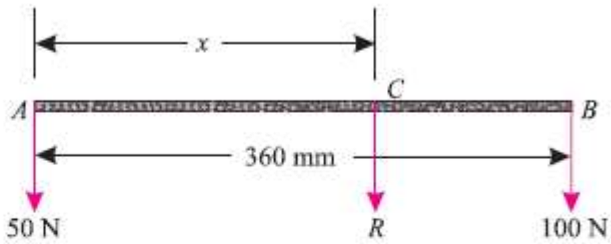
2. Downward force

Downward forces are negative

Example1

Two like parallel forces of 50 N and 100 N act at the ends of a rod 360 mm long. Find the magnitude of the resultant force and the point where it acts.

Solution. Given : The system of given forces is shown in Figure below



Magnitude of the resultant force

Since the given forces are like and parallel, therefore magnitude of the resultant force,

R = 50 + 100 = 150 N **Ans.**

Point where the resultant force acts

Let x = Distance between the line of action of the resultant force (R) and A (i.e. AC) in mm.

Now taking clockwise and anticlockwise moments of the forces about C and equating the same,

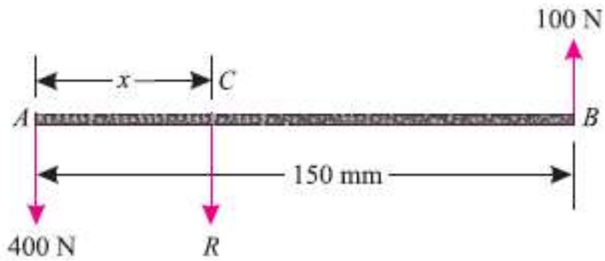
$50 \times x = 100\,(360 - x) = 36\,000 - 100\,x$

or $150\,x = 36\,000 \quad x = 240$ mm

Example2

Two unlike parallel forces of magnitude 400 N and 100 N are acting in such a way that their lines of action are 150 mm apart. Determine the magnitude of the resultant force and the point at which it acts.

Solution. Given : The system of given force is shown in Fig. 4.4



Magnitude of the resultant force

Since the given forces are unlike and parallel, therefore magnitude of the resultant force,

$R = 400 - 100 = 300$ N **Ans.**

Point where the resultant force acts

Let x = Distance between the lines of action of the resultant force and A in mm.

Now taking clockwise and anticlockwise moments about A and equating the same,

$300 \times x = 100 \times 150 = 15\,000$

X= 50 mm

Example 3

The two children shown in Figure are balanced on a seesaw of negligible mass.

The first child has a mass of 26.0 kg and sits 1.60 m from the pivot.

a. If the second child has a mass of 32.0 kg, how far is she from the pivot?

b. What is F_p , the supporting force exerted by the pivot?

Strategy

Both conditions for equilibrium must be satisfied. In part (a), we are asked for a distance; thus, the second condition (regarding torques) must be used, since the first (regarding only forces) has no distances in it. To apply the second condition for
equilibrium, we first identify the system of interest to be the seesaw plus the two children. We take the supporting pivot to be the point about which the torques are calculated. We then identify all external forces acting on the system.

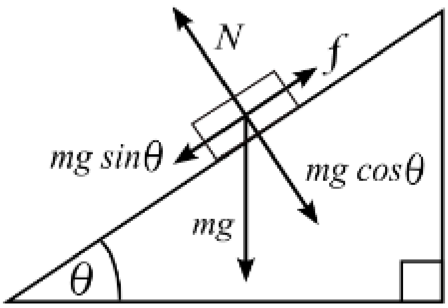
Solution (a)

The three external forces acting on the system are the weights of the two children and the supporting force of the pivot. Let us examine the torque produced by each. Torque is defined to be

As expected, the heavier child must sit closer to the pivot (1.30 m versus 1.60 m) to balance the seesaw.

2.2.2 Standing on a slope

The inclined plane is a problem setting in which a massive object is on a slope, and only subject to motion in the direction down the incline. Although gravity pulls an object straight down, the presence of the slope prevents this.



$$Horizontal\ components\ are: Applied\ force\ \ f\ and\ mg\sin\theta$$

$$Vertical\ components\ are: Normal\ force\ N\ and\ mg\cos\theta$$

Example 4

A particle of mass 5 Kg rests on a 30° inclined plane with the horizontal. A force F_a of magnitude 30 N acts on the particle in the direction parallel and up the inclined plane.

a) Draw a Free Body Diagram including the particle, the inclined plane and all forces acting on the particle with their labels.

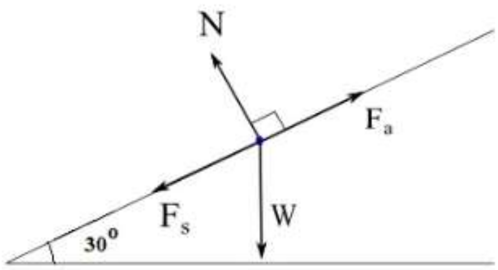
b) Find the force of friction acting on the particle.

c) Find the normal force exerted by the inclined on the particle.

Solution

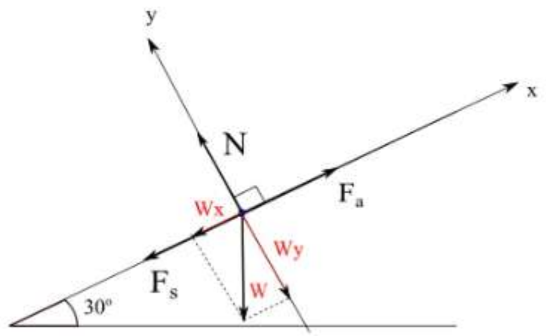
a) **Free Body Diagram**

The box is the small blue point. In the diagram below, W is the weight of the box, N the normal force exerted by the inclined plane on the box, F_a is the force applied to have the box in equilibrium and F_s the force of friction opposite F_a.



b)

The box is at rest, hence its acceleration is equal to 0, therefore the sum of all forces acting on the box is equal to its mass times its acceleration which is zero. (Newton's second law)



$F_a + W + N + F_s = 0$

The components form of all forces (vectors) acting on the box are:

$F_a = (30 , 0)$

$|W| = 5 \times 10 = 50$ N

$W = (W_x , W_y) = (- |W| \sin(30°) , - |W| \cos(30°)) = (- 50 \sin (30°) , - 50 \cos (30°))$

$N = (0 , |N|)$

$F_s = (-|F| , 0)$

The $F_a + W + N + F_s = 0$ in components form:

$(30 , 0) + (- 50 \sin (30°) , - 50 \cos (30°)) + (0 , |N|) + (-|F| , 0) = 0$

x components: $30 - 50 \sin(30) + 0 - |F| = 0$

$|F| = - 50 \sin(30) + 30 = 5$ N

c) y components equation:

$0 - 50 \cos (30) + |N| + 0 = 0$

$|N| = 50 \cos (30) = 25 \sqrt{3} \approx 43.3$ N

Theoretical learning Activity

- **In groups, trainees discuss on:**
  - ✓ Determination of magnitude of the upward force
  - ✓ Determination of balancing system
  - **In small groups, trainees discuss on:**

- ✓ The free body diagram for the ladder
- ✓ Techniques of applying conditions for the equilibrium to the ladder.

- ✓ Explain why the upward component is positive
- ✓ Explain why the downward component is negative

Practical learning Activity

o Individually, a trainee performs calculations on:

- ✓ Upward force
- ✓ Downward force
- ✓ Horizontal and vertical components applying conditions for equilibrium in solving problems

- ✓ Two unlike parallel forces of magnitude 400 N and 100 N are acting in such a way that their lines of action are 150 mm apart. Sketck two different diagrams representing these forces.

Points to Remember (Take home message)

- ☝ Upward force
- ☝ Downward force
- ☝ Free Body Diagram

Learning outcome 2.3 : Application of elastic properties

Duration: 3 hrs

Learning outcome 2.3. objectives:

By the end of the learning outcome, the trainees will be able to:

1. Apply clearly the Deformation of solids in terms of the concepts of stress and strain
2. Described clearly the types of deformation and elastic modulus
3. Draw and interpret clearly the Stress versus strain curve for an elastic solid.

2.3.1 Deformation of solids in terms of the concepts of stress and strain

1. Relation between stress and strain

a. Elasticity

The property by virtue of which a body tends to regain its original shape and size after removal of the deforming force is known as elasticity.

When an external force is applied on a body, which is not free to move, the shape and size of the body change. The force applied is called deforming force. When the deforming forces are removed, the body tends to regain its original shape and size due to a force developed within the body. The force developed within the body, which is equal and opposite to deforming force is called restoring force.

Bodies, which completely regain their original size and shape after the removal of the deforming force, are called **elastic bodies**. Bodies which change the shape and size on the application of force and which do not regain their original condition on removal of the deforming forces are said to be **plastic bodies**. Bodies which do not change their shape and size on application of force are called **rigid bodies**.

b. Stress :

When an external force is acting on an elastic body, it causes deformation (change in shape or in size or both). At the same time, due to elastic property, a force is developed within the material, which is equal and opposite to the applied force, to bring the body to its original shape and size. This force is 'restoring force'.

The stress is defined as the restoring force acting on unit area.

Since the applied force and the restoring force are equal in magnitude, the 'stress' is measured as the applied force acting per unit area.

The unit for stress is newton metre-2 with symbol $N\,m^{-2}$ or 'pascal' with symbol 'Pa'.

When the applied force tends to compress the body, the stress is **compressive**. When it tends to increase the length in the direction of the force, it is **tensile** and when it acts parallel to the surface of a body, the stress is **tangential stress.**

3.Strain

Strain is a measure of the degree of deformation of the object.

$$Strain = \frac{change\ in\ size}{Original\ size}$$

Types of strains:

a) Linear Strain:

$$Linear\ Strain = \frac{change\ in\ length}{Original\ length} = \frac{\Delta L}{L}$$

b) *Bulk (or) Volume Strain*

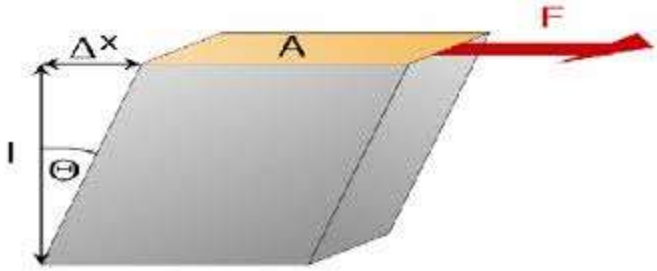
$$Volume\ Strain = \frac{change\ in\ volume}{Original\ volume} = \frac{\Delta V}{V}$$

c) *Shearing (or) Rigidity strain*

When a force is applied parallel to one face of a body, the opposite side being fixed, there is a change in shape but not in size of the body. This strain is called the shearing strain.

Solids alone can have a shearing strain. It is measured by the angle of the shear 'θ' in radian.

$$Shearing\ Strain = \frac{Dis\tan ce\ sheared}{Dis\tan ce\ betwee\ surfaces} = \frac{\Delta x}{L} = \tan\theta \approx \theta$$



Shear strain

4. Hooke's law:

Within the elastic limits, the strain produced in a body is directly proportional to the stress which causes it.

$$Elastic\ \mathrm{mod}ulus = \frac{Stress}{Strain}$$

2.3.2 Types of deformation and elastic modulus

1.Young's modulus (elasticity in length)

Measures the resistance of a solid to a change in its length.

It is defined as the ratio of linear stress to linear strain.

$$Young's\ \mathrm{mod}ulus = \frac{Linear\ Stress}{Linear\ Strain}$$

$$Linear\ stress = \frac{F}{A}$$

$$Linear\ strain = \frac{\Delta L}{AL}$$

$$Young's\ modulus = \frac{F/A}{\Delta L/L} = \frac{F\cdot L}{A\cdot \Delta L}$$

Example

A wooden box of 5 kg is attached to the free end of a wire of length 2 m and diameter 0.6 mm. If the extension of the wire is 0.2 mm, calculate:

(i) The cross-sectional area of the wire

(ii) The deforming force

(iii) The stress

(iv) The strain and

(v) The Young's modulus of the material of the wire.

Solution

(i) The cross-sectional area of the wire

$A = A = \prod r^2 = 3.14(0.3\times10^{-3})^2 = 2.83\times10^{-7}\ m^2$

(ii) The deforming force $F = mg = 5\times9.8 = 49\,N$

(iii) $Stress = \dfrac{F}{A} = \dfrac{49}{2\cdot83\times10^{-7}} = 1\cdot73\times10^{8}\,N/m^2$

(iv) $Stain = \dfrac{\Delta L}{L} = \dfrac{0\cdot2\times10^{-3}}{2} = 10^{-4}$

(v) $Y = \dfrac{Stress}{Strain} = \dfrac{1\cdot73\times10^{8}}{10^{-4}} = 1\cdot73\times10^{12}\,N/m^2$

2. Shear modulus (elasticity of shape)

The ratio of the shearing stress applied to the body to the shearing strain produced.

$$Shearing\ modulus = \frac{Shearing\ Stress}{Shearing\ Strain} = \frac{F/A}{\Delta x/L}$$

3.Bulk modulus (Volume elasticity)

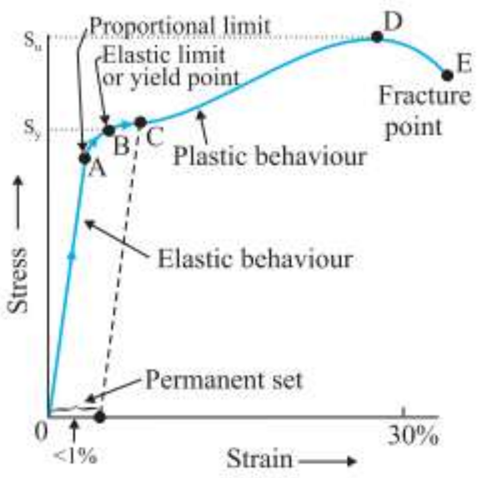
When a body is subjected to a uniform compressive force, its volume decreases and the strain produced is a bulk or volume strain

It is defined as the ratio of bulk stress to bulk strain.

$$Bulk\ stress = \frac{F}{A} = Variation\ in\ pressure = \Delta P$$

$$Bulk\ modulus = \frac{Bulk\ stree}{Bulk\ stress} = -\frac{\Delta P}{\frac{\Delta V}{V}} = -\frac{PV}{\Delta V}$$

2.3 .3 Stress versus strain curve for an elastic solid.



Theoretical learning Activity

- In small groups, trainees discuss on the deformation of solids in terms of stress and strain.

Practical learning Activity

o Individually, a trainee performs calculations on:

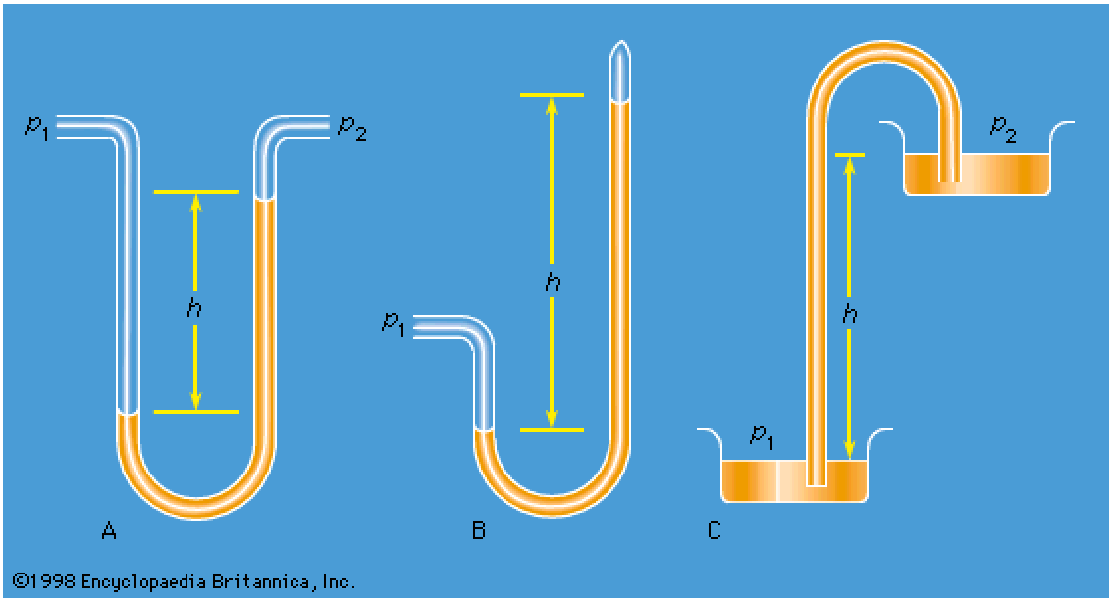
- ✓ Young's modulus (elasticity in length)
- ✓ Shear modulus (elasticity of shape)
- ✓ Bulk modulus (Volume elasticity)

o Individually, a trainee illustrates elastic behavior, elastic limit and breaking point on the curve.

- A copper wire of 3 m length and 1 mm diameter is subjected to a tension of 49 N. Calculate the elongation produced in the wire, if Young's modulus of elasticity of copper is 120 G Pa.

Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ The stress is defined as the restoring force acting on unit area
- ✓ Strain is the ratio between the change in size and the original size
- ✓ Elastic modulus is the ratio between stress and strain



STRUCTURE OF LEARNING UNIT

Learning outcomes:

3.1: Description of pressure and its variation with depth

3.2: Application of Archimedes' principle

3.3: Analysing fluid dynamics

Learning outcome 3.1 : Description of pressure and its variation with depth

Duration: 4 hrs

Learning outcome 3.1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Define clearly and calculate Pressure
2. Apply properly the formula of Variation of pressure with depth
3. Perform correctly Pressure measurements

Resources		
Equipment	Tools	Materials
PPE, Whiteboard and chalkboard	Computer, Projector, Textbooks, Scientific calculator	Chalks, Markers

Advance preparation:

.Force

.Area

.Acceleration due to gravity

CONTENT

3.1 Description of pressure and its variation with depth

A **fluid** is a substance that flows. Both gases and liquids are fluids. Fluids play a vital role in many aspects of everyday life. We drink them, breathe them, swim in them. They circulate through our bodies and control our weather. Airplanes fly through them; ships float in them.

3.1.1 Pressure

Pressure is defined as the force divided by the area perpendicular to the force over which the force is applied, or $P = \frac{F}{A}$

Where F is a force applied to an area A that is perpendicular to the force.

The SI unit for pressure is the *pascal*, where $1Pa = \frac{1N}{m^2}$

In addition to the pascal, there are many other units for pressure that are in common use. In meteorology, atmospheric pressure is often described in units of millibar (mbar), where $1mbar = 100Pa$

Force and pressure

The force exerted by the fluid is given by $F = PA$

Atmospheric pressure

Atmospheric pressure *pa* is the pressure of the earth's atmosphere, the pressure at the bottom of this sea of air in which we live. This pressure varies with weather changes and with elevation. Normal atmospheric pressure at sea level (an average value) is 1 *atmosphere* (atm), defined to be exactly 101,325 Pa. To four significant figures,

$$(p_a)_{av} = 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$
$$= 1.013 \text{ bar} = 1013 \text{ millibar} = 14.70 \text{ lb/in.}^2$$

A simple device for measuring the pressure exerted by a fluid

The Barometer

Atmospheric pressure is measured by a device called a barometer; thus, the atmospheric pressure is often referred to as the *barometric pressure*. The Italian Evangelista Torricelli (1608–1647) was the first to conclusively prove that the atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere,

as shown in Fig. 3–1. The pressure at point *B* is equal to the atmospheric pressure, and the pressure at point *C* can be taken to be zero since there is only mercury vapor above point *C* and the pressure is very low relative to *P*atm and can be neglected to an excellent approximation. Writing a force balance in the vertical direction gives $Patm = \rho\, g\, h$.

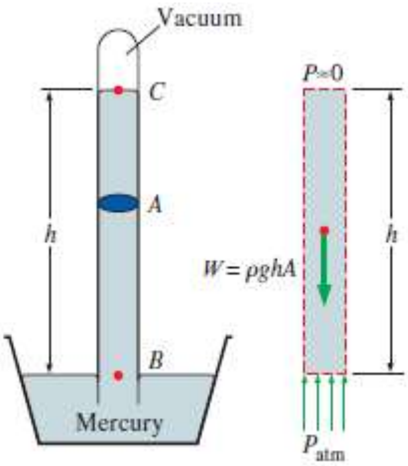


Fig3.1 The basic barometer.

where ρ is the density of mercury, *g* is the local gravitational acceleration, and *h* is the height of the mercury column above the free surface. Note that the length and the cross-sectional area of the tube have no effect on the height of the fluid column of a barometer fig3 .2

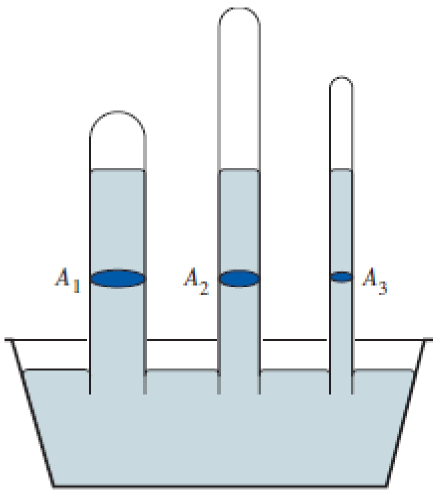


Fig 3.2 The length or the cross-sectional area of the tube has no effect on the height of the fluid column of a barometer, provided that the tube diameter is large enough to avoid surface tension (capillary) effects.

A frequently used pressure unit is the *standard atmosphere*, which is defined as the pressure produced by a column of mercury 760 mm in height at 0°C (ρ Hg = 13,595 kg/m^3) under standard gravitational acceleration (g = 9.807 m/s^2). If water instead of mercury were used to measure the standard atmospheric pressure, a water column of about 10.3 m would be needed.

3.1.2 Variation of pressure with depth

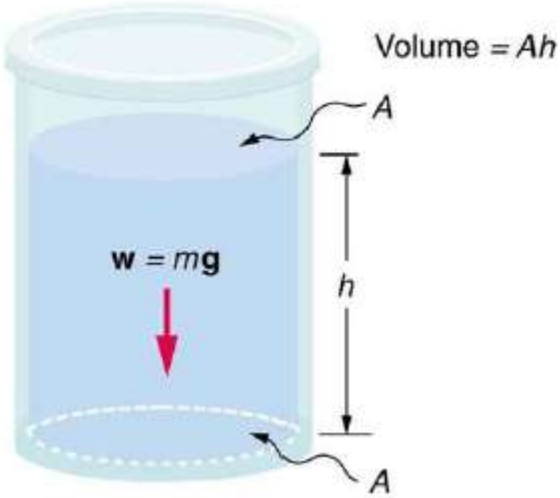


Fig.3.3 variation of pressure with depth

Consider the container in Figure 3.3. Its bottom supports the weight of the fluid in it. Let us calculate the pressure exerted on the bottom by the weight of the fluid. That pressure is the weight of the fluid mg divided by the area A supporting it (the area of the bottom of the container): $P = \frac{mg}{A}$

We can find the mass of the fluid from its volume and density: $m = \rho V$

The volume V of the fluid is related to the dimensions of the container. It is $V = Ah$ where A is the cross-sectional area and h is the depth. Combining the last two equations gives $m = \rho Ah$

If we enter this into the expression for pressure, we obtain $P = \frac{(\rho Ah)g}{A}$

The area cancels, and rearranging the variables yields $P = h\rho g$.

Thus Equation represents the pressure due to the weight of any fluid of *average density* ρ *at any depth* h below its surface.

Exercises

Calculate the pressure and force acting on the rectangular dam retaining water . The dam is 500 m wide, and the water is 80.0 m deep at the dam

Variation of atmospheric pressure against altitude

pressure decreases with increasing altitude. The pressure at any level in the atmosphere may be interpreted as the total weight of the air above a unit area at any elevation. At higher elevations, there are fewer air molecules above a given surface than a similar surface at lower levels.

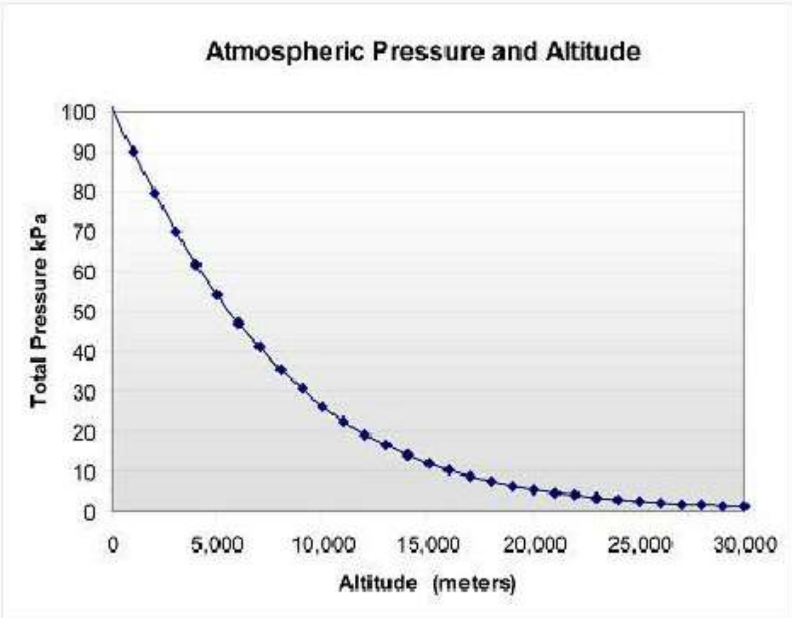


Fig.3.4 variation of pressure with altitude

Pascal's Principle

Pascal's Principle states that: Pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid and the walls of the containing vessel.

Application of Pascal's principle

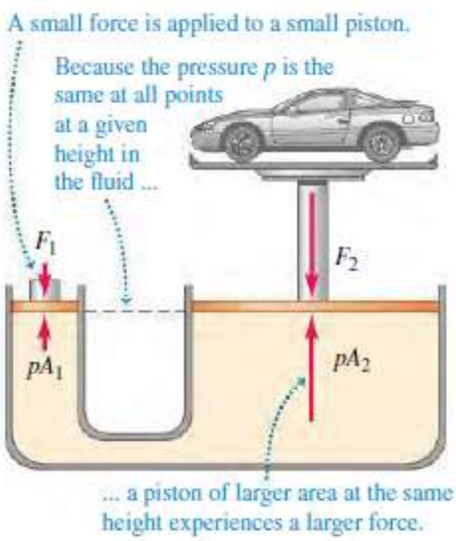


Fig.3.5 hydraulic lift

The hydraulic lift illustrates Pascal's law. A piston with small cross-sectional area $A1$ exerts a force $F1$ on the surface of a liquid such as oil.

The applied pressure $p = \frac{F_1}{A_1}$ is transmitted through the connecting pipe to a larger piston of area $A2$. The applied pressure is the same in both cylinders, so

$$p = \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{and} \quad F_2 = \frac{A_2}{A_1} F_1$$

3.1.3 Gauge Pressure, Absolute Pressure

It is very common for pressure gauges to ignore atmospheric pressure—that is, to read zero at atmospheric pressure. We therefore define gauge pressure to be the pressure relative to atmospheric pressure. Gauge pressure is positive for pressures above atmospheric pressure, and negative for pressures below it.

In fact, atmospheric pressure does add to the pressure in any fluid not enclosed in a rigid container. This happens because of Pascal's principle. The total pressure, or absolute pressure, is thus the sum of gauge pressure and atmospheric pressure.

$$P_{abs} = P_g + P_{atm}$$

Where P_{abs} is absolute pressure, P_g is gauge pressure, and P_{atm} is atmospheric pressure.

Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ Pressure is the force per unit perpendicular area over which the force is applied. In equation form, pressure is defined as

$$P = \frac{F}{A}$$

- ✓ The SI unit of pressure is pascal and $1Pa = \frac{1N}{m^2}$

- ✓ Discussion in small groups, on concepts of force and pressure
- ✓ In small groups, discuss on the variation of pressure with the depth
- ✓ Individually, state the pascal's principle
- ✓ Individually, explain the measurements of pressure.

Practical learning Activity

1-A substance has mass of 3 kg .

a) Find the force in Newton.

b) What is the pressure of it on a square of 4m for a side?

Points to Remember (Take home message

−The pressure within a fluid (gas or liquid) is a scalar quantity—that is, it has magnitude but no particular direction associated with it in space. In formula $P = \frac{F}{A}$, F is the magnitude not a vector.

- Gauge pressure is the pressure relative to atmospheric pressure.
- Absolute pressure is the sum of gauge pressure and atmospheric pressure.

3.3 : **Application of Archimedes' principle**

Archimedes' principle A fluid exerts an upward buoyant force $\vec{F}_B$ on an object immersed in or floating on the fluid. The magnitude of the buoyant force equals the weight of the fluid displaced by the object.

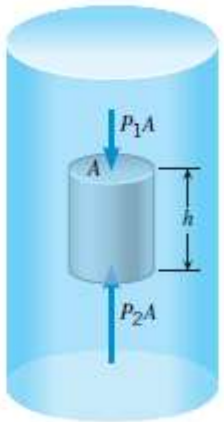


Fig.3.6 The fluid applies a downward force P_1A to the top face of the submerged cylinder and an upward force P_2A to the bottom face.

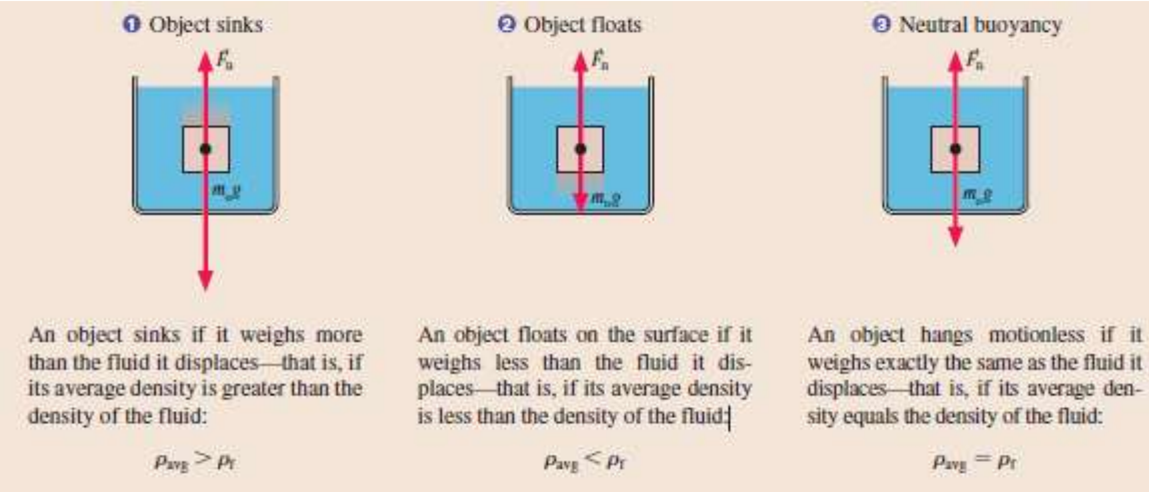
In Interactive Figure 3.6 a cylinder of height h is being held under the surface of a liquid.The pressure P1 on the top face generates the downward force P1A, where A is the area of the face.Similarly, the pressure P2 on the bottom face generates the upward force P2A. Since the pressure is greater at greater depths, the upward force exceeds the downward force. Consequently, the

liquid applies to the cylinder a net upward force, **or buoyant force**, whose magnitude F_B is F_B = P2A − P1A = (P2 − P1)A = ρghA

we find that the buoyant force equals ρghA. The quantity hA is the volume of liquid that the cylinder moves aside or displaces in being submerged, and ρ denotes the density of the liquid, not the density of the material from which the cylinder is made. Therefore, ρhA gives the mass m of the displaced

fluid, so that the buoyant force equals mg, the weight of the displaced fluid. The phrase "weight of the displaced fluid" refers to the weight of the fluid that would spill out if the container were filled to the brim before the cylinder is inserted into the liquid. The buoyant force is not a new type of force. **It is just the name given to the net upward force exerted by the fluid on the object**.

Finding whether an object floats or sinks



Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ Buoyancy is the upward force of a fluid on an object
- ✓ Archimedes' principle
- ✓ The magnitude of the buoyant force equals the weight of the fluid displaced by the object

Sink	$\rho_{avg} > \rho_f$	$F_B < m_o g$
Rise to surface	$\rho_{avg} < \rho_f$	$F_B > m_o g$
Neutrally buoyant	$\rho_{avg} = \rho_f$	$F_B = m_o g$

Theoretical learning Activity

- ✓ Individually, explain the meaning of Buoyant force.
- ✓ Individually, demonstrate the relationship between magnitude of Buoyant force and weight of the fluid displaced.
- ✓ In small groups, discuss on practical inventions of Archimedes' principle
- ✓ In small groups, trainees discuss on Archimedes' principle on totally submerged and floating object.

Practical learning Activity

- ✓ ……………………………………. (Example: Trainees in pair perform …………………)

Points to Remember (Take home message)

The applications of Archimedes' principle are:

(i) **Archimedes' principle is used in designing ships and submarines**. (ii) Lactometers based on Archimedes' principle are used to measure purity of a sample of milk

Learning outcome 3.3 : Analyzing fluid dynamics

Duration: 4 hrs

Learning outcome 3.3 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Define clearly viscosity
2. State Bernoulli's principle and give its application
3. Give applications of fluid dynamics

Resources

Equipment	Tools	Materials
PPE, Whiteboard and chalkboard	Computer, Projector, Textbooks, Scientific calculator	Chalks, Markers

Advance preparation:

1. Flow rate
2. Kinetic energy
3. Potential energy
4. Pressure energy
5. Total energy

CONTENT

3.3.1: viscosity

Let us consider a liquid flowing over a horizontal surface. The layer in contact with the surface is at rest. The top most layer have the maximum velocity. The intermediate layers have intermediate velocity. To maintain this relative motion of the layers, an external force must be acting on the liquid. Otherwise the liquid will come to rest due to internal frictional forces acting between the layers of the liquid. These internal frictional forces that bring the liquid to rest are known as viscous force and this property is known as viscosity.

The property by virtue of which the relative motion between the layers of a liquid is maintained is called viscosity. We can also say viscosity is the resistance to flow.

Coefficient of viscosity of a liquid

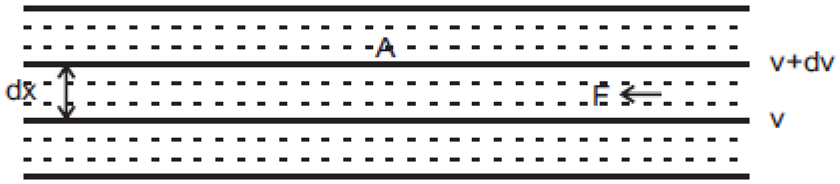
Let F be the viscous force acting between two layers of a liquid separated by a distance dx. Let dv be the difference in velocity between the two layers. Let A be the area of the layers. The velocity gradient dv/dx acts perpendicular to direction of flow of the liquid.
The viscous force F is found to be directly proportional to
i. the area of the layers 'A'
ii. the velocity gradient dv/dx

$$F = \frac{\eta A dv}{dx}$$

$$\text{If } A = 1 \text{ and } \frac{dv}{dx} = 1, \text{ then } F = \eta$$

Where η is constant, called Coefficient of viscosity of the liquid

Coefficient of viscosity of a liquid is defined as the viscous force acting between two layers of a liquid having unit area of layers and unit velocity gradient normal to the direction of flow of the liquid.



Fluids play a vital role in many aspects of everyday life. We drink them, breathe them, swim in them. They circulate through our bodies and control our weather. Airplanes fly through them; ships float in them.

Ideal Fluids

The motion of a real fluid is very complicated. Instead, we shall discuss the motion of an **ideal fluid** that will obey the following four assumptions:

1. ***Steady flow***: The velocity of the fluid at any specific point does not change with time. However, in general the velocity might vary from one point to another.

2. ***Incompressible flow***: The density of the fluid does not change with time. That is, the density has a constant uniform value.

3. ***Non-viscous flow***: A tiny object can move through the fluid without experiencing a viscous drag force; that is, there is no resistive force due to viscosity.

4. ***Irrotational flow***: A tiny object can move through the fluid without rotating about an axis passing through its center of mass.

The Equation of Continuity

This equation expresses the following simple idea: If a fluid enters one end of a pipe at a certain rate (e.g., 5 kilograms per second), then fluid must also leave at the same rate, assuming that there are no places between the entry and exit points to add or remove fluid. The mass of fluid per second (e.g., 5 kg/s) that flows through a tube is called the mass flow rate.

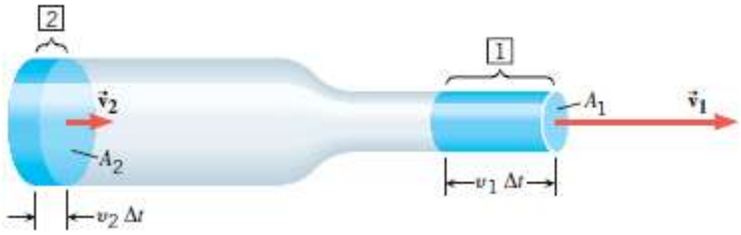


Fig.3.7 In general,a fluid flowing in a tube that has different cross-sectional areas A 1 and A 2 at positions 1 and 2 also has different velocities **v1** and **v2** at these positions.

Figure 3.7 shows a small mass of fluid or fluid element (dark blue) moving along a tube. Upstream at position 2, where the tube has a cross-sectional area A2, the fluid has a speed $\upsilon 2$ and a density ρ2. Downstream at location 1, the corresponding quantities are A1, $\upsilon 1$, and ρ1. During a small time interval Δt, the fluid at point 2 moves a distance of $\upsilon 2\Delta t$, as the drawing shows. The volume of fluid that has flowed past this point is the cross-sectional area times this distance, or A2υ2Δt. The mass Δm2 of this fluid element is the product of the density and volume: Δm2 = ρ2A2υ2Δt. Dividing Δm2 by Δt gives the mass flow rate (the mass per second):

$$\text{Mass flow rate at position 2} = \frac{\Delta m_2}{\Delta t} = \rho_2 A_2 v_2$$

Similar reasoning leads to the mass flow rate at position 1:

$$\text{Mass flow rate at position 1} = \frac{\Delta m_1}{\Delta t} = \rho_1 A_1 v_1$$

Since no fluid can cross the sidewalls of the tube, the mass flow rates at positions 1 and 2 must be equal. However, these positions were selected arbitrarily, so the mass flow rate has the same value everywhere in the tube, an important result known as the equation of continuity. The equation of continuity is an expression of the fact that mass is conserved (i.e., neither created nor destroyed) as the fluid flows.

The mass fl ow rate ($\rho A\upsilon$) has the same value at every position along a tube that has a single entry and a single exit point for fl uid fl ow. For two positions along such a tube

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

where ρ = fluid density (kg/m^3)
A = cross-sectional area of tube (m^2)
v = fluid speed (m/s)

SI Unit of Mass Flow Rate: kg/s

The density of an incompressible fluid does not change during flow, so that $\rho 1 = \rho 2$, and the equation of continuity reduces to

Incompressible fluid $\quad A_1 v_1 = A_2 v_2$

The quantity Av represents the volume of fluid per second (measured in m^3/s, for instance) that passes through the tube and is referred to as the **volume flow rate Q**:

Q = Volume flow rate = Av

3.3.2: Bernoulli's principle and its application

ENERGY OF THE FLUID

A fluid in steady or streamline flow may posses any or all of the three types of energy, *viz.*, (*i*) kinetic energy because of its velocity: $KE = \frac{1mv^2}{2}$

(*ii*) potential energy because of its position relative to the earth's surface and: $PE = mgh$

(*iii*) Pressure energy because of its pressure; for, if work be done on it against its pressure, it can do the same amount of work back for us and thus acquires energy. : $PV = \frac{Pm}{\rho}$

Where P is Pressure and V is volume.

The total energy : $E = \frac{1mv^2}{2} + mgh + \frac{Pm}{\rho}$

The total energy per unit mass: $\frac{E}{m} = \frac{v^2}{2} + gh + \frac{P}{\rho}$

BERNOULLI'S THEOREM

This theorem states that the total energy of an incompressible, non-viscous fluid in steady flow remains constant throughout the flow.

That is $\frac{v^2}{2} + gh + \frac{P}{\rho} = constant$ or $\frac{\rho v^2}{2} + \rho gh + P = constant$

Bernoulli's Equation

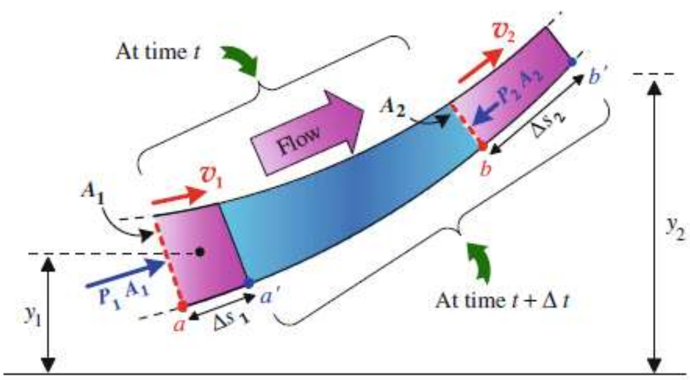


Fig.3.8

In static fluids, the pressure is the same at all points on the same horizontal level but increases with depth. This is not generally true when the fluid is in motion. In the year 1738, Bernoulli derived an expression for an **ideal fluid** (i.e. a fluid that is incompressible, non-viscous and flows in a non-rotational steady manner) that relates the pressure, speed, and elevation within different locations in the fluid.

∗ Consider a small portion of a tube of flow of an ideal fluid with density ρ through a non-uniform pipe as shown in Fig. 3.8. The width of the tube in this figure is exaggerated for clarity.

Applying the total mechanical energy conservation principle at points 1 and 2, we get:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

Applications of Bernoulli's Equation

When a moving fluid is contained in a horizontal pipe, all parts of it have the same elevation (y1 = y2), and Bernoulli's equation simplifies to

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

Thus, the quantity $\frac{\rho v^2}{2} + P$ remains constant throughout a horizontal pipe; if v **increases,** P **decreases, and vice versa**.

Venturi meter, used to measure flow speed in a pipe. Derive an expression for the flow speed v_1 in terms of the cross-sectional areas A_1 and A_2 the difference in height *h* of the liquid levels in the two vertical tubes.

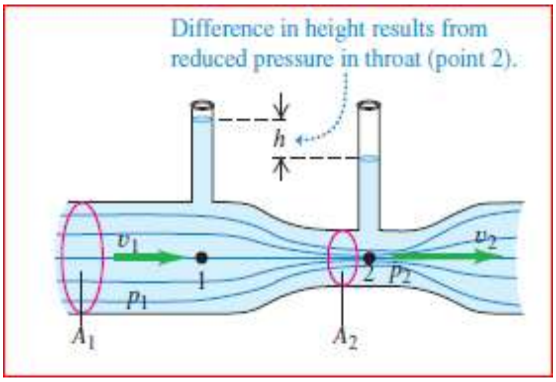


Fig.3.9

Points 1 and 2 have the same vertical coordinate, $y_1 = y_2$ say

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

From the continuity equation, substituting this $v_2 = (A_1/A_2)v_1$ and rearranging, we get

$$P_1 - P_2 = \frac{1}{2}\rho v_1^2\left[\left(\frac{A_1}{A_2}\right)^2 - 1\right],$$

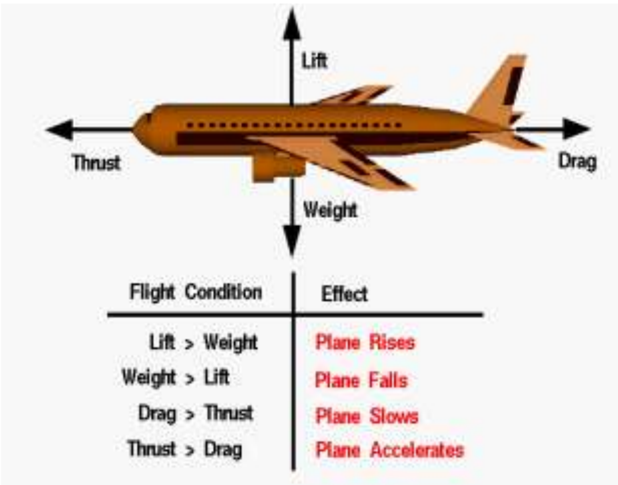
The pressure difference $P_1 - P_2 = g\rho h$, substituting this and solving for v_1, we get

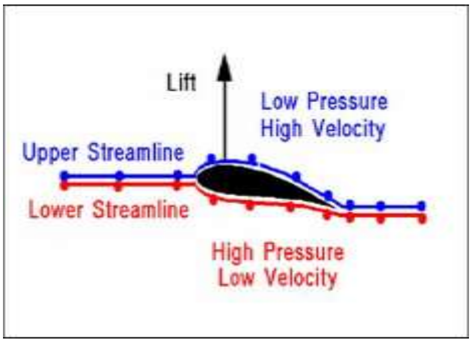
$$v_1 = \sqrt{\frac{2gh}{\left(\frac{A_1}{A_2}\right)^2 - 1}}$$

3.3.3 Applications of fluid dynamics

Streamline flow around a moving airplane wing

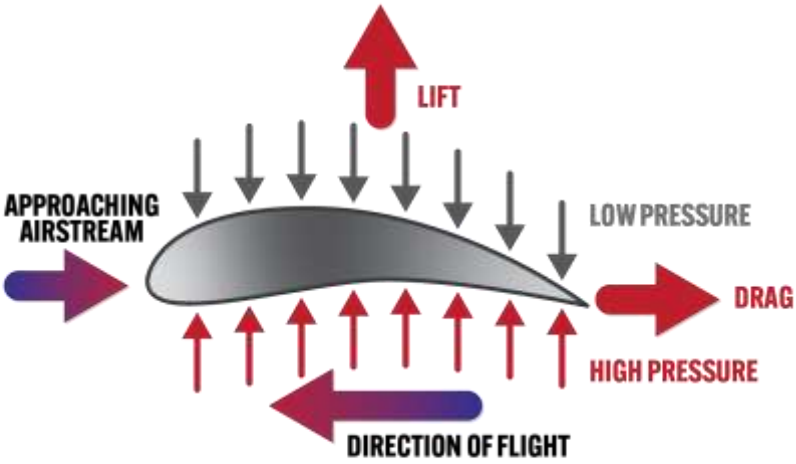
The airplane wing is a beautiful example of Bernoulli's principle in action. Figure 3.10 shows the characteristic shape of a wing. The wing is tilted upward at a small angle and the upper surface is longer, causing air to flow faster over it. The pressure on top of the wing is therefore reduced, creating a net upward force or lift. (Wings can also gain lift by pushing air downward, utilizing the conservation of momentum principle. The deflected air molecules result in an upward force on the wing — Newton's third law.)





Newton's third law about the airstream

A flat wing will fly if it is tipped into the wind, so that it forces air downward. Newton's third law tells us that for every action there must be an equal and opposite reaction: The reaction to the downward force of the wing on the air is the upward force of the air on the wing.



Summary for the trainer related to the content (key notes using bullets such as ticks etc)

An ideal fluid will obey four assumptions:

- ✓ Steady flow
- ✓ Incompressible flow
- ✓ Non-viscous flow
- ✓ Irrotational flow

Theoretical learning Activity

- ✓ In small groups, discuss on the four assumptions of model of ideal fluid flow
- ✓ In small groups, trainees discuss on Bernoulli's principle and its application.
- ✓ Individually, state Bernoulli's principle and explain Bernoulli's equations applied to an ideal fluid.
- ✓ Individually, explain with the help of illustration how streamline flow around a moving airplane behaves.

Practical learning Activity

- ✓ .... (Example: Trainees in pair perform ....)

Points to Remember (Take home message)

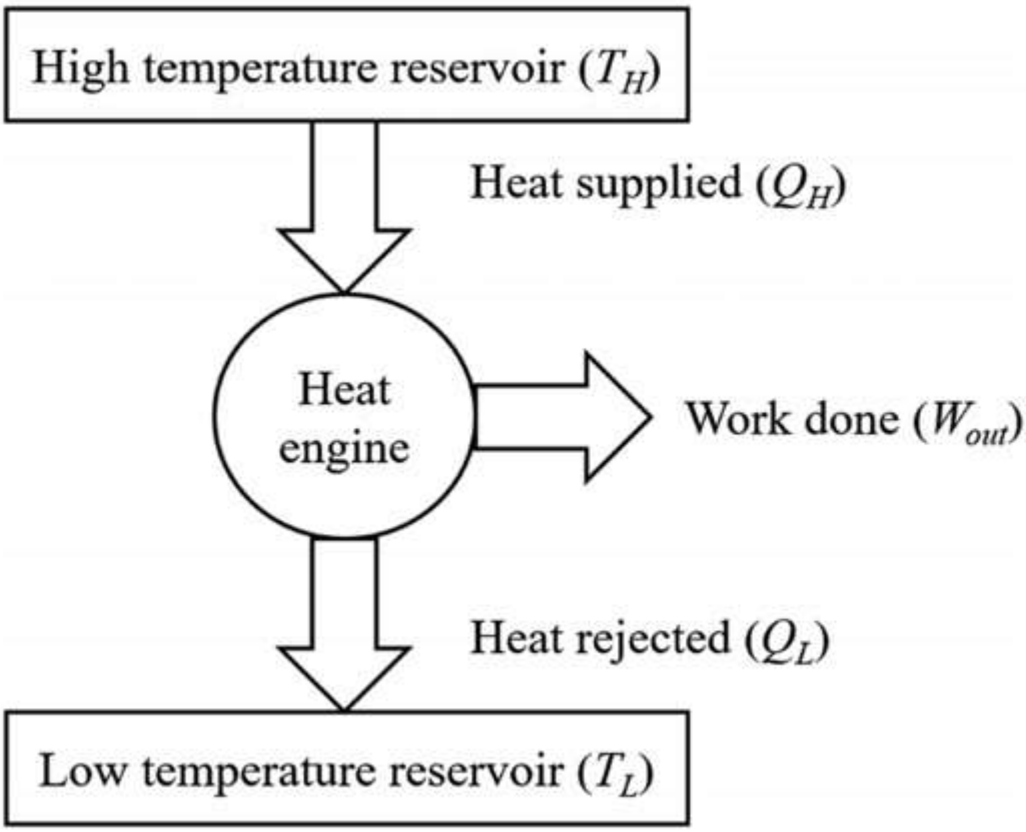
1-Equation of continuity

$$v_2 A_2 = v_1 A_1$$

2-Bernoulli's equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

Learning Unit 4: Apply Thermodynamics



STRUCTURE OF LEARNING UNIT

Learning outcomes:

- 4.1: Description of fundamental concepts
- 4.2: Analysing thermodynamic laws
- 4.3: Application of thermodynamic laws

Learning outcome 4.1: Description of fundamental concepts

Duration: 4 hrs

Learning outcome 4.1 objectives:

By the end of the learning outcome, the trainees will be able to:

1 Define **Key terms: system, boundary, surrounding, extensive & intensive properties, state process**

2: Calculate Heat transfer and quantity of heat

Resources

Equipment	Tools	Materials
PPE, Computer, whiteboard, chalkboard, projector, textbooks	scientific calculator, calorimeters, thermometers	Chalks, markers, internet

Advance preparation:

Thermodynamic system

4.1.1: THERMODYNAMIC SYSTEM

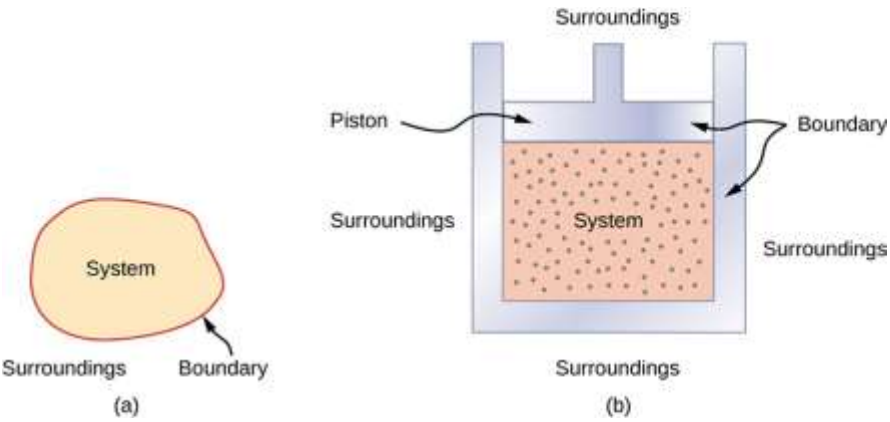


Fig. 4.1 Thermodynamic system

1.System

The ***system*** is whatever we want to study. A system is defined as a quantity of matter or a region in space chosen for study.

2. Boundary,

Boundary: the real or imaginary surface that ***separates the system*** from its ***surroundings***. The boundaries of a system can be fixed or movable. Mathematically, the boundary has zero thickness, no mass, and no volume.

The system is distinguished from its surroundings by a specified ***boundary,*** which may be at rest or in motion.

3. Surrounding

The mass or region outside the system is called the ***surroundings.***

Everything external to the system is considered to be part of the system's ***surroundings.***

4. Properties of a system

A property is any characteristic of a system such as pressure, volume, temperature, energy, pressure, density, number of moles, mass, …..

5. Extensive properties:

Extensive properties: values that are ***dependent on size of the system*** such as mass, volume, and total energy U. ***They are additive.***

A property is called ***extensive*** if its value for an overall system is the sum of its values for the parts into which the system is divided. Mass, volume, energy, and several other properties introduced later are extensive.

The extensive properties of a system can change with time,

6. Intensive properties:

Intensive properties: are those that are ***independent of the size (mass) of a system***, such as temperature, pressure, and density. ***They are not additive.***

In addition, there are properties that are known as **specific properties** because they are given per unit mass or per defined mass in the system. ***Specific properties are intensive properties.***

Specific properties are defined as the ***extensive property per unit mass.***

7.State

In thermodynamics, a thermodynamic state of a system is **its condition at a specific time**; that is, fully identified by values of a suitable set of parameters known as state variables, state parameters or thermodynamic variables.

8. Process:

When any of the properties of a system change, the state changes and the system is said to have undergone a ***process. A process is a transformation from one state to another***. However, if a system exhibits the same values of its properties at two different times, it is in the same state at these times. A system is said to be at ***steady state*** if none of its properties changes with time.

Summary for the trainer related to the content (key notes using bullets such as ticks etc)

- ✓ A thermodynamic system is defined as **a quantity of matter or a region in space that is of interest**.
- ✓ The mass or region outside the system is called the surroundings, and
- ✓ the surface that separates the system and the surroundings is called the boundary
- ✓ **An extensive property is a property that depends on the amount of matter in a sample**. Mass and volume are examples of extensive properties.
- ✓ An intensive property is a property of matter that depends only on the type of matter in a sample and not on the amount. Temperature and pressure are examples of intensive properties.
- ✓ Heat is transferred by three different methods: **conduction, convection, and radiation**.

Theoretical learning Activity

- ✓ Brainstorming on key terms
- ✓ Group discussion on measuring temperature using thermometers
- ✓ Group discussion on Conversion of thermometric scales
- ✓ Group discussion on calibration of Thermometers
- ✓ Individually work to solve measurements of temperature

Practical learning Activity

- ✓ ……………………………………. (Example: Trainees in pair perform ………………….)

Points to Remember (Take home message)

- System
- State
- Process
- Latent heat
- Conduction
- Convection
- Radiation

Learning outcome 4.2: Heat Transfer and Quantity of heat

Duration: 4 hrs

Learning outcome 4.2 objectives:

By the end of the learning outcome, the trainees will be able to:

1.Define Heat and temperature

2. Modes of heat transfer

3. Heat capacity

4.Specific heat capacity

5.Latent heat capacity

6.Thermal expansions

Resources

Equipment	Tools	Materials
PPE, Computer, whiteboard, chalkboard, projector, textbooks	scientific calculator, calorimeters, thermometer	Chalks, markers, internet

Advance preparation:

.Temperature and heat

.Heat capacity

.Latent heat

Thermal expansions

4.2.1. Generalities:

Distinction between Temperature, Heat and Internal energy

The **temperature is** a physical quantity, which indicates the degree **of *hotness or cold*ness of a body**.

Heat is defined as the *transfer of energy* from one system to another due to a temperature difference between them.

Internal energy

Internal energy is all the energy of a system that is associated with its microscopic constituents. Internal energy includes kinetic energy of random translational, rotational, and vibration motion of molecules, potential energy of molecules and between molecules.

Thermometers are devices that are used to measure the temperature of a system. All thermometers are based on the principle that some physical property of a system changes as the system's temperature changes.

Some physical properties that change with temperature are

(1) the volume of a liquid,

(2) the dimensions of a solid,

(3) the pressure of a gas at constant volume,

(4) the volume of a gas at constant pressure,

(5) the electric resistance of a conductor, and

(6) the color of an object.

A temperature scale can be established on the basis of any one of these physical properties. Any thermometric property can be used to establish a temperature scale. The common mercury thermometer consists of a glass bulb and tube containing a fixed amount of mercury.* When this thermometer is put in contact with a warmer object, the mercury expands, increasing the length of the mercury column (the glass expands too, but by a negligible amount).

We can create a scale along the glass tube by using the following procedure.

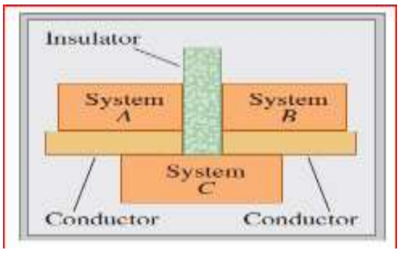
First, the thermometer is placed in ice and water in equilibrium at a pressure of 1 atm. When the thermometer is in thermal equilibrium with the ice water, the top of the mercury column is marked on the glass tube. This mark represents the **ice-point** temperature (also called the **normal freezing point** of water).

Next, the thermometer is placed in boiling water at a pressure of 1 atm. When the thermometer is in thermal equilibrium with the boiling water, the top of the mercury column is marked. This mark represents the **steam-point temperature** (also called the **normal boiling point** of water)

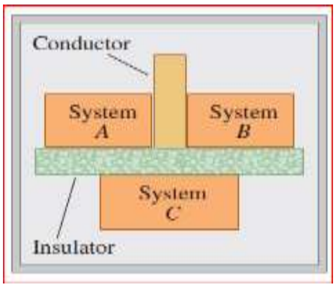
4.2.2 The Zeroth Law of Thermodynamics

We can discover an important property of thermal equilibrium by considering three systems, *A*, *B*, and *C*, that initially are not in thermal equilibrium . We surround them with an ideal insulating box so that they cannot interact with anything except each other. We separate systems *A* and *B* with an ideal insulating, but we let system *C* interact with both systems *A* and

B. This interaction is shown in the figure by a yellow slab representing a thermal **conductor,** a material that *permits* thermal interactions through it. We wait until thermal equilibrium is attained; then *A* and *B* are each in thermal equilibrium with *C*. **Two systems are in thermal equilibrium if and only if they have the same temperature.**



Systems A and B are in thermal with system C equilibrium with each other



Systems A and B are in *thermal equilibrium*

If systems A and B are each in thermal equilibrium with the system C

4.2.3 Temperature scales

Number of temperature measuring scales came up from time to time. The text ahead gives a brief idea of the different temperature scales used in thermometry. Different temperature scales have different names based on the names of persons who originated them and have different numerical values assigned to the reference states.

(*a*) Celsius Scale or Centigrade Scale

Anders Celsius gave this Celsius or Centigrade scale using **ice point of 0°C as the lower fixed point and steam point of 100ºC as upper fixed point** for developing the scale. It is denoted by letter *C*.

Ice point refers to the temperature at which freezing of water takes place at standard atmospheric pressure.

Steam point refers to the temperature of water at which its vaporization takes place at standard atmospheric pressure.

The interval between the two fixed points was equally divided into 100 equal parts and each part represented 1ºC or 1 degree celsius.

(*b*) Fahrenheit Scale

Fahrenheit gave another temperature scale known as Fahrenheit scale and has the lower fixed point as **32°F** and the upper fixed point as **212°F**. The interval between these two is equally divided into 180 parts. It is denoted by letter F. Each part represents **1°F**.

(*c*) Rankine Scale

Rankine scale was developed by William John MacQuorn Rankine, a Scottish engineer. It is denoted by letter *R*. It is related to Fahrenheit scale as given below.

$TR = TF + 459.67$

(*d*) Kelvin Scale

Kelvin scale proposed by Lord Kelvin is very commonly used in thermodynamic analysis. It also defines the absolute zero temperature. Zero Kelvin or **absolute zero temperature** is taken as **–273.15ºC**. It is denoted by letter K.

SCALE	*ICE POINT*	*STEAM POINT*	*TRIPLE POINT*
KELVIN	273.15K	373.15K	273.15K
RANKINE	491.67R	671.67R	491.69R
FAHRENHEIT	32^0F	212^0F	32.02^0F
CENTIGRADE	0^0C	100^0C	0.01^0C

To convert a temperature from one scale to the other, we must also take into account the fact that the zero temperatures of the two scales are not the same. The general relation between a Fahrenheit temperature T_F and Celsius T_C temperature is

$$T_F = \frac{9}{5}T_C + 32°F$$

FAHRENHEIT–CENTIGRADE CONVERSION

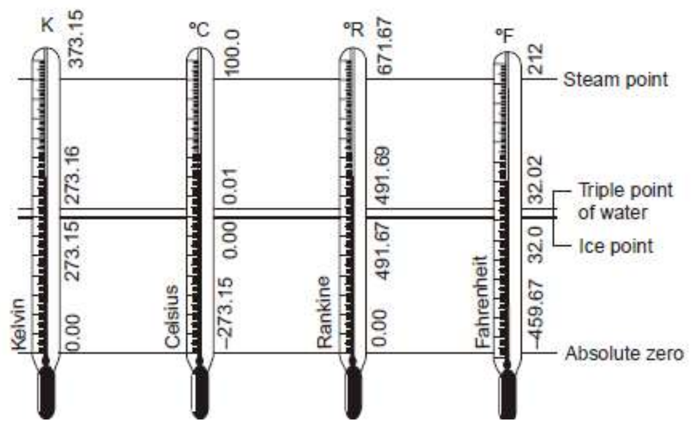
$$t_C = \frac{5}{9}(t_F - 32°) \qquad (\text{or } t_F = \frac{9}{5}t_C + 32°)$$

CELSIUS–ABSOLUTE CONVERSION

$$T = t_C + 273.15 \text{ K}$$

To find a relationship between changes in temperature on the Celsius, Kelvin, and Fahrenheit scales:

$$\Delta T_C = \Delta T = \frac{5}{9}\Delta T_F$$



$$\frac{T_C}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100} = \frac{T_R - 491.67}{180}$$

Examples

1. Determine the human body temperature in degree celsius (°C) if the temperature in Fahrenheit is 98.6°F.

Solution:

Degree Celsius and Fahrenheit are related as below,

$$T\,(^\circ C) = \frac{T^\circ(F) - 32}{1.8}$$

Substituting values.

$$T\,(^\circ C) = \frac{98.6 - 32}{1.8} = 37^\circ C$$

Temperature in degree celsius shall be **37°C**. **Ans.**

Example 2

The normal boiling point of nitrogen is −195.75 ∘C.

(a)What is this temperature in Kelvin and in Fahrenheit?

(b) If the temperature changes from −195.75 ∘C to −100 ∘C, find the change in the temperature on the Fahrenheit scale.

$$T = T_C + 273.15 = -195.75 + 273.15 = 77.4\ \text{K}$$

$$T_F = \tfrac{9}{5}T_C + 32 = \tfrac{9}{5} \times (-195.75) + 32 = -320.35\,^\circ\text{F}$$

Thus, −195.75 ∘C, 77.4K, and −320.35 ∘F are equivalent temperatures on differentscales.

(b) For a change ΔT_C =[−100 ∘C–(−195.75 ∘C)]=95.75C∘

We find the change in temperature on the Fahrenheit scale as:

$$\Delta T_F = \tfrac{9}{5}\Delta T_C = \tfrac{9}{5}[-100 - (-195.75)] = 172.35\,\text{F}^\circ$$

Thus, a change **95.75C∘ =172.35 F∘** , where the notations **C∘ and F∘ refer to temperature difference, not to be confused with actual temperatures**, which are written in terms of symbols ∘C and ∘F.

EXERCISES

(1) Convert the temperatures −30 ∘C, 10 ∘C, and 50 ∘C to Kelvin and Fahrenheit.

(2) Express the normal human body temperature, 37 ∘C, and the sun’s surface temperature, ∼6000 ∘C, in Fahrenheit and Kelvin.

(3) A Celsius thermometer indicates a temperature of−40 ∘C.

(a)What Fahrenheit and Kelvin temperatures correspond to this Celsius temperature?

(b) If the temperature changes from −40 ∘C to+10 ∘C, find the change in temperature on the Fahrenheit scale.

(4) The normal melting point of gold is 1064.5 ∘C and its boiling point is 2660 ∘C.

(a) Convert these two values to the Fahrenheit and Kelvin scales.

(b) Find the difference between those two values in Celsius.

(c) Repeat (b) using the Kelvin scale.

4.2. 4: Apply heat measurement, transfer and effects on a body

Heat capacities

The quantity of heat energy *Q* required to raise the temperature of an object by some amount ΔT varies from one substance to another.

The **heat capacity** C of an object is defined as the amount of heat energy needed to raise the object's temperature by one degree Celsius.

Accordingly, if Q units of heat energy are required to change the temperature by $\Delta T = T_f - T_i$, where T_i and T_f are the initial and final temperatures of the object, then:

$Q = C\,\Delta T$, where $\Delta T = T_f - T_i$

Heat capacity C has the unit J/C∘ (J/K) or kcal/C∘ (kcal/K).

4.2.5 Specific heat capacity:

The heat capacity for any object is proportional to its mass m. For this reason, we define the "heat capacity per unit mass" or the **specific heat** c which refers to a unit mass of the material of which the object is made.

Specific heat capacity c of an object is defined as the amount of heat energy needed to raise the temperature of a unit mass of the object by one degree Celsius.

Thus, with **$C = mc$,** becomes:

$Q = mc\Delta T$, where $\Delta T = T_f - T_i$

Specific heat c has the unit:

J/kg.C∘ ≡ J/kg.K Or **kcal/kg.C∘ ≡ kcal/kg.K**

The specific heat of water at 15 ∘C and atmospheric pressure is:

c_{water} = 4,186 J/kg.K = 1 kcal/kg.C∘

Note that, when heat energy is added to objects, Q and ΔT are both positive, i.e. the temperature increases. Likewise, when heat is removed from objects, Q and ΔT are both negative, i.e. the temperature decreases.

Table : Specific heat c of some substances at atmospheric pressure and room temperature (20 ∘C) with few exceptions

4.2.6 Measuring Specific Heat: Method of mixtures

Figure bellow shows an example of a calorimeter, which is a device used to determine the specific heat of a solid or liquid substance. The substance (represented by a circular object, having a specific heat c_x and mass m_x) is heated up to some known initial temperature T_x, and then placed in a perfectly insulated vessel containing water of specific heat c_w, mass m_w, and initial temperature T_w. If T_f is the final temperature after reaching equilibrium, then $T_w < T_f < T_x$. Using Eq. **$Q = mc\Delta T$**, we calculate the heat gained by the water to be $Q = m_w c_w (T_f - T_w)$, and calculate the heat energy lost by the object to be $-Q = m_x c_x (T_f - T_x)$.

Assuming that the entire system does not lose or gain any heat from its surrounding, then the heat gained by the water must equal the heat lost by the object. That is:

$Q = m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$ (12.5)

Solving for c_x gives:

$$c_x = c_w \frac{m_w}{m_x} \frac{(T_f - T_w)}{(T_x - T_f)}, \quad (T_w < T_f < T_x)$$

When calculating c_x, we neglected heat exchange with the vessel, which is acceptable when the mass of the water is considerably larger than that of the vessel, and when the vessel has a negligible specific heat.

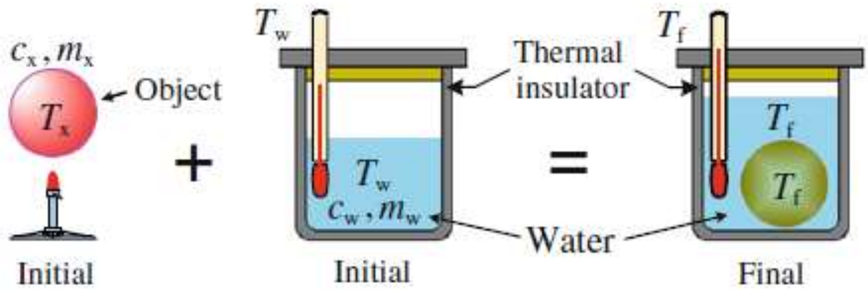


Fig. In the method of mixtures, a calorimeter filled with water is used to find the specific heat of unknown heated objects

Examples

The specific heat of zinc is 352 J/kg.C∘ for temperatures near 25 ∘C. Determine the amount of heat required to raise the temperature of 0.5 kg zinc from 20 to 30 ∘C. Take the specific heat to be constant in that temperature range.

Solution: The given values are c=352 J/kg.C∘
,m=0.5kg, T_i =20 ∘C, and
T_f =30 ∘C. The temperature change has the following magnitude:
$\Delta T = T_f - T_i$ = 30 ∘C − 20 ∘C = 10 C∘
We find the amount of heat required as follows:
$Q = mc\Delta T$ = (0.5kg)(352 J/kg.C∘)(10 C∘) = 1,760 J

Example 2

A steel metal object of mass 0.05 kg is heated to 225 ∘C and then dropped into a vessel containing 0.55 kg of water initially at 18 ∘C. When equilibrium is reached, the temperature of the mixture is 20 ∘C. Find the specific heat of the metal.

Solution: For the steel metal object, we are given m_x =0.05 kg and T_x =225 ∘C,
but its specific heat c_x is unknown. For water, the known values are m_w =0.55 kg,
T_w =18 ∘C, and c_w =4,186 J/kg.C∘ . For the mixture, the equilibrium temperature occurs at T_f =20 ∘C. Since the heat gained by the water is equal in magnitude to the heat lost by the steel, then we must
have:

$m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$, $\quad (T_w < T_f < T_x)$

Solving for c_x we get:

$$c_x = c_w \frac{m_w}{m_x} \frac{(T_f - T_w)}{(T_x - T_f)} = (4{,}186\ \mathrm{J/kg.C^\circ}) \frac{(0.55\,\mathrm{kg})}{(0.05\,\mathrm{kg})} \frac{(20\,^\circ\mathrm{C} - 18\,^\circ\mathrm{C})}{(225\,^\circ\mathrm{C} - 20\,^\circ\mathrm{C})} = 449\ \mathrm{J/kg.C^\circ}$$

4.2.7 Calorimetry and Phase Changes

Calorimetry means "measuring heat." We have discussed the energy transfer (heat) involved in temperature changes. Heat is also involved in *phase changes,* such as the melting of ice or boiling of water. Once we understand these additional heat relationships, we can analyze a variety of problems involving quantity of heat

Latent heat, energy absorbed or released by a substance during a change in its physical state (phase) that occurs without changing its temperature. The latent heat associated with melting a solid or freezing a liquid is called the heat of fusion; that associated with vaporizing a liquid or a solid or condensing a vapour is called the heat of vaporization. The latent heat is normally expressed as the amount of heat (in units of joules or calories) per mole or unit mass of the substance undergoing a change of state.

For any given pressure a phase change takes place at a definite temperature, usually accompanied by absorption or emission of heat and a change of volume and density.

A familiar example of a phase change is the melting of ice. When we add heat to ice at **0°C** and normal atmospheric pressure, the temperature of the ice *does not* increase. Instead, some of it melts to form liquid water. If we add the heat slowly, to maintain the system very close to thermal equilibrium, the temperature remains at **0°C** until all the ice is melted. The effect of adding heat to this system is not to raise its temperature but to change its *phase* from solid to liquid.

To change 1 kg of ice at 0°C to 1 kg of liquid water at 0°C and normal atmospheric pressure requires **3.34×10^5 J** of heat. The heat required per unit mass is Called the **heat of fusion** (or sometimes latent heat of fusion), denoted by L_f. For water at normal atmospheric pressure the heat of fusion is

$L_f = 3.34 \times 10^5$ j/kg = 79.6 cal/g.

More generally, to melt a mass m of material that has a heat of fusion Lf requires a quantity of heat Q given by

$Q = m\,L_f$.

This process is reversible. T freeze liquid water to ice at 0^0 C, we have to remove heat; the magnitude is the same, but in this case, Q is negative because heat is removed rather than added. To cover both possibilities and include other kinds of phase changes, we write

$Q = \pm mL$ (heat transfer in a phase change).

The plus sign (heat entering) is used when the material melts; the minus sign (heat leaving) is used when it freezes. The heat of fusion is different for different materials, and it also varies somewhat with pressure. For any given material at any given pressure, the freezing temperature is the same as the melting temperature. At this unique temperature the liquid and solid phases (liquid water and ice, for example) can coexist in a condition called **phase equilibrium.**

We can go through this whole story again for *boiling* or *evaporation*, a phase transition between liquid and gaseous phases. The corresponding heat (per unit mass) is called the **heat of vaporization** L_v. At normal atmospheric pressure the heat of vaporization L_v for water is

$$L_v = 2.256 \times 10^6 \text{ J/kg} = 539 \text{ cal/g} = 970 \text{ Btu/lb}$$

That is, it takes 2.256×10^6 J to change 1 kg of liquid water at 100°C to 1 kg of water vapor at 100°C. By comparison, to raise the temperature of 1 kg of water from 0°C to 100°C requires $Q = mc\,\Delta T = (1.00 \text{ kg})(4190 \text{ J/kg}\cdot\text{C°}) \times (100 \text{ C°}) = 4.19 \times 10^5$ J, less than one-fifth as much heat as is required for vaporization at 100°C. This agrees with everyday kitchen experience; a pot of water may reach boiling temperature in a few minutes, but it takes a much longer time to completely evaporate all the water away.

Like melting, boiling is a reversible transition. When heat is removed from a gas at the boiling temperature, the gas returns to the liquid phase, or *condenses,* giving up to its surroundings the same quantity of heat (heat of vaporization) that was needed to vaporize it. At a given pressure the boiling and condensation temperatures are always the same; at this temperature the liquid and gaseous phases can coexist in phase equilibrium.

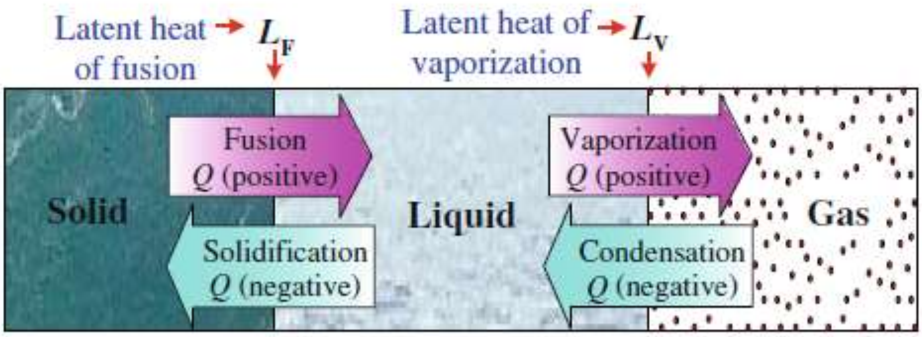


Fig. 12.3 A sketch showing heat of fusion/vaporization (positive Q) as well as heat of condensation/ solidification (negative Q)

Find the quantity of heat required to convert ice of mass 500 g at −10 °C into water at 20 °C. The specific heat of ice is $c_i = 2{,}220$ J/kg.C°, the latent heat of fusion is $L_F = 3.33 \times 10^5$ J/kg, and the specific heat of water is $c_w = 4{,}186$ J/kg.C°.

Solution: The ice gains heat throughout the following three stages.

In stage A we raise the temperature of ice from −10 to 0 °C. Using Eq. 12.4 we get:

$$Q_A = m_i c_i \,\Delta T = (0.5\,\text{kg})(2{,}220\,\text{J/kg.C°})(10\,\text{C°}) = 11{,}100\,\text{J} = 11.1\,\text{kJ}$$

In stage B we melt the 500 g of ice at constant temperature (0 °C) by supplying the latent heat of fusion. Using Eq. 12.7 we get:

$$Q_B = m\,L_F = (0.5\,\text{kg})(3.33 \times 10^5\,\text{J/kg}) = 166{,}500\,\text{J} = 166.5\,\text{kJ}$$

In stage C we raise the temperature of water from 0 to 20 °C. Using Eq. 12.4 we get:

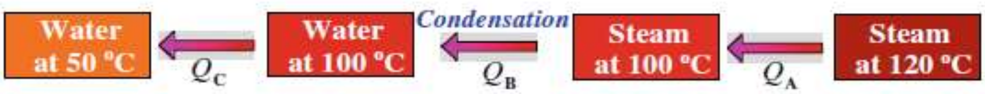
$$Q_C = m_w c_w \,\Delta T = (0.5\,\text{kg})(4{,}186\,\text{J/kg.C°})(20\,\text{C°}) = 41{,}860\,\text{J} = 41.86\,\text{kJ}$$

Note that $Q_B > Q_C > Q_A$ and the total required heat is $Q_{tot} = 219.46$ kJ.

Example 12.4

A glass beaker of water is at 20 °C. The beaker has a mass $m_g = 200$ g with specific heat $c_g = 840$ J/kg.C° and contains water of mass $m_w = 300$ g with specific heat $c_w = 4{,}186$ J/kg.C°. A quantity of steam initially at 120 °C is used to warm the system to 50 °C. If the specific heat of steam is $c_s = 2{,}010$ J/kg.C° and latent heat of vaporization is $L_V = 2.26 \times 10^6$ J/kg, what is the mass of the steam?

Solution: The heat lost by the steam equals the heat gained by both beaker and water. The steam loses heat over the stages shown below.



In the first stage, the steam is cooled from 120 to 100 °C, i.e. $\Delta T = T_f - T_i = 100\,°\text{C} - 120\,°\text{C} = -20\,\text{C°}$. The heat liberated in this stage by the unknown mass m_s of steam is:

$$Q_A = m_s c_s \,\Delta T = m_s(2{,}010\,\text{J/kg.C°})(-20\,\text{C°}) = -m_s(40{,}200\,\text{J/kg})$$

In the second stage, the steam is condensed to water at 100 °C. Since the latent heat of condensation equals the latent heat of vaporization, we use Eq. 12.7 to find the heat liberated as follows:

$$Q_B = -m_s\,L_V = -m_s(2.26 \times 10^6\,\text{J/kg})$$

In the last stage the temperature of water is reduced from 100 to 50 °C. This liberates an amount of heat given by:

$$Q_C = m_s c_w \Delta T = m_s(4{,}186\ \text{J/kg.C°})(-50\ \text{C°}) = -m_s(209{,}300\ \text{J/kg})$$

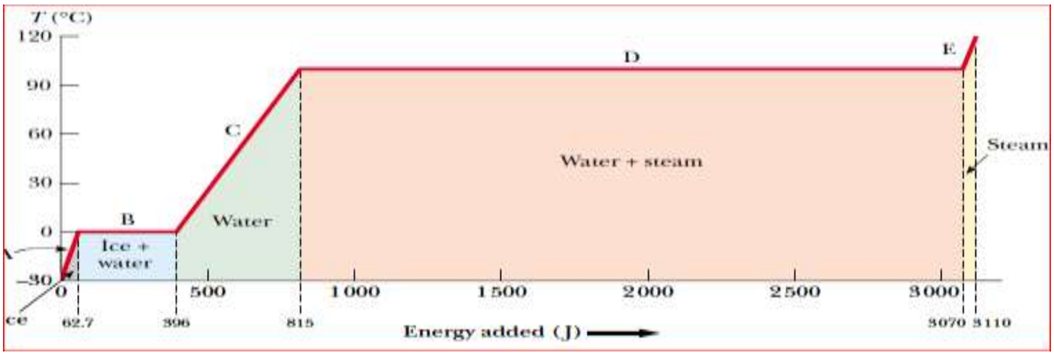
The heat lost is thus $Q_{lost} = Q_A + Q_B + Q_C = -m_s(2{,}509{,}500\ \text{J/kg})$. The heat gained by the beaker and water system from 20 to 50 C° is:

$$Q_{gained} = m_w c_w \Delta T + m_g c_g \Delta T = (m_w c_w + m_g c_g)\Delta T$$
$$= [(0.3\ \text{kg})(4{,}186\ \text{J/kg.C°}) + (0.2\ \text{kg})(840\ \text{J/kg.C°})](30\ \text{C°})$$
$$= 42{,}714\ \text{J}$$

If we equate the magnitude of heat lost by the steam, $|Q_{lost}|$, with the heat gained by the beaker and water system, Q_{gained}, we get:

$$m_s = 42{,}714\ \text{J}/(2{,}509{,}500\ \text{J/kg}) = 0.017\ \text{kg} = 17\ \text{g}$$

Example:



<u>EXERCISES ON CALORIMETRY</u>

1. Water at the top of Niagara falls has a temperature of 10^{0}C, it falls a distance of 50m and all its potential energy goes into heating the water. Calculate the temperature of water at the bottom of the falls.
2. A 400g iron that is initially at 500^{0}C is dropped into a bucket containing 20kg of water at 20^{0}C. What is the final equilibrium temperature. Neglect any heat transfer to or from surroundings C_i = 448J/kg^{0}C.
3. An aluminium cup contains 225g of water at 27^{0}C. A 400g sample of silver at an initial temperature of 87^{0}C is placed in the water. A 40g copper stirrer is used to stir the mixture until it reaches its final equilibrium at 32^{0}C.
Calculate the mass of Al cup, CA = 900J/kg^{0}C , C_{copper} = 387J/kg^{0}C, C_{silver} = 234J/kg^{0}C.
4. A 50g ice cube at 0^{0}C is heated until 45g has become water at 100^{0}C and 5 g has become steam at 100^{0}C. How much heat was added to accomplish this?
5. A 100g ice cube at 0^{0}C is placed in 650g of water at 25^{0}C, what is the final temperature of the mixture?

4..2.8 Mechanisms of Heat Transfer

The *conductors* and *insulators,* materials that permit or prevent heat transfer between bodies. Now let's look in more detail at *rates* of energy transfer. In the kitchen you use a metal or glass pot for good heat transfer from the stove to whatever you're cooking, but your refrigerator is insulated with a material that *prevents* heat from flowing into the food inside the refrigerator. How do we describe the difference between these two materials?

The three mechanisms of heat transfer are conduction, convection, and radiation.

Conduction occurs within a body or between two bodies in contact.

Convection depends on motion of mass from one region of space to another.

Radiation is heat transfer by electromagnetic radiation, such as sunshine, with no need for matter to be present in the space between bodies.

4.2.9 Conduction

Conduction:

In Conduction, the molecules of the body are responsible for the heat transfer. Here there is no actual movement of molecules from one place to another place. When a rod is heated at one end, the molecules at the hot end vibrate about their mean position and transfer the heat energy to the neighboring molecules and thus the heat energy reaches the other end of the rod. Conduction takes place in solids, liquids and gases. **Heat transfer occurs only between regions that are at different temperatures, and the direction of heat flow is always from higher to lower temperature.**

When a quantity of heat dQ is transferred through the rod in a time dt, the rate of heat flow is $\frac{dt}{dt}$. We call this rate the heat currents is proportional, denoted by H. that is

$$p = \frac{dQ}{dt}$$

$$p = Ae\sigma T^4$$

$$\sigma = 5.67 \times 10^{-8}\ {}^{w}\!/_{m^2k^4}$$

. Heat current is proportional to the cross section area A of the rod and the tmperature difference (T_H _ T_C) and it is inversely proportional to the rod length L.

$$p = \frac{dQ}{dt} = kA\frac{T_H - T_L}{L} \quad \text{(heat current in conduction)}$$

Hence, Coefficient of thermal conductivity (k) of the material of a conductor is defined as the quantity of heat conducted per second per unit area per unit temperature gradient at the steady state.

The materials with large k are good conductors of heat, materials with small k are poor conductors or insulators.

42. A glass window pane has an area of 3.00 m2 and a thickness of 0.600 cm. If the temperature difference between its faces is 25.0°C, what is the rate of energy transfer by conduction through the window?

$$\mathcal{P} = \frac{kA\Delta T}{L} = \frac{(0.800\ \text{W/m}\cdot{}^\circ\text{C})(3.00\ \text{m}^2)(25.0^\circ\text{C})}{6.00 \times 10^{-3}\ \text{m}} = 1.00 \times 10^4\ \text{W} = \boxed{10.0\ \text{kW}}$$

4.2.10 Uses of thermal conductors:-

1. Handles made of wood or ebonite are provided for cookers and hot water vessels.
2. Hot water bottles made of rubber are able to keep hot water at high temperature for a considerable period of time.

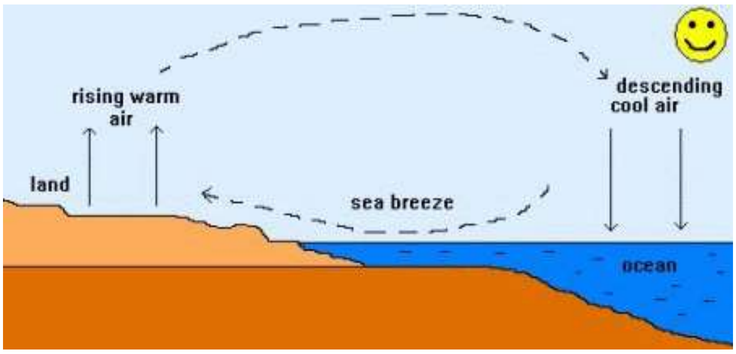
3. Use of double windows with a thin layer of air enclosed in between them keep the room warm in cold countries.
4. Wool, cork and ebonite are used for the purpose of heat insulation in refrigeration.
5. Woolen clothes are used in winter to keep the body warm.
6. Sawdust and jute sheet is used to cover ice to prevent it from melting.
7. Vessels made of copper, aluminum, etc., are used for cooking purpose as they easily conduct heat.
8. Copper is used in boilers and radiators, because of its good conductivity.

4.2.11 Convection

Convection is the transfer of heat by mass motion of a fluid from one region of space to another.

The portions of the fluid that get warmed up by contact with the heat source, expand and so move up through the body of the fluid due to the decrease in density. There is an inflow of cooler molecules to take the place of heated mass of the fluid which has moved up. This circulatory motion of the fluid mass by which heat is transferred from place to place is called Convection. Convection is the process in which heat is transmitted from one place to the other by the actual movement of heated particles. Convection takes place only in liquids and gases. It cannot take place in solids.

Wind formation: **Wind** is air in motion. It is produced by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of various land and water formations, it absorbs the sun's radiation unevenly. Two factors are necessary to specify **wind**: speed and direction.



Applications of Convection.

1. The wind flow is due to the convection currents in the atmosphere. During day time, parts of earth get heated by the Sun. As the air expands, it rises up and its place is taken by the flow of air from colder areas.
2. The land breeze and sea breeze are due to the convection in the atmosphere. During day time, land mass is heated to a higher level than the sea. So, the warm air over the land rises giving place to the

cool air flow from the ocean. This gives the sea breeze. During night time, the land mass cools quickly than the water in the sea. So, cool air flows from land mass towards sea which gives the land breeze.

4.2.12 Radiation

Radiation is the transfer of heat by electromagnetic waves such as visible light, infrared, and ultraviolet radiation. Everyone has felt the warmth of the sun's radiation and the intense heat from a charcoal grill or the glowing coals in a fireplace.

Most of the heat from these very hot bodies reaches you not by conduction or convection in the intervening air but by *radiation.* This heat transfer would occur even if there were nothing but vacuum between you and the source of heat.

The rate of energy radiation from a surface is proportional to the surface area A and to the fourth power of the absolute (kelvin) temperature T. T_h rate also depends on the nature of the surface. The quantity e is called emissivity. A dimensionless number between 0 and 1, e represents ratio of the rate of radiation from a particular surface to the rate of radiation from an equal area of an ideal radiating surface at the same temperature.

$p = Ae\sigma T^4$, $\sigma = 5.67 \times 10^{-8}\ {}^{w}\!/_{m^2k^4}$

Where σ is fundamental physical quantity called Stephan-Boltzmann constant.

Properties of thermal radiation:

The nature of thermal radiation is similar to that of light. Some of the properties of thermal radiation.

1. Thermal radiation travels with the velocity of light, which is 3 x 108 ms-1.
2. Thermal radiation obeys the same laws of reflection, refraction etc., as light.
3. Thermal radiation travels through vacuum.
4. It obeys the law of Inverse Square, as light.
5. It travels in straight lines.
6. When thermal radiation falls on anybody, which can absorb it, then converted into ordinary heat, which raises its temperature.
7. It is absorbed by dark rough surfaces and reflected by light smooth surface.

Applications of Radiation.

1. White coloured dresses are used in hot countries to keep the inside cool.
2. In some countries, shining aluminium sheets are used to cover the roof of the house to reflect back the radiant heat and to keep the inside cool.
3. A cooking vessel is painted black at the bottom for greater absorption of heat, but polished at the top to minimize radiation losses.
4. In cold countries, hot air or water runs through the pipes along the walls inside a building and the radiant heat energy keeps the occupants warm by 'Central Heating'.

Example 17.14 **Heat transfer by radiation**

A thin, square steel plate, 10 cm on a side, is heated in a blacksmith's forge to 800°C. If the emissivity is 0.60, what is the total rate of radiation of energy from the plate?

EXECUTE: The total surface area is $2(0.10\ \text{m})^2 = 0.020\ \text{m}^2$, and $T = 800°\text{C} = 1073\ \text{K}$. Then Eq. (17.25) gives

$$H = Ae\sigma T^4$$
$$= (0.020\ \text{m}^2)(0.60)(5.67 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4)(1073\ \text{K})^4$$
$$= 900\ \text{W}$$

4.2.13 EFFECT OF HEAT ENERGY

When a certain amount of heat energy is given to a substance, it will undergo one or more of the following changes:

- ✓ Temperature of the substance rises.
- ✓ The substance may change its state from solid to liquid or from liquid to gas.
- ✓ The substance will expand when heated.

When a liquid is heated, it is done by keeping the liquid in some container and supplying heat energy to the liquid through the container. The thermal energy supplied will be partly used in expanding the container and partly used in expanding the liquid. Thus, what we observe may not be the actual or real expansion of the liquid. Hence, for liquids, we can define real expansion and apparent expansion.

1. Expansion of Substances

When heat energy is supplied to a body, there can be an increase in the dimension of the object. This change in the dimension due to rise in temperature is called thermal expansion of the object. The expansion of liquids (e.g. mercury) can be seen when a thermometer is placed in warm water. All forms of matter (solid, liquid and gas) undergo expansion on heating.

a) Expansion in solids

When a solid is heated, the atoms gain energy and vibrate more vigorously. This results in the expansion of the solid. For a given change in temperature, the extent of expansion is smaller in solids than in liquids and gases. This is due to the rigid nature of solids.

The different types of expansion of solid are listed and explained below:

- Linear expansion
- Superficial (Areal) expansion
- Cubical expansion

1. Linear expansion:

When a body is heated or cooled, the length of the body changes due to change in its temperature. Then the expansion is said to be **linear or longitudinal expansion**.

The ratio of increase in length of the body per degree rise in temperature to its unit length is called as the **coefficient of linear expansion**. The SI unit of Coefficient of Linear expansion is K^{-1}. The value of coefficient of linear expansion is different for different materials.

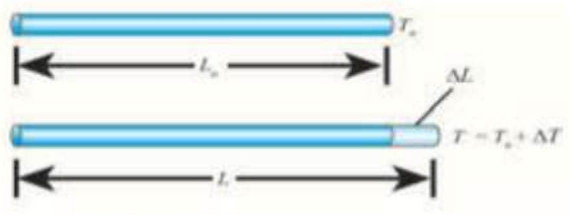


Figure 3.2 Linear expansion

The equation relating the change in length and the change in temperature of a body is given below:

$$\frac{\Delta L}{L_o} = \alpha_L \Delta T$$

ΔL- Change in length (Final length-Original length)
L_o-Original length
ΔT- Change in temperature (Final temperature - Initial temperature)
α_L -Coefficient of linear expansion.

2. Superficial expansion:
If there is an increase in the area of a solid object due to heating, then the expansion is called **superficial or areal expansion.**
Superficial expansion is determined in terms of coefficient of superficial expansion. The ratio of increase in area of the body per degree rise in temperature to its unit area is called as **coefficient of superficial expansion**. Coefficient of superficial expansion is different for different materials. The SI unit of Coefficient of superficial expansion is K^{-1}
The equation relating to the change in area and the change in temperature is given below:

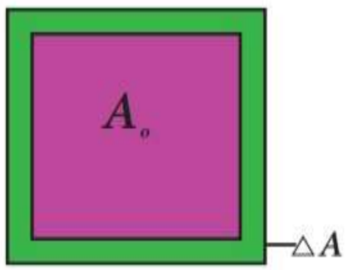


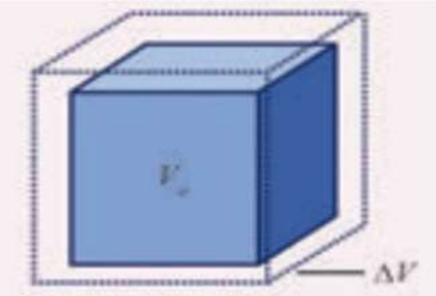
Figure 3.3 Superficial expansion

$$\frac{\Delta A}{A_o} = \alpha_A \Delta T$$

ΔA- Change in area (Final area - Initial area)
A_o-Original area
ΔT- Change in temperature (Final temperature - Initial temperature)
α_A-Coefficient of superficial expansion.

3. Cubical expansion:
If there is an increase in the volume of a solid body due to heating, then the expansion is called **cubical or volumetric expansion.**

As in the cases of linear and areal expansion, cubical expansion is also expressed in terms of coefficient of cubical expansion. The ratio of increase in volume of the body per degree rise in temperature to its unit volume is called as **coefficient of cubical expansion**. This is also measured in K^{-1}.



Cubical expansion

The equation relating to the change in volume and the change in temperature is given below:

$$\frac{\Delta V}{V_o} = \alpha_V \Delta T$$

ΔV - Change in volume(Final volume - Initial volume)
V_o-Original volume
ΔT - Change in temperature (Final temperature - Initial temperature)
α_V-Coefficient of cubical expansion.

Different materials possess different coefficient of cubical expansion. Table 3.1 gives the coefficient of cubical expansion for some common materials.

Coefficient of cubical expansion of some materials

S.No.	Name of the material	Coefficient of cubic expansion (K^{-1})
1	Aluminium	7×10^{-5}
2	Brass	6×10^{-5}
3	Glass	2.5×10^{-5}
4	Water	20.7×10^{-5}
5	Mercury	18.2×10^{-5}

b) Expansion in liquids and gases

The rise in temperature is in proportion to the amount of heat energy supplied. It also depends on the nature and mass of the substance. About the rise in temperature and the change of state, you have studied in previous classes. In the following section, we shall discuss about the expansion of substances due to heat.

When heated, the atoms in a liquid or gas gain energy and are forced further apart. The extent of expansion varies from substance to substance. For a given rise in temperature, a liquid will have more expansion than a solid and a gaseous substance has the highest expansion when compared with the other two. The coefficient of cubical expansion of liquid is independent of temperature whereas its value for gases depends on the temperature of gases.

EXERCISES ON EXPANSION

1. A metal scale is graduated at 0^0C. What would be the true length of an object which when measured with the scale at 25^0C, reads 50cm? α of metal is $18x10^{-6}/^0C$.

2. A metal rod is 64.522cm long at 12^0c and 64.576cm at 90^0c. Find the coefficient of linear expansion of its material.
3. At 20^0c, the length of a sheet of steel is 50cm and the width is 30cm. If the coefficient of linear expansion for steel is $10^{-5}\,{}^0c^{-1}$, determine the change in area and the final area at 60^0c.
4. At 30^0c, the area of sheet of aluminium is $40cm^2$ and the coefficient of linear expansion is $24x10^{-6}C^{-1}$. Determine the final temperature if the final area is 40.2 cm^2.
5. The length of iron rod at 100^0c is 300.36 cm and at 150^0c is 300.54cm. Calculate its length at 0^0c and coefficient of linear expansion of iron.
6. The radius of a ring at 20^0c is 20cm. if the final radius at 100^0c is 20.5 cm, determine the coefficient of area expansion and the

Theoretical learning Activity

- ✓ Group discussion on heat measurement
- ✓ Case study on modes of heat transfer
- ✓ Group discussion on heat effects

Practical learning Activity

- ✓ Individually work to solve problems related to heat measurement
- ✓ Individual work to Solve problems related to heat transfer

Points to Remember (Take home message)

- ✓ The **temperature is** a physical quantity, which indicates the degree **of** ***hotness or cold*****ness of a body**.
- ✓ **Heat** is defined as the *transfer of energy* from one system to another due to a temperature difference between them.
- ✓ They are three modes of heat transfer: Conduction, convection and radiation
- ✓ Heat capacity is the heat energy needed to rise the temperature of a body by one Celsius
  Degree
- ✓ Latent heat capacity is the quantity of absorbed or released by a unit mass of substance The temperature is a physical quantity, which indicates the degree of hotness or coldness of a body.
- ✓ Heat is defined as the transfer of energy from one system to another due to a temperature difference between them.
- ✓ They are three modes of heat transfer: Conduction, convection and radiation
- ✓ Heat capacity is the heat energy needed to rise the temperature of a body by one Celsius

Learning outcome 4.2: Analysing thermodynamic laws

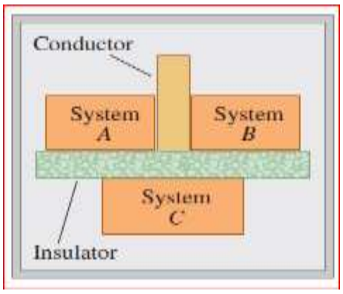
Duration: 4 hrs
Learning outcome 4.2 objectives: By the end of the learning outcome, the trainees will be able to: 1.Describe clearly Zeroth law and temperature measurement 2. Apply effectively First Law of Thermodynamics and Some Simple Processes 3. State correctly Second law statements

Resources		
Equipment	**Tools**	**Materials**
PPE, Computer, whiteboard, chalkboard, projector, textbooks	scientific calculator, calorimeters, thermometers	Chalks, markers, internet
Advance preparation: 1-Temprature 2-Energy and energy conservation 3-Inernal energy		

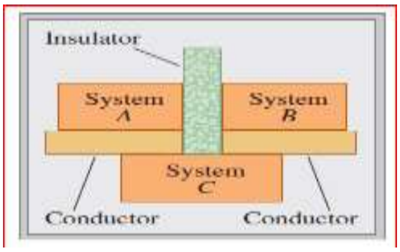
4.2.1 Zeroth law and temperature measurement

The Zeroth Law of Thermodynamics

We can discover an important property of thermal equilibrium by considering three systems, A, B, and C, that initially are not in thermal equilibrium. We surround them with an ideal insulating box so that they cannot interact with anything except each other. We separate systems A and B with an ideal insulating, but we let system C interact with both systems A and B. This interaction is shown in the figure by a yellow slab representing a thermal **conductor,** a material that permits thermal interactions through it. We wait until thermal equilibrium is attained; then A and B are each in thermal equilibrium with C. **Two systems are in thermal equilibrium if and only if they have the same temperature.**



Systems A and B are in thermal equilibrium



Systems A and B are in thermal with system C equilibrium with each other

Temperature scales : Number of temperature measuring scales came up from time to time. The text ahead gives a brief idea of the different temperature scales used in thermometry. Different temperature scales have different names based on the names of persons who originated them and have different numerical values assigned to the reference states.

(a) Celsius Scale or Centigrade Scale: Anders Celsius gave this Celsius or Centigrade scale using **ice point of 0°C as the lower fixed point and steam point of 100ºC as upper fixed point** for developing the scale. It is denoted by letter C.

Ice point refers to the temperature at which freezing of water takes place at standard atmospheric pressure.

Steam point refers to the temperature of water at which its vaporization takes place at standard atmospheric pressure.

The interval between the two fixed points was equally divided into 100 equal parts and each part represented 1ºC or 1 degree celsius.

(b) Fahrenheit Scale: Fahrenheit gave another temperature scale known as Fahrenheit scale and has the lower fixed point as **32°F** and the upper fixed point as **212°F**. The interval between these two is equally divided into 180 parts.

It is denoted by letter F. Each part represents **1°F**.

(c) Rankine Scale

Rankine scale was developed by William John MacQuorn Rankine, a Scottish engineer. It is denoted by letter R. It is related to Fahrenheit scale as given below.

$T_R = T_F + 459.67$

(d) Kelvin Scale: Kelvin scale proposed by Lord Kelvin is very commonly used in thermodynamic analysis. It also defines the absolute zero temperature. Zero Kelvin or **absolute zero temperature** is taken as **–273.15ºC**. It is denoted by letter K.

SCALE	*ICE POINT*	*STEAM POINT*	*TRIPLE POINT*
KELVIN	273.15K	373.15K	273.15K
RANKINE	491.67R	671.67R	491.69R
FAHRENHEIT	32^0F	212^0F	32.02^0F
CENTIGRADE	0^0C	100^0C	0.01^0C

To convert a temperature from one scale to the other, we must also take into account the fact that the zero temperatures of the two scales are not the same. The general relation between a Fahrenheit temperature $\mathbf{T_F}$ and Celsius $\mathbf{T_C}$ temperature is

$$T_F = \frac{9}{5}T_C + 32°F$$

Fahrenheit–centigrade conversion

$$t_C = \frac{5}{9}(t_F - 32°) \qquad (\text{or } t_F = \frac{9}{5}t_C + 32°)$$

Celsius–absolute conversion

$$T = t_C + 273.15 \text{ K}$$

To find a relationship between changes in temperature on the Celsius, Kelvin, and Fahrenheit scales:

$$\Delta T_C = \Delta T = \frac{5}{9}\Delta T_F$$

General expression which is combining Celsius, Kelvin and Fahrenheit temperature scales is

$$\frac{T_C}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

Examples

1. Determine the human body temperature in degree celsius (°C) if the temperature in Fahrenheit is 98.6°F.

Solution:

Degree Celsius and Fahrenheit are related as below,

$$T\,(°C) = \frac{T°(F) - 32}{1.8}$$

Substituting values,

$$T\,(°C) = \frac{98.6 - 32}{1.8} = 37°C$$

Temperature in degree celsius shall be **37°C**. **Ans.**

Example 2

The normal boiling point of nitrogen is −195.75 ◦C.

(a)What is this temperature in Kelvin and in Fahrenheit?
(b) If the temperature changes from −195.75 ◦C to −100 ◦C, find the change in the temperature on the Fahrenheit scale.

$$T = T_C + 273.15 = -195.75 + 273.15 = 77.4\ \text{K}$$

$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5} \times (-195.75) + 32 = -320.35\ ^\circ\text{F}$$

Thus, −195.75 ◦C, 77.4K, and −320.35 ◦F are equivalent temperatures on different scales.
(b) For a change ΔT_C =[−100 ◦C–(−195.75 ◦C)]=95.75C◦
We find the change in temperature on the Fahrenheit scale as:

$$\Delta T_F = \frac{9}{5}\Delta T_C = \frac{9}{5}[-100 - (-195.75)] = 172.35\ \text{F}^\circ$$

Thus, a change **95.75C◦ =172.35 F◦** , where the notations **C◦ and F◦ refer to temperature difference, not to be confused with actual temperatures**, which are written in terms of symbols ◦C and ◦F.

EXERCISES

(1) Convert the temperatures −30 ◦C, 10 ◦C, and 50 ◦C to Kelvin and Fahrenheit.
(2) Express the normal human body temperature, 37 ◦C, and the sun's surface temperature, ∼6000 ◦C, in Fahrenheit and Kelvin.
(3) A Celsius thermometer indicates a temperature of−40 ◦C.
(a)What Fahrenheit and Kelvin temperatures correspond to this Celsius temperature?
(b) If the temperature changes from −40 ◦C to+10 ◦C, find the change in temperature on the Fahrenheit scale.

4.2.2 First Law of Thermodynamics and Some Simple Processes

The thermodynamic process is the method by which a system is changed from one *state* to another. The state of a system is described by a set of **state variables** such as **pressure, temperature, volume, number of moles, and internal energy**. State variables describe the state of a system at some instant of time but not how the system got to that state. Heat and work are *not* state variables, they describe *how* a system gets from one state to another.

Thermodynamic processes can be precisely categorized as cyclic process and non-cyclic process. **The cyclic process is the one in which the initial and final states are identical i.e. system returns to its initial states after occurrence of process. The non cyclic process is the one in which the initial and final states are different i.e**. the occurrence of process is accompanied by the state change.

We can expand the work done by the gas as follows: $dw = pdv$.

If the gas expands then dV is positive and the work done by the gas is positive, whereas if the gas is compressed, dV is negative, indicating that the work done by the gas is negative. When we remove the amount of load from the piston, the volume of the gas changes from V_i to v_f and the total work done by the gas is:

$$W = \int dW = \int_{V_i}^{V_f} P\,dV$$

During the change in volume of the gas, the pressure and temperature of the gas may also change. To evaluate the integral in the last equation, we need to know how the pressure varies with volume. For example, Fig. 12.7 indicates that the work done by the gas is represented by the area under the PV diagram of the figure.

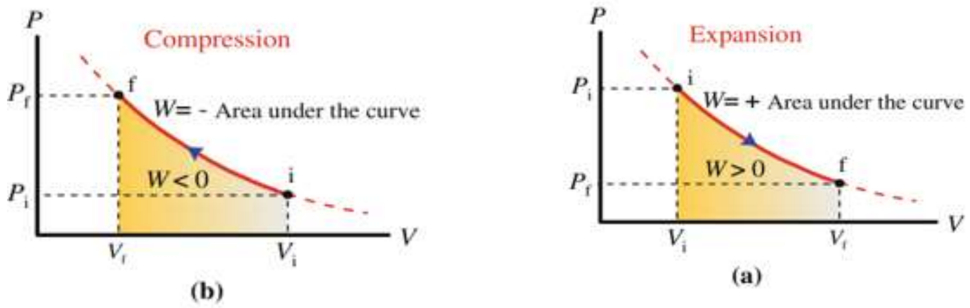


Figure 1

Figure 1. The figure shows a gas that goes from an initial state i to a final state f by means of a thermodynamic process. (a) When the gas expands, the work done by the gas is positive and equals the area under the PV curve. (b) Similar to (a), except that the gas is compressed and the work done by the gas is negative.

(*i*) *Constant pressure process or isobaric process*:

It refers to the thermodynamic process in which there is no change in pressure during the process. Such type of processes are also known as isobaric processes.

Some Special Cases of the First Law of Thermodynamic

Adiabatic processes : An adiabatic process is one that occurs so rapidly or occurs in a system that is so well insulated that no transfer of energy as heat occurs between the system and its environment. Putting Q = 0 in the first law (Eq. 18-26) yields

$$\Delta E_{int} = -W \qquad \text{(adiabatic process).}$$

This tells us that if work is done by the system (that is, if W is positive), the internal energy of the system decreases by the amount of work. Conversely, if work is done on the system (that is, if W is negative), the internal energy of the system increases by that amount.

Constant-volume processes : If the volume of a system (such as a gas) is held constant, that system can do no work. Putting W = 0 in the first law yields.

$$\Delta E_{int} = Q \qquad \text{(constant-volume process).}$$

Thus, if heat is absorbed by a system (that is, **if Q is positive**), the internal **energy of the system increases**. Conversely, if heat is lost during the process (that is, if Q is negative), the internal energy of the system must decrease.

Isobaric Process : An isobaric process is one that takes place at constant pressure. In general, the first law of thermodynamics does not assume any special values for the isobaric process; that is, Q, W, and ΔE int are all non-zero.

$$W_{isobaric} = P(V_f - V_i) \quad \text{(Isobaric process)}$$

Isothermal Process : An isothermal process is one that takes place at constant temperature.

$$W = nRT \ln\left(\frac{V_f}{V_i}\right)$$

Process	W (Work)	Q (Heat)	ΔU (internal energy)
Isochoric ΔV = 0	W = 0	W = 0	Q = n Cv ΔT
			ΔU = Q
Isobaric ΔP = 0	W = P ΔV	Q = n Cp ΔT	ΔU = n Cv ΔT
	= n R ΔT		
Isothermal ΔT = 0	W = P ΔV	Q = W	ΔU = 0
	W = nRT ln (P_1/P_2)	Q = nRT ln (P_1/P_2)	$P_1V_1 = P_2V_2$
Adiabatic Q = 0	W = -nc_v ΔT	Q = 0	ΔU = -W

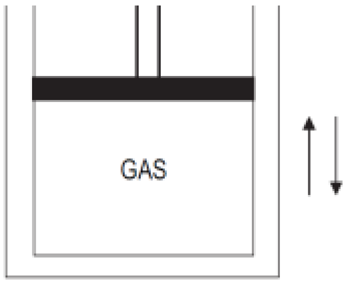
Where Cp is molar heat capacity at constant pressure and Cv is the molar heat capacity at constant volume.

Table 12.3 The first law of thermodynamics in five special cases

Process	Restriction	Consequence
Adiabatic	$Q = 0$	$\Delta E_{int} = -W$
Free expansion	$Q = W = 0$	$\Delta E_{int} = 0$
Isobaric	P = constant	$W_{isobaric} = P(V_f - V_i)$
Isovolumetric	V = constant, $W = 0$	$\Delta E_{int} = Q$
Isothermal (ideal gas)	T = constant, $\Delta E_{int} = 0$	$Q = W = nRT \ln(V_f / V_i)$

ADIABATIC EQUATIONS

When the pressure and volume of a gas change, but no heat is allowed to enter or leave the gas, the change is called as adiabatic change. During the adiabatic change, no heat leaves or enters the gas. That is dQ = 0. The work is done at the cost of internal energy. The gas energy equation, for the adiabatic change becomes,



dQ = Change in internal energy + External work

0 = dE + W (or) W = dE

For a perfect gas, adiabatic change can be represented by the equation,

PV^{γ} = a constant Also $P_1V_1^{\gamma} = P_2V_2^{\gamma}$

The equation relating the temperature and volume of the gas is

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

The equation relating the temperature and pressure of the gas is

$$T_1^{\gamma}P_1^{1-\gamma} = T_2^{\gamma}P_2^{1-\gamma}$$

Where $\gamma = C_P / C_V$ is the ratio of the two specific heat capacities of the gas.

Table 3.1 *Thermodynamic processes*

Sl. No.	*Process*	*Governing equations*	*Heat interaction*	*Displacement work or non flow work during state change from 1 to 2* $W = \int_1^2 p.dV$
1.	Isobaric process	p = constant $\frac{T_2}{T_1} = \frac{v_2}{v_1}$ index $n = 0$	$q = c_p \times (T_2 - T_1)$	$W = p(V_2 - V_1)$
2.	Isochoric process	V = constant $\frac{T_1}{T_2} = \frac{p_1}{p_2}$ index, $n = \infty$	$q = c_v \times (T_2 - T_1)$	$W = 0$

3.	Isothermal process	T = constant $p_1V_1 = p_2V_2$ index, $n = 1$	$q = p_1V_1 \times \ln\left(\frac{V_2}{V_1}\right)$	$W = P_1V_1 \ln \frac{V_2}{V_1}$
4.	Adiabatic process	$p_1V_1^\gamma = p_2V_2^\gamma$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$ $\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$ index, $n = \gamma$	$q = 0$	$W = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$

3. Worked Problems:

1. A gas at 2 ATP is compressed to half of its original volume. Calculate the final pressure, if the compression is (i) isothermal and (ii) adiabatic ($\gamma = 1.4$)

Let V be the original volume

Given; $P_1 = 2$ atmosphere, $V_1 = V$ and $V_2 = ½V$

1) For Isothermal change, the equation is $P_1V_1 = P_2V_2$

$$\therefore P_2 = \frac{P_1V_1}{V_2} = \frac{2 \times V}{(1/2)V} = 4 \text{ atmospheric pressure}$$

ii)Adiabatic equation is $P_1V_1^\gamma = P_2V_2^\gamma$

$$\therefore P_2 = \frac{P_1V_1^\gamma}{V_2^\gamma} = \frac{2 \times V^\gamma}{\frac{V^\gamma}{2}} = \frac{2 \times V^\gamma \times 2^\gamma}{V^\gamma}$$

$$= 2 \times 2^\gamma = 2 \times 2^{1.4}$$

$= 2 \times 2^{1.4} = 5.278$ Atmospheric Pressure.

2. Air at a pressure of 0.75 m of mercury and of volume 1 litre is compressed to a pressure of 1.5 m of mercury under isothermal process. Calculate the resulting volume.

The equation for Isothermal change is $P_1V_1 = P_2V_2$

Given; $P_1 = 0.75$m of Hg

$P_2 = 1.5$m of Hg

$V_1 = 1$ litre

$\therefore V_2 = (P_1V_1)/P_2 = (0.75 \times 1)/1.5 = 0.5$ litre

3. A certain mass of gas at 3 atmosphere is compressed adiabatically to half of its volume. Calculate the resulting pressure if $\gamma = 1.4$

Given; $V_1 = V$, $V_2 = ½V$ and $P_1 = 3$ At. pr.

$P_2 = P_1V_1^\gamma/V_2^\gamma$

$P_2 = P_1V^\gamma/(½V)^\gamma$

$P_2 = (3 \times V^{1.4})/(½V)^{1.4} = 3 \times 2^{1.4} = 7.92$ At. pr.

Clausius Statement:

It is impossible for a self-acting mechanism working in a cyclic process unaided by an external agency to transfer heat from a body at a lower temperature to the body at a higher temperature. This part of the law is applicable in the case of ice plants and refrigerators. i.e., Heat itself cannot flow from a body at a lower temperature to a body at a higher temperature, on its own.

EXERCISES ON FIRST LAW OF THERMODYNAMIC

1. Nitrogen amounting to 10.5 grams expands isothermally at a temperature of 23^0C from a pressure of P_1 = 2.5 atm. Find the work performed by the gas during expansion.
2. One litter of He in standard conditions expands isothermally to a volume of 2 liters at the expense of heat received from a hot source. Find a) the work performed by the gas during expansion, b) the amount of heat received by the gas
3. Upon isothermally expansion of $2m^3$ of a gas its pressure changes from P_1 = 5 atm. to P_2 = 4 atm.
4. What temperature of air at 0^0C be cooled to expand adiabatically from a volume of V to V_2 = 2V
5. Upon the isothermal expansion of 100grams of nitrogen at a temperature of 17^0c. The work performed equal to 860J. How many times did the pressure of nitrogen change upon expansion.
6. Two moles of air at the normal conditions compressed to pressure of 6 atm. Find the volume and temperature after compression if a) the air is compressed isothermally, b) the air is compressed adiabatically. Find the work in each process.

4.2.3 Second law statements

The second law clearly explains that it is impossible to convert heat energy to mechanical energy with 100 per cent efficiency.

Clausius's Statement : It is impossible to construct a device operating in a cycle that can transfer heat from a colder body to a warmer one without consuming any work. Also, energy will not flow spontaneously from a low-temperature object to a higher temperature object.

2nd Law of Thermodynamics:

1. Heat flows spontaneously from a hot body to a cool one.
2. One can not convert hear completely into useful work.
3. Every isolated system becomes disordered in time.

Summary for the trainer related to the content

- ✓ An adiabatic process is one that occurs so rapidly or occurs in a system that is so well insulated that no transfer of energy as heat occurs between the system and its environment
- ✓ An isobaric process is one that takes place at constant pressure
- ✓ Clausius's Statement: It is impossible to construct a device operating in a cycle that can transfer heat from a colder body to a warmer one without consuming any work. Also, energy will not flow spontaneously from a low-temperature object to a higher temperature object.
- ✓ General expression which is combining Celsius, Kelvin and Fahrenheit temperature scales is

Theoretical learning Activity

The trainees brainstorm about

1) processes done in the cylinders when the oil is burning.

2) relationship between Clausius statement and second law of thermodynamics.

Practical learning Activity

Trainees in pair perform the following activities:

1) In an isobaric process, there is no change in

A) pressure. B) temperature. C) volume. D) internal energy.

2) An ideal gas is compressed to one-half its original volume during an isothermal process. The final pressure of the gas

A) increases to twice its original value. B) increases to less than twice its original value. C) increases to more than twice its original value. D) does not change

3) When the first law of thermodynamics, Q = DU + W, is applied to an ideal gas that is taken through an isothermal process, A) DU = 0 B) W = 0 C) Q = 0

Points to Remember (Take home message)

- First and second law of thermodynamics
- Isothermal process
- Isobaric process
- Isovolumetric process
- Adiabatic process

Learning out come 2.2 : formative assessment

Multiple choice questions

1. A gas is allowed to expand at constant pressure as heat is added to it. This process is

A) isothermal. B) isochoric. C) isobaric. D) adiabatic

2. In an isochoric process, there is no change in

A) pressure. B) temperature. C) volume. D) internal energy.

3. A gas is confined to a rigid container that cannot expand as heat energy is added to it. This process is A) isothermal. B) isochoric. C) isobaric. D) adiabatic

4. A gas is confined to a rigid container that cannot expand as heat energy is added to it. This process is A) isothermal. B) isochoric. C) isobaric. D) adiabatic.

5. 200 J of work is done in compressing a gas adiabatically. What is the change in internal energy of the gas?

A) zero B) 100 J C) 200 J D) There is not enough information to determine.

6. A heat engine receives 7000 J of heat and loses 3000 J in each cycle. What is the efficiency?

A) 57% B) 30% C) 70% D) 43%

Learning outcome 4.3. Application of thermodynamic laws

Duration: 3 hrs

Learning outcome 2.3 objectives:

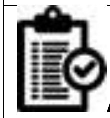
By the end of the learning outcome, the trainees will be able to:

1. apply second law of thermodynamics accurately on Refrigerators
2. apply second law of thermodynamics accurately on Heat engines
3. apply second law of thermodynamics accurately on Ventilators

Resources

Equipment	**Tools**	**Materials**

PPE, Whiteboard and chalkboard	Compute, projector, textbooks, scientific calculator, meter ruler, compass	Chalks, Markers



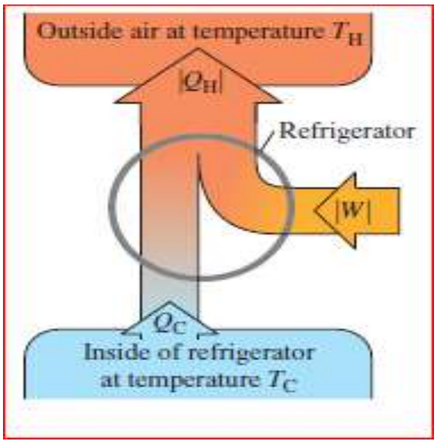
Advance preparation:

. The trainer shows to the trainees refrigerator, water heater and heat pumb where they are available.

4.3.1 Refrigerators

Refrigerators

We can think of a **refrigerator** as a heat engine operating in reverse. A heat engine takes heat from a hot place and gives off heat to a colder place. A refrigerator does the opposite; it takes heat from a cold place (the inside of the refrigerator) and gives it off to a warmer place (usually the air in the room where the refrigerator is located). A heat engine has a net *output* of mechanical work; the refrigerator requires a net *input* of mechanical work.

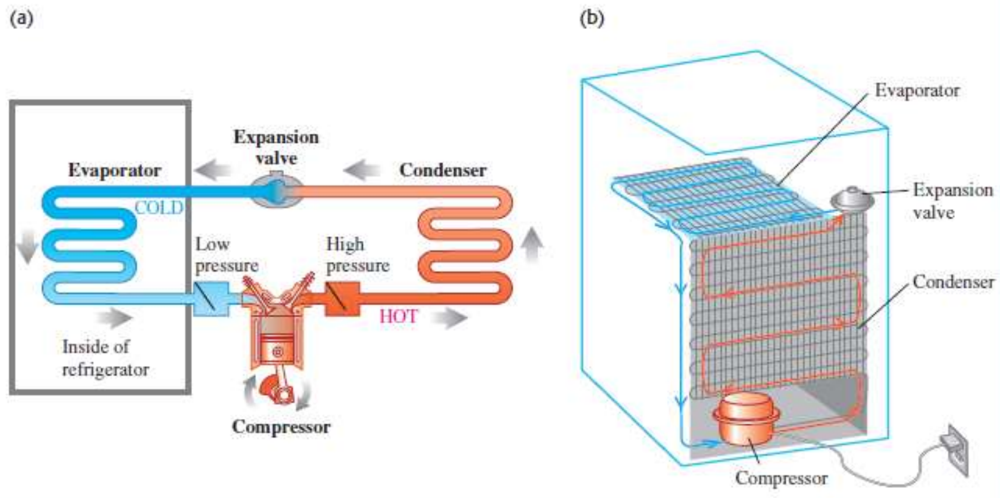


Coefficient of performance of refrigerator is

$$COP = \frac{Q_c}{w} = \frac{|Q_c|}{|Q_H - Q_c|}$$

From an economic point of view, the best refrigeration cycle is one that removes the greatest amount of heat $|Q_c|$ from the inside of the refrigerator for the least expenditure of mechanical work W,

(a) Principle of the mechanical refrigeration cycle. (b) How the key elements are arranged in a practical refrigerator.



The compressor takes in fluid, compresses it adiabatically, and delivers it to the condenser coil at high pressure. The fluid temperature is then higher than that of the air surrounding the condenser, so the refrigerant gives off heat Q_H and partially condenses to liquid. The fluid then expands adiabatically into the evaporator at a rate controlled by the expansion valve. As the fluid expands, it cools considerably, enough that the fluid in the evaporator coil is colder than its surroundings.

4.3.2 Heat engines

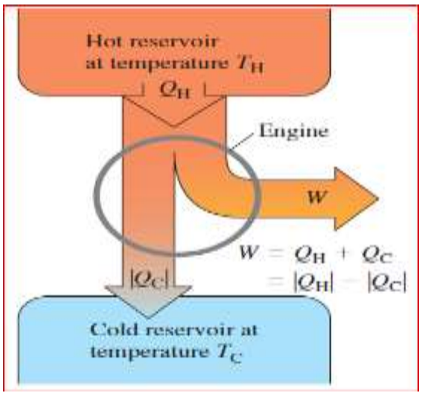
Heat reservoir is the system having very large heat capacity i.e. it is a body capable of absorbing or rejecting finite amount of energy without any appreciable change in its' temperature.

Thus in general it may be considered as a system in which any amount of energy may be dumped or extracted out and there shall be no change in its temperature. Such as *atmosphere* to which large amount of heat can be rejected without measurable change in its temperature. Large river, sea etc. can also be considered as reservoir, as dumping of heat to it shall not cause appreciable change in temperature.

Heat reservoirs can be of two types depending upon nature of heat interaction i.e. heat rejection or heat absorption from it.

Heat reservoir which rejects heat from it is called *source*. While the heat reservoir which absorbs heat is called ***sink.*** Sometimes these heat reservoirs may also be called Thermal Energy Reservoirs (TER).

Heat engine is a device used for converting heat into work. Thus, heat engine may be precisely defined as "a device operating in cycle between high temperature source and low temperature sink and producing work". Heat engine receives heat from source, transforms some portion of heat into work and rejects balance heat to sink. All the processes occurring in heat engine constitute cycle.



Block diagram representation of a heat engine is shown above.

When an engine repeats the same cycle over and over, and represent the quantities of heat absorbed Q_H and Q_c rejected by the engine *during one cycle; Q_H* is positive, and Q_C is negative. The *net* heat *Q* absorbed per cycle is

$$Q = Q_H + Q_c = |Q_H| - |Q_c|$$

The useful output of the engine is the net work *W* done by the working substance.

From the first law,

$$w = Q_H + Q_c = |Q_H| - |Q_c|$$

Efficiency of heat engine

Efficiency of heat engine can be given by the ratio of net work and heat supplied.

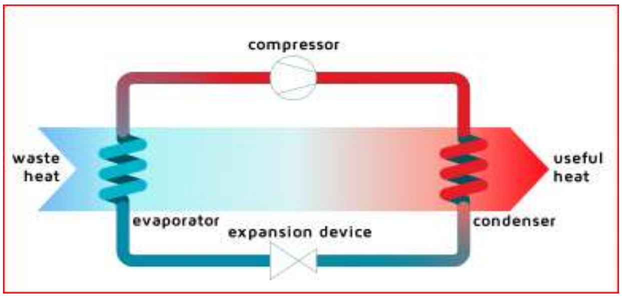
$\eta_{heat-engine} = \dfrac{W}{Q_1}$, where W is the net work and Q_1 is the heat supplied.

The efficiency can be given as $\eta = \dfrac{w}{Q_H} = 1 - \dfrac{Q_c}{Q_H}$, where work is $w = |Q_H| - |Q_c|$

Ideally, we would like to convert *all* the heat Q_H into work; in that case we would have $Q_H = w$ and $Q_c = 0$. Experience shows that this is impossible; there is always some heat wasted, and Q_c *is never zero.*

4.3.3 Heat pumb

A **heat pump** is a device used to warm and sometimes also cool buildings by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle, being the opposite direction in which **heat transfer** would take place without the application of external power. The heat pump has four main components: evaporator, compressor, condenser and expansion device. In the evaporator heat is extracted from a waste heat source. In the condenser this heat is delivered to the consumer at a higher temperature level. Electric energy is required to drive the compressor and this energy is added to the heat that is available in the condenser. The efficiency of the heat pump is denoted by its COP (coefficient of performance), defined as the ratio of total heat delivered by the heat pump to the amount of electricity needed to drive the heat pump.



Where CP is the coefficient of performance. Q_H is the input heat and W is the work done.

$$CP = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C} \Rightarrow \frac{T_H}{T_H - T_C}$$

Coefficient of Performance for Heat Pumps

$$COP_{hp} = \frac{\text{Heating Effect}}{\text{Work Input}}$$

$$COP_{hp} = \frac{Q_H}{W_{net}} = \frac{\dot{Q}_H}{\dot{W}_{net}}$$

4.3.4 Ventilators Power plant

Wind energy as a clean energy source that has an enormous potential, but in its use is still very small [6]. Small amount of electrical power generation turbo ventilator more efficient as camper to solar panel. There are two different modes of ventilation techniques. Passive Ventilation Technique 2. Active Ventilation Technique Turbo ventilators are Active ventilators .This ventilator works on natural wind energy. A turbo ventilator consists of number of vertical blades in a spherical array mounted on a frame. At the center, a shaft is supported by upper and lower bearings. A rainproof dome is provided on top of the frame of turbo ventilator. When wind blows on the blades the resulting lift and drag forces cause the turbine to rotate Due to this rotation, produces a negative Pressure at the center of the turbine ventilator which extracts hot air.

Summary for the trainer related to the content

- ✓ **System** : a set of things working together as parts of a mechanism or an interconnecting network; a complex whole..
- ✓ Surrounding : The surroundings are **everything outside the system** and are the place where the observation and measurements of the system are taken.
- ✓ **Clausius Statement:** It is impossible for a self-acting mechanism working in a cyclic process unaided by an external agency to transfer heat from a body at a lower temperature to the body at a higher temperature.
- ✓ Applications of refrigerator as uses second law of thermodynamics by

Theoretical learning Activity

In pair, the trainees perform the following tasks;

- ✓ In group, the trainees discuss about open and closed system and give some examples on each system.
- ✓ In group, the trainees discuss on 4 stages of Carnot cycle by relating each stage with second law of thermodynamics.
- ✓ In group, the trainees discuss about the differences between heat pump and refrigerator.

Practical learning Activity

Trainees in pair perform the following activities:

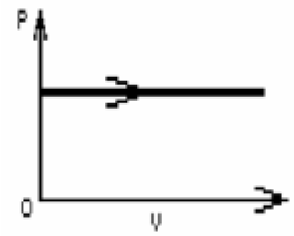
- ✓ Suppose you have an ideal refrigerator that cools an environment at -20^0C and has heat transfer to another environment at 50^0C. What is its coefficient of performance.
- ✓ In a very wild winter climate, a heat pump has heat transfer from an environment at 5^0C to one at 35^0C. What is the best possible coefficient of performance for these temperature?
- ✓ Suppose you want to operate an ideal refrigerator with a cold temperature of -10^0C and you could like it to have a coefficient of performance of 7. What is the hot reservoir temperature for such a refrigerator?
- ✓ An ideal heat pump is being considered for use in heating an environment with a temperature of 22^0C. What is the cold reservoir temperature if the pump is to have a coefficient of performance of 12.

Points to Remember (Take home message)

- o Open system
- o Closed system
- o First and second law of thermodynamic
- o Working principle of refrigerator
- o Working principle of heat pump

Formative assessment of learning outcome 4.3.

- ✓ A gas is expanded to twice its original volume with no change in its temperature. This process is A) isothermal. B) isochoric. C) isobaric. D) adiabatic.
- ✓ An ideal gas is compressed isothermally from 30 L to 20 L. During this process, 6.0 J of energy is expended by the external mechanism that compressed the gas. What is the change of internal energy for this gas?
- ✓ An ideal gas is compressed to one-half its original volume during an isothermal process. The final pressure of the gas A) increases to twice its original value. B) increases to less than twice its original value. C) increases to more than twice its original value. D) does not change.
- ✓ When the first law of thermodynamics, $Q = \Delta U + W$, is applied to an ideal gas that is taken through an adiabatic process, A) $\Delta U = 0$. B) $W = 0$. C) $Q = 0$. D) none of the above
- ✓ The process shown on the PV diagram is an



A) adiabatic expansion. B) isothermal expansion. C) isometric expansion.
D) isobaric expansion

Learning Unit 5: Examine effects of electric current flow in DC electric circuit

STRUCTURE OF LEARNING UNIT

Learning outcomes:

5.1 Describe simple electric circuit

5.2 Determine of electric current, resistances and voltages in DC electric circuit

Learning outcome 5.1 Describe simple electric circuit

Duration: 4 hrs

Learning outcome 5.1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe clearly simple electric circuit
2. Properly Determine electric current, resistances and voltages in DC electric circuits
3. Clearly Determine of electric energy, work and power in DC electric circuit

Resources

Equipment	Tools	Materials
PPE,whiteboard, chalkboard, optical benc, optical slides, computer,projector, textbooks	Scientific calculator	Chalks, Markers, Candles, Water

Advance preparation:

.Ohm's law

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.

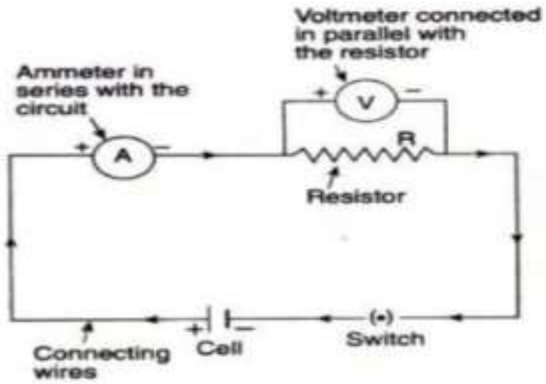
5.1 Describe correctly components of simple electric circuits

5.1.1 Electric Current: The flow of electric charge is known as Electric Current, Electric current is carried by moving electrons through a conductor.

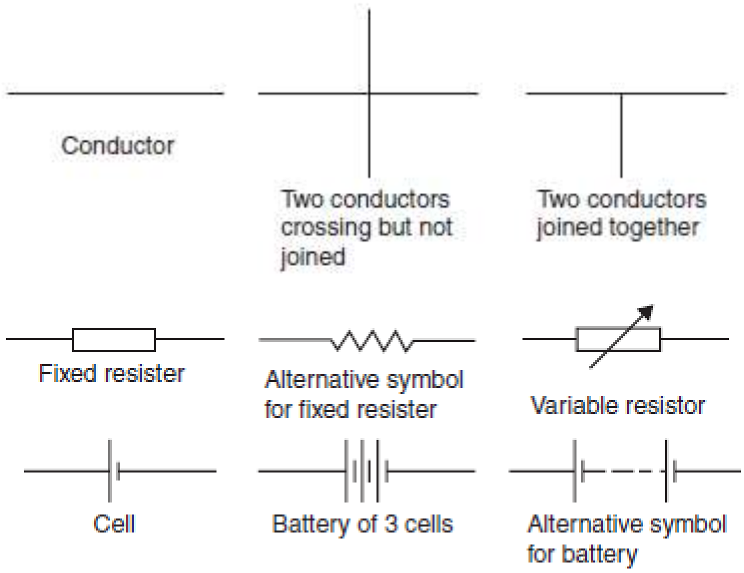
By convention, electric current flows in the opposite direction to the movement of electrons.

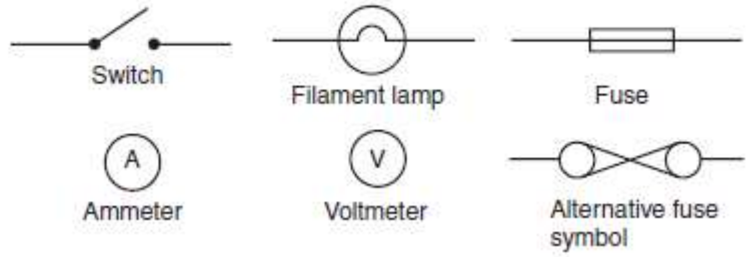
5.1.2 Electric Circuit: Electric circuit is a continuous and closed path of electric current.

A simple circuit is a circuit that contains the five basic components needed for an electric circuit to function. The five basic components are **a source of voltage, a connecting wires, an Ammeter , a Voltmeter and a resistor.**

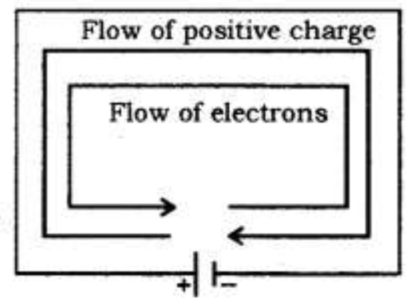


Common electrical component symbols





5.1.3 Expression of Electric Current: Electric current is denoted by the letter 'I'. Electric current is expressed by the rate of flow of electric charges. Rate of flow means, the amount of charge flowing through a particular area in unit time.



Conventional flow of electric charge.

If a net electric charge (Q) flows through a cross-section of a conductor in time t, then,

$$\text{Electric current (I)} = \frac{\text{Net charge (Q)}}{\text{Time } (t)} \quad \text{or,} \quad \boxed{I = \frac{Q}{t}}$$

Where I is electric current, Q is a net charge and t is a time in second.

S.I. Unit of Electric Charge and Current: S.I. unit of electric charge is coulomb (C).

One coulomb is nearly equal to 6×10^{18} electrons. S.I. unit of electric current is ampere (A). Ampere is the flow of electric charge through a surface at the rate of one coulomb per second. This means, if 1 coulomb of electric charge flows through a cross section for 1 second, it would be equal to 1 ampere.

Therefore, 1 A = 1 C/1 s

Small Quantity of Electric Current: Small quantity of electric current is expressed in milliampere and microampere. Milliampere is written as mA and microampere as μA.

1 mA (milliampere) = 10^{-3} A

1 μA. (microampere) = 10^{-6} A

5.1.4 Work

The **unit of work or energy** is the **joule∗ (J)**, where one joule is one newton metre. The joule is defined as the work done or energy transferred when a force of one newton is exerted through a distance of one metre in the direction of the force. Thus

work done on a body, in joules, W=Fs

where F is the force in newtons and s is the distance in metres moved by the body in the direction of the force.

5.1.5 Electrical Power and Energy

When a direct current of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts, then **power in watts**, **P = VI**

Electrical energy = Power×time= **VIt joules**

Although the unit of energy is the joule, when dealing with large amounts of energy the unit used is the **kilowatt hour (kWh)** where

1kWh = 1000 watt hour

= 1000×3600 watt seconds or joules

= 3600000J

The **unit of power** is the **watt**∗ (W), where one watt is one joule per second. Power is defined as the rate of doing work or transferring energy. Thus,

power, in watts P= W/t

where W is the work done or energy transferred, in joules, and t is the time, in seconds. Thus,

energy, in joules W=Pt

Problem .

A portable machine requires a force of 200N to move it. How much work is done if the machine is moved 20m and what average power is

utilized if the movement takes 25 s?

Work done = force × distance = 200N×20m = **4 000Nm or 4 kJ**

Power = work done/time taken = 4000J/25s = **160J/s** = **160W**

Problem: A current of 3A flows for 5minutes.What charge is transferred?

Problem: How long must a current of 0.1A flow so as to transfer a charge of 30C?

5.1.6 Resistance:

Resistance is a property of conductor due to which it resists the flow of electric current through it. A component that is used to resist the flow of electric current in a circuit is called a resistor. In practical application, resistors are used to increase or decrease the electric current.

The unit of electric resistance is the ohm (Ω)

Factors on Which Resistance of a Conductor Depends: Resistance in a conductor depends on nature, length and area of cross section of the conductor.

(i) Nature of Material: Some materials create least hindrance and hence, are called good conductors. Silver is the best conductor of electricity. While some other materials create more hindrance in the flow of electric current, i.e. flow of electrons through them. Such materials are called bad conductors. Bad conductor are also known as insulators. Hard plastic is the one of the best insulators of electricity.

(ii) Length of Conductor: Resistance (R) is directly proportional to the length of the conductor. This means, resistance increases with increase in length of the conductor. This is the cause that long electric wires create more resistance to the electric current. Thus, Resistance (R) ∝ length of conductor (l) or, $R \propto l$ …(i)

(iii) Area of Cross Section: Resistance R is inversely proportional to the area of cross section (A) of the conductor. This means R will decrease with an increase in the area of conductor and vice versa. More area of conductor facilitates the flow of electric current through more area and thus, decreases the resistance. This is the cause that thick copper wire creates less resistance to the electric current.

Thus, resistance (R) ∝ 1/Area of cross section of conductor (A)

or, R ∝ l/A ....(ii)

From equations (i) and (ii)

R ∝ l/A

R = ρ l/A

Where, ρ (rho) is the proportionality constant. It is called the electrical resistivity of the material of conductor.

From equation (iii) RA = ρl ⇒ ρ = RA/l ..(iv)

The S.I. of Resistivity: Since, the S.I. unit of R is Q, S.I. unit of area is m^2 and S.I. unit of length is m. Hence, unit of resistivity (ρ) = Ω×m2m = Ωm

Thus, S.I. unit of resistivity (ρ) is Ωm.

Resistivity: It is defined as the resistance offered by a cube of a material of side 1m when current flows perpendicular to its opposite faces. It's S.I. unit is ohm-meter (Ωm).

Resistivity, ρ = RA/l

Resistivity is also known as specific resistance.

Resistivity depends on the nature of the material of the conductor.

Materials having a resistivity in the range of 10^{-8} Ωm to 10^{-6} Ωm are considered as very good conductors. Silver has resistivity equal to 1.60 × 10^{-8} Ωm and copper has resistivity equal to 1.62 × 10^{-8} Ωm.

Rubber and glass are very good insulators. They have a resistivity in the order of 10^{-12} Ωm to 10^{-8} Ωm.

The resistivity of materials varies with temperature

5.1.7 Electrical Potential and Electromotive force (e.m.f.)

The unit of electric potential is the volt (V) where one volt is one joule per coulomb. One volt is defi ned as the difference in potential between two points in a conductor which, when carrying a current of one ampere, dissipates a power of one watt, i.e.,

$$\text{volts} = \frac{\text{watts}}{\text{amperes}} = \frac{\text{joules/second}}{\text{amperes}} = \frac{\text{joules}}{\text{ampere seconds}} = \frac{\text{joules}}{\text{coulombs}}$$

A change in electric potential between two points in an electric circuit is called a potential difference .

The electric potential created by a point charge at any distance r from the charge is

- Electric potential of a point charge is $V = kQ/r$.

where k is a constant equal to $9.0 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$.

Electromotive Force :emf

The battery as a device that produces a potential difference and causes charges to move. In fact, it is a device that works as an energy converter.

A battery is often called a source of electromotive force or, a source of emf (this unfortunate historical name describes a potential difference in volts, but not a force).

Spotlight

The emf $\mathcal{E}$ of a battery is the maximum possible potential difference that the battery can provide between its terminals, usually the voltage at zero current.

. **The emf is equal to the potential difference across the terminals of the source when no current flows**. When a current I flows, this potential difference is less than the emf because of the internal resistance of the source. If the internal resistance is r , then a potential drop of Ir occurs within the source. The terminal voltage V across a source of emf Ve whose internal resistance is r when it provides a current of I is therefore

$V = V_e - Ir$

Terminal voltage = emf − potential drop due to internal resistance

When a battery or generator of emf V_e is connected to an external resistance R, the total resistance in the circuit is R + r , and the current that flows is

$$I = \frac{V_e}{R + r}$$

$$Current = \frac{emf}{exterrnal\ resis\tan ce + \operatorname{int} ernal\ resis\tan ce}$$

$$\text{Current} = \frac{\text{emf}}{\text{external resistance} + \text{internal resistance}}$$

Figure 24.11a shows a device (a battery) with an emf **E** that is used in a simple circuit containing a resistor of resistance R. The battery keeps one terminal (labeled with the sign +) at a higher electric potential than the other (labeled with the sign −).

Therefore, within the battery, the conventional positive charge carriers move from a region of low electric potential (at the negative terminal) to a region of higher electric potential (at the positive terminal).

Because a real battery is made of matter, there is a resistance against the flow of charge within the battery. This resistance is called the battery's internal resistance and is usually denoted by **r**. For an ideal battery with zero internal resistance, the potential difference between its terminals is equal to its emf **E** (directed from the − terminal to the + terminal). For real batteries, this is not the case.

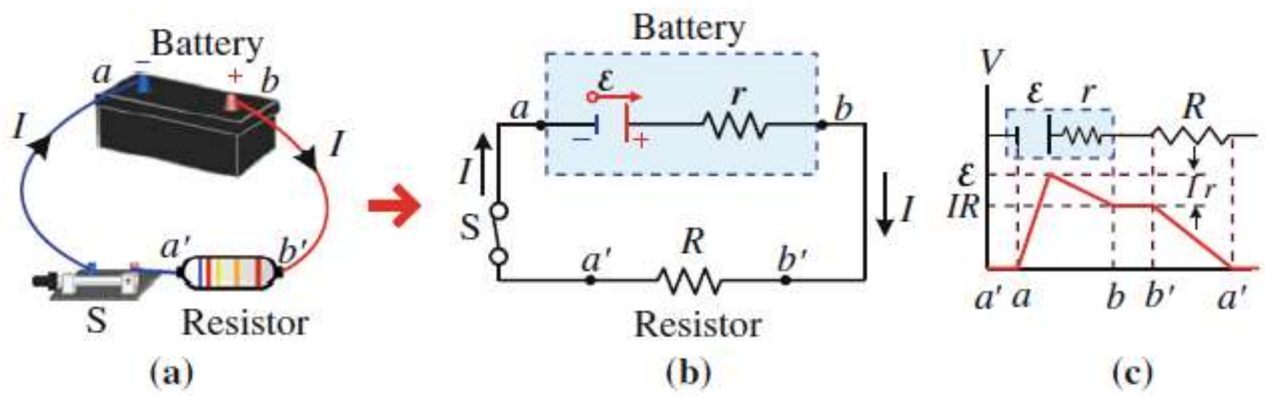


Fig. 24.11 (a) A simple circuit containing a resistor connected to a battery. (b) A circuit diagram of a source of emf $\mathcal{E}$ (the battery) of internal resistance r, connected to a resistor of resistance R. (c) Graphical representation of the electric potential at different points

We now consider the circuit diagram in Fig. 24.11b, which is the same as the real emf device of Fig. 24.11a, except we represent the battery with a dashed rectangular box containing an ideal emf **E** in series with an internal resistance r.

Let us start at point a (where the potential is Va), and move clockwise to point b (where the potential is Vb), and measure the electric potential at different locations.

When we move from the negative terminal to the positive terminal, the potential increases by the amount of the emf E. However, as we move through the internal resistance r in the direction of the current I, the potential drops by an amount Ir.

Thus, the potential difference between the terminals of the battery ΔV =Vb − Va is:

$$\Delta V = \mathcal{E} - Ir \quad (\Delta V = \mathcal{E} \text{ for an open-circuit}) \qquad \mathcal{E} = IR + Ir$$

Solving for the current, we get:

$$I = \frac{\mathcal{E}}{R + r}$$

Note that the current I depends on the resistance R of the external resistor (which is called the load) and the internal resistance r of the battery. Since **R>> r** in most circuits, we can usually neglect r.   If we multiply Equation

$$\mathcal{E} = IR + Ir$$

by the current I, we get

$$I\mathcal{E} = I^2R + I^2r$$

This equation tells us that the total power output $I\mathcal{E}$ of the source of emf is converted at the rate I^2R at which energy is delivered to the load resistance, *plus* the rate I^2r at which energy is delivered to the internal resistance. Again, if $r << R$, most of the power delivered by the battery is transferred to the load resistance.

5.1.8 Advantages and dangers Electricity

Benefits of electric power

1. It facilitates many processes of various kinds, whether personal, domestic, professional and industrial.
2. Generating and transporting this energy is very efficient.
3. Through certain instruments, we manifest it as artificial light.
4. It has led to a huge leap in the development of science and medicine.
5. Many means of transport are operating on the basis of electricity, vehicles and trains.
6. It can be transported over long distances through wiring and electrical laying.
7. It has boosted the economic development of cities.
8. It allows the execution of projects of great magnitude and social impact.
9. For countries that have surplus-generation, it serves as an additional income to be able to export energy to nearby countries.
10. It is currently accessible to the majority of the population.

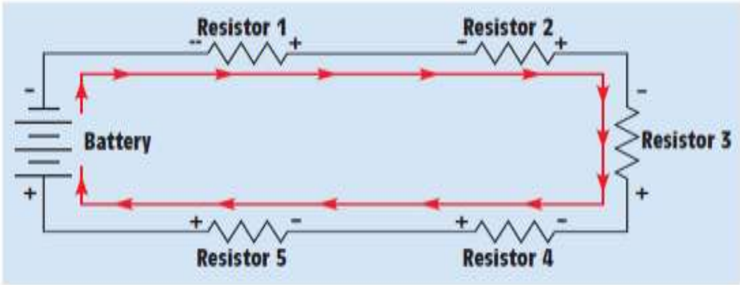
Disadvantages of electric power

1. The contact of this energy with the human body could generate deadly results.
2. One of the most common forms of generation is the hydro-electric, so it involves negatively affecting the environment.
3. There is a latent risk, for example, the short circuits have caused fires in residences and large factories.
4. In certain places, it can be very costly to enjoy the electricity service.
5. The availability of this energy is affected by drought and other climatic conditions.
6. The level of comfort and ease that is available with electricity, when this lack stops the normality of cities.
7. It is an extremely limited resource, and at present other means of generation are sought.
8. At the industry level there is no ability to satisfy some caloric uses.
9. An imbalance in energy levels can damage equipment and appliances.
10. When transported in carbon silver, it generates many highly toxic residues.

5.1.9 Categorization of electric circuits:

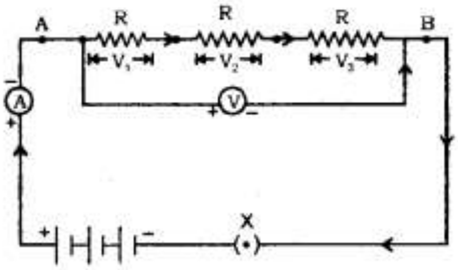
5.1.9.1 Resistors in Series:

A **series circuit** is a circuit that has only one path for current flow.
Because there is only one path for current flow, the current is the same at any point in the circuit.

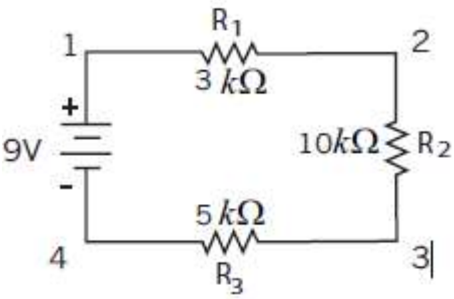


voltage drop: In a series circuit, the sum of all the voltage drops across all the resistors must equal the voltage applied to the circuit

When resistors are joined from end to end, it is called in series. In this case, the total resistance of the system is equal to the sum of the resistance of all the resistors in the system.

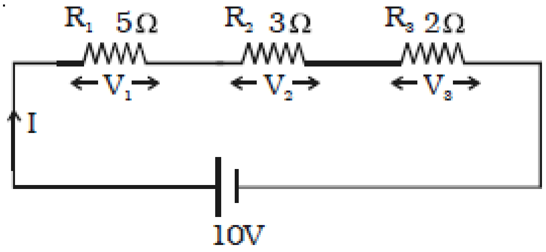


Let, three resistors R_1, R_2, and R_3 get connected in series.
Potential difference across A and B = V
Potential difference across R_1, R_2 and R_3 = V_1, V_2 and V_3
Current flowing through the combination = I
We, know that $V= V_1 + V_2 + V_3$ .... (i)
According to Ohm's Law : $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$ ..... (ii)
Let, total resistance = Rs
Then, $V = IR_s$ ...(iii)
From equations (i) and (ii) and (iii)
$IR_s = IR_1 + IR_2 + IR_3$
$R_s = R_1 + R_2 + R_3$
When the resistors are connected in series, the current flowing through each resistor is the same and is equal to the total current.
Problem: Find the equivalent resistance in the circuit below:



$$R = R_1 + R_2 + R_3$$
$$R = 3k\Omega + 10k\Omega + 5k\Omega$$
$$R = 18k\Omega$$

Three resistors are connected in series with 10 V supply as shown in the figure. Find the voltage drop across each resistor.



Data : $R_1 = 5\Omega$, $R_2 = 3\Omega$, $R_3 = 2\Omega$; $V = 10$ volt

Effective resistance of series combination,

$$R_s = R_1 + R_2 + R_3 = 10\Omega$$

Solution : Current in circuit $I = \frac{V}{R_s} = \frac{10}{10} = 1A$

Voltage drop across R_1, $V_1 = IR_1 = 1 \times 5 = 5V$

Voltage drop across R_2, $V_2 = IR_2 = 1 \times 3 = 3V$

Voltage drop across R_3, $V_3 = IR_3 = 1 \times 2 = 2V$

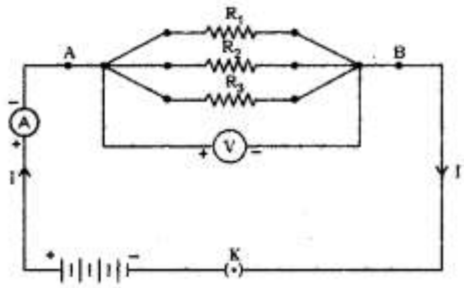
Summary

- Series circuits have only one path for current flow.
- The individual voltage drops in a series circuit can be added to equal the applied voltage.
- The current is the same at any point in a series circuit.
- The individual resistors can be added to equal the total resistance of the circuit.
- Fuses and circuit breakers are connected in series with the devices they are intended to protect.
- The total power in any circuit is equal to the sum of the power dissipated by all parts of the circuit.

Problem: A series circuit contains four resistors. The total resistance of the circuit is 360 V. Three of the resistors have values of 56 V, 110 V, and 75 V.
What is the value of the fourth resistor?

5.1.9.2 Resistors in Parallel:

When resistors are joined in parallel, the reciprocal of the total resistance of the system is equal to the sum of reciprocal of the resistance of resistors.



Let three resistors R_1, R_2 and R_3 connected in parallel.
Potential difference across point A and B = V
Total current flowing between point A and B = I

Currents flowing through resistors R_1, R_2 and R_3 = I_1, I_2 and I_3 respectively.
We, know that,
$I = I_1 + I_2 + I_3$ ....(i)
Since, the potential difference across R_1, R_2, and R_3 is the same = V
According to Ohm's Law,

$$I_1 = \frac{V}{R_1}, I_2 \frac{V}{R_2} \text{ and, } I_3 = \frac{V}{R_3} \quad ....(ii)$$

Let, Total Resistance = R_p

Thus, $I = \frac{V}{R_p}$ ...(iii)

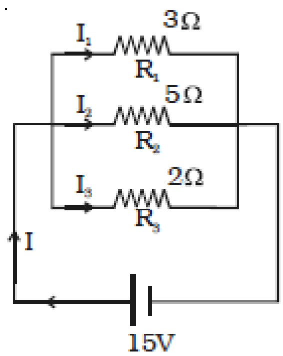
From equations (i), (ii) and (iii)

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \Rightarrow \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad ...(iv)$$

In parallel combination, the potential difference across each resistor is the same and is equal to the total potential difference.
The total current through the circuit can be calculated by adding the electric current through individual resistors.
I total = 6A + 48A + 30A + 12A + 24A = 120A

Find the current flowing across three resistors 3Ω, 5Ω and 2Ω connected in parallel to a 15 V supply. Also find the effective resistance and total current drawn from the supply.

Data : R_1 = 3Ω, R_2 = 5Ω, R_3 = 2Ω ; Supply voltage V = 15 volt



Solution :

Effective resistance of parallel combination

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{3} + \frac{1}{5} + \frac{1}{2}$$

R_p = 0.9677 Ω

Current through R_1, $I_1 = \frac{V}{R_1} = \frac{15}{3} = 5A$

Current through R_2, $I_2 = \frac{V}{R_2} = \frac{15}{5} = 3A$

Current through R_3, $I_3 = \frac{V}{R_3} = \frac{15}{2} = 7.5A$

Total current $I = \frac{V}{R_p} = \frac{15}{0.9677} = 15.5$ A

Summary

- A Parallel circuit is characterized by the fact that it has more than one path for current fl ow.
- Three rules for solving parallel circuits are as follows:

a. The total current is the sum of the currents through all of the branches of the circuit.

b. The voltage across any part of the circuit is the same as the total voltage.

c. The total resistance is the reciprocal of the sum of the reciprocals of each individual branch.

- Circuits in homes are connected in parallel.
- The total power in a parallel circuit is equal to the sum of the power dissipation of all the components.
- Parallel circuits are current dividers.
- The current fl owing through each branch of a parallel circuit can be calculated when the total resistance and the total current are known.
- The amount of current fl ow through each branch of a parallel circuit is inversely proportional to its resistance.

5.1.11 Components of simple circuit

5.1.11.1 Ammeter

An ammeter /ˈamɪtə/ (abbreviation of Ampere meter) is **a measuring instrument used to measure the current in a circuit**. Electric currents are measured in Amperes (A), hence the name. The ammeter is usually connected in series with the circuit in which the current is to be measured

5.1.11.2 Voltmeter

Voltmeter, **instrument that measures voltages of either direct or alternating electric current on a scale usually graduated in volts, millivolts (0.001 volt), or kilovolts (1,000 volts)**. Many voltmeters are digital, giving readings as numerical displays.

5.1.11.3 Rheostat

Rheostat, **adjustable resistor used in applications that require the adjustment of current or the varying of resistance in an electric circuit**. The rheostat can adjust generator characteristics, dim lights, and start or control the speed of motors.

Theoretical learning Activity

- ✓ Group work for Illustration of a simple DC electric circuit
- ✓ Experimental demonstration of connecting a DC electric circuit
- ✓ Laboratory work on measurement of electric current, resistance and voltage.
- ✓ Laboratory work on experimental verification of Ohm's law
- ✓ Individual work of problem solving on combination of resistors
- ✓ Group work of problem solving on combination of cells

Practical learning Activity

1- Four resistors are arranged as shown in Figure. Find

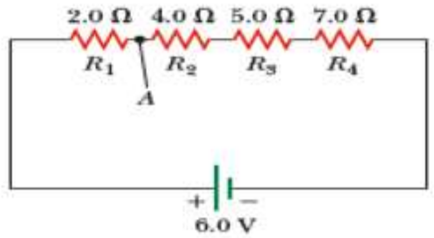
(a) the equivalent resistance of the circuit and

(b) the current in the circuit if the closed-circuit terminal voltage of the battery is 6.0 V.

(c) Calculate the electric potential at point A if the potential at the positive terminal is 6.0 V.

(d) Suppose the open circuit voltage, or emf E, is 6.2 V. Calculate the battery's internal resistance

. **(e)** What fraction f of the battery's power is delivered to the load resistors?



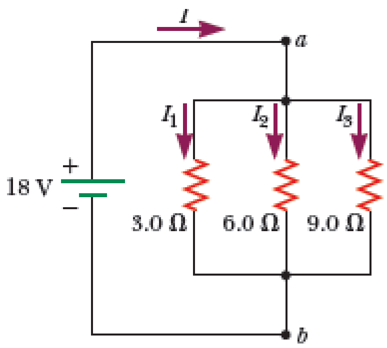
2- Three resistors are connected in parallel as in Figure 18.8. A potential difference of 18 V is maintained between points a and b.

(a) Find the current in each resistor

(b) Calculate the power delivered to each resistor and the total power.

(c) Find the equivalent resistance of the circuit.

(d) Find the total power delivered to the equivalent resistance.



Points to Remember (Take home message)

- ✓ Electric Current: The flow of electric charge
- ✓ Electric circuit is a continuous and closed path of electric current.
- ✓ Voltage=resistance x current
- ✓ Electrical energy = Power × time= VIt
- ✓ Resistance in a conductor depends on nature, length and area of cross section of the conductor.
- ✓ In series connection, the total resistance of the system is equal to the sum of the resistance of all the resistors in the system.

Learning Outcome 5.2: Determination of electric current, resistances and voltages in DC electric circuits

Duration: 4 hrs
Learning outcome 5.2 objectives: By the end of the learning outcome, the trainees will be able to 1. Analyzing correctly Circuit using Kirchhoff's laws
Resources

Equipment	**Tools**	**Materials**
PPE, whiteboard, chalkboard, optical benc,optical slides, computer, projector, textbooks	Scientific calculator	Chalks, Markers, Candles, Water

Advance preparation: .Ohm's law

5.2.1 Kirchhoff's laws

Ohm's law is applicable only for simple circuits.

The current that flows in each branch of a complex circuit can be found by applying Kirchhoff 's rules to the circuit. The first rule applies to junctions of three or more wires and is a consequence of conservation of charge. The second rule applies to loops, which are closed conducting paths in the circuit, and is a consequence of conservation of energy.

For complicated circuits, Kirchoff's laws can be used to find current or voltage.

There are two generalised laws : **(i) Kirchoff's current law (ii) Kirchoff's voltage law**

5.2.3 Kirchoff's first law (current law)

The sum of the currents entering any junction must equal the sum of the currents leaving that junction. (This rule is often referred to as the **junction rule**.)

This law refers to the currents in a junction or node.

The algebraic sum of the currents going into a node is equal to zero. Currents going in are positive and those going out of the node are negative.

Another easier way to understand is to say the sum of the currents going in are equal to the sum of the currents going out of the node.

$$\sum I_{in} = \sum I_{out}$$

5.2.4 Kirchoff's second law (voltage law)

The sum of the potential differences across all the elements around any closed circuit loop must be zero. (This rule is usually called the **loop rule**.)

The sum of the voltages around a closed loop are equal to zero.

Another way of saying the same thing, that is perhaps easier to understand is :The sum of voltage sources is equal to the voltage drops around a closed loop.

When applying Kirchhoff's rules, you must make two decisions at the beginning of the problem:

1. Assign symbols and directions to the currents in all branches of the circuit.

Don't worry about guessing the direction of a current incorrectly; the resulting answer will be negative, but its magnitude will be correct. (Because the equations are linear in the currents, all currents are to the first power.)

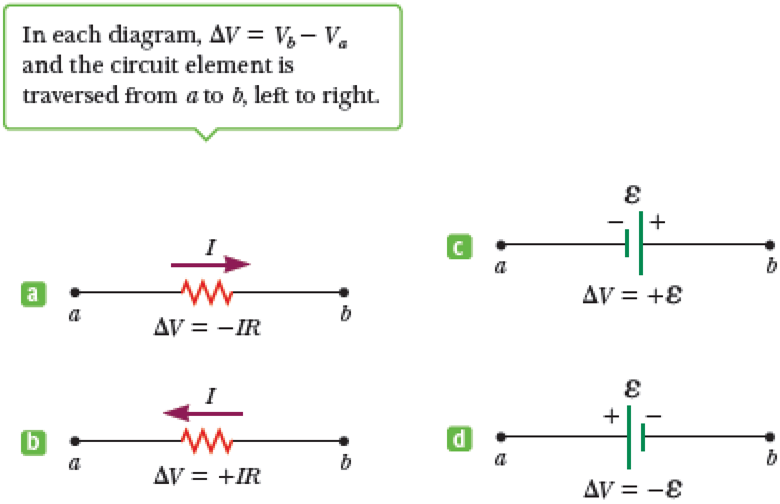
2. When applying the loop rule, you must choose a direction for traversing the loop and be consistent in going either clockwise or counterclockwise. As you traverse the loop, record voltage drops and rises according to the following rules (summarized in Fig. 18.13, where it is assumed that movement is from point a toward point b):

(a) If a resistor is traversed in the direction of the current, the change in electric potential across the resistor is $-IR$ (Fig. 18.13a).

(b) If a resistor is traversed in the direction opposite the current, the change in electric potential across the resistor is $+IR$ (Fig. 18.13b).

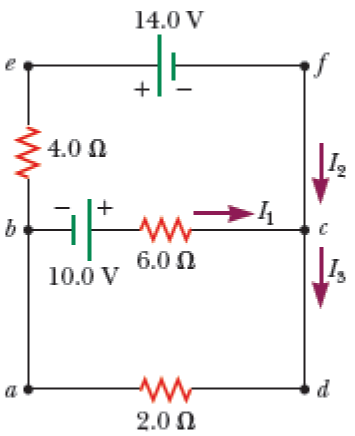
(c) If a source of emf is traversed in the direction of the emf (from $-$ to $+$ on the terminals), the change in electric potential is $+\mathcal{E}$ (Fig. 18.13c).

(d) If a source of emf is traversed in the direction opposite the emf (from $+$ to $-$ on the terminals), the change in electric potential is $-\mathcal{E}$ (Fig. 18.13d).



Find the currents in a circuit with three currents and two batteries when some current directions are chosen wrongly.

PROBLEM Find I_1, I_2, and I_3 in Figure



STRATEGY Use Kirchhoff's two rules, the junction rule once and the loop rule twice, to develop three equations for the three unknown currents. Solve the equations simultaneously.

SOLUTION

Apply Kirchhoff's junction rule to junction *c*. Because of the chosen current directions, I_1 and I_2 are directed into the junction and I_3 is directed out of the junction.

(1) $I_3 = I_1 + I_2$

Apply Kirchhoff's loop rule to the loops *abcda* and *befcb*. (Loop *aefda* gives no new information.) In loop *befcb*, a positive sign is obtained when the 6.0-Ω resistor is traversed because the direction of the path is opposite the direction of the current I_1.

(2) Loop *abcda*: $10\ \text{V} - (6.0\ \Omega)I_1 - (2.0\ \Omega)I_3 = 0$

(3) Loop *befcb*: $-(4.0\ \Omega)I_2 - 14\ \text{V} + (6.0\ \Omega)I_1 - 10\ \text{V} = 0$

Using Equation (1), eliminate I_3 from Equation (2) (ignore units for the moment):

$10 - 6.0I_1 - 2.0(I_1 + I_2) = 0$

(4) $10 = 8.0I_1 + 2.0I_2$

Divide each term in Equation (3) by 2 and rearrange the equation so that the currents are on the right side:

(5) $-12 = -3.0I_1 + 2.0I_2$

Subtracting Equation (5) from Equation (4) eliminates I_2 and gives I_1:

$22 = 11I_1 \rightarrow I_1 = 2.0\ \text{A}$

Substituting this value of I_1 into Equation (5) gives I_2:

$2.0I_2 = 3.0I_1 - 12 = 3.0(2.0) - 12 = -6.0\ \text{A}$

$I_2 = -3.0\ \text{A}$

Finally, substitute the values found for I_1 and I_2 into Equation (1) to obtain I_3:

$I_3 = I_1 + I_2 = 2.0\ \text{A} - 3.0\ \text{A} = -1.0\ \text{A}$

5.2.5 Heating Effect of Electric Current:

When electric current is supplied to a purely resistive conductor, the energy of electric current is dissipated entirely in the form of heat and as a result, resistor gets heated. The heating of resistor because of dissipation of electrical energy is commonly known as Heating Effect of Electric Current. Some examples are as follows: When electric energy is supplied to an electric bulb, the filament gets heated because of which, it gives light. The heating of electric bulb happens because of heating effect of electric current.

Cause of Heating Effect of Electric Current:

Electric current generates heat to overcome the resistance offered by the conductor through which it passes. Higher the resistance, the electric current will generate higher amount of heat. Thus, generation of heat by electric current while passing through a conductor is an inevitable consequence. This heating effect is used in many appliances, such as electric iron, electric heater, electric geyser, etc.

Joule's Law of Heating:

Let, an electric current, I is flowing through a resistor having resistance = R.

The potential difference through the resistor is = V.

The charge, Q flows through the circuit for the time, t

Thus, work done in moving of charge (Q) of potential difference (V),

$W = V \times Q$

Since this charge, Q flows through the circuit for time t

Therefore, power input (P) to the circuit can be given by the following equation :

$P = W/T$

$P = V \times Q/t$ …..(i)

We know, electric current, $I = Q/t$

Substituting $Q/t = I$ in equation (i), we get,

$P = VI$ …(ii)

i.e., **P = VI**

Since, the electric energy is supplied for time ?, thus, after multiplying both sides of equation (ii) by time t, we get,

$P \times t = VI \times t = VIt$ ……(iii)

i.e., $H = VIt$

Thus, for steady current I, the heat produced (H) in time t is equal to VIt

$H = VIt$ i.e., $H = VIt$

We know, according to Ohm's Law,

$V = IR$

By substituting this value of V in equation (iii), we get,

$H = IR \times It$

$H = I^2Rt$ ……(iv)

The expression (iv) is known as Joule's Law of Heating, which states that heat produced in a resistor is directly proportional to the square of current given to the resistor, directly proportional to the resistance for a given current and directly proportional to the time for which the current is flowing through the resistor.

Theoretical learning Activity

- ✓ Group discussion and presentation on key concepts
- ✓ Group work for interpretation of Kirchhoff's laws
- ✓ Individual work on determination of branch currents and branch voltages
- ✓ Homework on circuit analysis using Kirchhoff laws

Practical learning Activity

- ✓ …………………………………… (Example: Trainees in pair perform …………………)

Points to Remember (Take home message)

- ✓ Kirchhoff's Current Law. At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e., $\Sigma I = 0$.
- ✓ Kirchhoff's *Voltage Law. In any closed loop in a network, the algebraic sum of the voltage drops (i.e., products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop.*

STRUCTURE OF LEARNING UNIT

Learning outcomes:
6.1 : Identify types of lenses 6.2 Describe the image formulation by the eye 6.3 Describe application of optical instruments

Learning outcome 6.1 Identify types of lenses

Duration: 6 hrs

Learning outcome 1.1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify clearly types of lenses

2. Describe properly the image formulation by the eye

3. Describe effectively application of optical instruments.

Resources

Equipment	Tools	Materials
PPE,whiteboard, chalkboard, computer,projector, textbooks, telescope, microscope	Scientific calculator, digital camera, magnifying glass	Chalks, markers

Advance preparation:

. Laws of reflection

. Laws of refraction

CONTENT

Light is a form of energy that travels in a straight line. Some objects produce light on their own and these are called **luminous objects** e.g sun, fire worms, fire fly.

Most objects we see don't produce light on their own but reflect it from luminous objects and these are called **non-luminous objects** e.g. moon, the stars, etc.

Some objects do not allow light to go through them and these are called **opaque objects** e.g. wood, wall, people, etc.

Some of them allow most of the light to go through them and these are called **transparent objects** e.g. glass, clear water, clear polythene.

Other objects allow some light to go through them and these are called **translucent objects** e.g. paper, bathroom glasses, tinted glass, etc.

6.1.1 RAYS AND BEAMS

A ray is the direction of the path taken by light.

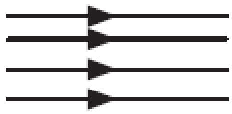
It is indicated by a straight line with an arrow on it.

A beam is a collection of light rays.

OR: A beam is a stream of light energy.

Types of beams

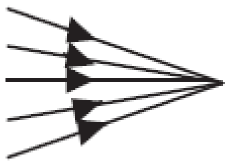
a) Parallel beam



Rays are parallel to each other.

This is obtained from light from a distant source and search lights.

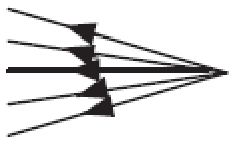
b) Convergent beam



Rays from different directions meet at a common point.

E.g. light behind a convex lens after passing through it.

c) Divergent beam



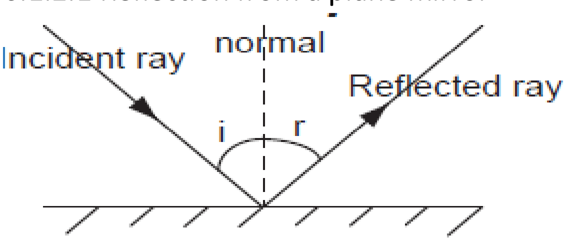
Rays start from a common point and separate into different directions.

E.g. light from a torch and car lights.

6.1.2 REFLECTION OF LIGHT

Reflection is the bouncing of light as it strikes a reflecting surface.

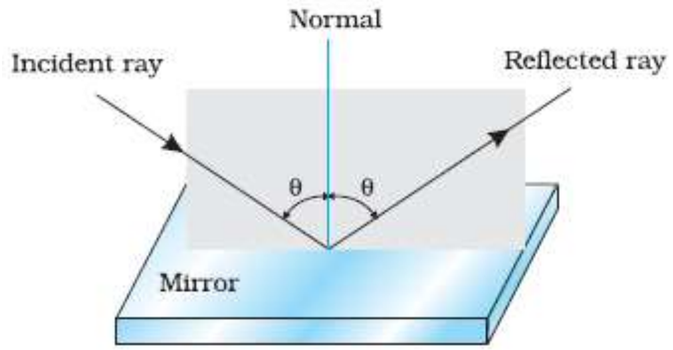
6.1.2.1 Reflection from a plane mirror

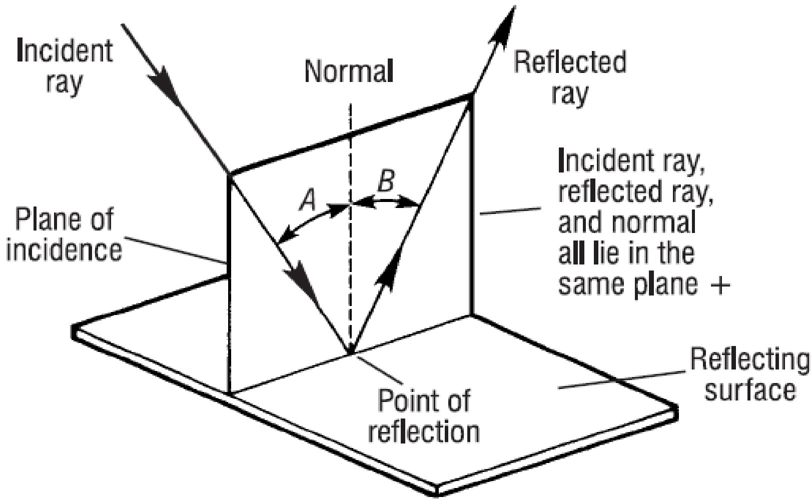


i= angle of incidence (angle between the normal and incident ray)

r = angle of reflection (angle between the normal and reflected ray)

Law 1: The incident ray, the reflected ray and the normal at the point of incidence all lie on the same plane.

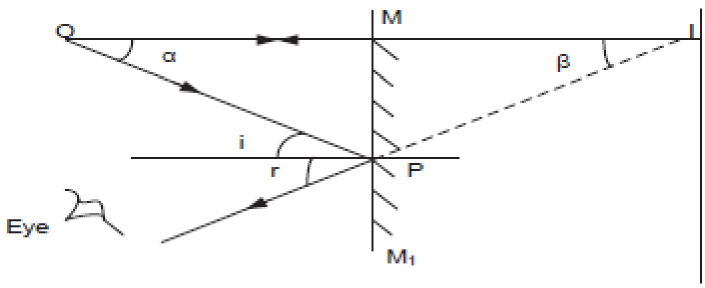




Law 2: The angle of incidence is equal to the angle of reflection.

6.1.2.2 Formation of images by a plain mirror

An image is formed by intersection of at least two rays.



Consider an object O placed in front of a plane mirror. Rays of light form O are reflected form the mirror and appear to come form I. I is the virtual image of O.

6.1.2.3 PROPERTIES OF IMAGES FORMED BY A PLANE MIRROR.

1. The images are the same distance behind the mirrors as the distance of the object in front of the mirror.
2. The images have the same size as the object.
3. The images are erect (upright)
4. The images are laterally inverted (rotated through 180° in the mirror).
5. The images are virtual (they cannot be formed on the screen).

6,1.2.4 THE REAL AND VIRTUAL IMAGES

A real image

It is one which can be formed on the screen and is formed by the actual intersection of light rays e.g. images formed by concave mirror and convex lenses.

A virtual image

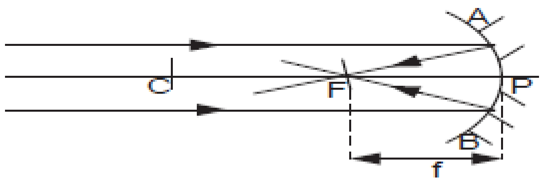
It is one that cannot be formed on a screen and is formed by the apparent intersection of light rays e.g. images formed by plane mirrors, concave lenses and convex mirrors.

6.1.2.5 REFLECTION IN CURVED MIRRORS

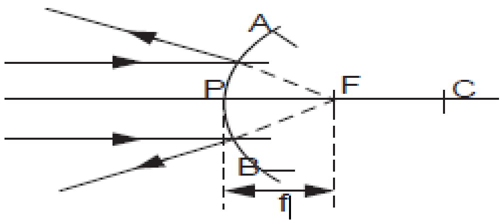
CURVED MIRRORS ((Spherical mirrors)

Curved mirrors are mirrors whose surfaces are obtained from a hollow transparent sphere.
There are two types of curved mirrors;
i) Concave mirror (converging mirror) ii) Convex mirror (diverging mirror)

Concave (Converging) mirror: it is part of the sphere whose centre **C** is in front of its reflecting surface.



Convex (Diverging) mirror: it is part of the sphere whose centre **C** is behind its reflecting surface.



Where;
P is the pole of the mirror
F is the principal focus (focal point)
C is the centre of curvature
f is the focal length
r is the radius of curvature.
APB – Aperture
PFC – Principal axis

6.1.2.6 Terms used in Curved mirrors

Definitions

1. **Centre of curvature C:** it is the centre of the sphere of which the mirror forms part.
2. **Radius of curvature r:** it is the radius of the sphere of which the mirror forms part.
3. **Pole of the mirror:** it is the mid-point (centre) of the mirror surface.
4. **Princpal axis CP**: it is the line that passes through the centre of curvature and the

pole of the mirror.

5. Secondary axis: line through the center of a thin lens or through the center of curvature of a

concave or convex mirror other than the principal axis of the lens or mirror

6. Paraxial rays: These are rays close to the principal axis and make small angles with the mirror axis.

7. Marginal rays: These are rays furthest from the principal axis of the mirror.

8. (i) Principal focus "F" of a concave mirror: it is a point on the principal axis where paraxial rays incident on the mirror and parallel to the principal axis converge after reflection by the mirror.

A concave mirror has a real (in front) principal focus.

(ii). Principal focus "F" of a convex mirror: it is a point on the principal axis where paraxial rays incident on the mirror and parallel to the principal axis appear to diverge from after reflection by the mirror

A convex mirror has a virtual (behind) principal focus.

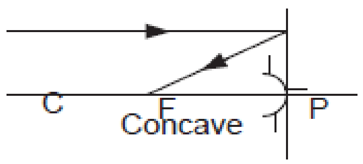
9.(i) Focal length "f" of a concave mirror: it is the distance from the pole of the mirror to the point where paraxial rays incident and parallel to the principal axis converge after reflection by the mirror.

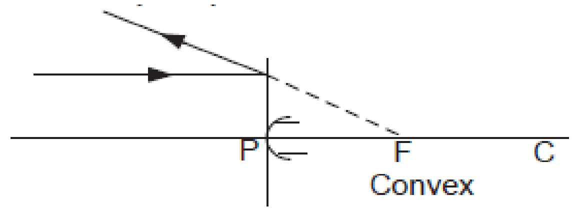
(***ii) Focal length "f" of a convex mirror:*** it is the distance from the pole of the mirror to the point where paraxial rays incident and parallel to the principal axis appear to diverge from after reflection by the mirror.

10. Aperture of the mirror: it is the length of the mirror surface.

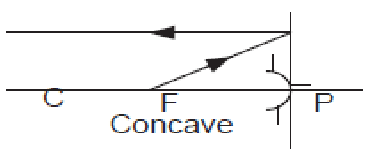
6.1.2.7 IMAGE POSITIONS)

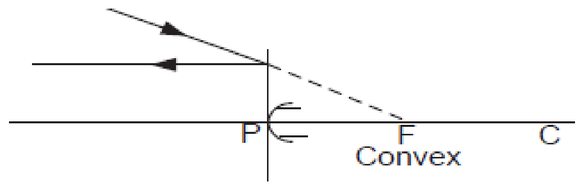
1. Rays are always drawn from the top of the object.
2. A ray parallel to the principal axis is reflected through the principal focus.



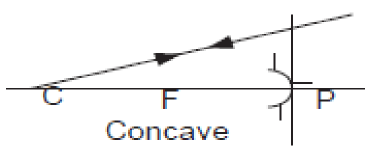


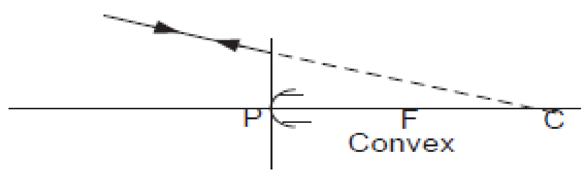
3. A ray through the principal focus is reflected parallel to the principal axis.





4. A ray through the centre of curvature is reflected along its own path.





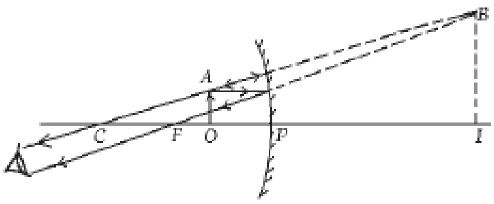
NOTE:

(i) The normal due to reflection at the mirror surface at any point must pass through the centre of curvature.

(ii) The image position can be located by the intersection of two reflected rays initially coming from the object.

6.1.2.8 IMAGES FORMED BY A CONCAVE MIRROR

The nature of the image formed by a concave mirror is either real or virtual depending on the object distance from the mirror as shown below;

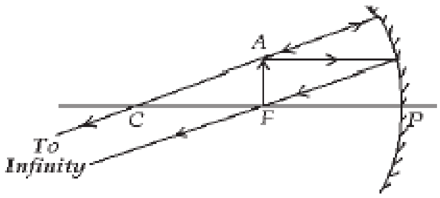


Object between F and P the image is

1) Behind the mirror
2) Virtual
3) Erect
4) Magnified

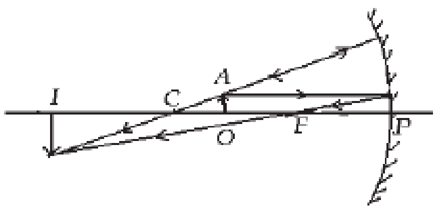
The property of a concave mirror to form erect, virtual and a magnified image when the object is

nearer to the mirror than its focus makes it useful as a shaving mirror and also used by dentists for teeth examination.



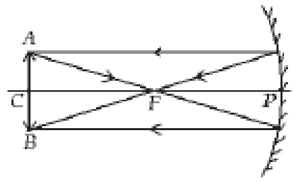
Object at F the image is

1) at infinity, virtual and upright



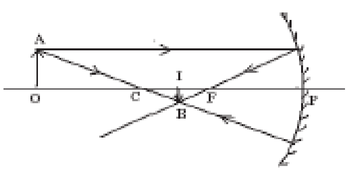
Object between F and C the image is

1) Beyond C
2) Real
3) Inverted
4) Magnified



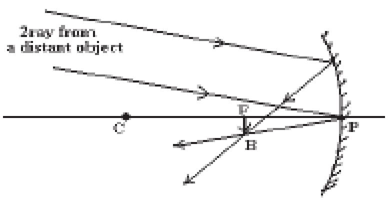
Object at C the image is

1) At C
2) Real
3) Inverted
4)Same size as the object



Object beyond C the Image is

1) Between C and F
2) Real
3) Inverted
4) Diminished



Object at infinity the image is

1) At F
2) Real
3) Inverted
4) Diminished

6.1.2.9 USES OF CONCAVE MIRRORS

(i) They are used as shaving mirrors.

(ii) They are used by dentists for teeth examination.

(iii) They are used as solar concentrators in solar panels.

(iv) They are used in reflecting telescopes, a device for viewing distant objects

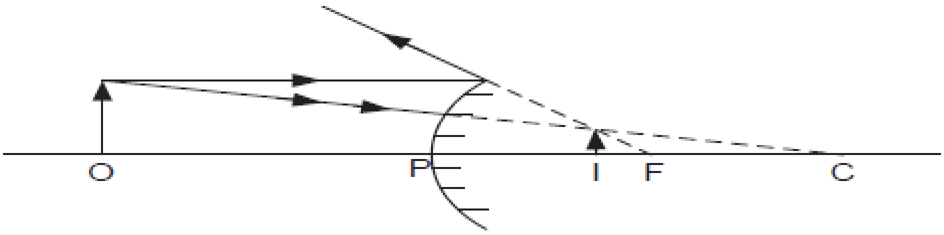
(v) They are used in projectors, a device for showing slides on a screen.

Advantage

It forms magnified and erect images

6.1.2.10 IMAGES FORMED BY A CONVEX MIRROR

The image of an object in a convex mirror is erect, virtual, and diminished in size no matter where the object is situated as shown below.



Convex mirrors

(i) They are used as driving mirrors. This is because they always form erect images and have a wide field of view.

(ii) Used in super markets to observe the activities of customers

(iii) Used in security check points to inspect under vehicles

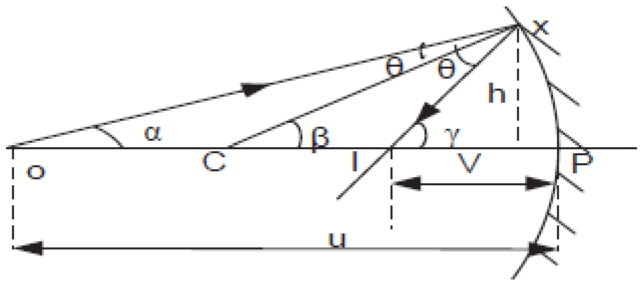
Advantages of convex mirrors over plane mirrors

i) They have a wide field of view

ii) They form erect images

6.1.2.11 MIRROR FORMULA

Consider a point object O on the principal axis of a concave mirror.



$$\boxed{\frac{1}{f} = \frac{1}{v} + \frac{1}{u}}$$

Where

u =object distance

v = image distance

f = focal length

r = radius of curvature

6.1.2.12 Sign convention

- Distances of real objects and real images are positive ie u and v for real objects and real images are positive.
- Distances of virtual objects and virtual images are negative ie u and v for virtual objects and virtual images are negative.
- Focal length f, for a concave mirror is positive and negative for a convex mirror.

6.1.2.13 LINEAR MAGNIFICATION

It is defined as the ratio of the image height to object height.

$$\boxed{m = \frac{height\ image}{height\ object}}$$

Magnification can also be obtained by determining the ratio of distance of the image from the mirror (v) to the distance of the object from the mirror (u)

$$\boxed{m = \frac{image\ distance\ (v)}{object\ distance\ (u)}}$$

Example

1. An object 1cm tall is placed 30cm in front of a concave mirror of focal length 20cm. find ;

(i) The position of the image

(ii) The size of the image formed

(iii) The magnification of the image

Solution

ho= 1cm, hi=?, u=30cm, v=?, f=20cm (concave mirror)

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

$$\frac{1}{v} = \frac{1}{20} - \frac{1}{30}$$

$$\frac{1}{v} = \frac{1}{60}$$

V =60cm

Positive sign means the image is real (60cm in front of the mirror)

$$M = \frac{h_i}{h_o} = \frac{v}{u}$$

$$\frac{h_i}{1} = \frac{60}{30}$$

h_i =2cm

$$m = \frac{v}{u} = \frac{60}{30}$$

m =2

Or

$$M = \frac{h_i}{h_o} = \frac{2}{1}$$

M = 2

2. An object 10cm tall is placed 30cm in front of a convex mirror of focal length 20cm. Find;

(i) The position

(ii) The size of the image formed.

Solution

ho= 10cm, hi=?, u=30cm, v=?, f= - 20cm (convex mirror)

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

$$\frac{1}{v} = \frac{1}{-20} - \frac{1}{30}$$

$$\frac{1}{v} = \frac{-5}{60}$$

V = - 12cm

Negative sign means the image is virtual (12cm behind the mirror)

$$M = \frac{h_i}{h_o} = \frac{v}{u}$$

$$\frac{h_i}{10} = \frac{12}{30}$$

h_i =4cm

6.1.3 REFRACTION OF LIGHT

Refraction is the change of direction of light propagation of light as it travels from one medium to another.

Explanation of refraction

The bending of light is as a result of the change in speed as light travels from one medium to another.

The change in speed of light usually leads to the change in direction unless if the ray is incident normally.

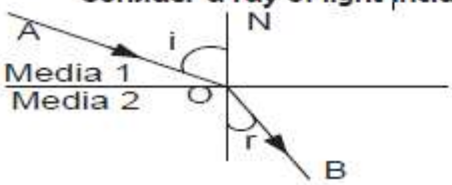
The speed of light in air is higher than the speed of light in glass or water.

Glass and water are therefore said to be denser than air also is denser than water.

6.1.3.1 LAWS OF REFRACTION

Consider a ray of light incident on an interface between two media as shown.

Consider a ray of light incident on an interface between two media as shown.



O = Point of incidence.

OA = Incident ray

OB = Refracted ray.

ON = Normal at O

$\angle i$ = Angle of incidence

$\angle r$ = Angle of refraction

LAW 1: The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane.

LAW 2: The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a given pair of media.

This is called ***Snell's law.***

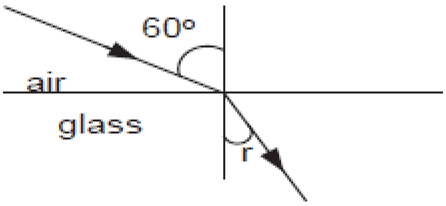
This constant ratio is called Refractive index, (n).

$n = \frac{\sin i}{\sin r}$ where;

i = angle of incidence r = angle of refraction.

Examples

1.



Find the angle of refraction if the refractive index of glass is 1.52

Solution

$n = \frac{\sin i}{\sin r}$

$1.52 = \frac{\sin 60}{\sin r}$

Sin r = $\frac{0.8666}{1.52}$

Sin r = 0.569

r = $sin^{-1}(0.569)$

r = 34.7°

2. The angle of incidence of water of refractive index 1.33 is $45°$. Find the angle of refraction.

Solution

$n = \frac{\sin i}{\sin r}$

$1.52 = \frac{\sin 45}{\sin r}$

Sin r = $\frac{0.707}{1.33}$

Sin r = 0.531

r = $sin^{-1}(0.531)$

r = 34.7°

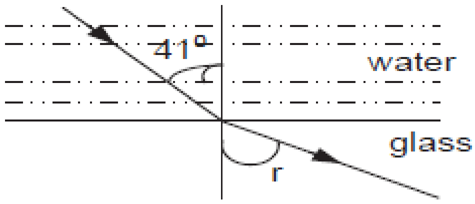
Exercise:4

1. The angle of incidence is 30° and angle of refraction is 19°. Find the refractive index of the material

2. A ray of light is incident in air at an angle of 30° . Find the value of angle of refraction, r, if the

refractive index is 1.5.

3. A ray of light is incident on a water- glass boundary at an angle of 41° as shown below.



Calculate the angle of refraction, if the refractive indices of water and glass are 1.33 and 1.50 Respectively.

6.1.3.2 Refractive index n

Refractive index of a material is the ratio of the sine of angle of incidence to the sine of angle of

refraction for a ray of light traveling from a vacuum to a given medium.

OR

Is the ratio of the speed of light in a vacuum to speed of light in a medium.

Thus **Refractive index,** $n = \frac{speed\ of\ light\ in\ a\ vacuum\ (c)}{speed\ of\ light\ in\ a\ medium\ (v)}$

Where speed of light in a vacuum $c = 3.0 \times 10^8\ ms^{-1}$.

NOTE:

The refractive index, **n** for a vacuum is **1**. However, if light travels from air to another medium, the value of **n** is slightly greater than **1**.

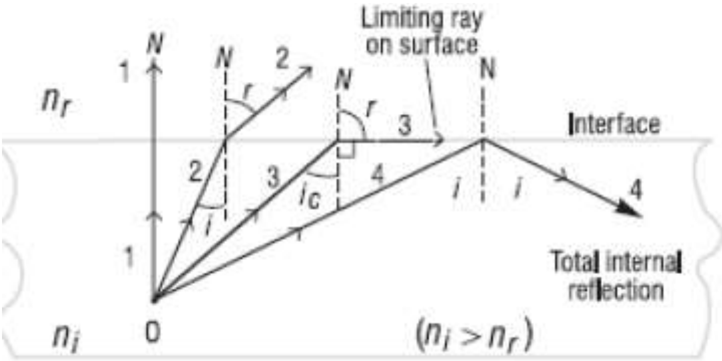
For example, $n = 1.33$ **for water and** $n = 1.5$ **for glass.**

6.1.3.3 Total Internal Reflection and Critical angle

Total internal reflection if light is a reflection within the dense medium when the angle of incidence exceeds the critical angle of the medium.

Critical angle and total internal reflection.

When light travels from a medium of higher index to one of lower index, we encounter some interesting results. Refer to Figure where we see four rays of light originating from point O in the higher-index medium, each incident on the interface at a different angle of incidence. Ray 1 is incident on the interface at 90° (normal incidence) so there is no bending.



The light in this direction simply speeds up in the second medium (why?) but continues along the same direction. Ray 2 is incident at angle *i* and refracts (bends away from the normal) at angle *r*. Ray 3 is incident at the *critical angle ic*, large enough to cause the refracted ray bending away from the normal (N) to bend by 90°, thereby traveling along the interface between the two media. (This ray is trapped in the interface.) Ray 4 is incident on the interface at an angle *greater than* the critical angle, and is *totally reflected* into the same medium from which it came. Ray 4 obeys the *law of reflection* so that its angle of reflection is exactly equal to its angle of incidence. We exploit the phenomenon of total internal reflection when designing light propagation in fibers by trapping the light in the fiber through successive internal reflections along the fiber. We do this also when designing "retroreflecting" prisms. Compared with ordinary reflection from mirrors, the sharpness and brightness of totally internally reflected light beams is enhanced considerably.

The calculation of the critical angle of incidence for any two optical media—whenever light is incident from the medium of higher index—is accomplished with *Snell's law*. Referring to Ray 3 in Figure and using Snell's law.

$$ni \sin ic = nr \sin 90°$$

here *ni* is the index for the incident medium, *ic* is the critical angle of incidence, *nr* is the index for the medium of lower index, and *r* = 90° is the angle of refraction at the critical angle. Then, since sin 90° = 1, we obtain for the critical angle.

$$i_c = \sin^{-1}\left(\frac{n_r}{n_i}\right)$$

Critical angle, C

Critical angle ,C of the medium is the angle of incidence for which the angle of refraction is 90° for a ray of light travelling from a more optically dense medium to a less optically dense medium.

6.1.3.4 Condition for total internal reflection to occur

(i) The ray of light must travel from a more dense medium to less dense eg from glass to water.

(ii) The angle of incidence must be greater than the critical angle of the medium.

Relationship between critical angle, C , and the refractive index, n

$n_g sin i = n_a sin r$

$n sin c = 1 x sin 90$

$$Sin\ C = \frac{1}{n}$$

Example

1. The refractive index of glass is 1.5, find the critical angle

Solution

$n_g sin\ c = n_a sin 90$

$1.5 sin\ c = 1$

$C = \sin^{-1}\left(\frac{1}{1.5}\right) = 41.8°$

2. Find the critical angle for the ray of light moving from water of refractive index 1.33 to air

Solution

$Sin\ C = \frac{1}{n}$

$C = \sin^{-1}\left(\frac{1}{1.33}\right)$

$C = 40.75°$

6.1.3.5 APPLICATION OF TOTAL INTERNAL REFLECTION.

(i) It is responsible for the formation of a mirage.

(ii) It is responsible for the formation of a rainbow.

(iii) It is responsible for the transmission of light in optical fibres.

(iv). It is responsible for the transmission of sky radio waves

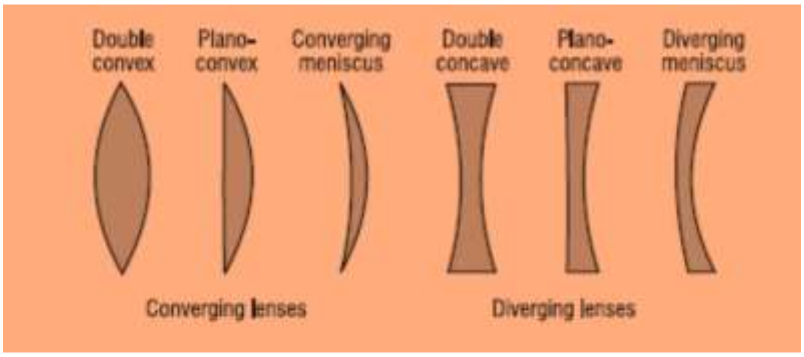
(v). It is responsible for the transmission of light in prism binoculars.

6.1.4 REFRACTION THROUGH LENSES

A lens is a piece glass bounced by one or two spherical surfaces.

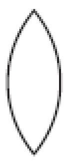
6.1.4.1 Types of lenses

There are two types of lenses as shown below.



a. Converging (convex) lens

It is a lens which is thicker in the middle than at the edges.

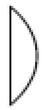


- ✓ Its curved outwards
- ✓ Thicker in the middle
- ✓ Thinner at the edge

Convex lenses are also divided into two namely;

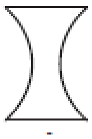
(i) Converging meniscus

(ii) Plano convex



b. Diverging (concave) lens

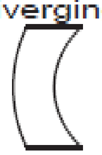
It is a lens which is thinner in the middle than at the edges.



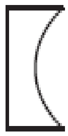
- ✓ Its curved inwards
- ✓ Thinner in the middle
- ✓ Thicker at the edge

Concave lenses are also divided into two namely;

(i) Diverging meniscus



(ii) Plano concave

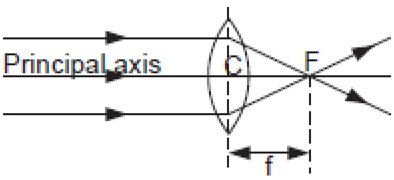


6.1.4.2 Refraction of light in lenses

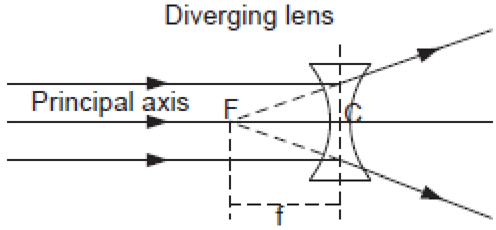
(i) A parallel beam of light, parallel and close to the principal axis of **a converging lens** is converged or brought to focus at the principal focus **F**

(ii) A parallel beam of light, parallel and close to the principal axis of **a diverging lens** is diverged such that the rays appear to come from the principal focus **F.**

Converging lens



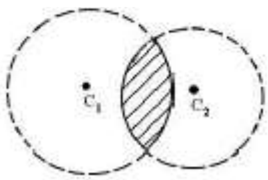
Diverging lens



6.1.4.3 Terms used in Lenses

Definitions:

1. Centres of curvature of a lens: These are centres of the spheres of which the lens surfaces form parts.



Points C1 and C2 are the centers of curvature of the lens surfaces.

2. **Radii of curvature of a lens:** These are distances from the centers to the surfaces of the spheres of which the lens surfaces form part.

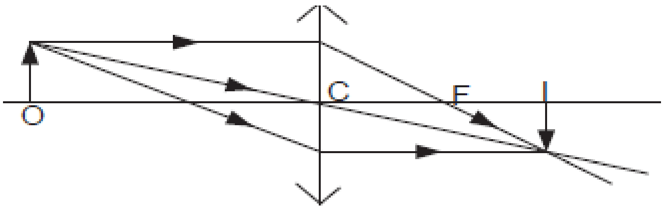
3. Principal axis of a lens: This is the line joining the centers of curvature of the two surfaces of the lens.

4. **Optical centre of the lens:** This is the mid-point of the lens surface through which rays incident on the lens pass un deviated.
5. **Paraxial rays:** These are rays close to the principle axis and make small angles with the lens axis.
6. (i) Principal focus "F" of a convex lens: it is a point on the principal axis where where rays originally parallel and closeto the principal axis converge after refraction by the lens.
A convex lens has a real (in front) principal focus.
(ii) Principal focus "F" of a concave lens: it is a point on the principal axis where where rays originally parallel and closeto the principal axis appear to diverge from after refraction by the lens. A concave lens has a virtual (behind) principal focus.
7. ***(i) Focal length "f" of a convex lens:*** it is the distance from the optical centre of the lens to the point where paraxial rays incident and parallel to the principal axis converge after refraction by the lens.
(***ii) Focal length "f" of a concave lens:*** it is the distance from the optical centre of the lens to the point where paraxial rays incident and parallel to the principal axis appear to diverge from after refraction by the lens.

6.1.4.4 Ray diagrams for a converging lens

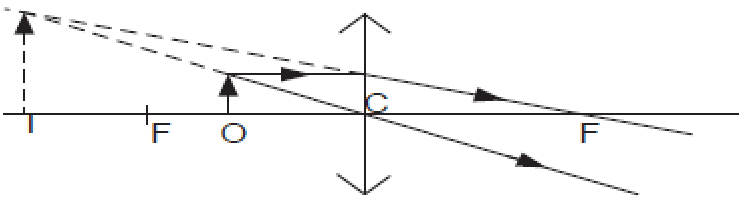
Principal rays for a converging lens

- A ray parallel to the principal axis is refracted to pass through the principal focus F
- A ray passing through the principal focus F is refracted to parallel to the principal axis
- A ray passing through the optical center, C is not refracted



6.1.5 IMAGES FORMED BY A CONVERGING LENS

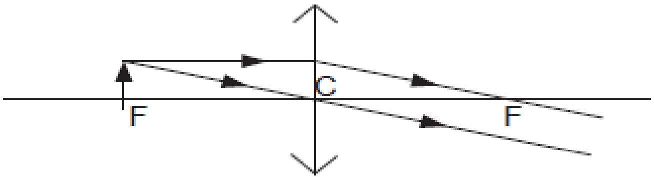
(i) Object between F and C (Magnifying glass)



Nature of image

- Virtual
- Erect
- Magnified

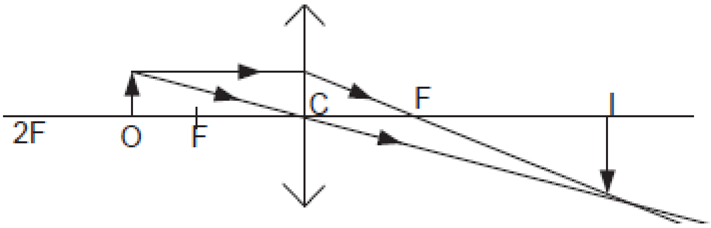
(ii) **Object at F**



Nature of image

- Image at infinity

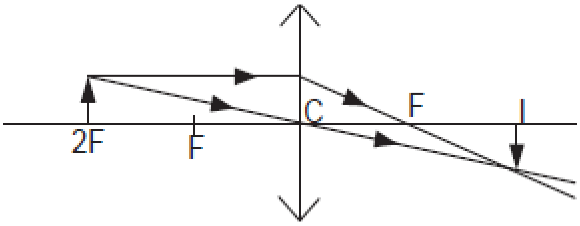
iii) Object between F and 2F



Nature of image

- Real
- Inverted
- Magnified
- Beyond 2F

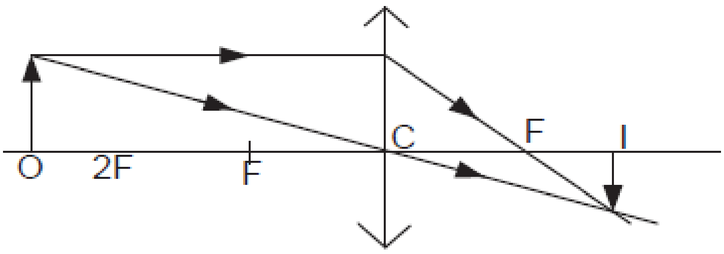
(iv) Object at 2F



Nature of image

- Real
- Inverted
- Same size as object
- Between F and 2F

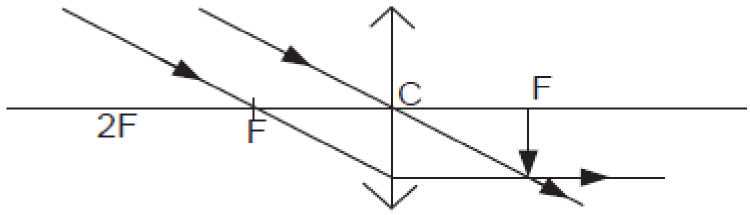
(v) Object beyond 2F



Nature of image

- Real
- Inverted
- Diminished
- Between F and 2F

(vi) Object at infinity



Nature of image

- Real
- Inverted
- Diminished
- At F

6.1.6 USES OF CONVEX LENSES

(i) They are used in spectacles for long-sighted people

(ii) They are used in cameras.

(iii) They are used in projectors.

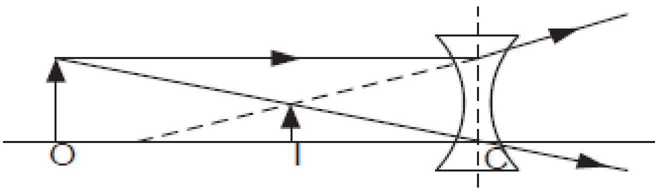
(iv)They are used in microscopes.

(v) They are used in astronomical telescopes.

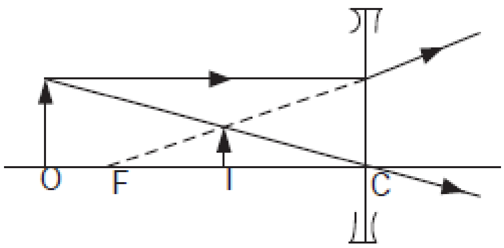
6.1.7 Ray diagrams for a diverging lens

a) Principal rays for a diverging lens

- A ray parallel to the principal axis is refracted to appear to come from the principal focus F
- A ray passing through the optical center, C is not refracted.



Formation of an image in a diverging lens



Nature of the image

- Virtual
- Erect
- Diminished
- Between F and C

USES OF CONCAVE LENSES

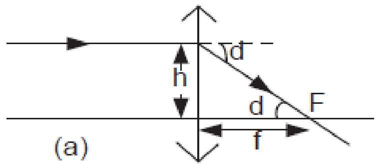
(i) They are used in spectacles for short-sighted people

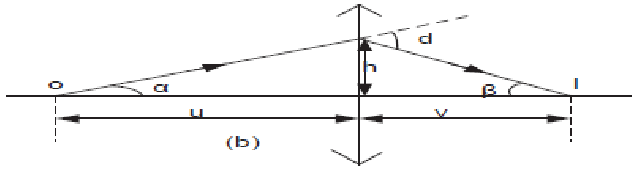
(ii) They are used in Galilean telescopes.

6.1.8 Thin lens formula

a. Convex lens

Consider array of light incident on a lens close to its principal axis and parallel to it.





From figure (a) above deviation d is small and if it is measured in radians

$$d \approx \tan d = \frac{h}{f} \ldots\ldots\ldots\ldots (1)$$

From figure (b): $\alpha + \beta = d \ldots\ldots\ldots\ldots (2)$

For small angles α, β measured in radians

$$\alpha \approx \tan\alpha = \frac{h}{u} \ldots\ldots\ldots\ldots (3)$$

$$\beta \approx \tan\beta = \frac{h}{v} \ldots\ldots\ldots\ldots (4)$$

$$\frac{h}{u} + \frac{h}{v} = \frac{h}{f}$$

From which;

$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$

$$\boxed{f = \frac{u\,v}{u+v}}$$

Where

u = object distance

v = image distance

f = focal length

Note:

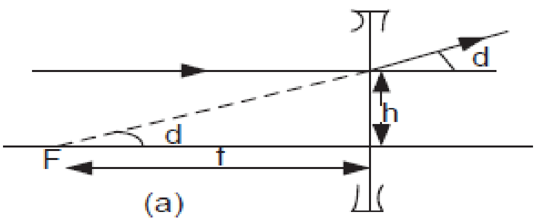
All distances are measured from the optical center of the lens.

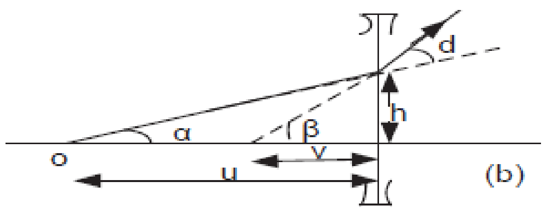
6.1.9 Sign convention for lenses

- ✓ Distances of **real objects and real images are positive** ie u and v for real objects and real images are positive.
- ✓ Distances of **virtual objects and virtual images are negative** ie u and v for virtual objects and virtual images are negative.
- ✓ **Focal length f, for a convex lens is positive and negative for a concave lens.**

Concave lens

Consider array incident on a concave lens parallel and close to the principal axis.





From figure (a) above deviation d is small and if it is measured in radians

$$d \approx \tan d = \frac{h}{f} \ldots\ldots\ldots\ldots (1)$$

From figure (b): $\alpha + d = \beta$

$$-d = (\alpha - \beta) \ldots\ldots\ldots\ldots (2)$$

For small angles α, β measured in radians

$$\alpha \approx \tan\alpha = \frac{h}{u} \ldots\ldots\ldots\ldots (3)$$

$$\beta \approx \tan\beta = \frac{h}{v} \ldots\ldots\ldots\ldots (4)$$

$$-\frac{h}{f} = \frac{h}{u} - \frac{h}{v}$$

$$-\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$$

$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$

6.1.10 The power of a lens

The power of a lens, P is the reciprocal of the focal length in metres.

The **S.I unit** of power of a lens is **Diopter** (**D**).

A diopter is the power of a lens of focal length one metre.

$$power = \frac{1}{focal\ lenght(metres)}$$

$$\boxed{\boldsymbol{P = \frac{1}{f(m)}}}$$

Examples

(a) Power of a single lens

1. A converging lens has a focal lens 15cm. Calculate the power of the lens.

Solution

$\boldsymbol{f} = 15cm$=**0.15m,** $P = ?$

$$\boldsymbol{P} = \frac{1}{f(m)}$$

$$\mathrm{P} = \frac{1}{0.15}$$

$$\mathrm{P} = 6.67\mathrm{D}$$

2. Find the power of a diverging lens of focal length 10cm

Solution

$\boldsymbol{f} = -10cm = -$**0.1m,** $P = ?$

$$P = \frac{1}{f(m)}$$

$$P = \frac{1}{-0.1}$$

$$P = -\text{`}10D$$

(b) Power of combination of two lenses in contact

When two lenses are in contact, the power of the combination is obtained by adding the power of the two lenses.

$$\boxed{\boldsymbol{P = P_1 + P_2}}$$

6.1.11 Linear or lateral magnification

It is defined as the ratio of the image height to object height.

$$\boxed{m = \frac{height\ image}{height\ object}}$$

Magnification is also defined as the ratio of distance of the image from the lens to the distance of the object from the lens.

$$m = \frac{image\ distance\ (v)}{object\ distance\ (u)}$$

Examples

1. An object is placed 20cm from a converging lens of focal length 15cm. Find the nature, position and the magnification of the image formed.

Solution

u = +20cm, f =+15cm, v =?

i) $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{15} = \frac{1}{20} + \frac{1}{v}$

$\frac{1}{v} = \frac{1}{15} - \frac{1}{20}$

$\frac{1}{v} = \frac{1}{60}$

v = 60cm

iii) $M = \frac{v}{u}$

$M = \frac{60}{20}$

$m = 3$

- Real image(since v = positive)
- Magnified image (since m > 1)

6.1.12 Condition for the formation of a real image by a convex lens

(i) The object distance must be greater than the focal length of the lens.

(ii) The distance between the object and the screen must be at least four times the focal length of the lens.

6.1.13 Defects in images (aberrations)

This is the distortion of images formed by either spherical mirrors or spherical lenses.

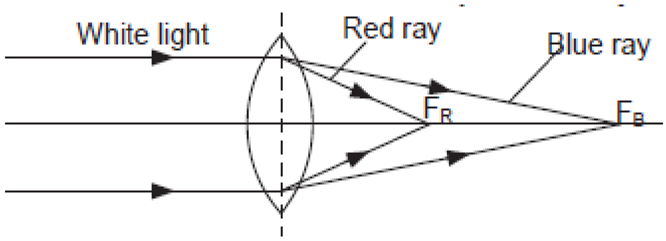
When mirrors and lenses under consideration are of large aperture, images formed by them can differ in shape and color from the object. Such defects are known as aberration or defects in images. There are two types of aberrations namely:

(i) Chromatic aberration.

(ii) Spherical aberration.

6.1.13.1 Chromatic aberration

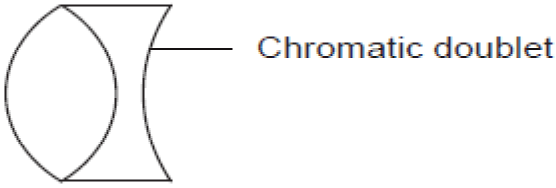
This is the coloring of the image produced by a lens.



- ✓ When white light is incident on a lens, the different color components are refracted by different amounts.
- ✓ Images corresponding to the different colors are formed in different positions along the principal axis of the lens.
- ✓ The image viewed has <u>colored edges</u>.

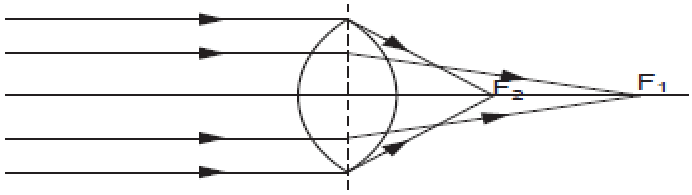
Minimizing chromatic aberration

Chromatic aberration can be reduced by using an achromatic doublet. This consists of a convex lens combined with a concave lens made from different glass materials. The convex lens deviates the rays while the concave lens nullifies the diversion.



6.1.13.2 Spherical aberration

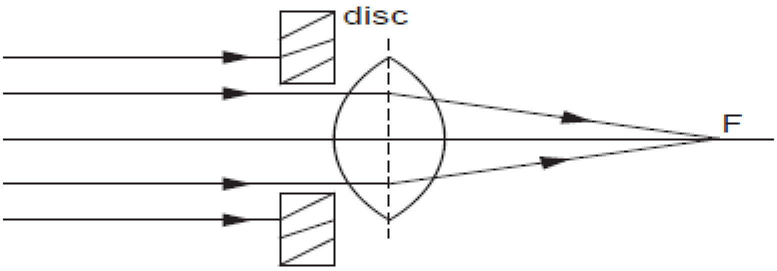
This is distortion of the image by **either** a lens **or** a mirror of wide aperture.



When a **wide beam of white light** is incident on **either** a lens **or** a mirror of **wide aperture**, **central rays** are brought to converge **far away** from the lens. The rays which are **far** from the principal axis are brought to converge **near** the lens. The image formed is **circular blurred** due to a series of images of the same object.

Minimizing SPHERICAL aberration

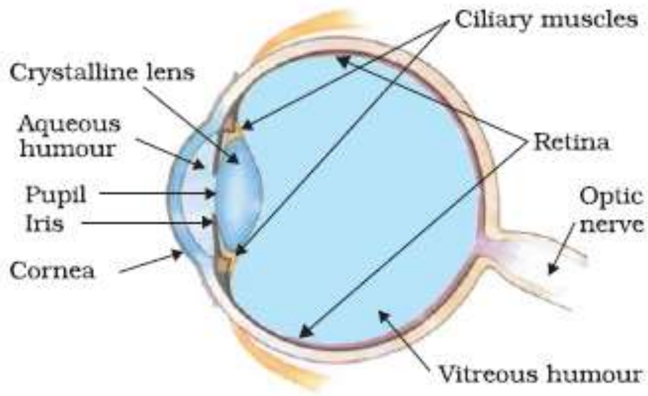
In lenses, Spherical aberration can be minimized using a stopper i.e. using an opaque disc with a central hole to cut off marginal rays.



The **disadvantage** with this method is light intensity is cut down and so the brightness of the image is reduced.

Learning outcome 6.2: Describe the image formulation by the

6.2.1 Identification of functions of the eye parts:



The human eye

The eye is a biological instrument used to see objects at different distances. It uses a convex lens system to form a small, inverted, real image of an object infront of it.

Functions of the parts of the eye

1. The cornea:

It is made out of a fairly dense, jelly like material which provides protection for the eye, and seals in the aqueous humor. It also provides most of the power of the eye Dioptres), having about 46 Dioptres. So it provides most of the bending of light rays.

2. The aqueous humour:

This is a waterly liquid that helps to keep the cornea in a rounded shape, similar to that of a lens.

3. The iris:

This controls the amount of light entering the eye. The amount of light that enters the eye is one of the factors determining how focused an image is on the retina. The brighter the light the eye is exposed to, the smaller the iris' opening will be. The brighter the light the eye is exposed to, the smaller the iris' opening will be.

The iris is the coloured part of the eye as seen from the outside.The iris opening or a gap through which light passes is called a pupil.

4. The lens:

This is used to focus an image on the retina. It controls the bending of light rays by change of its shape, a process called accommodation, which is done by the ciliary muscles.

5. The ciliary muscles:

These control the thickness of the lens during focusing.

By contracting or squeezing the lens, they make it thicker and vice versa. Because the power of the lens is directly related to its thickness, the ciliary muscles change the power of the lens by their movement.

6. The retina:

This is the light sensitive part of the eye and it is where images are formed. It contains millions of tiny cells which are sensitive to light. The cells send signals along the optic nerve to the brain. So the retina is the screen of the eye and the image is formed by successive refraction at the surfaces between air, the cornea, the aqueous humour, the lens and vitreous humour. The retina is black, which prevents any light rays that hit it from reflections and thereby changing the image.

7. **The vitreous humour:**

This is a jerry like substance that helps the eye to keep its round shape. It is very close in optical density to the lens material.

8. **The yellow spot:**

This is a small area on the retina where the sharpest image, that is, the finest detail can be seen.

9. **The optic nerve:**

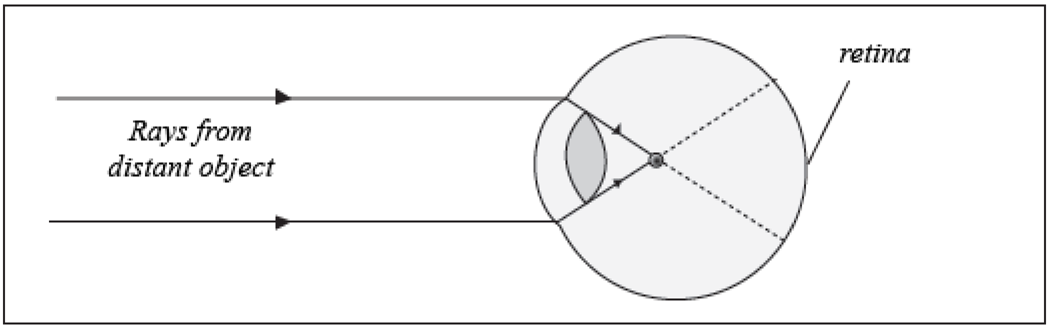
This is the nerve that transmits images received by the retina to the brain for interpretation. The part of the eye where the optic nerve joins the retina is called the **blind spot** because no images can be observed at this point.

6.2.2 Description of vision defects and their correction

1. Short-sightedness (myopia)

People with normal vision can focus clearly near and distant objects. Those who only focus near objects are said to be short-sighted, meaning that they see nearer.

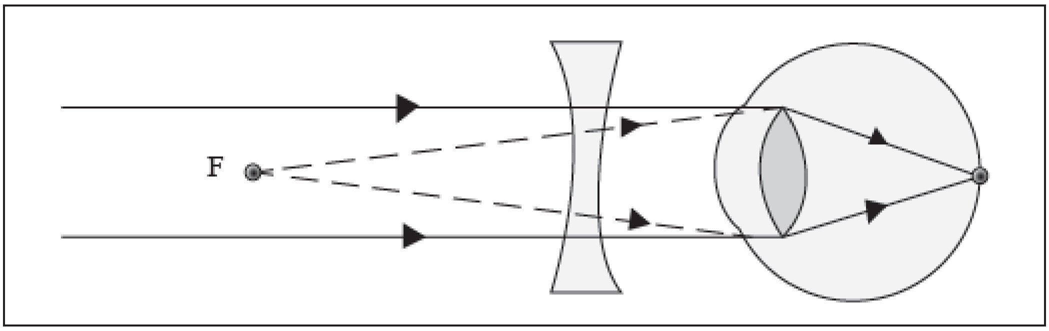
Short-sightedness is the defect whereby a person can see near objects clearly but cannot focus distant objects. His far point is nearer than infinity. This is because the eyeball is too long or the lens is too strong so that rays of light from a distance object are focused in front of the retina.



The rays are focused in front of the retina because the focal length of the eye lens is too short for the length of the eye ball.

Correction of Short-sightedness (myopia)

This defect can be corrected by wearing a concave (diverging) spectacle lens. The rays of light from a distant object are diverged so that they appear to come from a point near, and so they are focused by the eye.



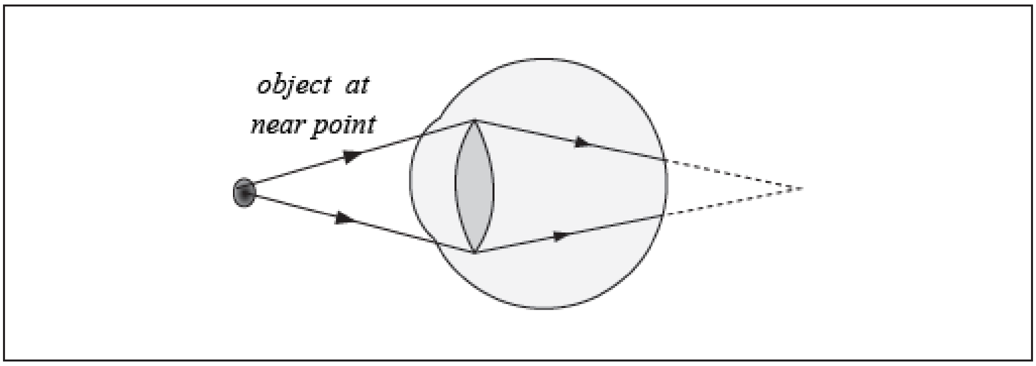
Rays from object at infinity appear to come from a near point F and converge to the retina.

2. Long-sightedness (hypermetropia)

This is where a person is able to see distant objects clearly but cannot focus
near objects.

This is because either his eye ball is too short or the eye lens is too weak (thin) so that rays of light from a close object are focused behind the retina.

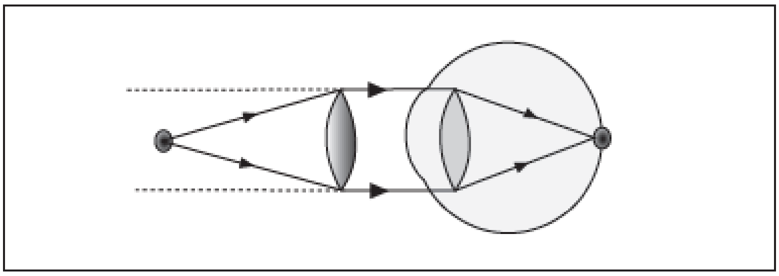
This eye's near point is further than 25 cm.



The image of the near object is focused behind the retina because the focal length of the eye lens is too long for the length of the eye ball.

Correction of Long-sightedness (hypermetropia)

This defect can be corrected by wearing a convex lens spectacle. The rays of light from a near object are converged so that the rays appear to come from a point far, and so are focused by the eye.



Rays from a near object O appear to come from a distant object.

3. **Presbyopia**

When people grow older, their eye lens become stiff and it becomes hard for the ciliary muscles to adjust it. Such people have a defect called Presbyopia. Presbyopia is the stiffening of the eye lens such that it is less capable of being adjusted by the ciliary muscles. This means that the eye lens becomes less flexible and loses its power (ability) to accommodate for objects at different distances.

Correction of Presbyopia

This defect is corrected by wearing bifocals spectacles whose lenses have a top part for looking at distant objects and a bottom part for close ones. These bifocal spectacles have a diverging top part to correct for distant vision and converging lower part for reading.

4. Astigmatism

This is the defect that occurs if the curvature of the cornea varies in different directions so that rays in different planes from an object are focused in different positions by the eye and the image is distorted. A person suffering from astigmatism sees one set of lines more sharply than others.

Correction of Astigmatism

This defect is corrected by wearing corrected lenses. These help to bend the incoming rays to correct for irregular refraction.

Formation of an image by the eye

Light enters the eye through the transparent cornea, passes through the lens and is focused on the retina. The retina is sensitive to light and sends messages to the brain for interpretation. Although the image is inverted, the brain interprets it correctly.

Learning outcome 6.3 Describe application of optical instruments

6.3.1 Identification of criteria that distinguish simple and compound microscope:

Difference Between Compound Microscope and Simple Microscope.

Characteristics	Simple Microscope	Compound Microscope
Number of lenses	One to magnify objects	3-5 to magnify objects
Condenser lens	Condenser lens is absent in Simple microscope.	Condenser lens is present in Compound Microscope.
Mirror type	Concave reflecting	One side is plain and the other side is concave
Source of Light	Natural	Illuminator
Level of magnification	One level only	Higher-level
Structure	Stand is small, hollow cylindrical attached to the base and is used to hold the microscope.	Arm is curved and is used to hold the microscope.

Usage of course, hooks, and knobs	The usage of course, hooks, and knobs is not that much.	The use of knobs is much, which help in focusing and as a result, a clear and concise image is seen.
Used	Can only be used in simple ways such as enlarging small letters while reading.	Has a wide range of use such as in studying the structure of different objects, e.g. details of cells in living organisms.
Magnifying power	Up to 300X	2,000X
Adjusting Magnification	No	Yes

6.3.2 Description of a simple microscope

- Simple Microscope refers to those microscopes consist of a single lens to enlarge an object through angular magnification alone, giving the viewer an erect enlarged virtual image.
- These types of microscopes are used different types of lenses for magnification such as; magnifying glass, loupes, and eyepieces.
- A Simple Microscope is a type of optical Microscope or light Microscope.
- This was the first microscope ever created.
- It was invented by Antony van Leeuwenhoek in the 17th century. He combined a convex lens and a holder for specimens.

Principle of Simple Microscope

All simple microscopes works on a principle, if you place a tiny object or specimen in front of a simple microscope's lens within its focus, a virtual, erect and magnified image of the object is formed at the least distance of distinct vision from the eye held close to the lens.

6.3.3 Working Mechanism of Simple Microscope

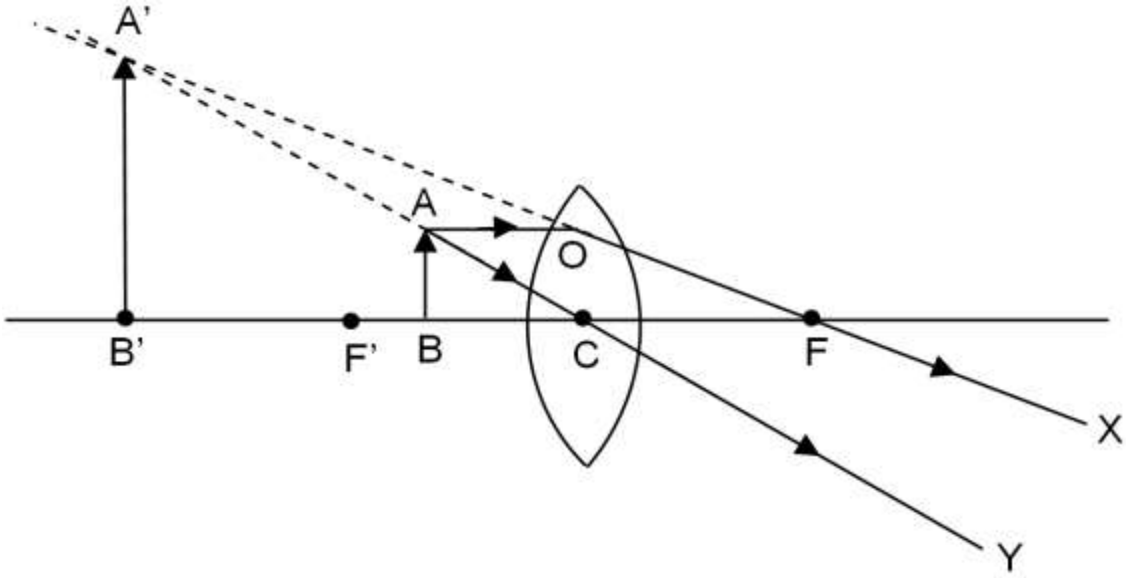


Figure: **Working Mechanism of Simple Microscope** |

This ray diagram in below, explains how simple microscopes is working;

1. A small object **AB** which is to be magnified is placed between the principal focus **F**' and optical center **C** of the convex lens.
2. Now, a ray of light **AO** parallel to a principal axis which is coming from point A of the object passes through the focus **F** along the straight line **OX** after getting refracted by the convex lens.
3. A second ray of light **AC** coming from the point **A** of the object passes through the optical center **C** of the convex lens along the straight line **CY**.
4. As is clear from the figure that the two rays i.e. **OX** and **CY** are diverging rays so these rays can intersect each other only at point **A'** when produced backward.
5. Now, on drawing **A'B'** perpendicular from point **A'** to the principal axis, we get the image **A'B'** of the object which is virtual, erect, and magnified.

6.3.4 Magnification of a simple Microscope

The magnifying power of simple microscopes is given by:

$$M = 1 + D/F$$

Where, D = the least distance of distinct vision

F = focal length of the convex lens

It should be noted,

- Smaller the focal length of the lens, greater will be its magnifying power.
- This microscope has a maximum magnification power of 10, which means the specimen will appear 10 times larger by using the simple microscopes of maximum magnification.

6.3.5 Parts of Simple Microscope with diagram

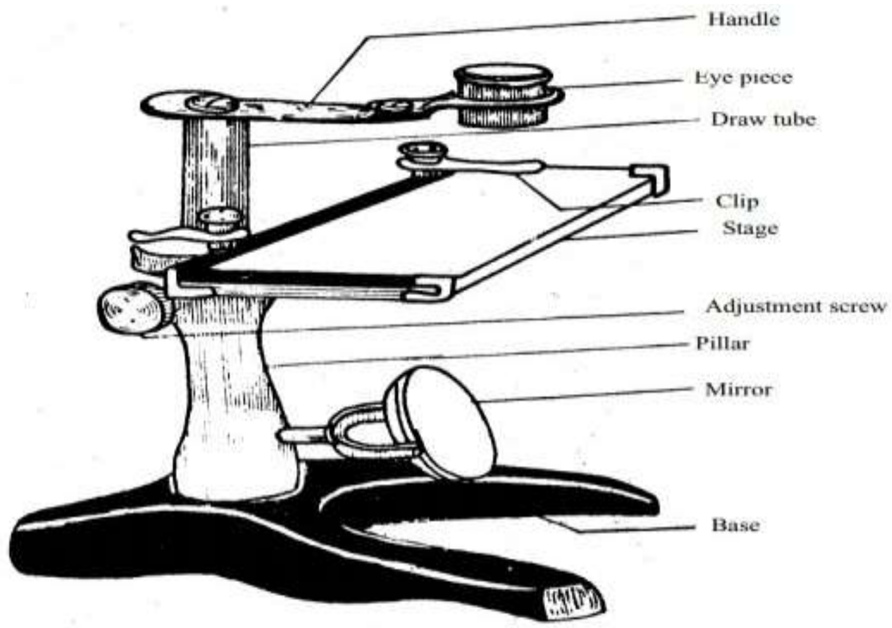


Fig. P.2A Simple Microscope

Figure: simple microscope diagram |

Simple microscopes are consisting of two important parts, includes;

1. The Mechanical Parts
2. The Optical Parts

1. The Mechanical Parts

The Mechanical Parts support the optical parts and help in their adjustment for focusing the object. They include the following components;

a. Metal Stand

- It has a heavy base plate and a vertical rod fitted to it.

Function of Metal Stand

- Metal Stand provides support and stability to other parts of the microscope.

b. Stage

- It’s refers to a rectangular metal plate fitted to the vertical rod.
- Stage also has a central hole for light to pass from below.
- Some simple microscopes have a pair of slanting wings projecting from both sides of the stage which provide support to hand for manipulating the object.

Function of stage

- The specimen slide place over it to be observed.

c. Base: The bottom portion of simple microscope is known as the base. This portion provides supports to the microscope.

d. Stage clips: located at the stage of simple microscope; helps to hold the specimen slides in the proper place.

e. Adjustment screw: It is used to adjust the focus on specimen.

2. The Optical Parts

The optical parts help in magnification and visualization of specimen. This part is consist of these following components;

1. Mirror

- It has a plano-convex mirror, which is located is below the stage to the vertical rod by means of a frame.

Function

- The primary function is to focus the surrounding light on the object being examined.

2. Lens

- Simple microscopes has a biconvex lens which is located above the stage, to the vertical rod, by means of a frame.
- For proper focusing, the lens can be moved up and down by the frame.

Function

- It magnifies the size of the object and the enlarged virtual image formed is observed by keeping the eye above it.

A modern simple microscope contains these following parts;

- **Eyepiece:** A set of lenses, located at the top of microscope, which used to visualize the samples. It has a magnification power of 10X to 15X.
- **Tube:** It connect the eyepiece to the objective lenses.
- **Revolving nose-piece:** The Revolving nose-piece or turret holds the objective lenses and it can rotate during the study of sample.
- **Fine adjustment knob:** The Fine adjustment knob is used to focus on oil.

6.3.4 Description of Compound Microscope

- The first question in your mind will be what is a compound microscope? A compound microscope is a laboratory instrument with high magnification power, which is consists of more than one lenses.
- Compound Microscopes are used for the study of structural details of a cell, tissue, or organ in sections.
- A compound microscope can magnify the image of a tiny object up to 1000.
- The term compound means "multiple" or "complex".
- The compound microscopes is consists of two lenses includes, **the objective lens** (typically 4x, 10x, 40x or 100x) in a rotating nosepiece closer to the specimen, and **the eyepiece lens** (typically 10x) in the binocular eyepieces.
- A compound binocular microscope is more commonly used today.
- Zacharias Jansen created a compound microscope that used collapsing tubes and produced magnifications up to 9X.
- compound microscopes are generally types of bright field microscope.
- Compound microscopes may be categorized as an upright microscope, and Inverted microscope.
- Upright compound microscopes are just like an ordinary microscope which has a lens system, followed by the stage where the specimen is kept, and then the light source.
- Inverted compound microscopes are exactly the reverse replica of the upright microscope with the illumination system first, followed by the stage, and then the lens system.

6.3.4.1 Types of Compound Microscope

Classification of Compound Microscope

Compound Microscope is classified in two categories;

A. Light Microscope

Light Microscope is further classified into four categories such as;

1. Bright-field Microscope
2. Dark-Field Microscope.
3. Phase-contrast Microscope.
4. Fluorescent Microscope.

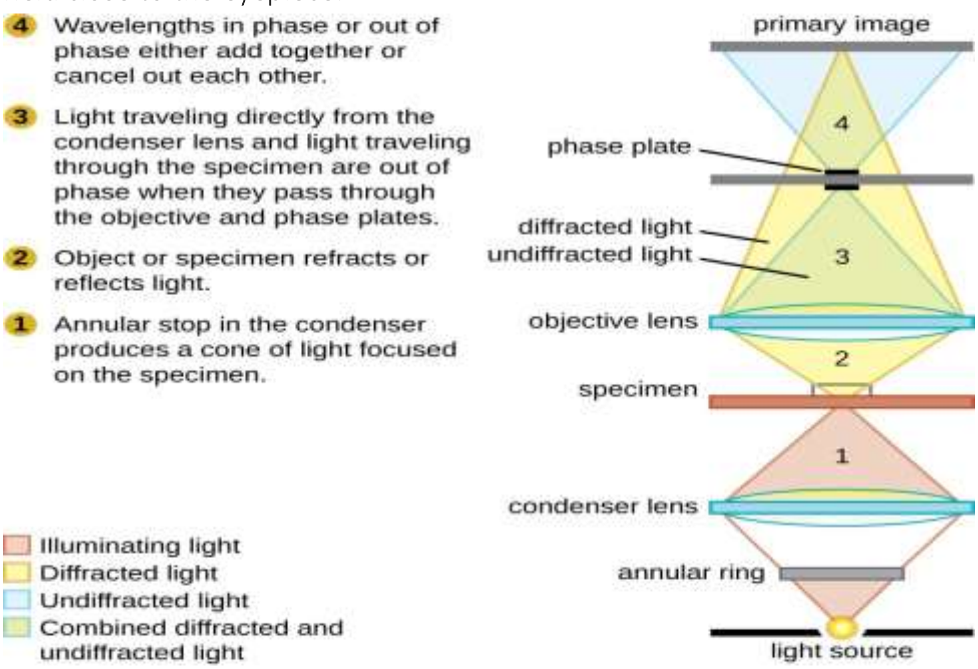
B. Electron Microscope

Electron Microscope is further classified into three categories such as;

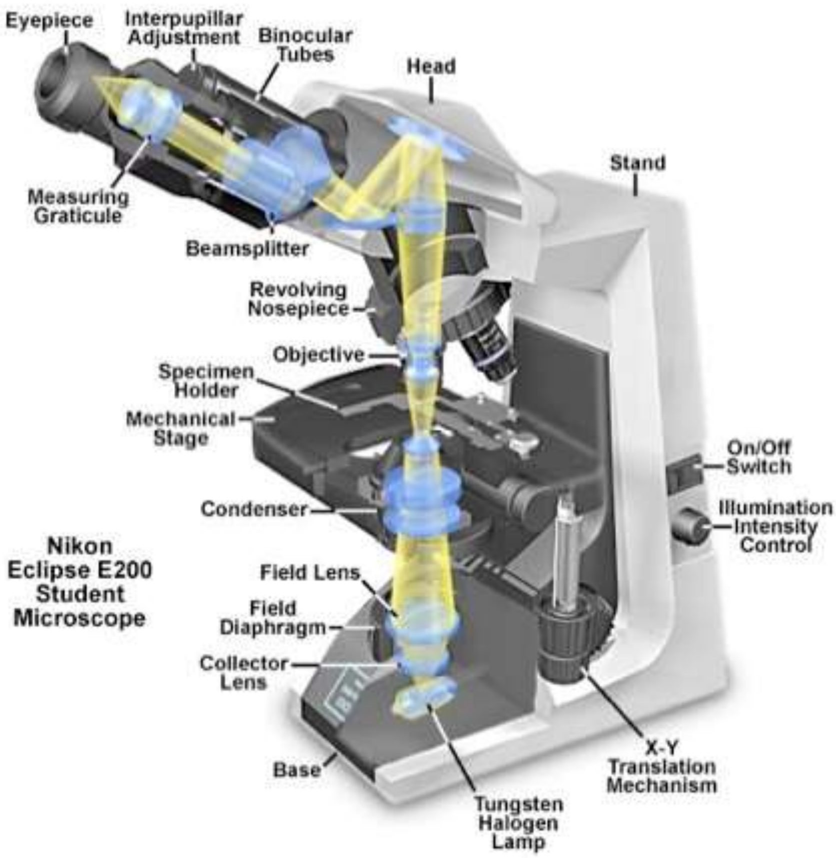
1. Scanning Microscope
2. Transmission Microscope
3. Confocal Microscope

6.3.4.2 Working Principle of Compound Microscope

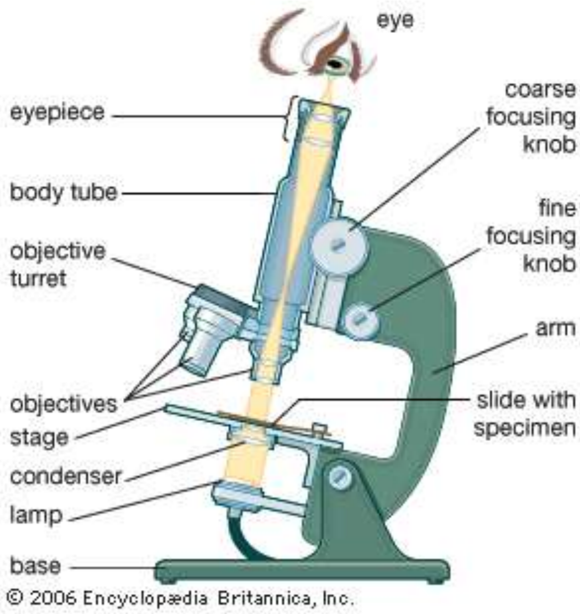
The compound microscopes are works on the principle that when a tiny specimen to be magnified is placed just beyond the focus of its objective lens, a virtual, inverted and highly magnified image of the object are formed at the least distance of distinct vision from the eye held close to the eyepiece.



Compound Microscope diagram of light path



Light Path of Binocular Compound Microscope diagram |



Compound Microscope diagram of light path

Mechanism of Compound Microscope

Compound microscopes create an image of specimen by these following steps;

1. First of all, a specimen is placed between the objective and condenser lens.

2. The light emitted from the light source is pointed over the specimen with the help of a condenser lens.

3. After that, the light is passed through the specimen and comes towards the objective lens.

4. The objective lens captures the light coming from the specimen and creates a magnified image of the specimen, which is called the primary image.

5. Then the objective lens passed this image through the body tube to the ocular lens or eyepiece and again magnifies the image.

6. At last, the viewer can see a clear and magnified image of the specimen through the eyepiece.

7. Occasionally or during the use of a 100x objective lens oil immersion method is used to produce a highly magnified image of the specimen. In this method, a drop of immersion oil is placed between the objective lens and specimen slide.

6.3.4.3 Magnification Power of Compound Microscope

The total magnification of image formed by the compound microscopes is calculated b this following formula;

$$m = D/ f_o * L/f_e$$

Where, D = Least distance of distinct vision (25 cm)

L = Length of the microscope tube

fo = Focal length of the objective lens

fe = Focal length of the eye-piece lens

6.3.4.4 Parts of compound microscope and Their functions

Figure: Compound Microscope

Image: compound microscope labeled diagram |

1. Head:

- It is located at the top portion of the microscope.
- It contains Eyepiece.

1. Eyepiece:

- It is also known as ocular, which is located at the top of a microscope. Viewers see the specimen through it.

Compound Microscope – Eyepiece

2. **Body Tube:**

- It's a long tube, which connects both eyepiece and objective lenses.

3. **Nosepiece:**

- Nosepiece is located at the bottom portion of body tube.
- Objective lenses are remain attached to it.
- It can rotate to adjust the objective lens.

compound microscope – Nosepiece

4. **Objective lens:**

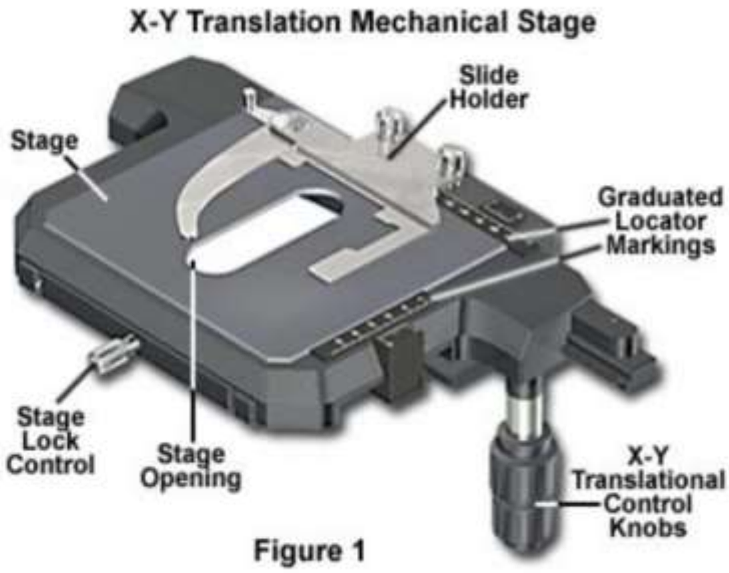
- Compound microscopes contain different types of objective lens (10x, 40x, 100x).

- These are located below the nosepiece.
- These lenses are closest to the specimen.

Objective lens of microscope

5. **Stage:**

- The flat metal platform located above the condenser and below the objective lens.
- The slide of the test specimen is placed over it.



Stage of microscope diagram

6. **Stage Clips:**

- It is above the stage.
- It holds the slide.

7. **Base:**

- It supports all the components of the microscope.

8. **Arm:**

- It connects the body tube and base of the microscope.

9. **Illuminator:**

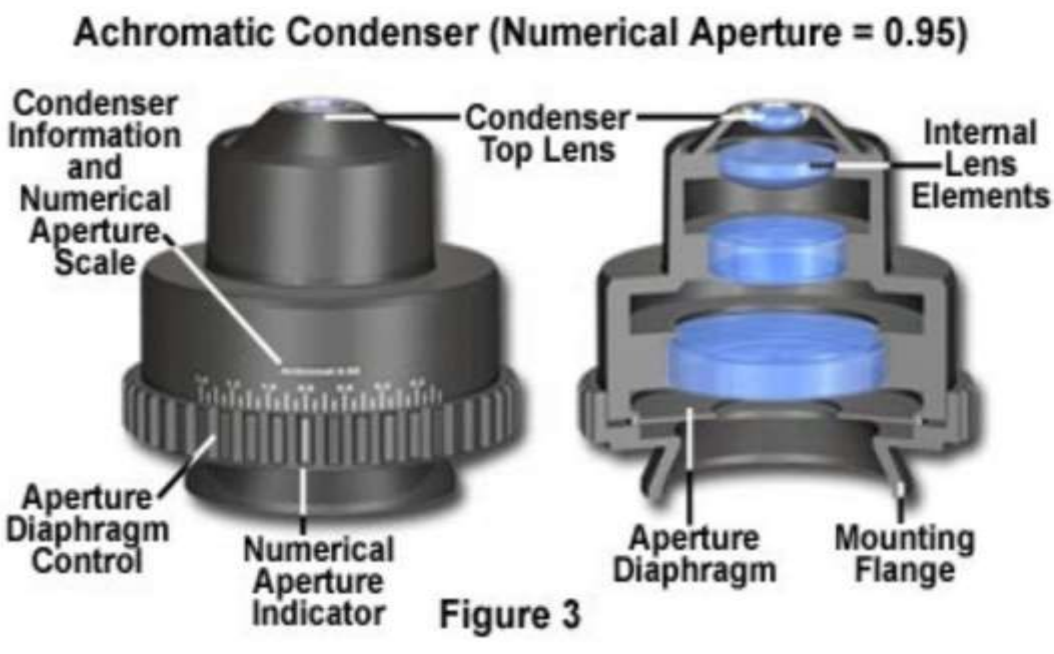
- An illuminator is the light source of compound microscopes.
- It is a low voltage bulb, which is located below the stage.

10. **Aperture:**

- It is a small hole in the middle of stage.
- It pass the light from the Illuminator to the specimen slide.

11. **Condenser:**

- It is located below the stage.
- It gathers and focuses light from the illuminator onto the specimen being viewed.



Condenser of microscope diagram

12. **Iris diaphragm:**

- It adjusts the amount of light that reaches the specimen.

13. **On/off switch:**

- It is located at the base.
- This switch turns the illuminator off and on.

14. **Stage Controller:**

- These knobs move the stage in left and right or up and down.

15. **Brightness Adjustment:**

- It located at the base.
- It adjust the brightness of Illuminator.

16. **Diaphragm:**

- It is a five holed disk placed under the stage.

17. Fine adjustment: Fine adjustments can be used to adjust the focus and increase the detail of the specimen.

18. Coarse adjustment: Focuses on the specimen.

19. Diopter Adjustment: Diopter Adjustment is a tool that allows you to adjust the focus of one eyepiece to correct any differences in vision between your eyes.

20. Slide or specimen: A specimen is an object that has been examined. Most specimens are mounted on slides. These flat rectangular pieces of thin glass are used for mounting.

A cover slip is placed above the specimen and the specimen is placed on top of the glass. This covers the microscope so that the slide can be easily removed or inserted. This allows for the specimen to be easily labeled and transported without damage.

6.3.4.5 Magnification of the Object Image by Compound Microscope

Bright-field and compound microscopes are used to magnify or enlarge the image of an object being viewed. This is not possible with the naked eye. Magnification can be described as the extent of magnifying an object's image using a microscope.

Magnification of a microscope depends on the individual magnifying abilities of the objectives and the oculars. If the objective is 40X and the ocular 10X, then the specimen will be magnified 400x. The specimen will be magnified 1000x if an oil immersion objective (100X), is used with the 10X ocular.

Factors play an important role in magnification

1. Length of optical tube.
2. The focal length of the objective lens.
3. Magnifying power of the ocular.

6.3.4.6 Compound Microscope Resolution Power (Resolving power)

A compound or bright-field microscope's resolution power (resolving ability) is its ability to distinguish between very close particles. A magnified image should show the object in a larger size. However, it should still have clear details.

This can be achieved when the microscope is able to see two points very close together as two distinct entities. The resolution power is the distance between two objects that can be clearly seen as separate structures in a magnified image.

This explanation is easily understood by comparing it to the human eye. The human eye works on the same principle as a light microscope or bright-field, meaning that objects can be seen by reflecting light.

The human eye has a resolution power of 0.25mm. Two dots placed 0.25mm apart (or more) can be seen only as two dots. Anything closer will appear as a single dot.

Factors that determine Resolution Power:

Two factors affect the resolution power of a bright field (light) microscope:

1. Wave length of light
2. Numerical aperture of the objective.

Wave length of the light

The visible wavelength of light used to illuminate light microscopes (bright field) falls within the visible range (400-750nm). The resolution will increase if the light used is shorter in this range. Blue light, for example, has a shorter wavelength that red light. A blue light can be used as an illumination source to achieve greater resolution than a red one.

The Objective's Numerical Aperture (NA)

The property of a lens which determines how much light can enter it is called numerical aperture (NA). It is dependent on two factors.

- The medium's refractive index is the area between the specimen, the front of an objective lens.

- The angle between the divergent rays that pass through the lens and the optical axis is called the angular aperture. The resolution power is greater if the objective can accept more divergent or oblique light.

Numerical aperture (NA) can be mathematically calculated with the help of following formula.

NA = n sin f

Where, n = refractive index of the medium

f = angular aperture

Calculation of Resolution Power

The resolution power of a bright-field microscope can be calculated using the following formula:

Resolution (resolving) power (RP) = Wave length of light used for illumination/2 x Numerical aperture (NA)

For convenience, if yellow light of wave length of 580 nm with numerical aperture (NA) of 1.0 is used in the microscope, the resolution power (RP) of the microscope will be:

Resolution power (RP) = 580/2 x 1 = 290 nm

6.3.4.7 Object Size Measurement by using Compound Microscope

A micrometer can accurately determine the size of objects when they are viewed under a compound microscope. This latter is made up of two scales: the eyepiece scale (also known as 'graticule or 'ocular'), and the stage microscope scale. The stage micrometer calibrates the eyepiece scale and then the latter is used to measure.

The microscope eyepiece scale is located inside the microscope eyepiece. The stage micrometer is on the microscope stage. The scale is approximately 1 mm in length and is divided into 100 divisions. Each division is 10 um. The stage micrometer is used for calibrating the eyepiece scale, as mentioned earlier.

(i) Calibration

1. It is important to note first which objective lens has been used on the microscope.
2. The stage micrometer is placed so that it is visible from the field of vision.
3. Rotating the eyepiece so that the two scales, either the eyepiece or the ocular scale, and the stage micrometer, are parallel is a good idea.

4. Now, the stage micrometer must be moved so that both scales' first division marks are in line.

It is now possible to see which divisions of the eyepiece and stage micrometer scale correspond with each other. One division on the stage microscope equals 10 um. This allows one to calculate the value of the eyepiece scale.

The four divisions of the eyepiece stage scale equal 10 divisions (i.e. 100 um) on the stage micrometer scale. 1 division on this eyepiece scale = 25nm for the specific objective lens in this case.

These positions can be repeated with objective lenses. The following information's are recorded onto an adhesive label. For future reference, adhesive labels are stuck to the base and sides of the microscope.

(iii) Use

After calibrating the eyepiece scales for all objective lenses, the microscope can be used to measure the dimensions and morphology of cells and sub-cellular structures.

6.3.4.8 Working Mechanism of The Compound Microscope

- Look into the eyepiece. Adjust the mirror so that enough light can pass through the microscope.
- Clean the mirrors, lenses, stage and slides.
- Place the slide in central position on the stage.
- Secure the slide securely with clips along the edges to stop it moving.
- The nose piece can be adjusted so that the low power objective aligns with the object of focal on the slide.
- You can adjust the coarse adjustment knob upwards or downwards so that the slide remains in focus.
- To get a sharp and clear image of the object in focus, turn the fine adjustment knob upwards or downwards.
- Under low power objectives, all details are captured. The diagrams that are necessary are drawn.
- To align the high power objective with the object, the nose piece must be turned. To get a clear and sharp view of the object, the fine adjustment knob must be adjusted as much as possible.

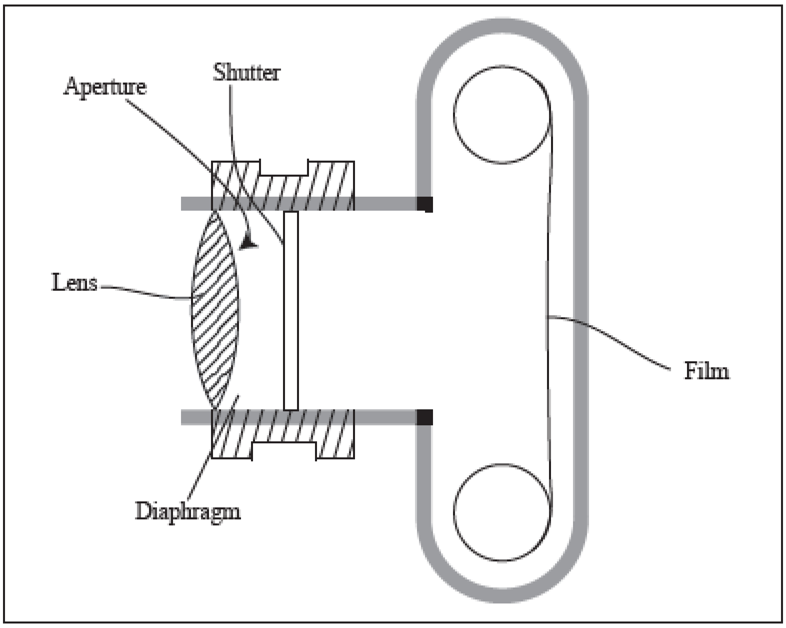
- High power can be used to observe the details of an object. Make the diagrams. When the object is being examined at high power, the coarse adjustment knob should be avoided as it could crush the slide.

6.3.4.9 Precautions

- Before using, clean the eyepiece and objective lenses with a silk cloth and some cleaning liquid.
- When using the microscope, it should not be tilted.
- Focus on the lowest power object first, then move on to the higher power.
- After all observations have been completed, the lower power must be retained.
- Focusing requires that you ensure the objective lens does not touch the slide or stage.
- When the high power objective needs to be achieved, the fine adjustment knob is the only thing that should be used.
- Always use a cover slip to cover well-mount preparations prior to observation under the microscope.
- Do not take apart the microscope.
- Always use both hands when carrying the microscope
- After using the microscope, place it in a container.
- Dimming the light should be used on the concave portion of your mirror.
- It is not recommended to use oil immersion lenses without oil.

6.3.4.5 Description and functionality of Camera

A camera consists of a light- tight box with a convex (converging) lens at one end and the film at the other end. It uses the convex lens to form a small, inverted, real image on the film at the back.



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. In many cameras, this happens automatically. In cheaper cameras, the lens is fixed and the photographer moves forwards and backwards to focus the object.

The diaphragm:

Is a set of sliding plates between the lens and the film. It controls the aperture (diameter) of a hole through which light passes.

In bright light, a small aperture is used to cut down the amount of light reaching the film and in dim light, a large hole is needed.

Very large apertures give blurred images because of aberrations so the aperture has to be reduced to obtain clear images.

In many cameras, the amount of light passing through the lens can be altered by an aperture control or stop of variable width.

This size of the hole is marked in f – numbers i.e 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32. The smaller the f-number, the larger the aperture. An f-number of 4 means the diameter d of the aperture is ¼ the focal length, f of the lens. To widen the aperture, the f number should therefore be decreased.

The aperture also controls the depth of field of the lens camera.

The depth of field is a range of distances in which the camera can focus objects simultaneously. This depth of field is increased by reducing the aperture.

This large depth of field ensures a large depth of focus. The depth of focus is the tiny distance the film plane can be moved to or from the lens without defocusing the image. A large depth of focus means that both near and far objects appear to be in focus at the same time which is obtained by a small hole in the diaphragm.

The shutter :

Controls the exposure time of the film. It opens and closes quickly to let a small amount of light into the camera.

The exposure time:

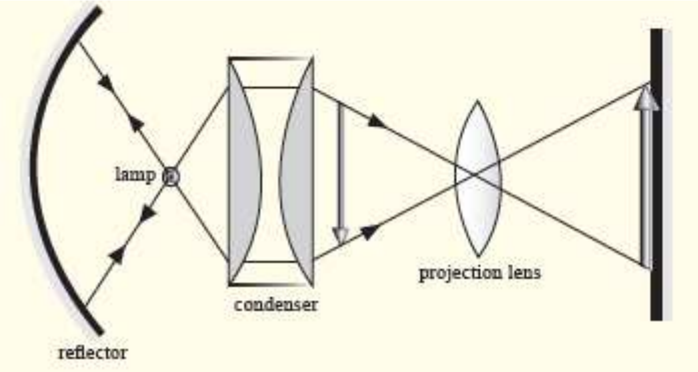
Affects the sharpness of the image. When the exposure time is short, the image is clear (sharp) but when it is long the image becomes blurred.

The film:

This is where the image is formed. It is kept in darkness until the shutter is opened. It is coated with light sensitive chemicals which are changed by the different shades and colors in the image. When the film is processed, these changes are fixed and the developed film is used to print the photograph.

6.3.4 The slide projector

A projector is a device used to throw on a screen a magnified image of a film or a transparent slide. It produces a magnified real image of an object.



It consists of an illumination system and a projection lens. The illumination system consists of a lamp, concave reflector and the condenser. The illuminant is either a carbon electric arc or a quartz lamp to give a small but very high intensity source of light in order to make the image brighter.

The lamp is situated at the centre of curvature of the mirror so that the rays are reflected back along their original path. The concave mirror reflects back light which would otherwise be wasted at the back of the projector housing. The condenser consisting of two Plano concave lenses collects light which would otherwise spread out and be wasted, and concentrates it on to the film (slide) so that it is very bright and evenly illuminated.

The light is then scattered by the film and focused by a convex projection lens on to 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.

6.3.5Microscope

Simple Microscope (Magnifying Glass)

A magnifying glass consists of a thin converging lens and It is used to view very small organisms or parts of organisms which cannot be easily seen by the naked eye.

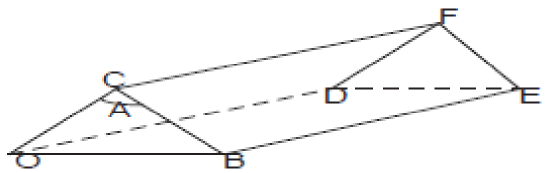
6.4 REFRACTION THROUGH PRISMS

A prism transmits light but slows it down. When light passes from air to the glass of the prism, the change in speed causes the light to change direction and bend. **Due to the differences in the refraction index between the air and the glass, light bends once entering the prism**.

In optics, a prism is transparent material like glass or plastic that refracts light.
At least two of the flat surfaces must have an angle less than 90o between them.
The exact angle between the surfaces depends on the application.

Terms associated with refraction through prism

REFRACTION IN A GLASS PRISM
A prism is a geometrical object with at least two plane surfaces. A prism is made up of glass.



- Triangular face; OBC=DEF
- Refracting surface; CBEF= CODF

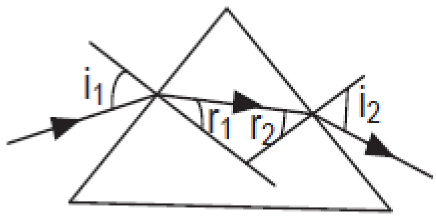
- Angle of a prism or refracting angle;

This is the angle between any two inclined surfaces of a prism and its denoted by A

Eg $< \dot{O}CB =< DFE = A$

- Base; OBED

6.4.1 Path followed by a ray of light in a glass prism



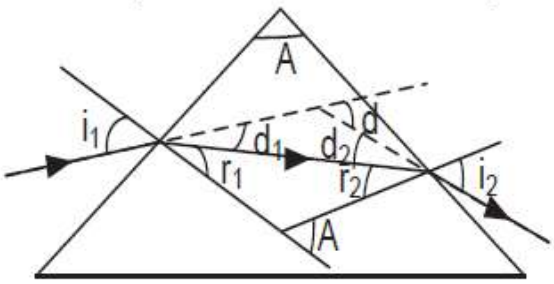
Exercise: Explain why a prism deviates light towards the base

This is because a **ray that moves form a less optically dense medium bends towards the normal** and a **ray that moves from a more optically dense medium bends away from the normal.**

6.4.2 Deviation by a prism:
It is the change in direction of a ray of light produced by a prism.
When light passes through a glass prism, the direction of the emergent ray is altered from the initial direction. The angle through which the beam direction is altered is called **deviation, d.**

Definition:

The angle of deviation caused by the prism is the angle between the incident ray and the emergent ray.
Consider a ray of light incident in air on a prism of refracting angle **A** and finally emerges into air as shown.



$$d = d_1 + d_2$$

Since $d_1 = i_1 - r_1$ and $d_2 = i_2 - r_2$

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

$$\boxed{d = (i_1 + i_2) - (r_1 + r_2)}$$

Since $A = r_1 + r_2$

$$\boxed{d = (i_1 + i_2) - A}$$

6.4.3 Minimum Deviation by a prism

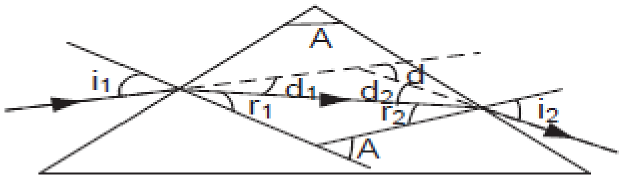
Minimum deviation occurs when;

- The ray of light passes symmetrically
- The angle of incidence must be equal to the angle of emergence i.e

$i_1 = i_2 = i$ and $r_1 = r_2 = r$

Relation of angle of prism A, minimum deviation and refractive index

Consider a ray on one face of the prism at an angle **i1** and leaves it at an angle **i2** to the normal as shown



$$d = d_1 + d_2$$

Since $d_1 = i_1 - r_1$ and $d_2 = i_2 - r_2$

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

$$\boxed{d = (i_1 + i_2) - (r_1 + r_2)}$$

Since $A = r_1 + r_2$

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

But for minimum deviation $i_1 = i_2 = i$ and

$$r_1 = r_2 = r$$

$$d_{min} = 2i - A \qquad \therefore \qquad i = \frac{d_{min} + A}{2}$$

Also $A = r_1 + r_2 = 2r$

$$r = \frac{A}{2}$$

$$n_a \sin i = n_g sinr$$

$$n_g = n_a \frac{\sin(i)}{sin(r)}$$

$$n_g = n_a \frac{\sin\left(\frac{d_{min} + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

But $n_a = 1$

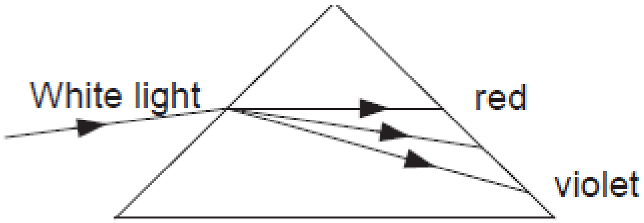
$$\boxed{n_g = \frac{\sin\left(\frac{d_{min} + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

Note: If the prism is surrounded by a medium of refractive index n_l

$$\boxed{n_g = n_l \frac{\sin\left(\frac{d_{min} + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

6.4.4 Dispersion of white light by a transparent medium

Dispersion of whit light is the separation of white light in to its component colours by a transparent medium due to their speed differences in the medium.



When white light falls on a transparent medium, its different component colours travel with different speeds through the medium. They are therefore deviated by different amounts on refraction at the surface of the medium and hence dispersion.

NOTE :

(i) White light is a mixture of various colours. This is called the spectrum of white light.

(ii) The spectrum of white light consists of red, orange, yellow, green ,blue, indigo and violet light bands. On refraction, violet is the most refracted colour away from the normal (violet is the most deviated colour) while red is least deviated.

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