Chapter 1

Reflection of light on different surfaces

In class 6, we have learnt about shadows and we did many experiments with light rays and also discussed the rectilinear propagation of light i.e., light travels in a straight line. In class 7 we learnt the laws of reflection.

Let us recall some of them.

– A source of light, an opaque object and a screen are needed to form a shadow.
– Light travels in a straight line.
– When light gets reflected from a surface, the angle of reflection is equal to the angle of incidence.
– The incident ray, the normal at the point of incidence and the reflected ray lie in the same plane.

You must have observed shadows and images in your daily life. You might have got questions in your mind while observing these shadows or images.

- Why does our image appear thin or bulged out in some mirrors?
- Why is there right-left inversion (lateral inversion) when we look in to mirror?
- Can we focus the sunlight at a point using a mirror instead of a magnifying glass?
- Why the angle of reflection is equal to the angle of incidence when a light ray reflects from a surface?
- Are angle of reflection and angle of incidence also equal for reflection on curved surfaces?

In this lesson we are going to learn reflection of light in detail so that we can answer the above questions. Let's start with some activities based on your previous knowledge.

Activity 1

Formation of image in pinhole camera

You might have remember, that how an image forms in a pinhole camera that you have learnt in class 6. Draw a ray diagram of formation of an image in pinhole camera.

Think, what happens if we increase the size of the hole of pinhole camera. Observe the flame of a candle with pinhole camera making a big hole to it. Try to draw a ray diagram for the formation of image in a pinhole camera with a big hole. Look at figure 1.

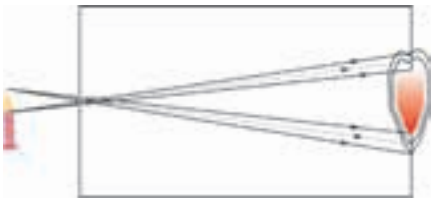
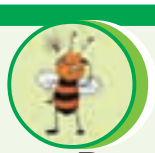


fig-1:

By observing the figure we can understand that the light rays coming from the top of the candle flame fall at different points on the screen. Similarly the rays coming from bottom of the candle flame also fall at different points on the screen. Thus we get blurred image on the screen due to the big hole of the camera as shown figure 1.



Think and discuss

- Does the explanation match with your observation?
- What happens if the hole is much bigger i.e. equal to the size of the flame?
- If it is so, can we get the image of flame on the screen of pinhole camera? Why?
- What happens if we observe the same flame with the same pinhole camera from a far distance?

Think and say. Do the experiment and check your answer.

Now think of reflection of light, and solve the task given below.

Activity -2

Find the shortest way:

A smart crow is on a tree at point 'A' as shown in figure-2. Some grains are on the ground. If the crow wants to take a grain and reach the point 'B' on the other tree as early as possible(in least time), from where should the crow pick up the grain?



fig-2:

With the mathematical knowledge yo have about angles and triangles can you guess the path that the crow selects? If you can't, read the following.

The crow can pick the grain from any point on the ground. But the condition is selecting a point on the ground to reach point 'B' from point 'A' in least possible time. If we assume that the speed of the crow is constant, the path that crow selects should be the shortest. Let us find the shortest path.

Observe some of the paths in the figure-3.

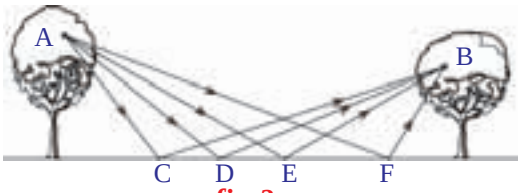


fig-3:

Which among the paths ACB, ADB, AEB and AFB is the shortest path?

To compare the lengths of these paths, make the duplicates of them as shown in figure-4.

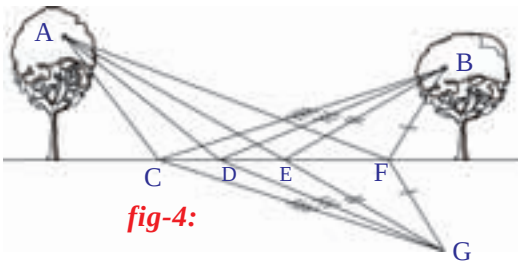


fig-4:

In the figure CB = CG. The length of path ACB = AC+CB = AC+CG = ACG. Thus the length of the path ACG is equal to the length of the path ACB. similarly ,

length of the path ADB = length of the path ADG

length of the path AEB = length of the path AEG

length of the path AFB = length of the path AFG

If you observe the Fig-4 carefully, you will notice that, among the paths ACG, ADG, AEG and AFG the shortest path is AEG, because it is the straight line distance between points A and G. You can measure and check this using a scale. As AEG=AEB, path AEB is the shortest path to reach point B from point A. It would take the least time. So the smart crow will pick the grain from point E.

Observe the path AEB once again in figure-5.

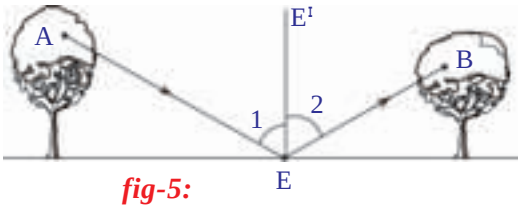


fig-5:

If we draw a normal EE^{I} at point E, we can easily find that angle AEE^{I} (angle 1) is equal to angle E^{I}EB (angle 2).

Like the crow in the above situation, light also selects the path which takes the least time to travel. This principle was first given by ***Pierre de Fermat***, a French lawyer and an amateur mathematician.

It is also applicable to reflection of light. When light gets reflected from a surface, it selects the path that takes the least time. That is why the

angle of incidence is equal to the angle of reflection as shown in figure-5.

Now, before the detailed discussion on reflection, peform a fun activity and refresh your previous knowledge.

Activity 3

Check your understanding of reflection:

Look at the figures 6a and 6b. Let us suppose that you have been given a plane mirror strip.

- What will you do to obtain figures that are shown in figure 6(b) using mirror strip and figure 6(a)?

Place the plane mirror strip on the figure shown in 6(a) in such a manner that you see one of the figures shown in figure-6b. The procedure is shown in figure-6c.

- Are you able to obtain all figures shown in 6(b)?

Take the help of your friends to complete the task.



fig-6a:



fig-6b:

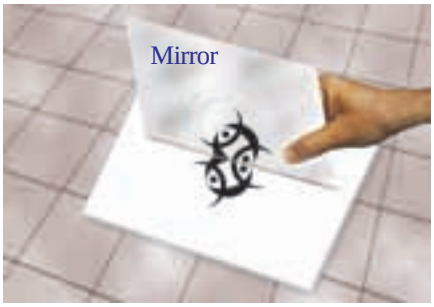


fig-6c:

Let us begin the detailed discussion on reflection of light on plane surfaces.

Lab Activity 1

Aim: Verification of laws of reflection:

Required material: mirror strip, drawing board, white paper, pins, clamps scale and pencil

Procedure: Take a drawing board and fix a white paper on it with the help of clamps. Draw a straight line AB at the centre of the paper and also

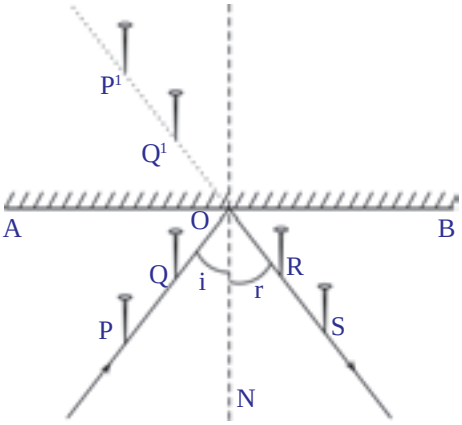


fig-7:

a normal (ON) to AB at the point 'O'. Draw a straight line PQ making certain angle (angle i) with ON as shown in figure 7. Fix two pins at the points P and Q on the paper vertically. Observe the image P^I of the pin P and Q^I of the pin Q, in the mirror kept along the line AB. Fix two more pins R and S such that they are in the same line as that of P^I and Q^I. Join R, S and O as shown in figure-7.

Measure the angle between RS and ON (angle of reflection). You will find that angle of incidence = angle of reflection. Repeat the experiment with different angles of incidence and measure the corresponding angles of reflection.

- Is the angle of reflection equal to the angle of incidence in all cases ?

What about the 2nd law of reflection of light? In which plane does the incidence ray, reflected ray and the normal lie? Let us discuss about that.

Plane of reflection:

In the above activity, the incident ray is the ray which is passing through the points 'P' and 'Q' touching the paper. The reflected ray is the ray which is passing through the points 'R' and 'S' touching the same paper, and ON is the normal to the mirror at point 'O'.

- Do the two rays and the normal lie in the same plane? If yes, which is that plane?

If the incident ray, reflected ray and normal are in the plane parallel to the plane of paper. Where will that plane be?

Assume that the heads of all pins pierced at points P,Q,R and S in the above activity are in the same height. If the incident ray is the ray which is passing through the heads of pins those are located at points P and Q, and reflected ray is the ray which is passing through the heads of pins those are located at points R and S.

- Where will the normal be?
- In which plane will the incident ray, reflected ray and the normal lie?

The plane in which the incident ray, reflected ray and normal will lie is the **plane of reflection**.

Assume that the heads of the pins those are located at the points P and Q are not at the same height.

- How will the incident ray be?

- How will the reflected ray be?
- How will the normal be?
- How will the plane of reflection be?

Arrange two pins with different height. Arrange the incident ray, reflected ray and the normal with the help of spokes of a cycle. Then think of the plane of reflection.

- How does a mirror form the image of a pin or any object?

Let us discuss.

Formation of an image by a plane mirror:

Observe the figure 8.

O is a point object. Some rays from O reached the mirror and get reflected. When we look into the mirror, the reflected rays seem to be coming from the point I. So point I is the image of point object O.

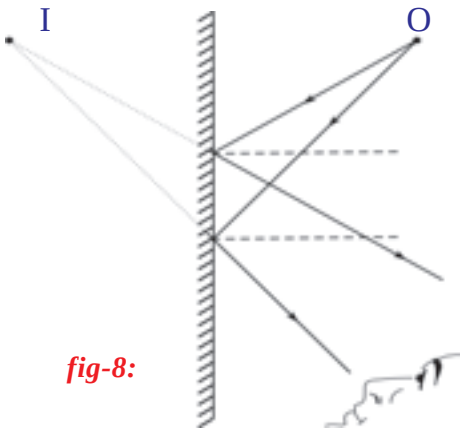


fig-8:

Observe the distances of object O and image I from the mirror in figure 8. We can see that these distances are equal.

In the same way draw an erect object in front of a mirror. Draw some incident rays from the object to the mirror and reflected rays from the mirror using laws of reflection.

Your drawing may be as shown in figure 9.

In the figure, the rays coming from the point O get reflected from the mirror and seems to be coming from the point I. So we say I is the image of O.

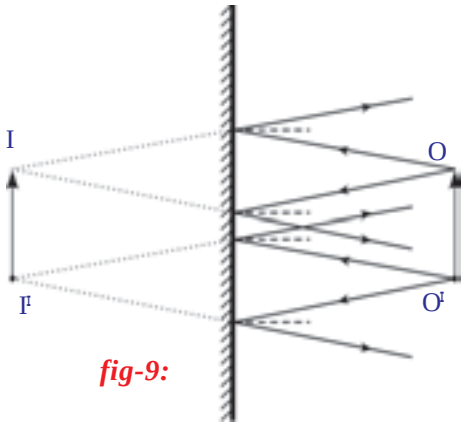


fig-9:

The rays coming from the point O^I get reflected from the mirror and seems to be coming from the point I^I. So we say I^I is the image of O^I.

The rays coming from the middle part of the O and O^I will form their images between I and I^I.

Thus, II^I is the image of the object OO^I.

- What is the size of the image compared to the size of object?

Let us discuss some of the characteristics like size, distance and right-left inversion of an image formed by a plane mirror.

Characteristics of an image formed by a plane mirror:

Take an object, say pen or pencil. Put it infrontof a plane mirror, touching the surface of mirror.

- What do you say about the size of the image compared to the size of the object?
- Move the object towards your eye. What do you observe?
- Is the size of the image decreasing or increasing?

Figure 9 shows the formation of an image by a plane mirror. In that figure you might have noticed that the size of the image is equal to the size of the object. Why does the size of the image decrease when you move the object towards your eye?

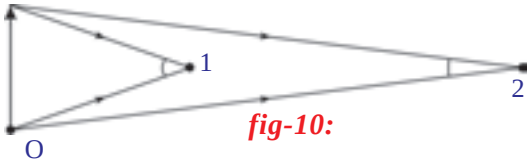


fig-10:

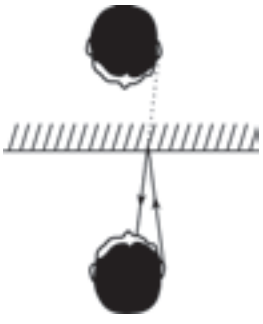
To understand this see the figure 10, which shows how our eye sense the size of an object.

Observors 1 and 2 are looking at the object which is at point O. It looks smaller to the observer 2 than to the observer 1. Why because, the light rays coming from the object makes a smaller angle at the eye of the observer 2 who is at a far distance compared to the observer 1. The angle plays the role in sensing the size of the object. (The size of the object as angular size.)

In the same way when we move the object from the mirror to our eye, the image in the mirror seems to move back in the mirror. Then the distance from the image to our eye increases. The angle formed by image at our eye is smaller than that of angle formed by the object. That is why the image looks smaller than the object.

When you stand in front of a mirror you might have observed that the distance of your image in a plane mirror seems to be equal to the distance to you form the mirror. What you observe can be treated as correct. You can verify this by observing figure-9.

You also might have observed the right-left inversion of your image in plane mirror.


fig-11:

- Why does an image suffer lateral (right-left) inversion? See figure-11.
- What do you understand from the figure 11?

The light rays which come from our right ear get reflected from the plane mirror and reach our eye. Our brain feels that the ray (reflected ray) is coming from the inside the mirror (shown by dotted line in the figure-11). That is why our right ear looks like left ear in the image.

Now observe the lateral inversion of a letter with a ray diagram in figure-12.

Think and explain the process of image formation with plane mirrors and lateral inversion by observing the figure-12.

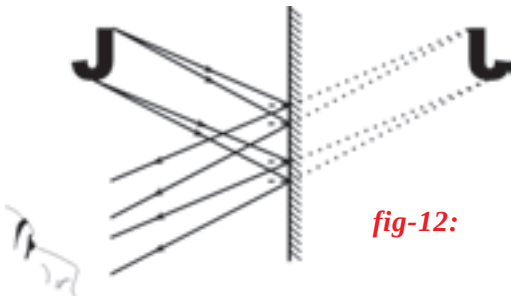


fig-12:

Spherical mirrors:

We now know how light reflects from plane surfaces. In class 7, we learnt about the types of spherical mirrors and why they were called spherical mirrors.

We already did a simple activity to get an image with concave mirror in class 7. Now we will study the reflection of light by curved surfaces in detail.

Reflection by spherical mirrors

The first law of reflection tells us:

A light ray incident at an angle to the normal at the point of incidence will get reflected making the same angle with the normal.

This law is true for all surfaces, be it a plane surface or a curved one. The important words here are 'the angle made to a normal at the point of incidence'. If for any surface one can decide the normal and find the incident angle, it is possible to deduce the angle of the reflected ray. It was very easy to find a normal at any point on the plane surface. But for a curved or uneven surface it is not straightforward.

Activity 4

Finding the normal to a curved surface:

Take a small piece of thin foam or rubber (like the sole of a slipper). Put some pins in a straight line on the foam as shown in the figure -13a.



fig-13(a):

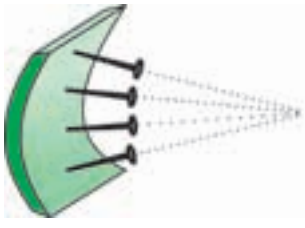


fig-13(b):

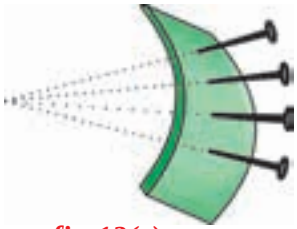


fig-13(c):

All these pins are perpendicular to the foam. If the foam was considered as a mirror, each pin would represent normal at that point. Any ray incident at the point where the pin makes contact with the surface will reflect at the same angle the incident ray made with the pin-normal.

Now bend the foam piece inwards as shown in figure-13b, what happens to the pins?

They still represent the normal at various points, but you will notice that all the pins tend to converge at a point (or intersect at a point).

If we bend the foam piece outwards, we will see that the pins seem to move away from each other or in other words they diverge as shown in figure-13c.

This gives us an idea of what is likely to happen with a spherical mirror. A concave mirror will be like the rubber sole bent inwards (fig-13b) and the convex mirror will be like the rubber sole bent out wards (fig-13c).

For a concave mirror, like these pins in figure-13b, all normals will converge towards a point. This point is called **centre of curvature(C)** of the mirror.

Recall a little bit of geometry: while learning about circles and tangents you may have learnt that a radius drawn from the centre of the circle to point on the circle will be perpendicular to the tangent to that point on the circle.



This gives us a clue about how we can find normal to any point on a spherical mirror. All that we have to do is to draw a line from the point on the mirror to centre of the circle.

It is much easier to imagine this in two dimension as shown in the figure-14a. The concave mirror is actually a part of a big sphere. So to find this centre point (centre of curvature) we have to think of centre of the sphere to which the concave mirror belongs.

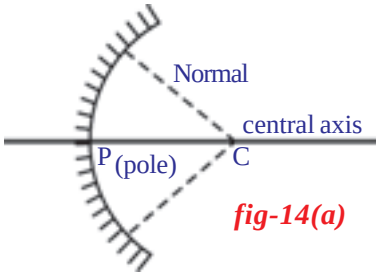


fig-14(a)

For the ray R, the incident angle is the angle it makes with the normal shown as **i** and the reflected angle is shown as **r** in figure-14b. We know by first law of reflection i = r.

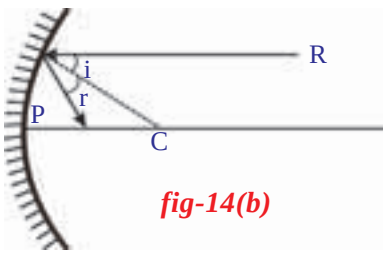


fig-14(b)

The mid point (Geometrical centre) of the mirror is called **pole (P)** of the mirror. The horizontal line shown in the figures which passes through the centre of curvature and pole is called **central axis / principal axis** of the mirror. The distance between P and C is **radius of curvature (R)** of the mirror.

Using the construction method described above, try to construct different reflected rays for an array of rays that are parallel to the principal axis. What is your conclusion?

Verifying your drawing with experiments:

To verify this we must first find out some way of making a beam of parallel rays. How do we do that?

First we need to find out a situation in which one gets parallel rays of light.

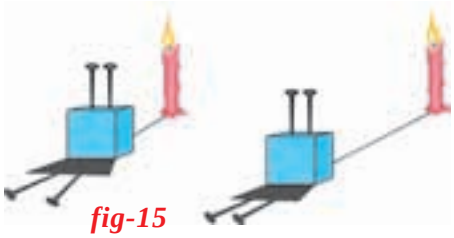


fig-15

In the figure-15 we have stuck two pins on a thermo coal block. The pins are exactly parallel to each other. As we can see in the figure, when a source of light is kept very near, we see the shadows diverging (from the base of the pins), as we move the source away from the pins, the divergent angle starts reducing. If we move the source far away we will get parallel shadows. But as we move the candle away the light intensity starts to reduce. That means to get a beam of parallel rays all that we need is a powerful source far away.

Where do we find one such source?

Yes, we have one easily available source, you probably have guessed it: The Sun.

Let us do an experiment with sun rays and a concave mirror.

Activity-5

Identifying the focal point:

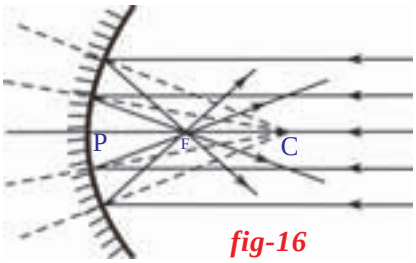


fig-16

Hold a concave mirror perpendicular to the direction of sunlight. Take a small paper and slowly move it in front of the mirror and find out the point where you get smallest and brightest spot, which is the image of the sun. (See to it that your paper is small so that it does not obstruct the incoming sun rays.)

The rays coming from sun parallel to the concave mirror are converging at a point (see figure-16). This point is called **Focus or focal point (F)** of the concave mirror. Measure the distance of this spot from the pole of the mirror. This distance is the **focal length (f)** of the mirror. The radius of curvature will be twice of this distance (R=2f).

- Does this help you to verify the conclusions those you have arrived at theoretically?

- What happens if you hold the paper at a distance shorter than the focal length from the mirror and move it away?
- Is the image of the sun become smaller or bigger?

You will notice that the image of the sun keeps on becoming smaller. Beyond the focal point it will become bigger.

Note: while drawing a ray diagram sometimes it is not clear which is the reflecting side of the mirror. Hence we follow a convention of showing hatching on the non-reflecting side.

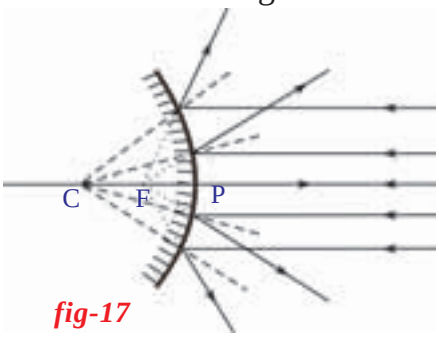


fig-17

Can you draw the same diagram for a convex mirror?

See the figure-17. The parallel rays are diverging after reflection. If we extend the reflected rays backwards they meet at 'F' i.e. focal point of the convex mirror.



Think and discuss

- See the figure-17. A set of parallel rays falling on a convex mirror. What conclusions can you draw from this?
- Will you get a point image if you place a paper at the focal point?

When the parallel rays incident on a concave mirror, on reflection they meet at focus.

- Do we get the image with a concave mirror at the focus every time? Let us find out.



Lab Activity 2

Aim: Observing the types of images and measuring the object distance and image distance from the mirror.

Material required: A candle, paper, concave mirror (known focal length), V-stand, measuring tape or meter scale.

Procedure: Place the concave mirror on V-stand, a candle and meter scale as shown in figure-18.

Keep the candle at different lengths from the mirror (10cm to 80cm) along the axis and by moving the paper find the position where you get the

sharp image on paper. (Take care that flame should be above the axis of mirror, paper should be below the axis).

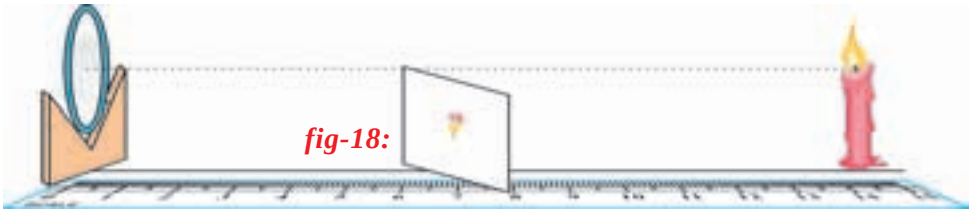


fig-18:

Note down your observations in table-1.

Table-1

Observation no.	Distance of candle from mirror (object distance-u)	Distance of paper from mirror (image distance-v)	Bigger/smaller than object	Inverted or erected
1				
2				
3				
4				

Group your observations based on the type of image you see (e.g. Image is bigger and inverted). It is possible you may not get any image at some positions, note down that too!

Since we know the focal point and centre of curvature, we can reclassify our above observations as shown in table-2. See if you can get a pattern.

At this point we suggest that you make one more observation. You have been trying to get the image on a paper when the object is at different positions. At the same time also look into the mirror and note your observations about whether and how you see the image of the candle.

- Is it inverted or erected, enlarged or small?

Table - 2

Position of the candle (object)	Position of the image	Bigger/smaller than object	Inverted or errected	Real or virtual
Between mirror & F				
On focal point				
Between F and C				
On centre of curvature				
Beyond C				

What do you infer from the above table?

Let us try to draw ray diagrams with concave mirrors and compare with your inferences.

Ray diagrams: with concave mirror

In activity-5 we saw the ray diagram of sunrays coming parallel to the concave mirror and the image of the sun would become very small at the focal point (See figure-13). Now we will develop a technique to draw ray diagrams when an object is placed anywhere on the axis of the mirror and validate the above observations.

Here we will take at least two rays originating from the same point on the object but with different orientation (direction), see how they reflect from the mirror and find out the point where they meet to form the image.

Let us take an example.

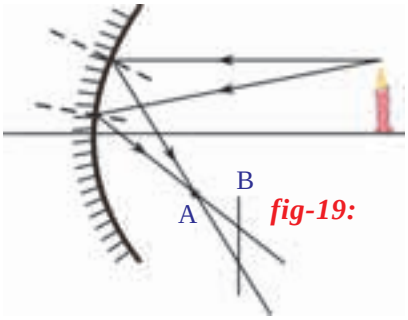


fig-19:

As shown in the figure-19, assume a concave mirror and a candle placed at some distance along the axis of the mirror.

The diagram shows two rays starting from the tip of the flame (object). The reflected rays are constructed based on the laws of reflection.They meet at point A. The tip of the flame of the reflected image will be at the intersection point A.

- Why only at point A?

If we hold the paper at any point before or beyond point A (for example at point B), we see that the rays will meet the paper at different points. So the image of the tip of the flame will be formed at different points due to these rays. If we draw more rays emanating from the same tip we will see that at point A they will meet but at point B they won't. So the image of the tip of the flame will be sharp if we hold the paper at point A and will become blurred (due to mixing of multiple images) when we move the paper slightly in any direction (forward or backward). Is this not something that you observed during the previous experiment with sun rays?

However, it is not going to be easy to construct reflected angle for any arbitrary ray, every time we will have to find the normal, measure the incident angle and construct a ray with equal angle on the other side. This would be a tedious task, can we find some shortcuts?

Yes, there are few. Based on our discussion so far we can identify some 'easy' rays which we can take as representative to find the point 'A'.

We have seen that all rays that are parallel to the axis get reflected such that they pass through the focal point of the mirror. So, for drawing any diagram the easiest ray to draw will be the one that starts from the object and goes parallel to the axis of the mirror. The reflected ray will be the line drawn from the point where the incident ray meets the mirror and goes through the focal point of the mirror. To make it more convenient we will always take rays that start from the tip of the object. See the ray R_1 in the figure-20.

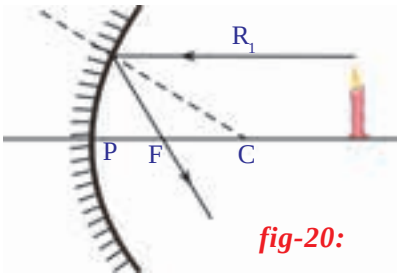


fig-20:

The opposite situation of previous one is also true; that is, a ray that goes through the focal point of the mirror will, when reflected, travel parallel to the axis.

This gives us our second ray. This will be the ray starting from the tip of the flame and going through the focal point and falling on the mirror. This ray will be reflected in such a manner that it will become parallel to axis. So we draw the reflected ray as a line parallel to axis starting from the point where the incident ray meets the mirror. See R_2 in figure-21.

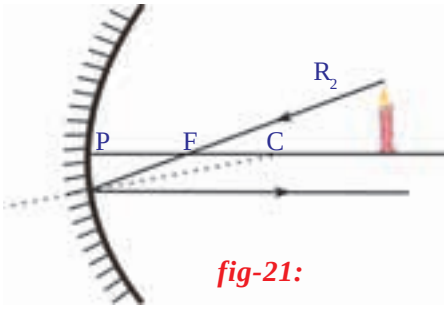


fig-21:

Using the rays R_1, R_2 and finding the point where they intersect we know the point where the tip of the flame is going to be in the image.

There is one more ray that is easy to draw.

We have seen earlier that any ray that is normal to the surface, on reflection, will travel along the same ray but in the opposite direction. What can be such a ray for a spherical mirror?

We know that a line drawn from the centre of curvature to the mirror is perpendicular to the tangent at the point the line meets the curve. So if we draw a ray starting from the tip of the object going through the centre of curvature to meet the mirror, it will get reflected along the same line. This ray is shown as R_3 in the figure-22.

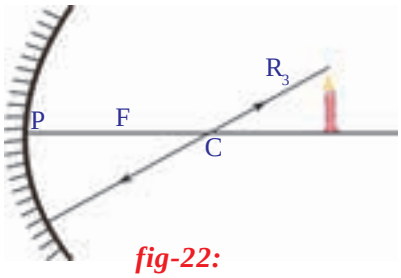


fig-22:

Along with these three rays 'the ray which comes from the object and reaches the pole of the mirror' is also useful in drawing ray diagrams. For this ray, the primcipal axis is the normal.

If we have our object placed as shown in figure-23, we can draw the ray diagram to get the intersection point A with any two rays coming from

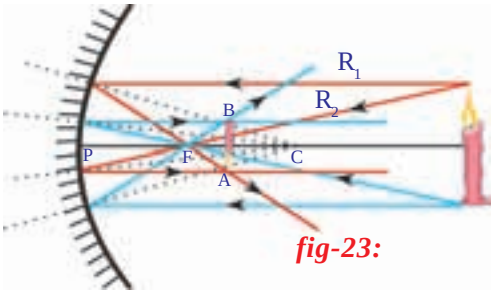


fig-23:

top of the object and intersection point B of any two rays coming from the botom of the object. we notice that the point B is exactly at the same distance from mirror as the point A. Hence the image is vertical, and here the image is inverted also.

- Where the base of the candle is going to be in the image when the object is placed on the axis of the mirror?

Since any ray starting from a point on the axis and travelling along the axis will reflect on the axis itself, we can conclude that the base of the image is going to be on the axis. Using the knowledge that if the object is placed vertically on the axis, the image is going to be vertical all that we do is to draw a perpendicular from point A to axis. The intersection point is the point where the base of the image of the candle is going to be formed. See figure-24. Hence, as shown in the diagram the image will be inverted and smaller than the object.

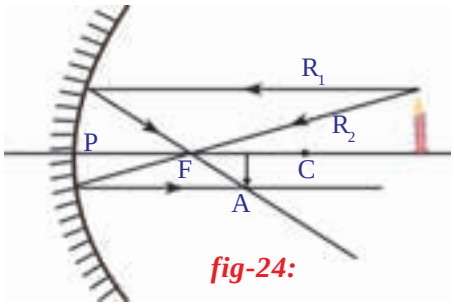


fig-24:

Figure-24 is drawn for the case where the object is placed beyond the centre of curvature.

Does this conclusion match with your observations? (Lab Activity 2)

Draw similar diagrams for other cases and verify that they match with your observations.

- During the experiment, did you get any points where you could not get an image on the screen?

Consider the case shown in the figure-25. The candle object (O) is placed at a distance less than the focal length of the mirror.

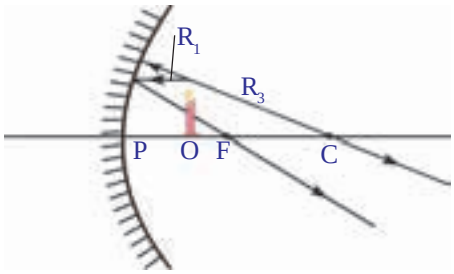


fig-25:

The first ray (R_1) will start from tip of the object and run parallel to axis to get reflected so as to pass through the focal point. This one is easy to draw. The second ray (R_2) that we chose for earlier ray diagrams is the ray starting from the tip of the object and going through the focal point but it is not possible as such a ray will not meet the mirror. So we must use the third ray (R_3), a ray starting from the tip of the object and going through the centre of curvature.

But that too does not seems to be possible. So we make a small change. Instead of drawing a ray from the tip to centre of curvature, we consider a

ray that starts from the tip and goes in such a direction that it would go through the centre of curvature if extended backwards. This ray is normal to the surface and so will be reflected along the same line in opposite direction and will go through centre of curvature.

We notice that the two reflected rays diverge and will not meet. While doing the experiments for a case such as this we were unable to find any place where we got a sharp image on the screen. This ray diagram tells us that since the reflected rays are diverging we will not get an image anywhere. So even if we had moved the paper much away from the mirror, we would not have found an image.

But in such situations we do see an image when we look in the mirror. Is it possible to explain this image with the ray diagram?

Yes, we can.

Remember what we did to find image in a plane mirror, we extended the reflected ray backwards till they met to decide the position of image. We will do the same here. When we look in the mirror we are looking at these diverging reflected rays. They appear to be coming from one point. We can get this point by extending the rays backwards as shown in figure-26. The image does not really exist the way we saw in other cases, but it is visible to us.

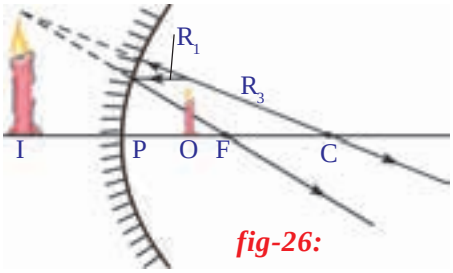


fig-26:

As seen in the figure-26, the image will be erect and enlarged. Does this match with your observations?

This image that we got by extending the rays backwards is called a **virtual image.** We can not get this on a screen like a **real image**.

The case with the object on the centre of curvature is another interesting situation. See figure-27.

From the ray diagram (figure-27) we conclude that the image of the object will be formed at the same distance as the object and it will be inverted and of the same size. What is your observation?

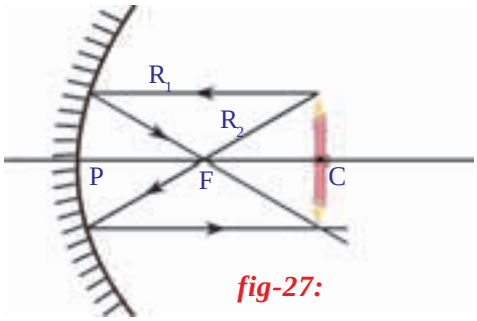


fig-27:



Think and discuss

- How does one see an image formed on the object itself? Draw a ray diagram. Do the experiment.

From the ray diagrams and the observations you may have noticed some peculiar properties of concave mirror. They enlarge the image when the object is held close to the mirror (less than the focal length). Also the image is erect. This property is used at many places, the most commonly used in shaving mirrors and dental mirrors.

Another property is the way it can concentrate rays at its focal point. This is extensively used in many places. Look at the shape of TV dish antenna in your village.

If you look around you will see many curved surfaces and very interesting reflection. But all surfaces are not concave, many of these are convex.



fig-28:

Did you observe headlights of a car?

What type surface does it contain?

Have you observed images formed on rear glass and window glasses of a car? What type of surfaces do these glasses contain? See figure -28.

Can we draw ray diagrams with convex surfaces?

Ray diagrams: with convex mirrors

One can draw ray diagrams for a convex mirror too. The 'easy' rays that we identified earlier can be used in this case with small modification. Here there are three rules which describe these rays. The procedure for drawing the diagram is similar so is not repeated here.

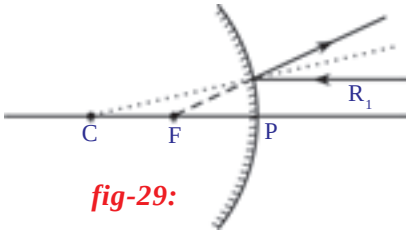


fig-29:

Rule 1: A ray running parallel to axis, on meeting the convex mirror will get reflected so as to appear as if it is coming from the focal point. See figure-29.

Rule 2: This is converse of Rule 1. A ray going in the direction of the focal point after reflection will become parallel to main axis. See figure-30.

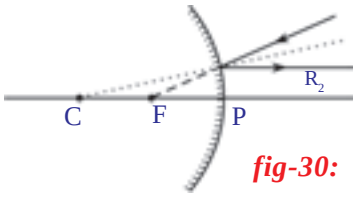


fig-30:

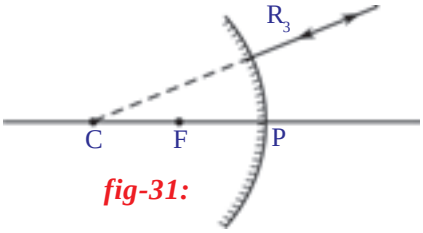


fig-31:

Rule 3: A ray going in the direction of the centre of curvature will on reflection get back in opposite direction, and looks that it is coming from the centre of curvature. See figure-31.

Using these rules draw ray diagrams to show formation of image when the object is placed at different positions and note down your conclusion. Verify your results experimentally.

If necessary use another ray which comes from the object and reach the pole of the mirror.

You may get the image at a particular distance when you place the object at a certain distance. Did you find any relation between the object distance(u) and the image distance(v)?

Derivation of mirror formula:

Observe the figure 32.

A ray coming from the point O which is on the principal axis of the mirror incidents on the mirror at point A which is at height 'h' from the axis and gets reflected through point I which is also on the axis.

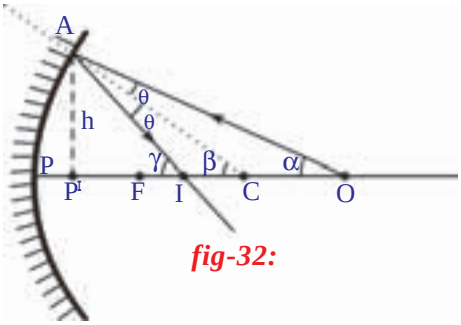


fig-32:

Here AC is the normal. The angle of incidence (angle OAC) and the angle of reflection (angle CAI) are equal and they are denoted by θ in the figure. Line segment AP^I is the perpendicular drawn to the axis from the point A. Now we can observe three right angled triangles namely, Triangle AOP^I, ACP^I and AIP^I.

Let the angles at the vertices O, C and I of three triangles be α, β and γ respectively as shown in the figure 32.

In a triangle, some of the interior angles is equal to the exterior angle.

From the triangle AOC; $\beta = \alpha + \theta$

$\theta = \beta - \alpha$

From the triangle ACI; $\gamma = \beta + \theta$

By substituting $\theta = \beta - \alpha$ in the above equation, we get

$\gamma = \beta + \beta - \alpha$

$2\beta = \alpha + \gamma$ .....(1)

- What happens when 'h' becomes very small?

Observe the figure 33.

When 'h' become very small,

1. P^I may coincide with point P, which is pole of the mirror.

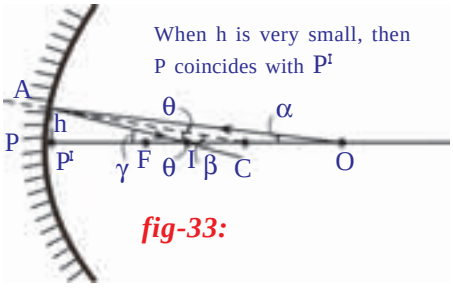


fig-33:

Then we can say P^{I}O = PO, P^{I}C = PC and P^{I}I = PI.

2. The angles α, β and γ become very small as shown in figure 33.

Let us calculate "Tan" values of the angles α, β and γ.

(In a right angled triangle, Tan value of a acute angle is the ratio of the length of the opposite side to the length of the adjacent side of that acute angle)

Here,

Tan $\alpha = P^IA/ P^IO = h / P^IO = h/PO$

Tan $\beta = P^IA/ P^IC = h / P^IC = h/PC$

Tan $\gamma = P^IA/ P^II = h / P^II = h/PI$

When an angle θ becomes very small i.e. nearer to the value of zero, in the value of Tan θ the value of numerator (length of the opposite side of the θ) become very small. You can observe this in figure 33. Then the value of Tan θ becomes very small i.e. nearer to the value of zero. So the value of Tan θ is treated as θ. That is Tan $\theta = \theta$. Similarly here,

Tan $\alpha = \alpha = h/PO$

Tan $\beta = \beta = h/PC$

Tan $\gamma = \gamma = h/PI$

By substituting the values of α, β and ã in the equation- 1, we get:

$2\ h/PC = h/PO + h/PI$

$2/PC = 1/PO + 1/PI$ ..... (2)

To take the values with correct sign (direction), follow the sign conventions given below.

Sign convention for the use of the mirror equations:

1. All distances should be measured from the pole.
2. The distances measured in the direction of incident light, to be taken positive and measured in the opposite direction of incident light to be taken negative.
3. Height of object (H_o) and height of image (H_i) are positive if measured upward from the axis and negative if measured downwards.

Substitute the values of PC, PO and PI in equation 2 according to the sign convenction.

Radius of curvature, PC = –R

Object distance PO=–u

Image distance, PI= –v

$2/–R = 1/–u + 1/–v$

$2/R = 1/u + 1/v$

We know that, radius of curvature(R) = 2 (focal length) = 2f

So,

$2/2f = 1/u + 1/v$

$1/f = 1/u + 1/v$

Another method for derivation of mirror formula:

We can derive this simple relation between object distance, image distance and focal length of a spherical mirror by drawing the rays to form the simplified diagram shown in figure 34, and then applying the principles of elementary geometry. (Figure 34 is shown for convenience of explanation. But treat the mirror as concave mirror with certain focal length).

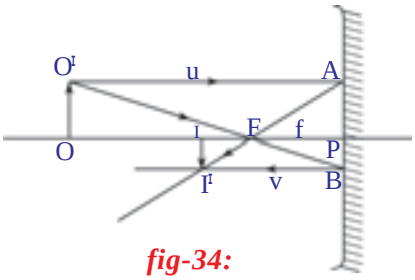


fig-34:

From similar triangles BOA and BFP, we can write proportionalities for corresponding sides as follows:

$AB/AO^I = PB/PF$ ..... (1)

From similar triangles AI^IB and AFP, we can also write

$AB/BI^I = PA/PF$ ..... (2)

By adding equations 1 and 2, we obtain

$AB/AO^I + AB/BI^I = PB/PF + PA/PF$

$AB/AO^I + AB/BI^I = AB/PF$

$1/AO^I + 1/BI^I = 1/PF$

By taking AO^I, BI^I and PF values as per sin convenction; we get,

$1/(–v) + 1/(–u) = 1/(–f)$

$1/v + 1/u = 1/f$

This mirror formula should be used according to the sign convention in every situation.

Now let us know about magnification, another relation between the characteristics of an object and the image i.e. the relation between the size of the object and the size of the image.

Magnification (m): since the image formed by a spherical mirror varies in size we refer to the linear magnification 'm'.

m = size of image (height)/size of object (height)

In all cases it can be shown that m = image distance from mirror (v)/ object distance from mirror (u)

Calculate the magnifications with the information you have in table-2, for all the five cases.

We have learnt the reflection of light by curved mirrors. Let us make use of it in our daily life.

Making of solar cooker:

You might have heard the story of **Archimedes** that he burned ships using mirrors.

Can we at least heat up a vessel using a mirror?

Let us try:

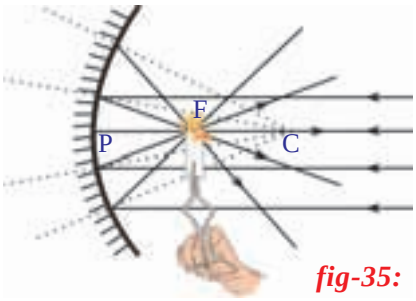


fig-35:

We already learnt that concave mirror focus the parallel sun rays at focal point of the mirror. So with a small concave mirror we can heat up and burn a paper as shown in the figure-35. Try with convex mirror also. What do you observe?

In the same way make a big concave mirror to heat up a vessel.


fig-36:

You might have observed the TV dish antenna. Make a wooden/ iron frame in in the shape of TV dish. Cut the acrylic mirror sheets in to 8 or 12 pieces in the shape of isosceles triangles with a height equal to the radius of your dish antenna. The bases of 8 or 12 triangles together make the circomference of the dish. Stick the triangle mirrors to the dish as shown in figure-36.

Your solar heater/cooker is ready.

Face it towards the Sun. find its focal point and place a vessel at that point. It will get heated. Even you can cook rice in that vessel.

It will be very effective if we make the solar heater as shown in the figure 37.

Why because, with a concave mirror all the rays coming parallel to it may not be focused at focal point (F). Those rays which are very nearer to principal axis will only be focused at focal point. See the figure 38.

The rays which are very nearer to the principle axis are called paraxial rays. The other rays will be focused at different points on the principle axis as shown in figure-38. This phenomenon is known as spherical aberration. We can overcome this using parabolic mirror as shown in 37.

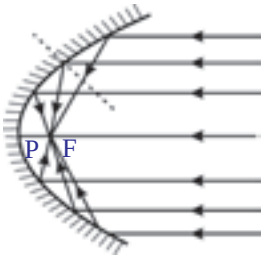


fig-37:

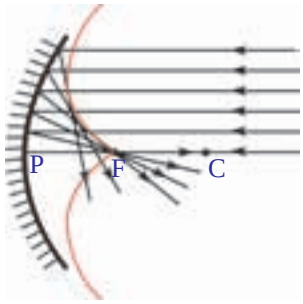


fig-38:



Think and discuss

- Do you find any disadvantage inusing a parabolic mirror for a solar heater/cooker?



Key words

angle of incidence, angle of reflection, normal, plane of reflection, lateral inversion, centre of curvature, radius of curvature, principal axis, pole, focus/focal point, focal length, objecti distance, image distance, virtual image, real image



What we have learnt

- **Fermat principle:** Light chooses the path which takes the least time to travel. It is also applicable to reflection of light.
- **Mirror formula:** $1/f = 1/u + 1/v$
- Magnification m = size of the image/ size of the object (or)
  m = object distance/ image distance

Position of the candle (object)	Position of the image	Bigger/smaller than object	Inverted or erected	Real or virtual
Between mirror & F	Behind the mirror	Bigger	Erected	Virtual
On focal point	At infinity	Bigger	Inverted	Real
Between F and C	Beyond C	Bigger	Inverted	Real
On centre of curvature	On C	Same size	Inverted	Real
Beyond C	Between F and C	Smaller	Inverted	Real



Improve your learning

1. State the laws of reflection of light. (AS1)
2. Why concave and convex mirrors are called spherical mirrors? (AS1)
3. How do you find the focal length of a concave mirror? (AS1)
4. Where will the image form when we place an object, on the principal axis of a concave mirror at a point between focus and centre of curvature? (AS1)

5. Find the distance of image, when an object is placed on the central axis, at 10 cm distance in front of a concave mirror whose of radius of curvature is 8 cm. (AS1)
6. State the differences between convex and concave mirrors. (AS1)
7. What is a real image? What is virtual image? (AS1)
8. Distinguish between real and virtual image? (AS1)
9. What do you know about the terms given below related to the spherical mirrors? (AS1)

a) Pole	b) Centre of curvature	c) Focus
d) Radius of curvature	e) Focal length	f) Principal axis
g) Object distance	h) Image distance	i) Magnification

10. Write the rules mentioned for sign convention. (AS1)
11. Why periscopes are made in 'Z' shape? Why not in other shapes? Make a guess. Try to check whether your guess is correct or not. (AS2)
12. Imagine that spherical mirrors are not known to human being, guess the consequences. (AS2)
13. By observing steel vessels and different images in them; Surya, a third class student asked some questions his elder sister Vidya. What may be those questions? (AS2)
14. How do you verify the 1st law of reflection of light with an experiment? (AS3)
15. How do you verify the 2nd law of reflection of light with an experiment? (AS3)
16. What do you infer from the experiment which you did with concave mirror and measured the distance of object and distance of image? (AS3)
17. Find the plane of the reflection experimentally for the incident ray which passes through the heads of the pins pierced in front of mirror. (AS3)
18. Collect the information about the history of spherical mirrors in human civilization. Display in your class room. (AS4)
19. Write your own inferences with the information filled in tables 1 and 2 in this lesson. (AS4)
20. Draw and explain the process of formation of image with a pinhole camera? (AS5)
21. Draw a normal at any point of a concave mirror. (AS5)
22. Draw suitable rays by which we can guess the position of the image formed by a concave mirror. (AS5)
23. Show the formation of image with a ray diagram, when an object is placed on the principal axis of a concave mirror away from the centre of curvature. (AS5)
24. Make a solar heater/cooker and explain the process of making. (AS5)
25. To form the image on the object itself, how should we place the object in front of a concave mirror? Explain with a ray diagram. (AS5)
26. How do you appreciate the working process of TV antenna dishes? (AS6)
27. How do you appreciate the role of spherical mirrors in our daily life? (AS6)
28. Write any two uses of each of concave and convex mirror in our daily life. (AS7)
29. Which objects at your home acts as spherical mirrors? (AS7)
30. What is your opinion on elevating buildings with mirrors? (AS7)
31. Suggest a new use with a spherical mirror. (AS7)

Chapter 2

Refraction at Plane Surface

We have learnt about the reflection of light in an earlier chapter. Beauty of the nature comes with light. Behaviour of light is very interesting phenomenon in many situations.

let us try to explore a few of them.

You might have observed a coin kept at the bottom of a vessel filled with water appears to be raised. Similarly, a lemon kept in water of glass tumbler appears to be bigger than its size. When a thick glass slab is placed over some printed letter, the letters appear raised when viewed through the glass slab.

- What could be the reasons for above changes in appearance?

Activity 1

Take some water in a glass tumbler. Keep a pencil in it. See the pencil from the side of glass and from the top of the glass.

- How does it look?
- Do you find any difference between two views?

Activity 2

Go to a long wall (nearly of length of 30 feet) facing the sun. You go to the one end of a wall and ask your friend to bring a bright metal object near the other end of the wall. When the object is a few inches from the wall, it will distort and you will see a reflected image in the wall as though the wall were a mirror.

- Why is there an image of the object on the wall?

To answer the above questions and to give reasons for the situations mentioned we need to understand the idea of refraction of light.

Refraction

Activity 3

Take a shallow vessel with opaque walls such as a mug, a tin or a pan. Place a coin at the bottom of the vessel. Move away from the vessel until you cannot see the coin. See figure 1(b). Stand there. Ask your friend to fill the vessel with water. When the vessel is filled with water the coin comes back into view. See figure 1(c).

- Why could you are able to see the coin when the vessel is filled with water?

You know that the ray of light originated from the coin, doesn't reach your eye when the vessel is empty (see figure1b) Hence you couldn't see the coin. But the coin becomes visible to you after the vessel is filled with water.

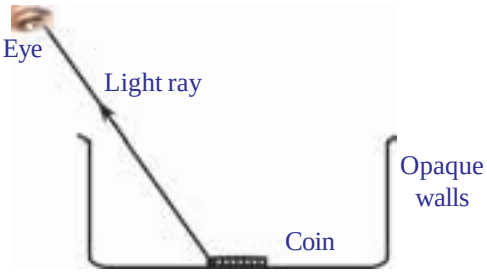


fig-1(a):

- How is it possible?
- Do you think that the ray reaches your eye at third instance?

If yes, draw a ray diagram from the coin to the eye keep in mind that the light ray travelling in a medium takes a straight line path.

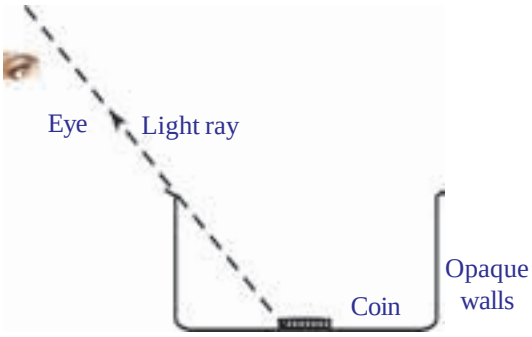


fig-1(b):

- What happens to the light ray at interface between water and air?
- What could be reason for this bending of ray at second instance?

The above questions can be answered by the Fermat's principle, which states that the light ray always travels in a path which needs shortest possible time to cover the distance between the two given points. Let us apply this principal to our activity.

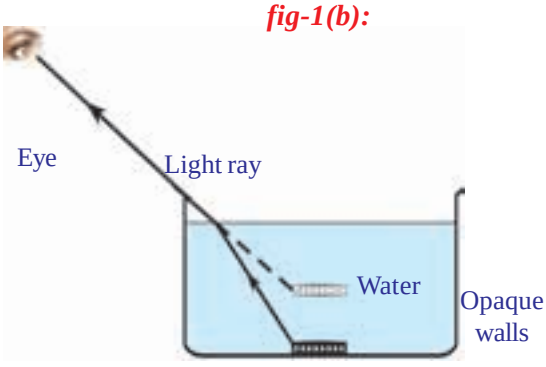


fig-1(c):

By observing the path of the ray, it is clear that the light ray changes its direction at the interface separating the two media i.e, water and air. This path is chosen by light ray so as to minimize time of travel between coin and eye. This can be possible only when the speed of the light changes at interface of two media. If we say it

in another way the speed of light is different in different media. Thus we can conclude that the speed of the light changes when light propagates from one medium to another medium.

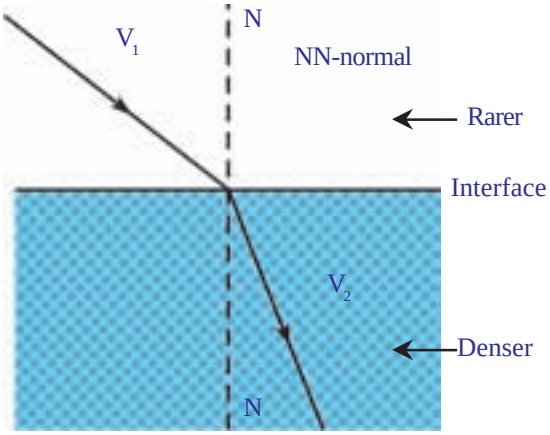


fig-2(a):

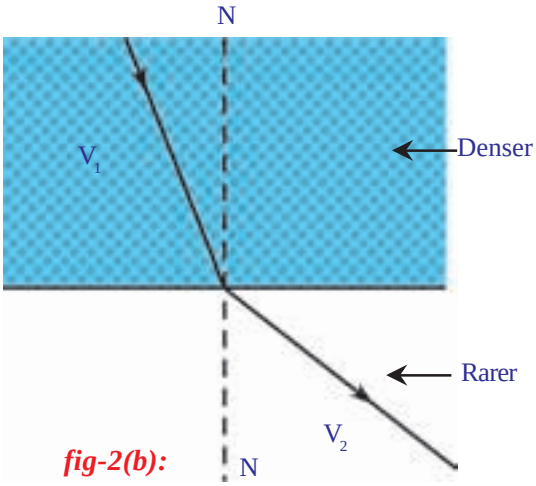


fig-2(b):

"The process of changing speed when light travels from one medium to another is called refraction of light".

Consider that light travels from medium 1with speed v_1 to medium 2 with speed v_2 as shown in figures 2(a) and (b).

- What difference do you notice in fig 2(a) and Fig 2(b) with the respect to refracted rays?
- Is there any relation between behaviour of refracted rays and speeds of the light?

Experiments showed that refraction depends upon the speed of the light in the medium. Inturn the speed of light of a medium depends upon optical density of the medium.

If v_2 is less than v_1 then medium 2 is said to be denser with respect to medium 1.

If v_2 is greater than v_1 then medium 2 is said to be rarer with respect to medium 1.

If light ray enters from rarer medium to denser medium then refracted ray moves towards the normal drawn at the interface of separation of two media. When it travels from denser medium to rarer medium it bends away from normal. We have seen that the ray of light deviates from its path at the interface. Draw a normal at the point of deviation draw a normal as shown in figure (3).

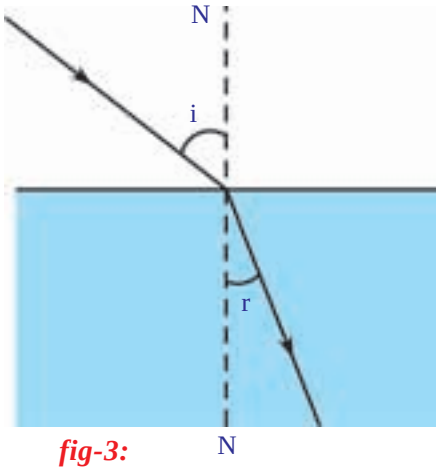


fig-3:

Let 'i' be the angle formed by incident ray and normal and r be the angle formed by refractive ray and normal. These angles are called angle of incidence and angle of refraction respectively.

To explain the process of refraction we need to know about a constant called refractive index. Let us learn about it.

The extent of the change in direction that takes place when a light ray propagates through one medium to another medium is expressed in terms of refractive index.

Refractive index

Light travels in vaccum with a speed nearly equal to $3x10^8$ m/s (denoted by letter 'c'). The speed of light is smaller than 'c' in other transparent media.

Let 'v' be the speed of light in a certain medium. Then the ratio of speed of light in vacuum to the speed of light in that medium is defined as refractive index 'n' with respective to the vacuum. It is called absolute refractive index.

Absolute refractive index = Speed of light in vacuum/ Speed of light in medium.

$$n = c/v \text{ .....(1)}$$

It is dimensionless quantity because it is a ratio of same physical quantity. Refractive index gives the idea of how fast the light travels in a medium. The speed of light in a medium is low when refractive index of the medium is high and vice versa. The refractive index 'n' means that the speed of light in that medium is nth part of speed of light in vacuum.

For example the refractive index of glass is 3/2 .Then the speed of light in glass is (2/3) of $3 x10^8$ m/s equal to $2 x10^8$ m/s.

Table:1 Refractive index of some material media.

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Canada balsam	1.53
Ice	1.31	Rock salt	1.54
Water	1.33	Carbon Diasulphide	1.63
Kerosene	1.44	Dense flint glass	1.65
Fused quartz	1.46	Ruby	1.71
Turpentine oil	1.47	Sapphire	1.77
Crown glass	1.52	Diamond	2.42
Benzene	1.50		

Note : From table 1, you know that an optically denser medium may not possess greater mass density. For example, kerosene having higher refractive index, is optically denser than water, although its mass density is less than water.

- Why different material mediums possess different values of refractive Index?

- On what factors does the refractive index of medium depend?

Refractive index depends on following factors.

(1) nature of material (2) wavelength of light used. (You will learn this in the chapter Human-eye-and Colourful world)

Relative refractive index:

The refractive index of a medium with respect to another medium is defined as the ratio of speed of light in first medium to the speed of light in second medium. Let v_1 and v_2 be the speed of light in first and second media respectively, then,

Refractive index of second medium with respect to first medium is given by

n_{21} = speed of light in medium -1 / speed of light in medium – 2

$n_{21} = v_1/v_2$ = Dividing both numerator and denominator by c we get

$n_{21} = (v_1/C) / (v_2/C) = (1/n_1) / (1/n_2)$

$\Rightarrow n_{21} = n_2 / n_1$ 2

This is called relative refractive Index. We define relative Refractive index as follow

$$\text{Relative refractive index, } (n_{21}) = \frac{\text{Refractive index of second medium } (n_2)}{\text{Refractive index of first medium } (n_1)}$$

Lab Activity 1

Aim: Identifying relation between angle of incidence and angle of refraction.

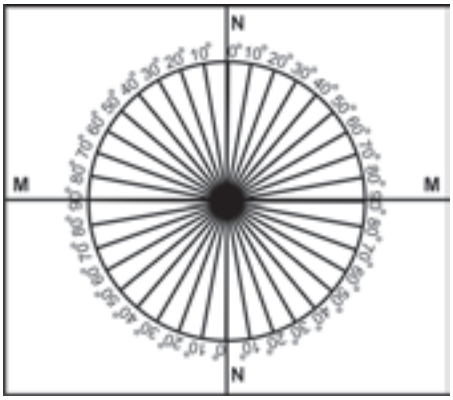


fig-4(a):

Materials required: A plank, white chart protractor, scale, small black painted plank, a semi circular glass disc of thickness nearly 2cm pencil and laser light.

Procedure:

Take a wooden plank which is covered with white chart. Draw two perpendicular lines, passing through the middle of the paper as shown in the figure 4(a). Let the intersecting point be O. Mark one line as NN which is normal to the another line marked as MM. Here MM represents the line drawn along the interface of two media and NN represents the normal drawn to this line at 'O'.

Take a protractor and place it along NN in such way that its centre coincides with O as shown in figure 4(a). Then mark the angles from 0^0 to 90^0 on both sides of the line NN as shown in figure 4(a). Repeat the same on the other side of the line NN. The angles should be represented on the circular line.



fig-4(b):

Now place semi circular glass disc so that its diameter coincides with the interface line (MM) and its center coincides with the point O. Take laser light. Send it along NN in such a way that laser propagates from air to glass through the interface at point O and observe the way of laser light coming from other side of disc as shown in figure 4 (b). (If you can not observe the way of laser light put black coloured plank against the circular line and observe the light point and imagine the light way).

- Is there any deviation?

Send Laser light along a line which makes15^0 (angle of incidence) with NN and see that it must pass through point O. Measure its corresponding angle of refraction, by observing laser light coming from other side (Circular side) of the glass slab. Note these values in table (2). Do the same for the angles of incidence such as 20^0,30^0,40^0,50^0 and 60^0 and note the corresponding angles of refraction.

Table 2

i	r	Sin i	Sin r	Sin i / Sin r

Find sin i, sin r for every ‘i’ and ‘r’ and evaluate sin i/ sin r for every incident angle ‘i’.

Note : Take the help of your teacher to find the values of Sin i and Sin r for each case.

Finally, we will get sin i / sin r as a constant ratio.

- Is this ratio equal to refractive index of glass? Why?

This ratio gives the value of refractive index of glass. In above experiment you might have noticed that ‘r’ is less than ‘i’ in all cases and refracted ray bends towards normal in each case.

- What do you conclude from these observations?

From the above experiment we can conclude that when light ray travels from rarer medium (air) to denser medium (glass) the value of r is less than the value of 'i' and refracted ray bends towards the normal.

- Can you guess what happen when light ray travels from denser medium to rarer medium?

Let us do another activity to find this.

Actitivy 4

Take a metal disk. Use protractor and mark angles along its edge as shown in the figure 5(a). Arrange to straws from the centre of the disk, in such a way that they can be rotated freely about the centre of the disc.



fig-5(a):

Adjust one of the straws to the angle 10^0. Immerse half of the disc vertically into the water, filled in a transparent vessel. While dipping, verify that the straw at 10^0 must be inside the water. From the top of the vessel try to view the straw which is inside the water as shown in figure 5(b). Then adjust the other straw which is outside of the water until both straws looks like they are in a single straight line.

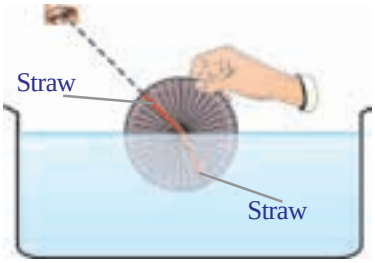


fig5(b):

Then take the disc out of the water and observe the two straws on it. You will find that they are not in a single straight line. Of course it could be seen from the side view while half of the disc is inside the water.

- Why do straws appear in a straight line when we view them from the top?

Measure the angle between the normal and second straw. Draw table (2) again in your notebook and note the value. Do the same for various angles. Find the corresponding angles of refraction and note them in the table drawn. Use table and find refractive index of water. Don't do this activity with angle of incidence greater than 48 degree. You will learn reasons for this in later course.

You will observe that in above activity 'r' is greater than 'i' in all cases that means when light travels from water (denser) to air (rarer). It behaves in quite opposite way to that we observed in lab activity 1.

From this activity we can generalize that when the light ray travels from denser to rarer, it bends away from the normal and r > i.

- Can we derive the relation between the angle of incidence and the angles of refraction theoretically?

Consider the following analogy to derive it.

Let us imagine that a girl has fallen out of boat and she is screaming for help in the water at point B as shown in figure 6(a).

The line marked through point 'X' is the shore line. Let us assume that we are at a point 'A' on the land of the shore and we saw the accident. In order to save the girl we need to travel certain distance on land and certain distance in water. We know that, we can run faster on land than that we swim in water.

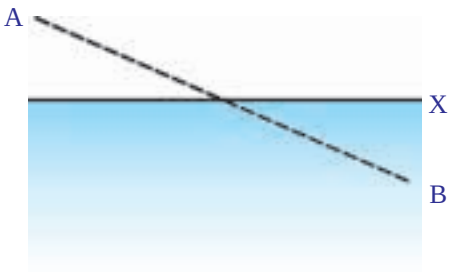


fig-6(a):

- What do we do to save her?
- Which path enable us to save the girl in shortest possible time?
- Do we go in a straight line?

By using a little intelligence, we would realize that it would be advantageous to travel a little greater distance on the land in order to decrease the distance in water because we go much slow in water. For any rate, of our speeds on land and in water final path that one has to follow to reach the girl is ACB, and that this path takes the shortest time of all the possible ones (see figure 6c). If we take any other route, it will be longer. If we plot a graph for the time taken to reach the girl against the position of any point when cross the shore line, we would get a curve something like that one shown in figure 6(b).

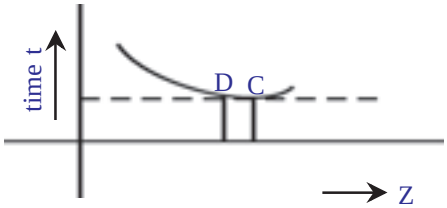


fig-6(b):

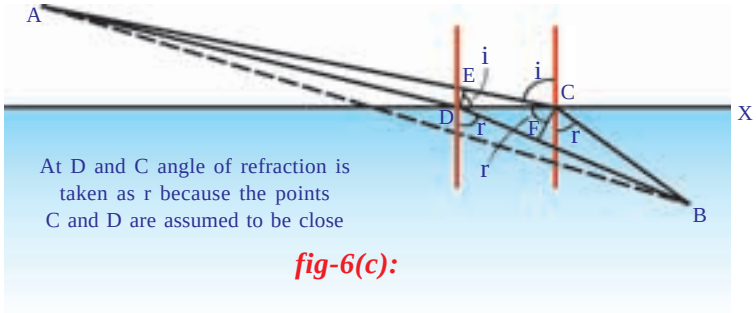


fig-6(c):

Where 'C' the point on shore line corresponds to the shortest time of all possible times. Let us consider a point 'D' on shore line which is very close to point 'C' such that there is essentially no change in time between path ACB and ADB.

Let us try to calculate how long it would take to go from A to B by the

two paths one through point D and another through point C (see figure 6c). First look at the path on the land as shown in figure 6(c). If we draw a perpendicular DE; between two paths at D, we see that the path on land is shortened by the amount EC. On the other hand, in the water, by drawing a corresponding perpendicular CF we find that we have to go the extra distance DF in water. In other words, we gain a time is equal to go through distance EC on land. But we lose the time that is equal to go extra distance DF in water. These times must be equal since we assumed there no change in time between two paths.

Let the time taken by the man to travel from E to C and D to F be Δt and v_1 and v_2 be the speeds of the running and swimming. From figure 6(c) we get,

$EC = v_1 \Delta t$ and $DF = v_2 \Delta t$

$\Rightarrow EC / DF = v_1/v_2$ ——————(3)

Let i and r be the angles measured between the path ACB and normal NN, perpendicular to shore line X.

- Can you find sin i and sin r from figure 6(c)?

  (Note: Take the help of your teacher)

  Therefore, we see that when we have the right point

  $\sin i = EC / DC$ and $\sin r = DF / DC$

  Therefore,

  $\sin i / \sin r = EC / DF$ ——————(4)

  from equations (3) and (4), we have

  $\sin i / \sin r = v_1 / v_2$ ——————(5)

Thus the person who wants to save the girl, should run in such a path to satisfy the above equation. We used the principle of least time to derive the above result. Hence we can apply the same for the light ray also. From (5) we get,

$\sin i / \sin r = v_1 / v_2 = n_2 / n_1$, (since $v_1 / v_2 = n_2 / n_1$)

$\Rightarrow n_1 \sin i = n_2 \sin r$.

This is called **Snell's law**.

From the above discussion we can conclude that when light travels from one medium to another, the ratio of speeds is equal to n_2 / n_1. The light should enter at such an angle that the ratio of sine of the angles 'i' and 'r' is equal to ratio of speeds v_1/v_2 in the two media.

Above experiments and activities show that refraction of light occurs according to certain laws.

Following are the laws of refraction.

1. The incident ray, the refractive ray and the normal to interface of two transparent media at the point of incidence lie in the same plane.
2. During refraction, light follows Snell's law

$n_1 \sin i = n_2 \sin r$ (or) $\sin i / \sin r$ = constant.

- Is there any chance that angle of refraction is equal to 90^0? When does this happen?

Let us find out

Total Internal Reflection

Activity 5

Use same material used in lab activity 1. Place the semi circular glass disc in such a way that its diameter coincides with interface line MM and its center coincides with point 'O' as we have done in lab activity. Now send light from the curved side of the semicircular glass disc. This means that we are making the light travel from denser medium to rarer medium. Start with angle of incidence (i), equals to 0^0 i.e., along the normal and observe for refracted on other side of the disc.

- Where do you find the refracted ray?
- Does it deviate from its path when it enter into rarer medium?

You might have noticed that it doesn't deviate.

Send laser light along angles of incidences 5^0, 10^0, 15^0 etc.. And measure the angle of refraction from the other side of the disc. Make a table (3) as shown below and note the values 'i' and 'r' in the table.

Table 3

i	r

- At what angle of incidence do you notice that refracted ray traces along the interface separating the media air and glass?

You will observe that at a certain angle of incidence, refracted ray traces along the interface separating air and glass. Measure this angle of incidence. This angle is known as **critical angle**.

The above results can be explained with Fermat's principle.

Let us consider the light ray propagates from medium 1 with refractive

index n_1 to medium 2 with refractive index n_2.See figure (7). It is already found that the angle of refraction is more than angle of incidence when the light ray propagates from denser(n_1) to rarer (n_2).

For the angle of incidence i, let r be the angle of refraction.

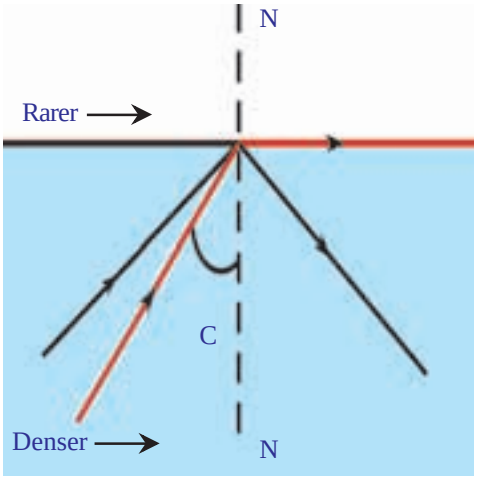


fig-7:

From Snell's law

$n_1 \sin i = n_2 \sin r \Rightarrow n_1/n_2 = \sin r/ \sin i$

we know that, n_1/n_2 is greater than 1, so that sin r/ sin i is greater than 1.So we conclude that the angle of refraction is greater than the angle of incidence, i.e, r is greater than i.

The angle of incidence at which the light ray propagating from denser to rarer grazes along interface is called critical angle of denser medium. It is shown in figure7.

Let C be the critical angle. Then r becomes 90^0

we get, $n_1/n_2 = \sin 90^0/ \sin c \Rightarrow n_1/n_2 = 1/\sin c$.

We get $\sin c = n_2/ n_1$ .We know that n_1/n_2 is called *refractive index* of denser medium with respect to rarer medium

$\sin c = 1/n_{12}$

- Can you find the critical angle of water using the above equation? Discuss about it in your class room.
- What happens to the light when the angle of incidence is greater than critical angle?

When the angle of the incidence is greater than critical angle, the light ray reflected into denser medium at interface i.e., light never enter to rarer medium. This phenomenon is called total internal reflection. It is shown in figure 7.

Discuss these things in your class and find out the critical angle of water.

- Let us see an example on total internal reflection.

Example

A rectangular glass wedge is immersed in water as shown in the figure E-a. For what value of angle α, will the beam of light which normally incident on AB reach AC entirely as shown in figure E-b. Take the refractive index of water as 4/3 and the refractive index of glass is 3/2.

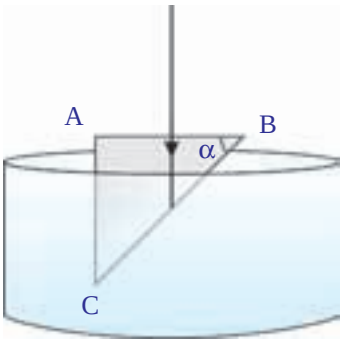


fig E-a

Solution: From the geometry of figure E-b it is clear that, the angle of incidence on the side BC is equal to α (dotted line is a normal drawn at the point of incidence). The ray should undergo total internal reflection to reach AC. For occurance of total internal reflection the value of α must be greater than critical angle at interface of water and glass.

Let 'c' be the critical angle at the interface.

From the given condition, $\alpha > c$ ———(1)

We know, $\text{Sin } c = 1/n_{12}$ ———(2)

$n_{12} = n_1/n_2 = (3/2)/(4/3) = 9/8.$

From equation 2, we get

$\text{Sin } c = 8/9 \Rightarrow c = 62^0 30^1$

Hence α is greater than $c = 62^0 30^1$

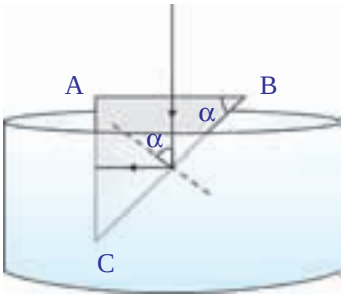


fig E-b

Let us see few activities of total internal reflection.

Activity 6

Take a transparent glass and coin. Place a coin on a table and place glass on the coin. Observe the coin from the side of the glass.

- Can you see the coin?

Now fill the glass with water and observe the coin from the side of the glass.

- Can you see the coin?
- Explain why does the coin disappear from view?

Activity 7

Take a cylindrical transparent vessel (you may use 1 L beaker). Place a coin at the bottom of the vessel. Now pour water until you get the image of the coin on the water surface. See figure 8.

- Can you explain why the image of the coin is formed?

There are many interesting situations around us that are linked with total internal reflection. One of that is a mirage which we witness while driving on a road during the hot summer day.

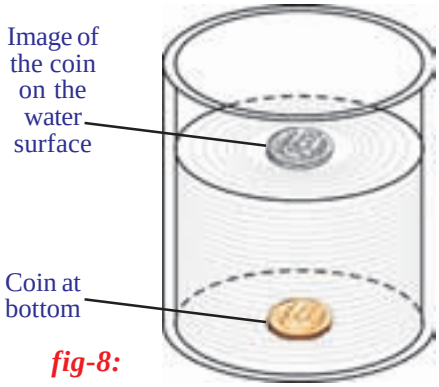


fig-8:

Mirages

Mirage is an optical illusion where it appears that water is collected on the road at a distant place but when we get there, the road is dry.

- Do you know the reason why it appears so?



fig-9(a):

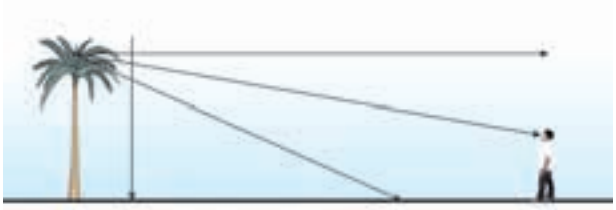


fig-9(b):

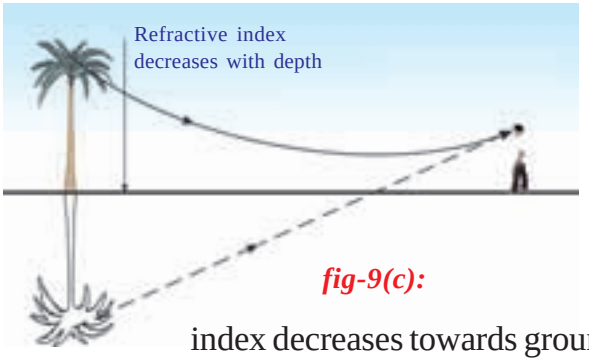


fig-9(c):

During the hot summer day, air just above the road surface is very hot and the air at higher altitudes is cool. We know that refractive index of air increases with density. So, the cooler air at the top has greater refractive index than hotter air just above the road. Light travels faster through the thinner hot air than through, the denser cool air above it.

- What way is that light takes to minimize its time?

The formation of mirage is the best example where refractive index of a medium varies throughout the medium. On hot days, the temperature decreases with height. As a result density of air increases with height. Thus the refractive index of air increases with height.

When the light from a tall object such as tree or from the sky passes, through a medium just above the road whose refractive index decreases towards ground suffers refraction and takes a curved path because of total internal reflection.

This refracted light reaches the observer in a direction shown in Figure-9c. This appears to the observer that the ray is reflected from ground. Hence we will see water on road (shown in figure 9a) which is the virtual image of sky and an inverted image of tree on the road (shown in figure 9c). Such virtual images of distant high objects causes the optical illusion called 'mirage'



Think and discuss

- Why should you see a mirage as a flowing water?
- Is mirage real? Could you take a photo of it?

Applications of total internal reflection:

i) **Brilliance of diamonds:** Total internal reflection is the main cause for brilliance of diamonds. The critical angle of diamonds is very low(24.4^{o}). So if a light ray enters into a diamond it is very likely to get total internal reflection which makes the diamond shine brilliant.

ii) **Optical fibres:** Total internal reflection is the basic principle for working of optical fibre. An optical fibre is very thin fibre made of

glass (or) plastic having radius about a micrometer (10^{-6} m). A bunch of such thin fibres forms a light pipe.

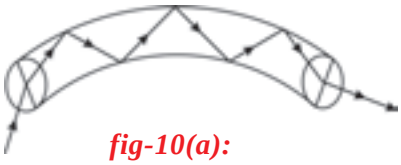


fig-10(a):

Figure 10(a) shows the principle of light transmission by an optical fibre. Figure 10(b) sketches a light pipe. Because of the small radius of the fibre, light going into it makes a nearly glancing incidence on the wall. The angle of incidence is greater than the critical angle and hence total internal reflection takes place. The light is thus transmitted along the fibre.



fig-10(b):

Light pipes using optical fibres may be used to see places which are difficult to reach such as inside of a human body. For example, a patient's stoomach can be viewed by inserting one end of a light piple into the stomach through the mouth. Light is sent down through one set of fibres in the pipe. This illuminates the inside of the stomach. The light from the inside travels back through another set of fibres in the pipe and the viewer gets the image at the outer end.

The other important application of fibre optics is to transmit communication signals through light pipes. For example, about 2000 telephone signals, appropriately mixed with light waves, may be simultaneously transmitted through a typical optical fibre. The clarity of the signals transmitted in this way is much better than other conventional methods.

- How does light behave when a glass slab is introduced in its path?

Let us see

Refraction Trough a Glass Slab

A thin glass slab is formed when a medium is isolated from its surroundings by two plane surfaces parallel to each other. Let us determine position and nature of image formed when the slab is placed in front of an object. Let us do an activity for it.

Lab Activity 2

Aim: Determination of position and nature of image formed by a glass slab.

Material required: plank, chart paper, clamps, scale, pencil, thin glass slab and pins.

Procedure:

Place a piece of chart on a plank. Clamp it. Place a glass slab in the middle of the paper. Draw border line along the edges of the slab by using

a pencil. Remove it. You will get a figure of a rectangle. Name the vertices of the rectangle as A, B, C and D.

Draw a perpendicular to the one of the longer side (AB) of the rectangle. Again keep the slab on paper such that it coincides with the sides of the rectangle ABCD. Take two pins. Stick them on the vertical line drawn. Take two more pins and stick them on the other side of the slab in such a way that all pins come to view along a straight line. Remove the slab from its place. Take out the pins. Draw a straight line by using the dots formed by the pins such that it reaches first edge (AB) of the rectangle. You will get a long straight line.

- What does it mean?

The light ray that incidents perpendicular to one side of the slab surface comes out with out any deviation.

Now take another piece of white chart on the plank. Clamp it. Place a glass slab in the middle of the paper. Again draw a border line along the edges of the slab by using a pencil. Remove the slab and name the vertices of the rectangle formed as A,B,C and D. Draw a perpendicular to one of the longer side AB of the rectangle formed by slab. Now draw a line, from the point of intersection where side AB of rectangle and perpendicular meet, in such a way that it makes 30^0 angle with normal. This line represents the incident ray falling on the slab and the angle it makes with normal represents angle of incidence.

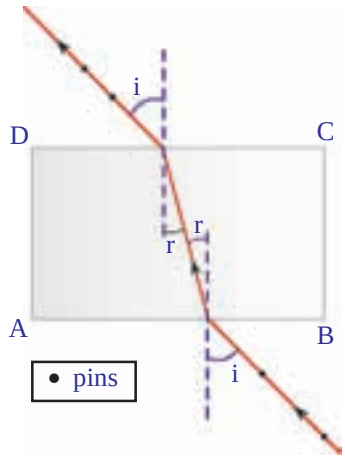


fig-11:

Now place the slab on the paper in such way that it fits in the rectangle drawn. Fix two identical pins on the line making 30^0 angle with normal such that they stand vertically with same height. By looking at the two pins from the other side of the slab, fix two pins in such a way that all pins appear to be along a straight line. Remove slab and take out pins. Draw a straight line by joining the dots formed by the pins up to the edge CD of the rectangle. This line represents emergent ray of the light.

Draw a perpendicular to the line CD where our last line drawn meets the line CD. Measure the angle between emergent ray and normal. This is called angle of emergence. (Check your drawing with the figure 11).

- Does the line formed is a straight line?
- Are the angles of incidence and emergence are equal?
- Are the incident and emergent rays parallel?

We get the result that the incident and emergent rays are parallel.

- Can you find the distance between the parallel rays?

The distance between the parallel rays is called shift. Measure this shift. Repeat the experiment for different angles of incidence and tabulate the values of angle of incidence and shift corresponding to each angle of incidence in table (4).

Table 4

Agle of Inciddene	Shift

- Can you find any relation between the angle of incidence and shift?
- Can you find refractive index of the slab?

Let us find refractive index of the slab.

Activity 8

Measure the thickness of the slab. Note it in your notebook. Take a white chart and fix it on the table. Take the slab and place it in the middle of the chart. Draw a line around it. Remove the slab from its place. The lines form a rectangle. Name the vertices of it as A,B,C and D. Draw a perpendicular to the longer line AB of the rectangle at any point on it. Place slab again in the rectangle ABCD. Take a needle. Place at a point P in such a way that its length is parallel to the AB on the perpendicular line at a distance of 20cm from the slab. Now take another needle and by seeing the first needle from the other side of the slab try to keep the needle so that it forms a straight line with the first needle. Remove the slab and observe the positions of the pins.

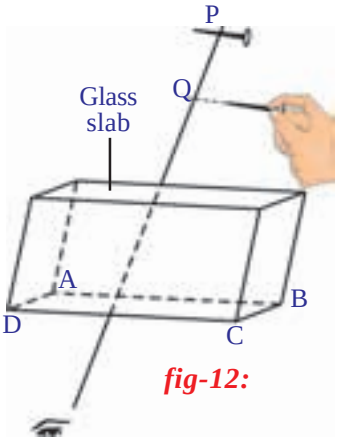


fig-12:

- Are they in the same line?

Draw a perpendicular line from the second needle to the line on which first needle is placed. Call the intersection point Q. Find the distance between P and Q. We may call it vertical shift.

- Is this shift independent of distance of first needle kept from slab?

To find this, do the same activity for another distance of the needle from the slab. You will get the same vertical shift. We could use below formula to find out refractive index of the glass.

R.I = Thickness of the slab / (thickness of slab – vertical shift)

- Can you derive the above formula?

To find this, use the Snell's law of refraction and try to solve it.

Key words

Incident ray, Refracted ray, Angle of incidence, Angle of Refraction, Refraction, Absolute refractive index, Relative refractive index, Snell's law, Critical angle, Total internal Reflection, Mirage, Shift, Optical fibre.

What we have learnt

- The process of changing speed when light travels from one medium to another is called refraction of light.
- Absolute refractive index = Speed of light in vacuum/ Speed of light in medium ⇨ n=c/v.
- Relative refractive index , $n_{21} = v_1/v_2 = n_2/n_1$.
- Snell's law is given by, $n_1 \sin i = n_2 \sin r$.
- The angle of incidence, at which the light ray travelling from denser to rarer medium grazes along the interface, is called the critical angle of that interface. $\sin c = n_2/ n_1$, where n_1 is the refractive index of denser medium and n_2 is the refractive index of rarer medium.
- When the angle of incidence is greater than the critical angle, the light ray is reflected into denser medium at interface. This phenomenon is called total internal reflection.

Improve your learning

1. Why is it difficult to shoot a fish swimming in water? (AS1)
2. The speed of the light in a diamond is 1, 24, 000 km/s. Find the refractive index of diamond if the speed of light in air is 3,00,000 km/s. (AS1) (Ans: 2.42)
3. Refractive index of glass relative to water is 9/8. What is the refractive index of water relative to glass? (AS1) (Ans: 8/9)
4. The absolute refractive index of water is 4/3. What is the critical angle of it? (AS1) (Ans: 48.5^0)
5. Determine the refractive index of benzene if the critical angle of it is 42^0.(AS1) (Ans: 1.51)
6. Take a bright metal ball and make it black with soot in a candle flame. Immerse it in water. How does it appear and why? (Make hypothesis and do the above experiment). (AS2)
7. Take a glass vessel and pour some glycerine into vessel and next pour water up to the brim. Take a quartz glass rod. Keep it in the vessel. Observe glass rod by the sides of glass vessel.
   - What changes do you notice? • What could be the reasons for these changes?(AS2)
8. Do activity-7 again. How can you find critical angle of water? Explain your steps briefly. (AS3)
9. Collect the values of refractive index of the following media. (AS4)
   Water, coconut oil, flint glass, crown glass, diamond, benzene and hydrogen gas.

10. Collect information on working of optical fibres. Prepare a report about various uses of optical fibres in our daily life. (AS4)
11. Take a thin thermocol sheet. Cut it in circular discs of different radii like 2cm, 3cm, 4cm, 4.5cm, 5cm etc and mark centers with sketch pen. Now take needles of length nearly 6cm. Pin a needle to each disc at its centre vertically. Take water in a large opaque tray and place the disc with 2cm radius in such a way that the needle must be inside the water as shown in fig-Q11. Now try to view the free end (head) of the needle from surface of the water.



fig-Q11:

- Did you able to see the head of the needle?

Now do the same with other discs of different radii. Try to see the head of the needle, each time.

Note: the position of your eye and the position of the disc on water surface should not be changed while repeating the activity with other discs.

- At what maximum radius of disc, did you not able to see the free end of the needle?
- Why didn't you able to view the head of the nail for certain radii of the discs?
- Does this activity help you to find the critical angle of the medium (water)?
- Draw a diagram to show the passage of light ray from the head of the nail in different situations. (AS4)

12. Explain the refraction of light through the glass slab with a neat ray diagram. (AS5)
13. Place an object on the table. Look at the object through the transparent glass slab. You will observe that it will appear closer to you. Draw a ray diagram to show passage of light ray in this situation. (AS5)
14. What is the reason behind the shining of diamond and how do you appreciate it? (AS6)
15. How do you appreciate the role of Fermat principle in drawing a ray diagram. (AS6)
16. A light ray is incident on air-liquid interface at $45^0$and is refracted at 30^0. What is the refractive index of the liquid? For what angle of incidence will the angle between reflected ray and refracted ray be 90^0? (AS7) (Ans: 1.414, 54.7^0)
17. Explain why a test tube immersed at a certain angle in a tumbler of water appears to have a mirror surface for a certain viewing position? (AS7)
18. What is the angle of deviation produced by the glass slab? Explain with ray diagram. (AS7)
19. In what cases a light ray does not deviate at interface of two media?(AS7)
20. A ray of light travels from an optically denser to rarer medium. The critical angle of the two media is 'c'. What is the maximum possible deviation of the ray? (AS7) (Ans:π-2c)
21. When we sit at camp fire, objects beyond the fire seen swaying. Give the reason for it. (AS7)
22. Why do stars appear twinkling? (AS7)
23. Why does a diamond shine more than a glass piece cut to the same shape? (AS7)

Chapter 3

Refraction at Curved Surface

You might have seen a few people using spectacles for reading. The person in a watch repairing shop uses a small magnifying glass to see tiny parts.

- Have you ever touched magnifying glass with your hand?
- Have you touched the glass in the spectacles used for reading with your hand?
- Is it a plane surface or curved?
- Is it thicker in the middle or at the edge?

We have learnt about refraction at a plane surface in the previous chapter. Now let us understand refraction at curved surfaces.

Let us do an activity to understand refraction of light at curved surfaces.

Activity 1

Draw an arrow of length 4 cm using a black sketch pen on a thick sheet of paper. Take an empty cylindrical-shaped transparent vessel. Keep it on the table. Ask your friend to bring the sheet of paper on which arrow was drawn behind the vessel while you look at it from the other side.

- What do you see?

  You will see a diminished (small-sized) image of the arrow
- Why do you see a diminished image?
- Is the image real or virtual?
- Can you draw a ray diagram showing how it is formed?

Ask your friend to fill vessel with water. Look at the arrow from the same position as before.

- What do you see now?
- Do you get an reversed image?
- How could this happen?

In the first case, when the vessel is empty, light from the arrow refracts at the curved interface, moves through the glass enters into air then it again undergoes refraction on another curved surface of vessel (at other end from where we are looking) and comes out into the air. In this way light travels in two media comes out of the vessel and forms a diminished image.

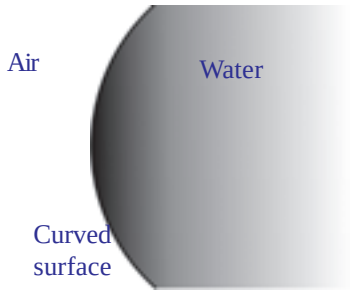


fig-1:

In the second case, light enters the curved surface, moves through water, comes out of the glass and forms an inverted image.

When the vessel is filled with water, there is a curved interface between two different media (air and water). Assume that the refractive index of both water and glass are the same (they really are not equal). This is the setup appears as air and water are two different media separated by a curved surface as shown in figure 1.

- What happens to a ray that incident on a curved interface separating two media?
- Does it behave like in the case of incident of a ray at plane surface?
- Would the law of refraction still be valid?

Let us find:

Consider a curved surface as shown in figure 2. The centre of the sphere which contains the part of curved surface is called as *centre of curvature*. It is denoted by letter 'C'.

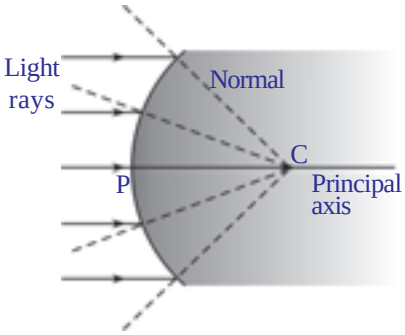


fig-2:

Any line drawn from the centre of curvature to a point on the curved surface becomes normal to the curved surface at that point. The direction of the normal changes from one point to another point of the curved surface. The centre of the curved surface is called the *pole* (P) of the curved surface. The *line joining the centre of curvature and the pole is called 'principal axis'*.

- How do rays bend when they are incident on a curved surface?

As in the case of plane surfaces, a ray will bend towards the normal if it travels from rarer to denser medium and it bends away from the normal if it travels from denser to a rarer medium .

Let us see how to draw ray diagrams for certain useful cases.

Ray passing along normal:

- What happens to a ray that moves along the principal axis or moves through the centre of curvature?

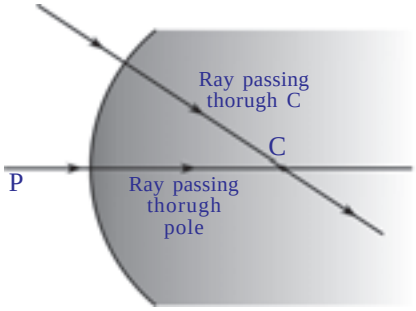


fig-3:

According to Snell's law the ray which move along the normal drawn to the surface do not deviate. Hence both rays mentioned in above condition travel along the normal (see figure 3), so they do not deviate.

- What happens to the ray travelling parallel to the principal axis?

Observe the following figures 4a, 4b, 4c, and 4d. In all the cases represented by diagram, the incident ray is parallel to principal axis.

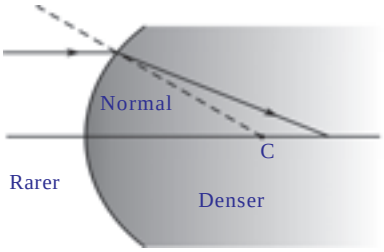


fig-4(a):

Case1: An incident ray is travelling parallel to principle axis and propagating from a rarer medium to denser medium striking a convex surface.

Case2: An incident ray is travelling parallel to principle axis and propagating from denser medium to rarer medium striking at a convex surface.

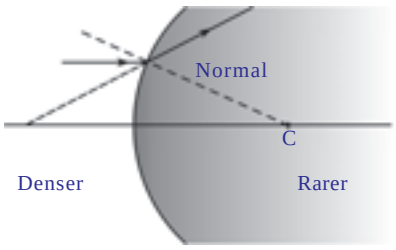


fig-4(b):

Case3: An incident ray is travelling parallel to principle axis and propagating from denser medium to rarer medium striking a concave surface.

Case4: an incident ray travelling parallel to principle axis and propagating from rarer medium to denser medium striking a concave surface.

- What difference do you notice in refracted rays among 4a and 4b?

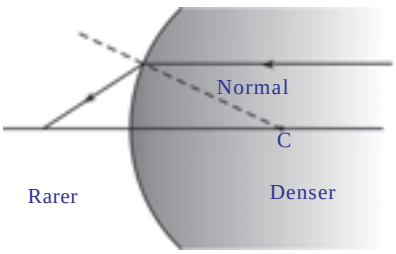


fig-4(c):

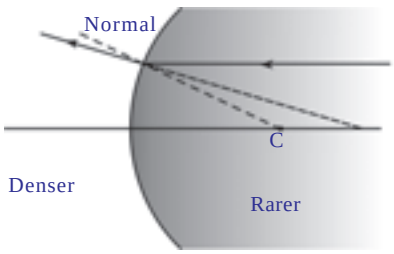


fig-4(d):

- What could be the reason for that difference?
- What difference do you notice in refracted ray among figure 4c and 4d?
- What could be the reasons for that difference?

You might have noticed that in figures 4(a) and 4 (c) the refracted ray reaches a particular point on the principal axis. In figures 4(b) and 4(d) the refracted ray moves away from the principal axis., When you extend the refracted ray back along the ray as shown in 4b and 4d, the extended ray intersects the principal axis at some point. The point where refracted ray intersect the axis in all the above cases is called the *focal point*.

You might have observed that a lemon in the water of a glass tumbler appears bigger than its actual size, when viewed from the sides of tumbler.

- How can you explain this appeared change in size of lemon?
- Is the lemon that appears bigger in size i.e., an image of lemon or real lemon?
- Can you draw a ray diagram to explain this phenomenon?

Let us find:

IMAGE FORMATION

Consider a curved surface separating two media of refractive indices n_1 and n_2 (figure 5) . A point object is placed on the principal axis at point O. The ray, which passes along the principal axis, moves the interface without deviation. The second ray, which forms an angle α with principal axis, meets the interface at A. The angle of incidence is θ_1. The ray bends and passes through the second medium along the line AI. The angle of refraction is θ_2. The two refracted rays meet at I and the image is formed there. Let, the angle made by the second refracted ray with principal axis is γ and the angle between the normal and principal axis is β. (see figure 5)

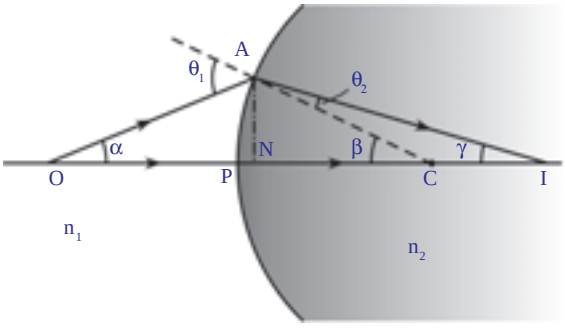


fig-5:

In the above figure 5,

PO is the object distance which we denote as ‘u’

PI is image distance which we denote as ‘v’

PC is radius of curvature which we denote as ‘R’

n_1, n_2 are refractive indices of two media.

Can you establish any relation among the above mentioned quantities?

Let us find,

In a triangle ACO, $\theta_1 = \alpha + \beta$

And in a triangle ACI, $\beta = \theta_2 + \gamma \Rightarrow \beta - \gamma = \theta_2$

According to Snell's law, we know

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

substituting the values of θ_1 and θ_2, we get,

$n_1 \sin(\alpha + \beta) = n_2 \sin(\beta - \gamma)$ ————(1)

If the rays move very close to the principal axis, the rays are called *paraxial rays*. Then the angles α, β and γ become very small. This approximation is called *paraxial approximation*.

$\sin(\alpha + \beta) = \alpha + \beta$ and $\sin(\beta - \gamma) = \beta - \gamma$

Substituting in equation (1)

$n_1(\alpha + \beta) = n_2(\beta - \gamma) \Rightarrow n_1\alpha + n_1\beta = n_2\beta - n_2\gamma$——-(2)

since all angles are small, we can write

$\tan\alpha = AN/NO = \alpha$

$\tan\beta = AN/NC = \beta$

$\tan\gamma = AN/NI = \gamma$

Substitute these in equation (2), we get,

$n_1 AN/NO + n_1 AN/NC = n_2 AN/NC - n_2 AN/NI$ ..... (3)

As the rays move very close to principal axis, the point N coincides with pole of the interface (P). Therefore NI, NO, NC can be replaced by PI, PO and PC respectively.

After substituting those values in equation (3), we get,

$n_1/PO + n_1/PC = n_2/PC - n_2/PI$

$n_1/PO + n_2/PI = (n_2 - n_1)/PC$ ————(4)

Equation (4) shows the relation among refractive indices of media, object distance, image distance and radius of curvature.

The above equation is true for the case we considered.

We can generalize equation (4) if we use the following sign convention.

For all purposes of applications of refraction at through curved surfaces and through lenses following conventions are used.

- All distances are measured from the pole.
- Distances measured along the direction of the incident light ray are taken as positive
- Distances measured opposite to the direction of the incident light ray are taken as negative

– The heights measured vertically above from the points on axis are taken as positive
– The heights measured vertically down from points on axis are taken as negative.

Here PO is called the *object distance* (u)

PI is called the *image distance* (v)

PC is called *radius of curvature* (R)

According to sign convention mentioned above, we have

PO = -u ; PI = v ; PC = R

Substituting these values in equation (4) we get,

$n_2/v - n_1/u = (n_2-n_1)/R$ ————————(5)

This formula can also be used for plane surfaces. In the case of a plane surface, radius of curvature (R) approaches to infinity. Hence 1/R becomes zero. Substituting this in equation 5, we get

$n_2/v - n_1/u = 0 \Rightarrow n_2/v = n_1/u$

NOTE: The distances u and v are measured from the plane interface.

Let us consider the following examples.

Example 1

A bird is flying down vertically towards the surface of water in a pond with constant speed. There is a fish inside the water. If that fish is exactly vertically below the bird, then bird will appear to fish as it will:

a. be farther away than its actual distance.
b. be closer than its actual distance.
c. be moving faster than its actual speed.
d. be moving slower than its actual speed.

Which of the four options is true? How can you prove it?

Solution: For refraction at a plane surface,

we use $n_2/v = n_1/u$ ————(1)

Let *x* be the height of the bird above the water surface at an instance and n be the refractive index of water.

n_1 = refractive index of air,

Then $n_1 = 1$, $n_2 = n$, u= -*x* and let v = -y, (see figure E-1)

Substituting these values in equation (1)

$n/(-y) = 1/(-x) \Rightarrow y = nx$

In the above equation,

We know that n is greater than 1. Hence y is greater than x. Thus bird appears to fish that it is farther away than its actual distance. We have

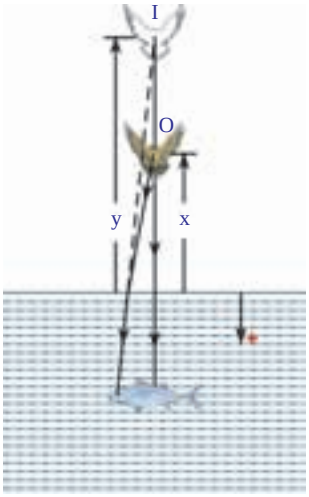


fig-E1:

assumed that bird is flying vertically down with constant speed. For the observer on ground birds appear that it has covered 'x' distance for certain time. But for fish it appears that bird has covered is at the same time. As y is greater than x , we can conclude that the speed of the bird observed by the fish is greater than its actual speed.

So, options (a) and (c) are correct.

Example 2

A transparent sphere of radius R and refractive index n is kept in air. At what distance from the surface of the sphere should a point object be placed on the principal axis so as to form a real image at the same distance from second surface of the sphere?

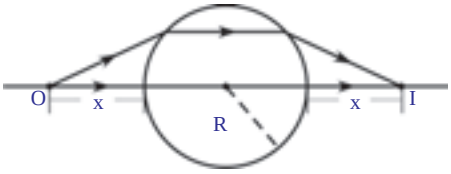


fig-E2:

Solution: From the symmetry of the figure E-2, the rays must pass through the sphere parallel to the optical axis.

From the figure,

$u = -x$, $v = \infty$ (refracted ray is parallel to the optical axis after refraction at first surface)

$n_1 = 1$ and $n_2 = n$, (where n_1 is refractive index of air)

Using $n_2/v - n_1/u = (n_2-n_1)/R$

$n/\infty - 1/(-x) = (n-1)/R \Rightarrow 1/x = (n-1)/R$

$\Rightarrow x = R/(n-1)$

Object distance from the first surface of the sphere is $x = R/(n-1)$

Example 3

A transparent sphere has a small, opaque dot at its centre. Does the apparent position of the dot will be the same as its actual position when observed from outside?

Solution: Let $n_1 = n$ (refractive index of glass)

$n_2 = 1$(refractive index of air)

Then $u = -R$ (radius of sphere) ; Radius of curvature $R = -R$

Using $n_2/v - n_1/u = (n_2-n_1)/R$

$1/v - n/(-R) = (1-n)/(-R)$

After solving this equation, we get

Image distance $v = -R$

Thus we can say that the image distance and object distance are equal then the apparent position of dot is equal to its actual position.

It is independent of refractive index of the material of the sphere.

Till now we have discussed about refraction of light through a single curved surface either convex surface or concave surface. Let us suppose that a transparent material has two curved surfaces.

- What happens to the light ray when a transparent material with two curved surfaces is placed in its path?
- Have you heard about lenses?
- How light ray behaves when it is passed through a lens?

Let us learn about lenses.

LENSES

A lens is formed when a transparent material is bounded by two surfaces of which one (or) both surfaces are spherical. That is lens is bounded by atleast one curved surface. Lenses can be of various types. Some typical lenses along with their names are shown in figure 6.



fig-6(a): Biconvex *fig-6(b): Biconcave* *fig-6(c): Plano-convex* *fig-6(d): Plano-concave* *fig-6(e): Concavo-convex*

Figure 6 : Different types of lenses

A lens may have two spherical surfaces bulging outwards. Such lens is called Double convex lens (Biconvex lens, see figure 6(a)). It is thick at the middle as compared to edges.

Similarly, a double concave lens is bounded by two spherical surfaces curved inward. (Biconcave lens, see figure 6(b)). It is thin at the middle and thicker at the edges.

Observe the 6(c), 6(d) and 6(e) to understand structure of Plano-Convex lens, Plano-Concave lens; Concavo-Convex lens.

Here we are concerned only with thin lenses i.e. the thickness of the lens is negligible.

Let us learn the terminology used with lenses.

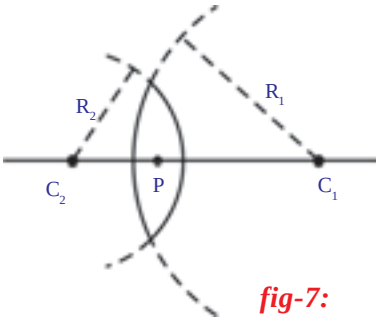


fig-7:

Each curved surface of a lens is part of a sphere. The centre of the sphere which contains the part of the curved surface is defined *centre of curvature*. It is denoted by a letter 'C'. If a lens contains two curved surfaces then their centres of curvature are denoted as C_1 and C_2.The distance between the centre of curvature and curved surface is called *radius of curvature (R)*. Radii of curvature are represented by R_1 and R_2 respectively. Let us consider a double convex lens as shown in figure 7.

The line joining the points C_1 and C_2 is called *principal axis*. The *midpoint of a thin lens* is called as *pole(*P). It is also called as *optical centre* of lens.

FOCAL LENGTH OF THE LENS:

A parallel beam of light incident on a lens converges to a point as shown in the figure 8(a) or seems to emanate from a point on the principal axis as shown in the figure 8(b). The point of converge (or) the point from which rays seems emanating is called *focal point* or *focus* (F). Every lens has two focal points. The distance between the focal point and pole is called *focal length* of lens denoted by 'f'.

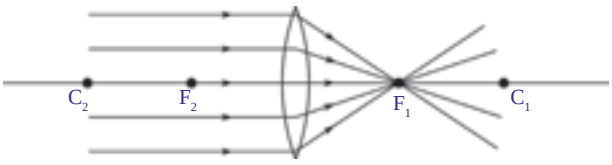


fig-8(a):

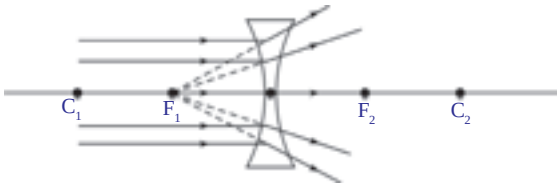


fig-8(b):

For doing further ray diagrams related to lens we represent convex lens with a symbol ↕ and concave lens with ⋋⋌.

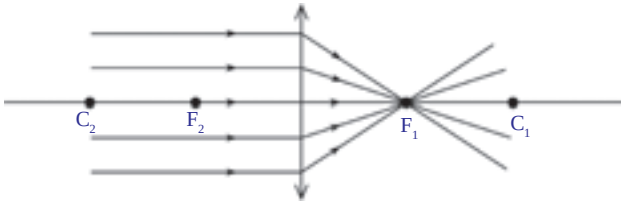


fig-8(c):

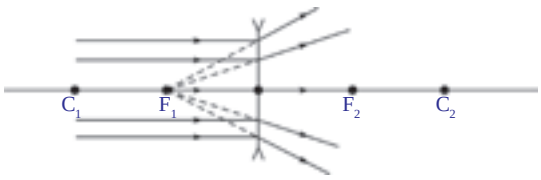


fig-8(d):

- How does the lens form an image?

To know the formation of image by lenses, we need to know the behavior of light rays when they meet a lens.

Though we know that the lens has two surfaces; while drawing ray diagrams, we can consider the lens as a single surface element because we assume that the thickness of lens is very small and show the net refraction at only one of the surface as shown in the figure 8(c) and 8(d).

Behaviour of certain light rays when they incident on a lens:

The behaviour of light ray when it passes through a lens can be understand by observing its behaviour in following situations:

Situation I: Ray passing through the principle axis

Any ray passing through the principal axis is undeviated. (see Figures 9a and 9b)

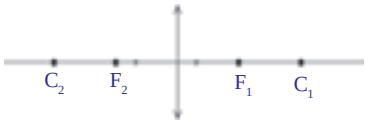


fig-9(a):

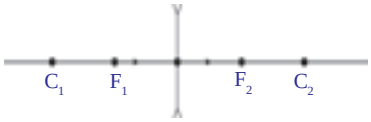


fig-9(b):

Situation II: Ray passing through the pole.

Any ray passing through the pole is also undeviated. (see Figure 10a and 10b)

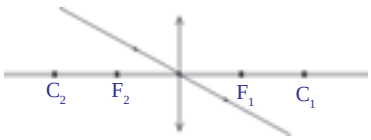


fig-10(a):

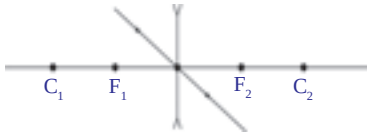


fig-10(b):

Situation III: Rays travelling parallel to the principal axis.

We know that,

The rays passing parallel to the principal axis converge at focus or diverge from the focus as shown in figure 8(c) and 8(d).

- If we allow the light ray to pass through the focus, which path does it take?

Situation IV: Ray passing through focus.

Light rays obey the principle of least time. Hence the ray passing through focus will take a path parallel to principle axis after refraction.(see Figure 11(a) and 11(b))

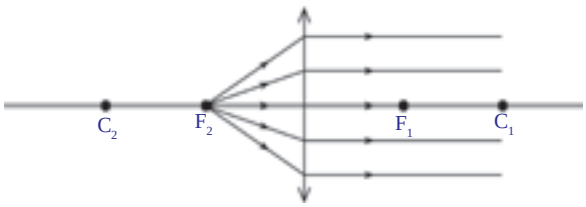


fig-11(a):

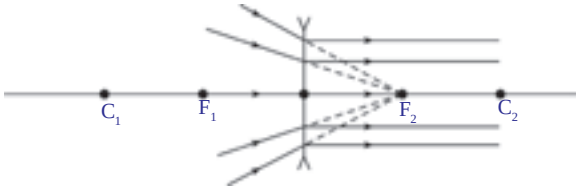


fig-11(b):

- What happens when parallel rays of light fall on a lens making some angle with principle axis?

  Let us observe following figures

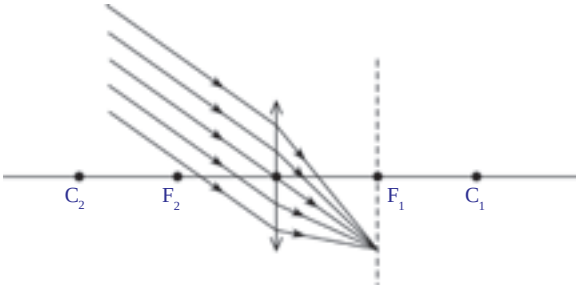


fig-12(a):

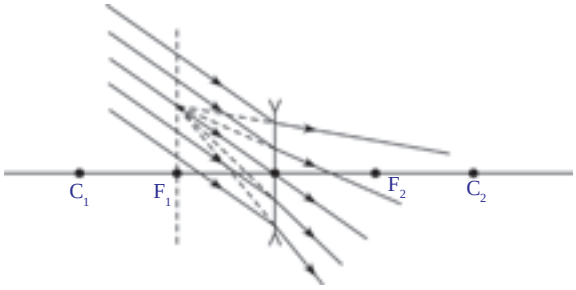


fig-12(b):

When parallel rays fall on a lens as shown in figures 12(a) and 12(b) making certain angle with principle axis. The rays converge at a point or appear to diverge from a point lying on a focal plane. Focal plane is the plane perpendicular to principal axis at the focus.

Rules to draw ray diagrams for image formation by lenses:

Let us know few basic rules to draw ray diagrams to locate the position of images.

For drawing a ray diagram to find position and size of the image formed by lens for any position of object on principle axis you need to follow the rules mentioned below:

For locating position and to final the size of image, we need two rays out of four rays that were mentioned in the situation I to IV.

- Select a point on the object placed at a point on the principle axis.
- Draw two rays that were chosen by you from rays mention in situation I to IV.
- Extend both rays to intersect at a point. This point gives position of the image.
- Draw a normal from point of intersection to principal axis.
- Length of this normal represents the size of the image.

Observe the following diagrams. They represent image formation by a convex lens for various positions of the object.

1. Object at infinity

- What do you mean by an object at infinity?
- What type of rays fall on the lens?

You know that the rays falling on the lens from an object at infinity are parallel to the principal axis.

They converge to the focal point or seem to emanate from that focal point. So a point sized image is formed at the focal point. This can be seen in figures 8(a) and 8(b).

2. Object placed beyond the centre of curvature on the principle axis

In figure (13) you notice that when object is placed beyond the centre of curvature (C_2), a *real*, *inverted* and *diminished* image is formed on principle axis between the points F_1 and C_1.

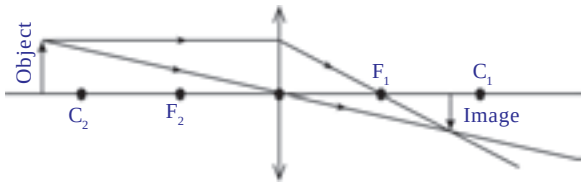


fig-13:

In figure (13) we have chosen two rays, one ray passing parallel to principal axis and another ray passing through the pole to locate the position of image.

Try to draw ray diagram using the pair of rays, one passing parallel to axis another passing through focus.

- Where do you get image on axis?
- Is it diminished or enlarged image?

Formed image is *real*, *inverted* and *diminished*.

3. Object placed at the centre of curvature

When object is placed at the centre of curvature (C_2) on the principle axis, you will get an image at C_1 which is *real*, *inverted* and of the *same size* as that of object. See figure 14.

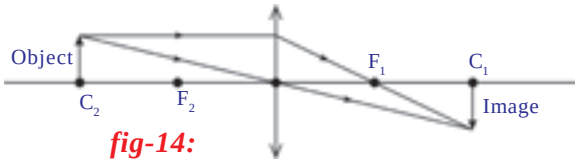


fig-14:

4. Object placed between the centre of curvature and focal point

When the object is placed between centre of curvature (C_2) and focus (F_2), you will get an image which is *real*, *inverted* and *magnified*. See figure 15. The image will form beyond C_1.

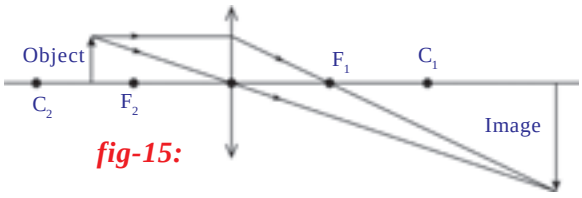


fig-15:

5. Object located at the focal point

When the object is placed at focus (F_2), the image will be at infinity. See figure 16. When the image forms at infinite distance, we could not discuss the size and nature of the image.

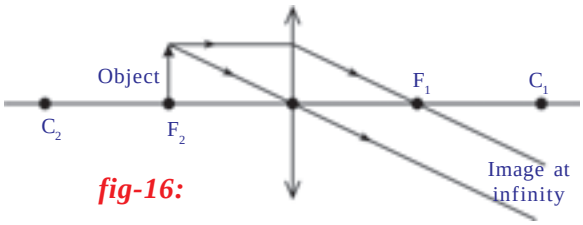


fig-16:

6. Object placed between focal point and pole

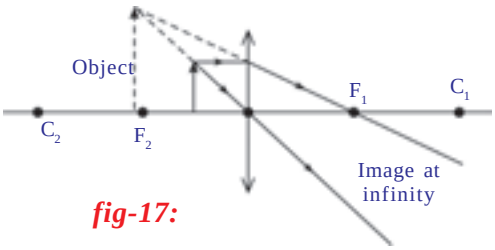


fig-17:

If we place object between focus and pole, we will get an image which is *virtual*, *erect* and *magnified*.

From the ray diagram shown in figure 17, you will notice that the image formed is a *virtual*, *erect* and is formed on the same side of the lens where the object is placed. The size of the image is larger than that of the object. It is a *magnified image*.

In the above situation of image formation, we understand two things:

1. As the image formed is virtual, we can see it with our eyes. In all other cases the image is real which we can't see with our eyes but can be viewed if image is captured on screen.
2. A magnified virtual image is formed on side of the lens where object is placed. Thus the image you are seeing through lens is not real, it is a virtual image of the object.

This particular behaviour of convex lens helps to construct a microscope, which magnifies the size of the image. You might have remembered that the magnification of the virtual image is possible only when the object is at the distance less than the focal length of the lens.

Till now we have drawn ray diagrams for various positions of object placed on principle axis using convex lens. Try to draw ray diagrams for an object placed at all positions for a concave lens.

- What do you notice?

Verify your ray diagram with the ray diagram we have drawn for a convex lens. See figure 18

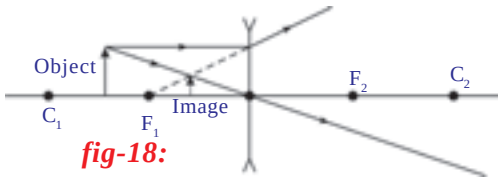


fig-18:

Notice that irrespective of the position of object, on the principal axis, you will get an *errected*, *virtual image*, *diminished in size* in between the focal point and pole for concave lens.

Let us see a few examples of ray diagrams

Example 4:

Draw a ray diagram to locate the position of image when a point source (S) is placed on optical axis MN of a convex lens, in such a way that it is beyond focal point (F).

Solution:

– Draw a perpendicular line to principle axis passing the focus (F^I).

– Draw a ray from point source (S) in any direction to meet lens at point (P^I).
– Now draw another line parallel to the ray drawn from the point source (S) and passes through the pole (P); This line intersect the normal at point F_O.

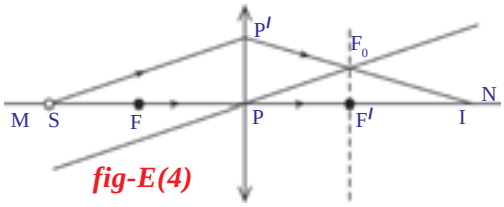


fig-E(4)

– Now draw a line passing from point P^I to pass through the point F_O such that it meet principle axis at a point say (I).
– 'I' is the image point for the point source (S).

Example 5:

Complete the ray diagram to show the paths of the rays after refraction through the lenses shown in the figures E-5(a) and 5(b)?

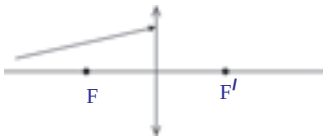


fig-E(5a)

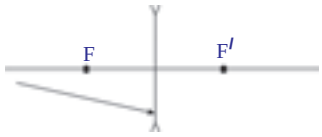


fig-E(5b)

Solution:

Follow the steps mentioned in Example (4) to complete the ray diagrams.

You will notice that the paths of the rays are shown in figures E-5(c) and 5(d).

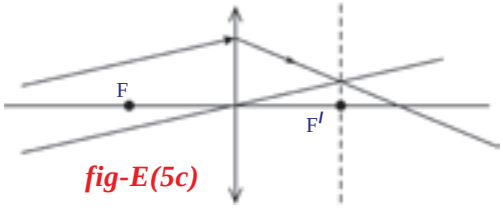


fig-E(5c)

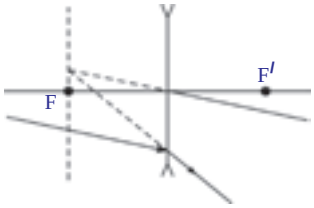


fig-E(5d)

- Do we get the same results as in the ray diagrams when we perform experiments with lens?

  Let us see

Activity 2

Take a v-stand and place it on a long (nearly 2m) table at the middle. Place a convex lens on the v-stand. Imagine the principle axis of the lens. Light a candle and ask your friend to take the candle far away from the lens along the principle axis. Adjust a screen (a sheet of white paper placed perpendicular to the axis) which is on other side of lens until you get an image on it.

- Why are you using a screen to view this image? Why don't you see it directly with your eye?

Measure the distance of the image from the stand of lens and also measure the distance between the candle and stand of lens.

Record the values in a table 1.

Table 1

Object distance (u)	Image distance (v)	Focal length (f)

Now place the candle at a distance of 60 cm from the lens. such as the flame of the candle lie on the principle axis of the lens. Try to get an image of the candle flame on the other side on a screen. Adjust the screen till you get a clear image. Measure the distance of image (u) from lens and record the value of 'u' and 'v' in the table. Repeat this for various object distances like 50 cm, 40 cm, 30 cm, etc. Measure distances of images in all the cases and note it in table (1).

- Could you get an image on the screen for every object distance?
- Why don't you get an image for certain object distances?
- Can you find the minimum limiting object distance for obtaining a real image?
- What do you call this manimum limiting object distance?

When you do not get an image on the screen, try to see the image with your eye directly from the place of the screen.

- Could you see the image?
- What type of image do you see?

You will see a magnified image on the same side where we kept the object. This is a *virtual* image of the object which we cannot capture on the screen.

- Can you find the image distance of this virtual image?
- How could you do it?

In table-1, you got different values of 'v' for various position of candle (u).

- Could you find focal length of the lens from the values recorded in table-1?
- Can we establish a relation among 'u', 'v' and 'f'?

Let us find.

Consider an object OO^{I} placed on principal axis in front of a convex lens as shown in figure(19). Let II^{I} be the real image formed by the lens on the other side of it. Observe the following figure(19).

- How is the image formed?

The ray starting at O^{I} and moving parallel to the principal axis and falls on the lens, should pass through the focal point F_1 as shown in figure (19).

To locate the point of image (I^{I}) for the object point (O^{I}).

Let another ray passes through the pole. We know that any ray passing the pole will not deviate.

If we consider another ray starting from O^{I} and passing through pole it will meet the refracted ray (First ray) at the point I^{I}. This point is called as the image of the point O^{I} of the object. Similarly the image of the point O on the principal axis is formed at point I on the principal axis (see Figure 19). We get the inverted image II^{I} of object OO^{I} on principle axis.

PO, PI and PF_1 are the object distance, image distance and focal length respectively.

From the figure (19), triangle $PP^{I}F_1$ and triangle F_1II^{I} are similar triangles,

$\Rightarrow PP^{I}/II^{I} = PF_1/F_1I$ ———(1)

But from the figure 19,

$F_1I = PI - PF_1$

substituting F_1I in equation (1) above, we get

$PP^{I}/II^{I} = PF_1/(PI - PF_1)$ ———(2)

We have another set of similar triangles $OO^{I}P$ and PII^{I}.

From these triangles we get, $OO^{I}/PO = II^{I}/PI$ => $OO^{I}/II^{I} = PO/PI$

but from figure (19), $OO^{I} = PP^{I}$, hence we have

$PP^{I}/II^{I} = PO/PI$———(3)

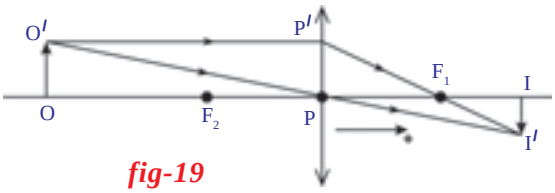


fig-19

From (2) and (3), we get

$PO/PI = PF_1/(PI-PF_1)$

$PI/PO = (PI-PF_1)/PF_1$

$PI/PO = PI/PF_1 - 1$

On dividing the equation by PI, we get

$1/PO = 1/PF_1 - 1/PI$

$1/PO + 1/PI = 1/PF_1$ ———(4)

The above equation is derived for a particular case of the object while using a convex lens.

To convert this into a general equation, we need to use the sign convention.

According to the sign convention

$PO = -u$; $PI = v$; $PF_1 = f$

Substituting these values in equation 4, we get

$1/v - 1/u = 1/f$

This equation is called *lens formula*. It can be used for any lens. But remember to use the sign convention while using this equation.

We have 'u' and 'v' values in table – 1 that were measured during activity – 2. Find focal length of the lens from the values of the table for each set of values of 'u' and 'v'.

- Is the focal length same for each set of values?

You might have noticed that irrespective of object distance and image distance, you will get same focal length. If you are not getting same value of focal length, there may be some experimental errors involved while doing experiment. In such a case, find average of all the values. This will be equal to focal length of the lens.

Let us see an example

Example 6

An electric lamp and a screen are placed on the table, in a line at a distance of 1m. In what positions of convex lens of focal length of f = 21 cm will the image of lamp be sharp?

Solution:

Let 'd' be distance between the lamp and screen and 'x' be the distance between lamp and lens. From figure E-6, we have u = -*x* and v = d-*x*

By substituting these in lens formula,

We get

$1/f = 1/(d-x) + 1/x$

After solving this equation, we get

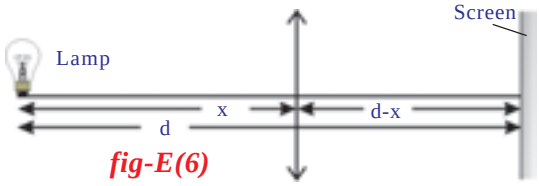


fig-E(6)

$x^2 - dx + fd = 0$

It is a quadratic equation. Hence we get two solutions. The solutions of above equation are

$x = [d \pm \sqrt{(d^2-4fd)}] / 2$——(1)

Given that f = 21cm and d= 1m =100cm.

Substituting these values in equation 1, we get

x_1 =70 cm and x_2 = 30cm.

NOTE: Image of the lamp can be sharp only when f is less than or equal to 25cm.

Discuss the reason for this using equation (1). Take the help of your teacher.

- On what factors the focal length of the lens depends?

Let us find out.

Activity 3

Take the same lens that was used in activity 2. Note the average focal length of the lens that was calculated in the activity. Take a cylindrical vessel. Its height must be greater than the focal length of the lens. Keep a black stone inside the vessel at its bottom. Now pour water into the vessel up to a height such that the height of the water surface from the top of the stone is slightly greater than focal length of lens. Now dip the lens horizontally using a circular lens holder as shown in the figure (20) above the stone to a small depth from the surface of the water. Set the distance between stone and lens that is equal to or less than focal length of lens measured in activity 2. Now see the stone through the lens. (Do this in open ground)

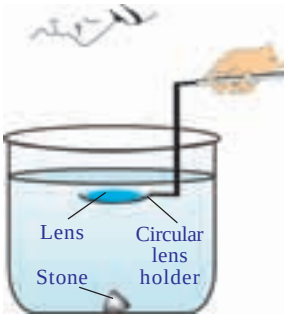


fig-20

- Can you see the image of stone?
- If Yes / Not, why? Give your reasons.

Now reduce the distance between lens and stone until you view the image of the stone.

- What do you conclude from this activity?
- Does the focal length of the lens depend on surrounding medium?

You have dipped the lens to a certain height which is less than the focal length of lens in air. But you didn't see the image. When lens is dipped further, you could able to see the image. This shows that the focal length of lens has changed in water. Thus we conclude that the focal length of lens depend upon the surrounding medium in which it is kept.

Lens making formula:

Imagine a point object 'O' placed on the principal axis of the thin lens as shown in figure 21. Let this lens be placed in a medium of refractive index n_1 and let refractive index of lens be n_2.

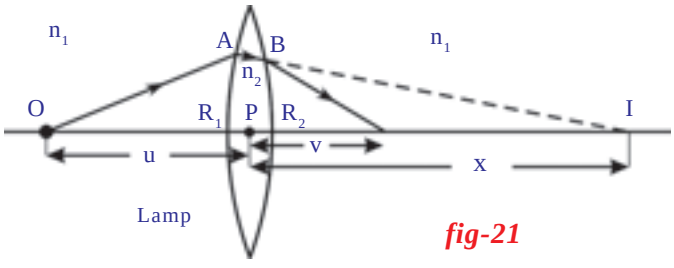


fig-21

Consider a ray, from 'O' which incident on the convex surface of the lens with radius of curvature R_1 at A as shown in figure 21.

The incident ray refracts at A.

Let us assume that, it forms image at Q, if there is no concave surface.

From the figure(21), PO = -u and PQ = x

Substitute the above values in the equation, $n_2 / v - n_1 / u = (n_2-n_1) / R$

⇨ $n_2 / x + n_1 / u = (n_2-n_1) / R_1$ (sign convention is used) ——(1)

But the ray that has refracted at A suffers another refraction at B on the concave surface with radius of curvature (R_2). At B the ray is refracted and reaches at I on the principal axis.

The image Q of the object due to the convex surface is taken as object for the concave surface. So, we can say that I is the image of Q for concave surface. See figure 21.

PQ = +x (object distance); PI = v (image distance)

Substituting the above values in equation $n_2 / v - n_1 / u = (n_2-n_1) / R$

For the refraction at concave surface of the lens is considered as medium-1 and surrounding medium is considered as medium2. Hence the suffixes of refractive indices interchange. Then we get,

$n_1 / v - n_2 / x = (n_1-n_2) / (-R_2)$ (sign convention is used) ———(2)

By adding (1) and (2) we get,

⇨ $n_1 / v + n_1 / u = (n_2-n_1)(1 / R_1 + 1 / R_2)$

Deviding both sides by n_1, We get

⇨ $1 / v + 1 / u = (n_2 / n_1 – 1)(1 / R_1 + 1 / R_2)$

We know $n_2 / n_1 = n_{21}$ called refractive index of lens with respect to surrounding medium.

$1 / v +1 / u = (n_{21}– 1)(1 / R_1 + 1 / R_2)$

This is derived for specific case for the convex lens so we need to generalize this relation. For this we use sign convention. Applying sign convention to this specific case we get,

$1/v - 1/u = (n_{21}– 1)(1/R_1 - 1/R_2)$

We know that

$1/v -1/u = 1/f$

So, we get

$1/f = (n_{21}– 1)(1/R_1 - 1/R_2)$ ————(3)

If the surrounding medium is air, then the relative refractive index could be absolute refractive index of lens.

$1/f = (n– 1)(1/R_1 - 1/R_2)$.

This can be used only when lens is kept in air.

Where n is absolute refractive index and this equation is called lens maker formula.

NOTE: Always use sign convention while using any formula derived in this chapter and the above formula can be used for any thin lenses.

The convex lens behaves as a converging lens, if it is kept in a medium with less refractive index than refractive index of lens. But it behaves like a diverging lens when it is kept in medium with greater refractive index than the lens.

For example the air bubble in water behaves like diverging lens.

Let us see an example for lens maker formula.

Example 7

What is the focal length of double concave lens kept in air with two spherical surfaces of radii R_1 = 30cm and R_2 =60cm. Take refractive index of lens as n = 1.5.

Solution:

From the figure E-7 using sign convention we get

R_1 = -30cm, R_2 = 60cm and also given that n = 1.5

using $1/f = (n-1)(1/R_1 - 1/R_2)$

$1/f = (1.5 - 1)[1/(-30)-1/60]$

Solving this, we get

f = -120cm

Here minus indicates that the lens is divergent.

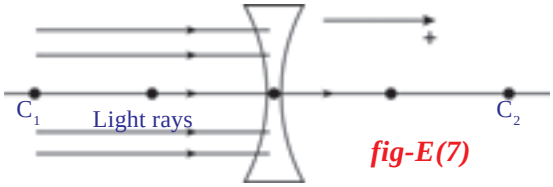


fig-E(7)

Key words

Lens, Focal length, Focus, Pole, Principle axis, Radius of curvature, Centre of curvature.

What we have learnt

- The formula below is used when a light ray enters a medium with refractive index n_2 from a medium with refractive index n_1 at curved interface with a radius of curvature R.
  $n_2/v - n_1/u = (n_2 - n_1)/R$
- A lens is formed when one medium is separated from another medium by two surfaces, one of which is curved.
- Lens formula is $1/f = 1/v - 1/u$
  where f is the focal length of lens, u is the object distance and v is the image distance.
- Lens maker's formula is
  $1/f = (n-1)(1/R_1 - 1/R_2)$
  where R_1 and R_2 are radii of curvature , n is the refractive index and f is the focal length.

Improve your learning

1. A man wants to get a picture of a zebra. He photographed a white donkey after fitting a glass, with black stripes, on to the lens of his camera. What photo will he get? Explain. (AS1)
2. Two converging lenses are to be placed in the path of parallel rays so that the rays remain parallel after passing through both lenses. How should the lenses be arranged? Explain with a neat ray diagram. (AS1)
3. The focal length of a converging lens is 20cm. An object is 60cm from the lens. Where will the image be formed and what kind of image is it? (AS1)

   (Ans: A real, diminished, inverted image formed at 30cm from the lens)
4. Total internal reflection can take place only if (AS1)
   a) Light goes from optically rarer medium to optically denser medium.
   b) Light goes from optically denser medium to rarer medium.
   c) The refractive indices of the two media widely different
   d) The refractive indices of the two media are close to each other.



fig-Q(8):

5. A double convex lens has two surfaces of equal radii 'R' and refractive index ì = 15. The focal length 'f' is (AS1)
   a) f = R/2 b) f = R c) f = -R d) f = 2R
6. Harsha tells Siddhu that the double convex lens behaves like a convergent lens. But Siddhu knows that Harsha's assertion is wrong and corrected Harsha by asking some questions. What are the questions asked by Siddhu? (AS2)
7. Assertion (A): A person standing on the land appears taller than his actual height to a fish inside a pond. (AS2)

   Reason (R): Light bends away from the normal as it enters air from water.

   Which of the following is correct? Explain.
   a) Both A and R are true and R is the correct explanation of A.
   b) Both A and R are true and R is not the correct explanation of A.
   c) A is true but R is false. d) Both A and R are false.
   e) A is false but R is true.
8. A convex lens is made up of three different materials as shown in the figure.

   How many of images does it form? (AS2)
9. Can virtual image be photographed by a camera?(AS2)
10. You have a lens. Suggest an experiment to find out the focal length of the lens. (AS3)

11. Let us assume a system that consists two lenses with focal length f_1 and f_2 respectively. How do you find the focal length of the system experimentally, when (AS3)
    i) two lenses are touching each other
    ii) they are separated by a distance 'd' with common optical axis.
12. Collect the information about the lenses available in an optical shop. Find out how the focal length of a lens may be determined by the given 'power' of the lens. (AS4)
13. Collect the information about lenses used by Galileo in his telescope. (AS4)
14. Use the data obtained by activity-2 in table-1 of this lesson and draw the graphs of u *vs* v and 1/u *vs* 1/v. (AS5)
15. A parallel beam of rays is incident on a convergent lens with a focal length of 40cm. Where should a divergent lens with a focal length of 15 cm be placed for the beam of rays to remain parallel after passing through the two lenses? Draw a ray diagram. (AS5)
16. Figure Q-13 shows ray AB that has passed through a divergent lens. Construct the path of the ray up to the lens if the position of its foci is known. (AS5)
17. Figure Q-14 shows a point light source and its image produced by a lens with an optical axis N_1N_2. Find the position of the lens and its foci using a ray diagram. (AS5)

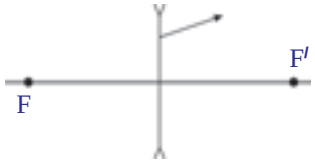


fig-Q(13):



fig- (14)

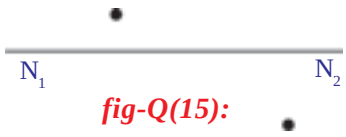


fig-Q(15):

18. Find the focus by using a ray diagram using the position of source S and the image S^I (AS5)
19. How do you appreciate the coincidence of the experimental facts with the results obtained by a ray diagram in terms of behaviour of images formed by lenses? (AS6)
20. Find the refractive index of the glass which is a symmetrical convergent lens if its focal length is equal to the radius of curvature of its surface. (AS7) (Ans:1.5)
21. Find the radii of curvature of a convexo –concave convergent lens made of glass with refractive index n=1.5 having focal length of 24cm. One of the radii of curvature is double the other. (Ans:R_1=6cm,R_2=12cm) (AS7)
22. The distance between two point sources of light is 24cm .Where should a convergent lens with a focal length of f=9cm be placed between them to obtain the images of both sources at the same point? (AS7)
23. Suppose you are inside the water in a swimming pool near an edge. A friend is standing on the edge. Do you find your friend taller or shorter than his usual height? Why?(AS7)

Chapter 4

Human eye and Colourful world

You have studied refraction of light by lenses in previous chapter. You have learnt about nature, position and relative size of image formed by lenses for various distances of objects. In class IX, chapter VI on sense organs in Biological science text book, explained about structure of human eye. The human eye uses light and enables us to see the object. It has a lens in its structure.

In previous chapter you learned that the focal length of lens and object distance determines the nature, position and size of image.

- What is the function of lens in human eye?
- How it helps to see the object at far distances and near distances?
- How is it possible for getting image at same distance in eye ball i.e, on retina of eye?
- Are we able to see all objects in front of our eye clearly?
- Why do we use lenses in spectacles to correct defects in vision?
- How do the lenses used in spectacles correct defects of vision?

To answer these questions, you need to understand the structure and functioning of human eye.

Let us do the following activities to know about some interesting facts about our vision.

Least distance of clear vision:

Activity 1:

Take a text book and hold it with your hands in front of you at certain distance. Now try to read the content on the page. Slowly move the book towards your eye, till it reaches very close to your eyes.

- What changes do you notice?

You may see that printed letters on the page of text book appears blurred or you will feel strain in eye.

Now slowly move the book backwards to a position where you can see clear printed letters without strain in your eye. Ask your friend to measure the distance between your eye and text book at this position. Note down its value. Repeat the activity to other friends and note down the distances for clear vision in each case.

Find the average of all these distances of clear vision.

- What value do you get for average distance?

From this activity you will come to know that to see an object comfortably and distinctly, you must hold it at a distance about 25 cm from your eyes. This distance is called least distance of clear vision. This varies from person to person and with age. At a young age (say below 10 years) the muscles around the eye are strong and flexible and can bear more strain. Therefore the least distance of clear vision at this age is as close as 7 to 8 cm. In old age the muscles cannot sustain more strain hence the least distance of clear vision shifts to large value say about 1 to 2 m or even more.

- Are you able to see the top and bottom of an object placed at a distance about 25 cm from your eye irrespective of its shape?

Let us find.

Activity-2:

Arrange a retort stand as shown in fig-1. Collect wooden sticks used in cloth roller in clothes store (or) collect waste PVC pipe that are used for electric wiring. Prepare sticks or pipes of 20 cm, 30 cm, 35 cm, 40 cm, 50 cm from them and keep the retard stand on a table and stand near the table such that your head is beside the vertical stand (see fig 1). Adjust the clamp on horizontal rod and fix at a distance of 25 cm from your eyes. Ask one of your friends to fix wooden stick of 30 cm height to the clamp in vertical position as shown in fig1.

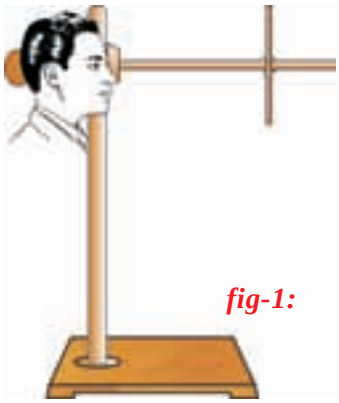


fig-1:

Now keeping your vision parallel to horizontal rod of the stand, try to see the top and bottom of wooden stick kept in vertical position.

- Are you able to see both ends of the stick simultaneously without any movement in your eyes?

In activity-1, you learned that least distance for clear vision is about 25 cm. It varies from person to person. If you are not able to see both end of stick at this distance (25 cm), adjust the vertical stick on the horizontal rod till you are able to see both ends of the stick at nearest possible distance from your eye. Fix the clamp of containing vertical stick at this position.

Without changing the position of the clamp on horizontal rod, now replace this stick of 30 cm length with other sticks of various lengths one by one and try to see the top and bottom of the stick simultaneously without any change in the position of eye either upside and down or side by side.

- Are you able to see both ends of the sticks in all these cases? If not why?

Let us know

Observe the following figure-2. You can see the whole object AB which is at a distance of 25 cm (least distance of clear vision) because the rays coming from the ends A and B of the object AB will enter into the eye. Similarly you can also see complete object CD with eye as explained above. Let us assume that AB is moving closer to eye to a position A' B' as shown in figure2.

- Will you able to see the whole object now?

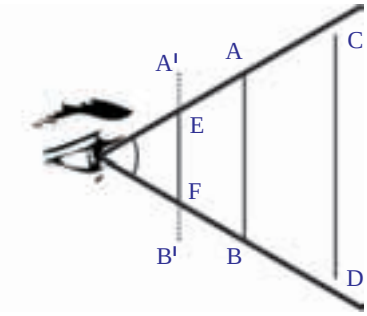


fig-2:

From the figure 2, you notice that you will be able to see only the part (EF) of the object A' B' because the rays coming from E and F enter into your eye. The rays coming from A2 and B2 cannot enter into your eye.

The rays coming from the extreme ends of an object forms an angle at the eye. If this angle is below 60^0, we can see whole object. If this angle is above 60^0, then we see only the part of the object.

This maximum angle, at which we are able to see the whole object is called angle of vision. The angle of vision for a healthy human being is about 60^0. It varies person to person and with age.

You have learnt that the value of least distance of clear vision is about 25 cm and the value of angle of vision of human beings is about 60^0. You also learnt these values changes from person to person and with age of person.

- Why do the values of distance of clear vision and angle of vision change with person and age?

To answer the above question, we need to understand the structure of eye and its functioning.

The human eye is one of the most valuable and sensitive sense organs. It enables us to see the object and colours around us.

Figure 3 shows schematically the basic components of an eye. The eye ball is nearly spherical in shape. The front portion is more sharply curved and is covered by a transparent protective membrane called the cornea. It is this portion which is visible from outside. Behind the cornea, there is place filled with a liquid called aqueous humour and behind this a crystalline lens which is responsible for the image formation. Between the aqueous humour and the lens, we have a muscular diaphragm called 'iris' which has a small hole in it called pupil. Iris is the coloured part that we see in an eye.

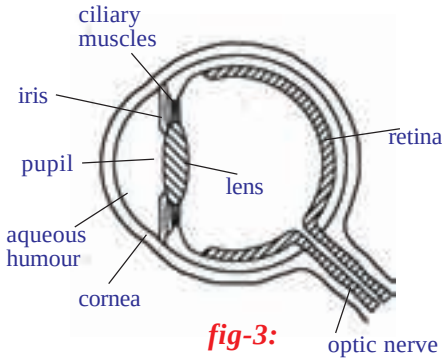


fig-3:

The pupil appears black because any light falling on it goes into the eye and there is almost no chance of light coming back to the outside. Iris helps in controlling the amount of light entering the eye through 'pupil'. In low light condition ,the iris expands the pupil to allow more light to go in and bright (or) excess light condition ,it contracts the pupil, there by prevent the excess light not to go into eye. Thus 'iris' enables pupil to act as a "variable aperture" for entry of light rays into the eye.

The lens is hard in the middle and gradually becomes soft towards the outer edge. The light that enters the eye forms an image on the retina. It covers inside rear part of eyeball. The distance between the lens and retina is about 2.5 cm i.e., for any position of object in front of the eye the image distance is fixed that it is about 2.5 cm.

- How can we get same image distance for various positions of objects?
- Can you answer above question with concept of refraction through lenses?

In previous chapter, you have studied for different positions of object, the image distance remain constant only when there is a change in focal length of lens. Further, the focal length of a lens depends on the material by which it has been made and radii of curvature of lens. We need to change focal length of eye lens to get same image distance for various positions of object in front of eye. This is only possible when the eyelens can be able to change its shape.

- How eye lens changes its focal length?
- How this change takes place in eye ball?

Let us know

The ciliary muscle to which eye lens is attached (see fig-3) helps the eye lens to change its focal length by changing radii of curvature of eye lens.

When the eye is focussed on a distant object, the ciliary muscles are relaxed so that the focal length of eye lens has its maximum value which is equal to its distance from the retina. The parallel rays coming into the eye are then focussed on the retina and we see the object clearly.

When the eye is focussed on a closer object the ciliary muscles are strained and focal length of eye-lens decreases. The ciliary muscles adjust the focal length in such a way that the image is formed on retina and we see the object clearly. This process of adjusting focal length is called "accommodation". However these muscles cannot strain beyond a limit and hence if the object is brought too close to eyes, the focal length cannot be adjusted to form an image on the retina. Thus there is a minimum distance for clear vision of an object which is roughly equal to 25 cm as we have learned in activity-1.

- Does eye lens form a real image or virtual image?
- How does the image formed on retina help us to perceive the object without change in shape size and colour?

Let us know

The eye-lens forms a real and inverted image of object on retina. This retina is delicate membrane, which contains about 125 millions of receptors called 'rods' and 'cones' which receive the light signal (rods-identify the colour: cones-identify the intensity of light). These signals are transmitted to brain through about 1 million of optic-nerve fibres. The brain interprets these signals and finally processes the information so that we perceive the object in terms of it's shape, size and colour.

In previous discussion you have learnt that eye-lens itself changes its focal length in accordance with distance of the object with the help of ciliary muscles.

- Is there any limit to change of focal length of eye-lens?
- What are the maximum and minimum focal lengths of the eye lens? How can we find them?

Let us find

When the object is at infinity, the parallel rays from the object falling on the eye lens are refracted and they form a point sized image on retina (see fig-4a).

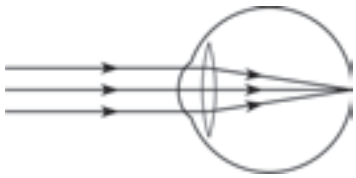


fig-4(a):

In this situation, eye-lens has a maximum focal length.

When the object is at infinity,

u= - ∞; v = 2.5 cm (image distance which is equal to distance between eye-lens and retina)

using the formula 1/f = 1/v – 1/u

$1/f_{max} = 1/2.5 + 1/\infty$

$1/f_{max} = 1/2.5+0$

$f_{max} = 2.5$ cm

we get, $f_{max} = 2.5$ cm

consider that an object is placed at distance of 25 cm from our eye. In this situation eye has minimum focal length.

Here u = - 25 cm; v = 2.5 cm

Using the formula 1/f = 1/v – 1/u

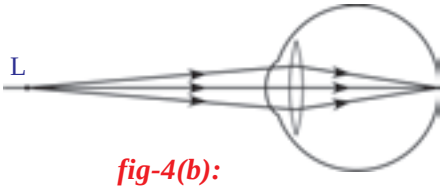


fig-4(b):

$1/f_{min} = 1/2.5 + 1/25$

$1/f_{min} = 11/25$

$f_{min} = 25/11 = 2.27$ cm

if the position of an object is between infinity and the point of least distance of clear vision, then the eye lens adjusts it's focal length in between 2.5 cm to 2.27 cm to form clear image on retina.

The ability of eye-lens to change its focal length is called "accommodation of lens".

- What happens if eye lens is not able to adjust its focal length?
- What happens if the focal length of eye lens is beyond the range of 2.5 cm to 2.27 cm?

let us find.

Sometimes the eye may gradually lose its power of accommodation. In such conditions the person cannot be able to see the object clearly and comfortably. The vision becomes blurred due to the defects of eye lens. There are mainly three common defects of vision.

They are:

i. Myopia

ii. Hypermetropia

iii. Presbyopia.

Myopia:

Some people cannot see objects at far distances but can see nearby objects clearly. This type of defect in vision is called 'Myopia'. It is also called 'near sightedness'. For these people the maximum focal length is less than 2.5 cm. In such cases the rays coming from the distance objects, after refraction through eye lens, form image before retina as shown in figures 5(a) and (b) .

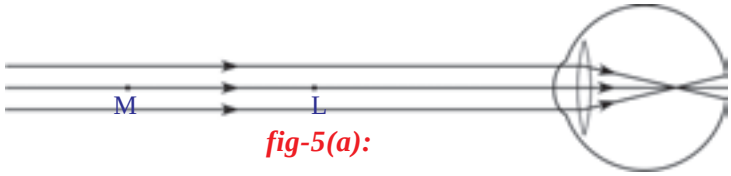


fig-5(a):

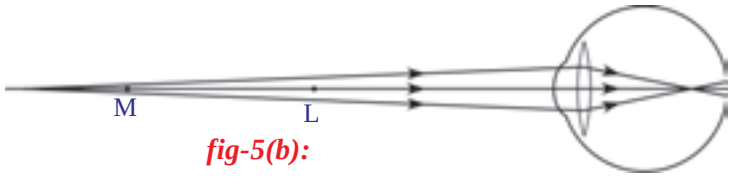


fig-5(b):

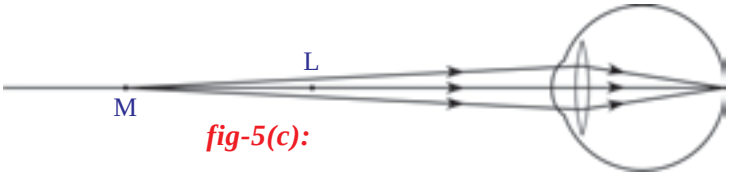


fig-5(c):

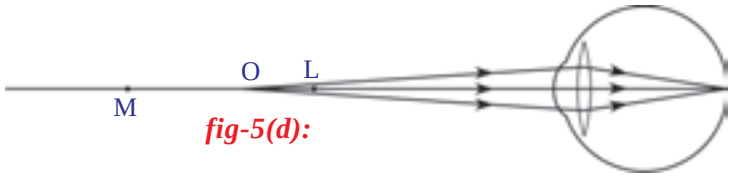


fig-5(d):

A healthy person can see objects at all distances more than 25 cm clearly. But a person with myopia can see objects clearly up to a certain distance. Let the extreme point from where an object appears clearly to a person with myopia be 'M' (shown in figure 5(c)).

If the object is at M or in between M and point of least distance of clear vision (L),the eye lens can form the image on retina (see figure 5(c) and 5(d)). This point M is called 'far point'.

The point of maximum distance at which the eye lens can form an image on retina is called 'far point'.

The defect in which people cannot see objects beyond far point is called 'Myopia'.

- What can we do to correct myopia?

Eye lens can form clear image on retina, when an object is placed between far point and point of least distance of clear vision. If we could able to bring the image of the object kept beyond far point , between the far point and the point of least distance of clear vision

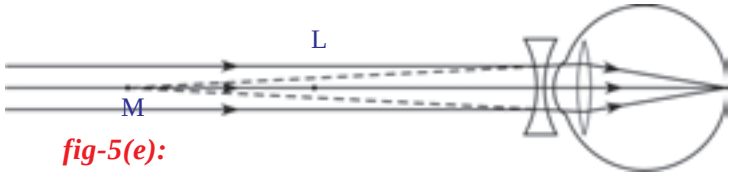


fig-5(e):

using a lens, this image act as an object for eye lens.

This can be possible only when a concave lens is used (remember the image formation by refraction through concave lens).

- How can you decide the focal length of the lens to be used to remove myopia?

To correct one's Myopia, we need to select a lens which forms image at the far point for an object at a distance of infinity. We need to select bi-concave lens to achieve this.

This image acts like an object for eye lens. Hence final image is formed on retina.

Let us find the focal length of this bi-concave lens.

Here object distance (u) is infinity and image distance is equal to distance of far point.

u = - ∞ ; v = distance of far point = -D

let 'f' be the focal length of bi-concave lens.

Using lens formula, $1/f = 1/v - 1/u$

$1/f = 1/-D \Rightarrow f = -D$

Here 'f' is negative showing that it is a concave lens.

- What happens when the eye has a minimum focal length greater than 2.27 cm?

Let us find

Hypermetropia:

Hypermetropia is also known as far sightedness. A person with hypermetropia can see distant objects clearly but cannot see objects at near distances. Because the focal length of eye lens for the person of hypermetropia is greater than 2.27 cm. In such cases, the rays coming from the nearby object after refraction at eye lens, forms image beyond the retina as shown in figures 6 (a) .



fig-6(a):

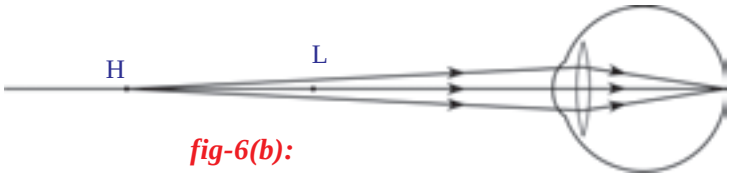


fig-6(b):

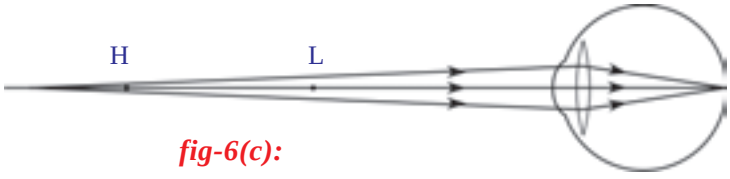


fig-6(c):

figures 6(a),6(b) and 6(c)

let the point of least distance at which the eye lens forms clear image on retina for a person with hypermetropia be 'H'. See figure 6(b).

If an object is at H or beyond H, the eye can form its image on retina (see figures 6(b) and 6(c)). If the object is between H and point of least distance of clear vision (L) then it cannot form image. See figure 6(a).

The point of minimum distance at which the eye lens can form an image on retina is called near point (H). The people with defect of hypermetropia cannot see objects placed between near point (H) and point of least distance of clear vision (L).

- How can you correct this defect?

Eye lens can form clear image on retina when any object is placed beyond near point. To correct the defect of hypermetropia, we need to use a lens which forms image of object beyond near point between near point (H) and least distance of clear vision (L).

This can be possible only when a double convex lens is used.

- How can you decide the focal length of convex lens to be used?

To find the focal length of lens, let us consider that the object is at point of least distance of clear vision (L). Then the defect of vision, hypermetropia is corrected when the image of the object at L is formed at the near point (H) by using a bi-convex lens as shown in figure 6(d).

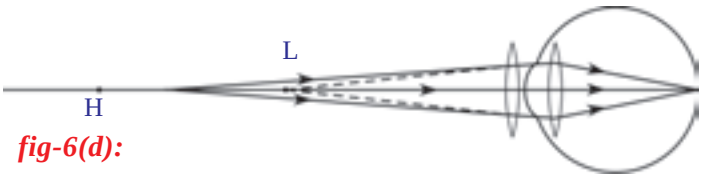


fig-6(d):

This image acts like an object for the eye lens. Hence final image due to eye is formed at retina (see figure 6(d))

Here object distance (u) = -25 cm

Image distance (v) = distance of near point = -d

Let 'f' be the focal length of bi-convex lens.

Using lens formula, $1/f = 1/v - 1/u$

$1/f = 1/-d - 1/(-25)$

$1/f = -1/d + 1/25$

$1/f = (d - 25)/25d$

$f = 25d / (d - 25)$ (f is measured in centi meters)

we know that d > 25cm, then 'f' becomes +ve i.e., we need to use biconvex lens to correct defect of hypermetropia.

Presbyopia:

Presbyopia is vision defect that the power of accommodation of the eye usually decreases with ageing. For most people the near point gradually recedes away. They find it difficult to see nearby object clearly and distinctly.

This happens due to gradual weakening of ciliary muscles and diminishing flexibility of the eye lens. This effect can be seen in aged people. Sometimes a person may in suffer from both myopia and hypermetropia with ageing .

To correct this type of defect of vision we need bi-focal lenses which both concave and convex lenses. Its upper position consist a concave lens and lower position consists convex lens.

If you go to an eye hospital to test your vision defects, after testing doctor gives you a prescription that contains some information regarding type of lens to be used to correct vision.

- Have you ever observed details in the prescription?

You might have heard about people saying "my vision sight is increased or decreased".

- What does it mean?

Usually doctors after testing the defects of vision prescribe corrective lenses indicating their power which determine the type of lens to be used and its focal length.

- What do you mean by power of lens?

Power of lens:

The degree of convergence or divergence of light rays that can be achieved by a lens is expressed in terms of its power.

The reciprocal of focal length is called power of lens.

Let 'f' be the focal length of lens.

Power of lens $P = 1 / f$(in m); $P = 100 / f$ (in cm)

The unit of power is dioptre.

It is denoted by the letter 'D'.

Example1:

Doctor advised to use 2D lens. What is the focal length of it?

Solution: Given that, power of lens P = 2D

Using, $P = 100 / f$ (in cm); $2 = 100 / f$

Therefore, $f = 100/2 = 50$ cm.

The lens has focal length, f = 50 cm.

DISPERSION AND SCATTERING OF LIGHT

You might have seen rainbow formed in the sky just after rain shower. It must have fascinated you with spectacular colour appeared as semi-circular band of colours.

- How could the white light of the sun give us various colours of the rainbow?

In previous chapters, you have studied the behaviour of light when it refracts through plane surface and curved surfaces, such as a lens. You also studied the nature, position and relative size of image formed by lenses.

- What happens to a light ray when it passes through a transparent medium bounded by plane surfaces which are inclined to each other?
- What is a prism?

PRISM

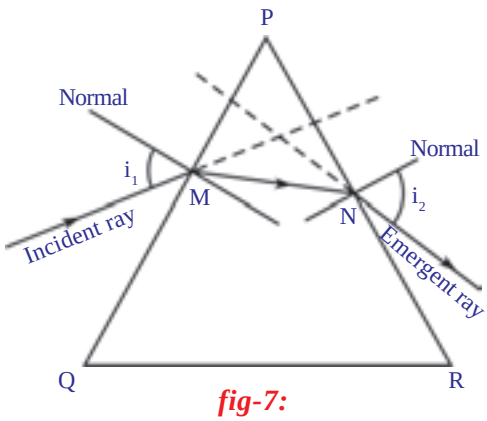


fig-7:

A prism is a transparent medium separated from the surrounding medium by at least two plane surfaces which are inclined at certain angle in such a way that, light incident on one of the plane surfaces emerges from the other plane surface. To understand the behaviour of light when it is incident on the plane of prism, we need to define certain terms associated with prisms.

Consider a triangular glass prism. It contains two triangular bases and three rectangular plane lateral surfaces. These lateral surfaces are inclined to each other.

Let us consider that triangle PQR represents outline of the prism where it rests on its triangular base. Let us assume that a light ray incident on the plane surface PQ of a prism at M as shown in figure 7. Draw a perpendicular to the surface at M. It becomes a normal to that surface. The angle between the *incident ray* and normal is called *angle of incidence* (i_1). The ray is refracted at M. It moves through prism and meets the other plane surface at N and finally comes out of the prism. The ray which comes out of the surface PR at N is called *emergent ray*. Draw a perpendicular to PR at point N. The angle between the emergent ray and normal is called *angle of emergence* (i_2).The angle between the plane surfaces PQ and PR is called the *angle of the prism or refracting angle* of prism and the angle between the incident ray and emergent ray is called *angle of* deviation(d).

Let us now do an activity to study the refraction of light through a triangular prism.

Lab Activity 1

Aim: Finding the refractive index of the prism.

Material required: Prism, piece of white chart of size 20x20 cm, pencil, pins, scale and protractor.

Procedure: Take a prism and place it on the white chart in such a way that the triangular base of the prism is on the chart. Draw a line around the prism using a pencil. Remove the prism.

- What is the shape of the outline drawn?

It is a triangle. Name its vertices as P,Q, and R.[for many prisms the triangle formed is equilateral]. The refracting surfaces could be rectangular in shape. Find the angle between PQ and PR . This is the angle of the prism (A).

Mark M on the side of triangle PQ and also draw a perpendicular to the PQ at M. Place the centre of the protractor at M and along the normal. Mark an angle of 30^0 and then draw a line up to M. This angle is called angle of incidence. Note it in a table (1). This line denotes the incident ray. Draw a small arrow on it as shown in figure 8.

Place the prism in its position (triangle) again. Now fix two pins vertically on the line at points A and B as shown in figure 8. Look for the images of pins through the prism from the other side (PR) and fix another two pins at points C and D in such a way that all the four pins appear to lie along the same straight line. Do it carefully. Now remove the prism and take out pins. Draw a line joining the two pin-holes formed by the pins to meet surface 'PR', this is the emergent ray which 'emerges from' the surface PR at a point 'N'. The angle between the normal at N and the emergent ray is the angle of emergence. Measure this angle and note its value in the table (1).

Table 1

Angle of incidence (i_1)	Angle of emergence (i_2)	Angle of deviation (d)

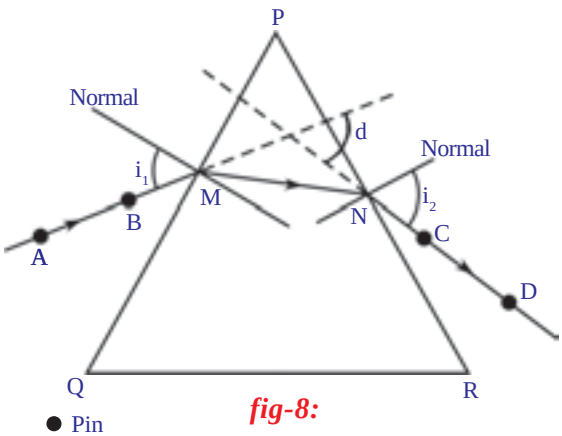


fig-8:

Now join the points M and N by a straight line. The line passing through the points A,B, M,N,C and D represents the path of light when it suffers refraction through prism.

- How do you find the angle of deviation?

Extend both incident and emergent rays till they meet at a point 'O'. Measure the angle between these two rays. Thus is the angle of deviation. It is denoted by a letter 'd'. Note it in table (1). Do the same for various angles of incidence such as 40^0,50^0 etc. Find the corresponding angles of deviation and angles of emergence and note them in table (1).

- What do you notice from the angles of deviation?

You will notice that the angle of deviation decreases first and then increases with increase of the angle of incidence.

- Can you draw a graph between angle of incidence and angle of deviation?

Take angle of incidence along X- axis and the angle of deviation along Y- axis. Using a suitable scale, mark points on a graph paper for every pair of angles. Finally join the points to obtain a graph (smooth curve). Check your graph with graph shown in figure 9.

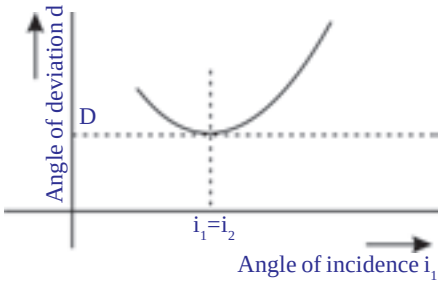


fig-9:

- From the graph, can you find the minimum of the angles of deviation?

Yes we can. Draw a tangent line to the curve, parallel to X- axis, at the lowest point of the graph. The point where this line cuts the Y- axis gives the angle of minimum deviation. It is denoted by D. Draw a parallel line to y-axis through the point where the tangent touches the graph. This line meets x-axis at a point showing the angle of incidence corresponding to the minimum deviation. If you do the experiment with this angle of incidence you will get that angle of emergence is equal to this angle of incidence. Look at your table (1).

- Is there any relation between the angle of incidence and angle of emergence and angle of deviation?
- Can you find refractive index of a prism? If yes, how?

Let us find,

Derivation of formula for refractive index of a prism:

Observe the ray diagram in the figure 10(a)

From triangle OMN, we get

$d = i_1 - r_1 + i_2 - r_2$

$d = (i_1+i_2) - (r_1+r_2)$ —— (1)

From triangle PMN, we have

$A + (90^0-r_1) + (90^0-r_2) = 180^0$

By simplification, we get

$r_1 + r_2 = A$ ———(2)

From (1) and (2), we have

$d = (i_1+i_2) - A$

$A+d = i_1+i_2$ ——(3)

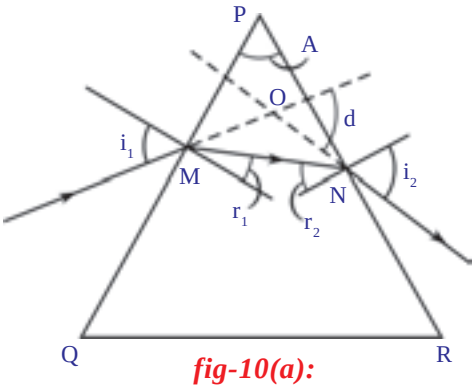


fig-10(a):

This is the relation between angle of incidence, angle of emergence, angle of deviation and angle of prism.

From Snell's law, we know that $n_1 \sin i = n_2 \sin r$

Let n be the refractive index of the prism.

Using Snell's law at M, with refractive index of air $n_1 = 1$; $i = i_1$; $n_2 = n$; $r = r_1$, gives

$\sin i_1 = n \sin r_1$ ———(4)

similarly, at N with $n_1 = n$; $i = r_2$; $n_2 = 1$; $r = i_2$, gives

$n \sin r_2 = \sin i_2$ ———(5)

We know that at the angle of minimum deviation (D), the angle of incidence is equal to the angle of emergence i.e., $i_1 = i_2$. Observe figure 10(b). You will note that MN is parallel to the side QR, actually ray MN is parallel to the base of the prism.

When $i_1 = i_2$, angle of deviation (d) becomes angle of minimum deviation (D).this situation is called minimum deviation.

Then equation (3) becomes

$A+D = 2i_1$

or $i_1 = (A+D)/2$

When $i_1 = i_2$ then, it is clear that $r_1 = r_2$

So from equation (2) we get,

$2r_1 = A$

or $r_1 = A/2$

Substituting i_1 and r_1 in (4) we get

$\sin\{(A+D)/2\} = n. \sin(A/2)$

Therefore, $n = \sin(A+D/2)/\sin(A/2)$ —(6)

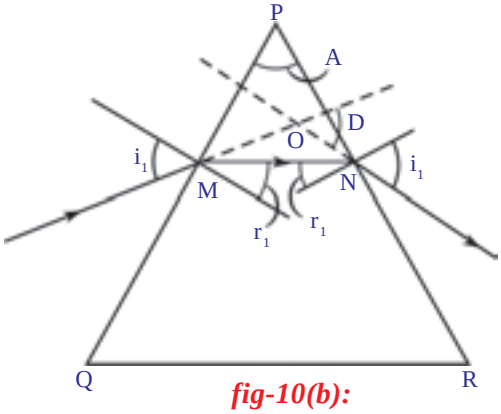


fig-10(b):

This is the formula for the refractive index of the prism.

Now use the result of lab activity (1) and find refractive index of the prism using the equation (6)

Let us see an example.

Example 2

A prism with an angle A = 60^0 produces a angle of minimum deviation of 30^0. Find the refractive index of material of the prism.

Solution: Given that A = 60^0 and D = 30^0.

Using n = Sin[(A+D)/2]/Sin(A/2) = Sin(90^0/2)/Sin(30^0) = Sin 45^0/ Sin30^0 = (1/√2)/(1/2) = √2

⇨ n = √2

thus, the refractive index of the given prism = √2

Let us do a small activity with prism.

Activity -3

Do this experiment in the dark room. Take a prism and place it on the table near a vertical white wall. Take a thin wooden plank. Make a small hole in it and fix it vertically on the table. Place the prism between the wooden plank and wall. Place a white light source behind the wooden plank. Switch on the light. The rays coming out of the hole of plank become a narrow beam of light. Adjust the height of the prism such that the light falls on one of the lateral surfaces. Observe the changes in emerged rays of the prism. Adjust the prism by slightly rotating it till you get a image on the wall.

- What do you observe on the wall?
- Could you get a coloured image on the wall?
- Why does white light split into colours?
- What colours do you see?
- Can you notice any change in the angle of deviation of each colour?
- Which colour has the minimum deviation?

Let us do another experiment.

Activity -4

Take a tray and fill it with water. Place a mirror in the water such that it makes an angle to the water surface. Now focus white light on the mirror through the water as shown in figure 11. Try to obtain colour

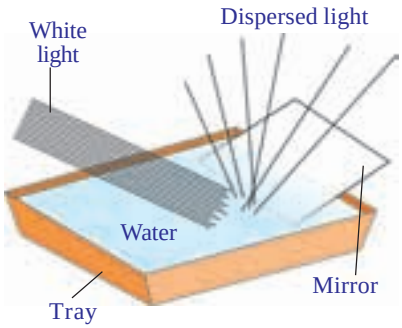


fig-11:

on a white card board sheet kept above the water surface. Note the names of the colours you could able to see in your book.

In activity (3) and (4), we observed that a white ray of light is splitting into certain different colours.

- Is this splitting of white light into colours explained by using ray theory?

It is not possible to explain the splitting of white light into different colours using ray theory.

- Why is this so?

Let us see

DISPERSION OF LIGHT

In activity 3, we observe that the angle of deviation is minimum for red as compared to the angles of deviation of other colours and maximum for violet.

The splitting of white light into different colours (VIBGYOR) is called **dispersion**.

In previous discussion, we studied that for a particular refractive index of prism there must be only one angle of deviation and according to Fermat's principle, light ray always chooses shortest time path. But in activity-3,we noticed that light has chosen different paths.

- Does this mean that the refractive index of the prism varies from colour to colour?
- Is the speed of each colour different?

So the situation thus we witnessed in above activities (3) and (4) rule out ray theory of light. Thus we can consider a white light is a collection of waves with different wavelengths. Violet is the shortest wavelength, while red is the longest wavelength.

According to wave theory, light can be thought of as a wave propagating in all directions. Light is an electromagnetic wave. Here no particle physically oscillates back and forth. Instead, the magnitude of electric and magnetic fields, associated with the electromagnetic wave, vary periodically at every point. These oscillating electric and magnetic fields propagate in all directions at the speed of light.

- Can you guess now, why does light split into different colours when it passes through a prism?

The reason lies in the fact that, while speed of light is constant in vacuum for all colours, it depends on the wavelength of light when it passes through a medium. We know that refractive index is the ratio of speeds in vacuum and in medium. Consequently, the refractive index of a medium depends on wavelength of light. When white light passes through a medium, each colour selects its least time path and we have refraction of different colours to different extents. This results in separation of colours, producing a spectrum on the wall and in the mirror as we see in activities (3) and (4). It has been experimentally found that refractive index decreases with an increase in wave length. If we compare the wave lengths of seven colours in VIBGYOR, red colour has longest wave length and violet colour has shortest wave length. Hence refractive index of red is low so that it suffers low deviation.

We noticed that when white light passes through a prism, it splits into seven colours. Let us assume that you have sent a single colour ray through the prism.

- Does it split into more colours? Why?

We know that the frequency of light is the property of the source and it is equal to number of waves leaving the source per second. This cannot be changed by any medium. Hence frequency doesn't change due to refraction. Thus coloured light passing through any transparent medium retains its colour.

While refraction occurs at the interface, the number of waves that incident on the interface in a second must be equal to the number of waves passing through any point taken in another medium. This means that the frequency of the light wave remains unaltered while its wave length adjusts according to the medium through which it passes. We know that the relation between the speed of wave (v), wavelength (λ) and frequency (f).

$$v = f \lambda$$

For refraction at any interface, v is proportional to ë. Speed of the wave increases with increase in wavelength of light and vice versa.

- Can you give an example in nature, where you observe colours as seen in activity 3?

Your answer certainly is a rainbow. That is a good example of dispersion of light.

- When do you see a rainbow in the sky?
- Can we create a rainbow artificially?

Let us see how?

Activity 5

Select a white coloured wall on which the sun rays fall. Stand in front of a wall such a way that the sun rays fall on your back. Hold a tube through which water is flowing. Place your finger in the tube to obstruct the flow of water. Water comes out through the small gaps between the tube and your finger like a fountain. Observe the changes on wall while you are showering the water, you can see the colours on the wall.

- How is that you are able to see the colours on wall?
- Whether the sun rays coming back to your eyes are from that of the wall or from water drops?

Let us find

The beautiful colours of rainbow are due to dispersion of the sunlight by millions of tiny water droplets. Let us consider a case of an individual water drop.

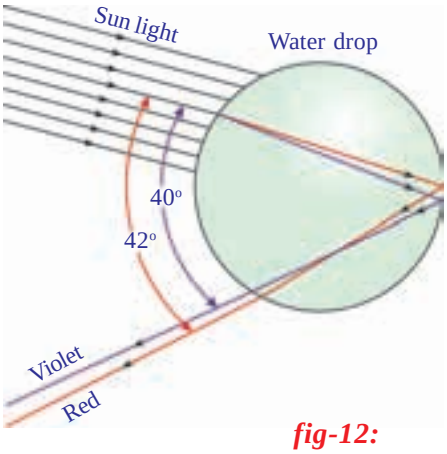


fig-12:

Observe figure 12. The ray of sunlight enters the drop near its top surface. At this first refraction, the white light is dispersed into its spectrum of colours, violet being deviated the most and red the least. Reaching the opposite side of the drop, each colour is reflected back into the drop because of total internal reflection. Arriving at the first surface of the drop, each colour is again refracted into air. At the second refraction the angle between red and violet rays further increases when compared to the angle between those at first refraction.

The angle between the incoming and outgoing rays can be anything between 0^0 and about 42^0. We observe bright rainbow when the angle is between incoming and outgoing rays near the maximum angle of 42^0. Diagrammatically it is shown in figure 12.Although each drop disperses a full spectrum of colours, an observer is in a position to see only a single colour from any one drop depending upon its position.

If violet light from a single drop reaches the eye of an observer, red light from the same drop can't reach his eye. It goes elsewhere towards the feet of the observer (see in figure 13). To see red light, one must look at the drop higher in the sky. The colour red will be seen when the angle between a beam of sunlight and light sent back by a drop is 42^0. The colour violet is seen when the angle between a sunbeam and light sent back by a

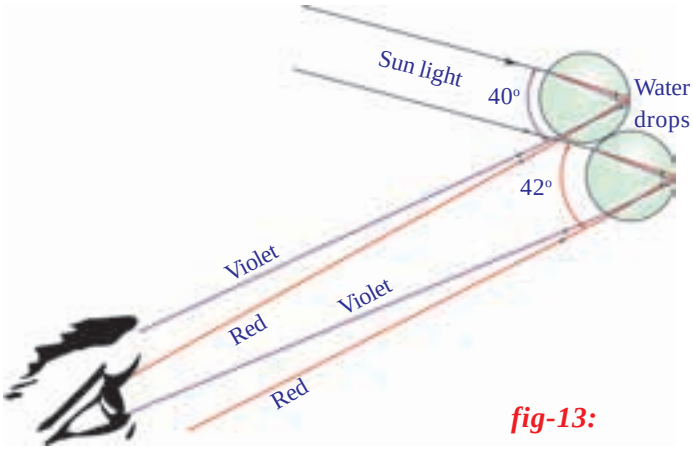


fig-13:

drop is 40^0. If you see at an angle between 40^0 and 42^0 ,you will observe remaining colours of VIBGYOR

- Why does the light dispersed by the raindrops appear as a bow?

To answer this question, we need a little geometric reasoning. First of all, a rainbow is not the flat two dimensional arc as it appears to us. The rainbow you see is actually a three dimensional cone with the tip at your eye as shown in figure 14. All the drops that disperse the light towards you lie in the shape of the cone – a cone of different layers. The drops that disperse red colour to your eye are on the outer most layer of cone, similarly the drops that disperse orange colour to your eye are on the layer of the cone beneath the cone that disperse red colour. In this way the cone responsible for yellow lies beneath orange and so on it continues till to violet colour which the innermost cone.(see in figure 14).

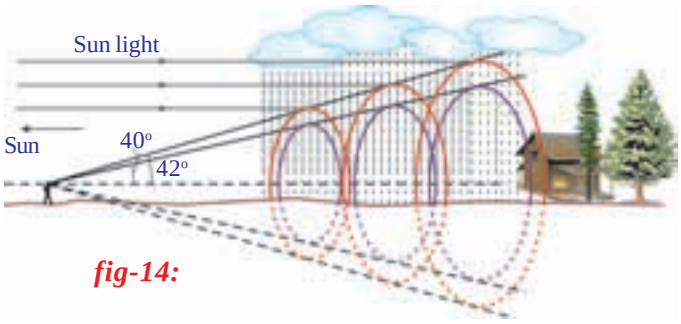


fig-14:

It is our common experience that the sky appears in blue in colour on bright dry day.

- Why is the sky blue?

To answer this question, you need to understand another phenomenon of light called scattering.

- What is scattering?

Let us see

SCATTERING OF LIGHT

Scattering of light is a complex phenomenon. Let us try to understand the idea of scattering.

- Do you know what happens to the free atom or molecule when it is exposed to certain frequency of light?

Atoms or molecules which are exposed to light absorb light energy and emit some part of the light energy in different directions. This is the basic process happens in scattering of light.

The effect of light on a molecule or an atom depends on the size of atom or molecule. If the size of the particle (atom or molecule) is small, it will be affected by greater frequency (lower wave length) of light and vice versa.

Let us consider that a certain frequency of light is incident on an atom. Then the atom comes into vibration due to this light. This in turn releases or reemits light in all direction with different intensity.

The intensity of light is nothing but the energy of light passing through unit area of plane, taken normal to the direction of propagation of light, in one second.

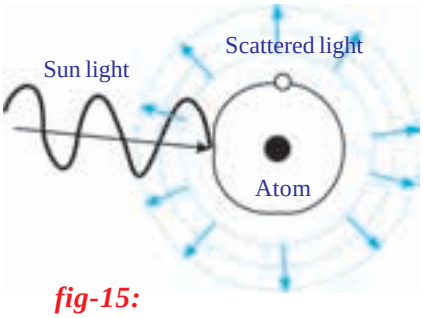


fig-15:

Let us consider that the free atom or free molecule is somewhere in the space as shown in figure 15.

A light of certain frequency falls on that atom or molecule. This atom or molecule responds to the light whenever the size of the atom or molecule comparable to the wave length of light. If this condition is satisfied, atom absorbs light and vibrates. Due to these vibrations, atom reemits certain fraction of absorbed energy in all directions with different intensities. The reemitted light is called scattered light and the process of reemission of light in all directions with different intensity is called scattering of light. The atoms or molecules are called scattering centre. Let us take the angle 'è' between the incident light and a direction in which the intensity of scattered light is observed, we call this angle as angle of scattering. It is experimentally observed that the intensity of scattered light varies with angle of scattering. The intensity is maximum at 90^0 of angle of scattering.

This is the reason for the appearance of the sky in clear blue colour when we see the sky in a perpendicular direction to the direction of the sun rays. If our angle of view is changed, the intensity of blue colour also changes.

Now you might have got a doubt that why scattering of light gives blue colour only? Why can't it give other colour?

Let us find whether the scattering centres are responsible for the blue sky?

We know that our atmosphere contains different types of molecules and atoms. The reason to blue sky is due to the molecules N_2 and O_2. The sizes of these molecules are comparable to the wavelength of blue light. These molecules act as scattering centres for scattering of blue light.

- Why is it the sky appears white sometimes when you view it in certain direction on hot days?

Our atmosphere contains atoms and molecules of different sizes. According to their sizes, they are able to scatter different wavelengths of light. For example, the size of the water molecule is greater than the size of the N_2 or O_2. It acts as a scattering centre for other frequencies which are lower than the frequency of blue light.

In a hot day due to rise in the temperature, water vapour enters into atmosphere which leads to abundant presence of water molecules in atmosphere. These water molecules scatter the colours of other frequencies (other than blue). All such colours of other frequencies reaches your eye and white colour is appeared to you.

- Can we demonstrate scattering of light by an experiment?

Let us try

Activity 6

Take the solution of sodium-thio-sulphate (hypo) with sulphuric acid in a glass beaker. Place the beaker in which reaction is taking place in open place where abundant sun light available. Watch the formation of grains of sulphur and observe changes in beaker.

You will notice that sulphur precipitates as the reaction in progress. At the beginning, the grains of sulphur are smaller in size as the reaction progress, their size increases due to precipitation.

Sulphur grains appear blue in colour at beginning and slowly their colour becomes white as their size increases. The reasons for this is scattering of light. At the beginning, the size of grains is small it is almost comparable to the wave length of blue light. Hence they appear blue in the beginning. As the size of grains increases, their size becomes comparable to wave lengths of other colours. As a result of this, they act as scattering centres for other colours. The combination of all these colours appears as white.

- Do you know the reasons for appearance of sun in red colour during sunrise and at sunset?

Atmosphere contains of free molecules and atoms with different sizes. These molecules and atoms scatter the light of different wavelengths which

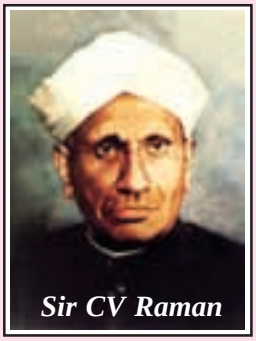
are comparable to their size. Molecules having the size that is comparable to the wavelength of redlight are less in atmosphere. Hence scattering of red light is less when compare to the other colours of light. The light from the sun needs to travel more distance in atmosphere to reach your eye. In morning and evening times, during sunrise and sunset except red light all colours scatter more and vanishes before they reach you. Since scattering of redlight is very less, it reaches you. As a result sun appearce red in colour during sunrise and sunset.

- Can you guess the reason why sun doesnot appeare red during noon hours?

During noon hours, the distance to be travelled by the sun rays in atmosphere is less when compared to that of morning and evening hours. Therefore all colours reaches your eye without much scattering. Hence light appear white in noon hours.

Do you know?

Our beloved scientist and Noble prize winner, Sir C.V. Raman explained the phenomenon of scattering in gases and liquids. He found experimentally that the frequency of scattered light by the liquids is greater than the frequency of incident light. This is called Raman Effect. By using this effect scientists determine the shapes of the molecules.



Sir CV Raman

So far, we have learned some ideas of the light such as refraction, dispersion and scattering. These are wonderful phenomenon surrounding us. When you face any situation regarding these phenomena, try to resolve the problem and appreciate the wonderful world and behaviour of light.

Key words

Least distance of clear vision, Angle of vision, Accommodation of eye lens, Myopia, Hypermetropia, Presbyopia, Power of lens, Prism, Angle of prism or refracting angle of prism, Angle of minimum deviation, Dispersion, Scattering.

What we have learnt

- The least distance of clear vision is about 25cm and the angle of vision is about 60^0.
- The ability of eye lens to change its focal length is called accommodation of lens.
- The defect in which people cannot see objects beyond far point is called **Myopia.**
- The defect in which people cannot see objects before near point is called **Hypermetropia.**
- **Presbyopia** is a vision defect that the power of accommodation of the eye usually decreases with ageing.
- The reciprocal of focal length is called power of the lens.
- The refractive index of prism is given by
  $n = \sin[(A+D)/2]/\sin(A/2)$
  where A is angle of prism and D is minimum angle of deviation.
- The splitting of white light into colours (VIBGYOR) is called dispersion.
- The process of reemission of absorbed light in all directions with different intensities by the atom or molecule, is called scattering of light.

Improve your learning

1. Light of wavelength ë1 enters a medium with refractive index n2 from a medium with refractive index n1. What is the wavelength of light in second medium?
   (Ans: $\lambda_2 = n_1\lambda_1/n_2$) (AS 1)
   NOTE: For questions 4 and 5 the following options are given. Choose the correct option by making hypothesis based on given assertion and reason. Give an explanation.
   a. Both A and R are true and R is the correct explanation of A.
   b. Both A and R are true and R is not the correct explanation of A.
   c. A is true but R is false.
   d. Both A and R are false.
   e. A is false but R is true.
2. Derive refractive index of the material in the case of prism. (AS1)
3. Explain the formation of rainbow. (AS1)
4. **Assertion (A):** The refractive index of a prism depends only on the kind of glass of which it is made of and the colour of light. (AS 2)
   Reason (R): The refractive index of a prism depends on the refracting angle of the prism and the angle of minimum deviation.
5. **Assertion (A):** Blue colour of sky appears due to scattering of light.
   Reason (R): Blue colour has shortest wavelength among all colours of white light. (AS 2)
6. Suggest an experiment to produce rainbow in your classroom and explain procedure. (AS 3)
7. Prisms are used in binoculars. Collect information why prisms are used in binoculars. (AS 4)

8. Incident ray on one of the face (AB) of prism and emergent ray from the face AC are given in figure Q-8. Complete the ray diagram. (AS 5)
9. How do you appreciate the role of molecules in the atmosphere for the blue colour of the sky? (AS 6)
10. Eye is the only organ to visualise the colourful world around us. This is possible due to accommodation of eye lens. Prepare a six line stanza enlighten your wonderful feelings. **(AS 6)**

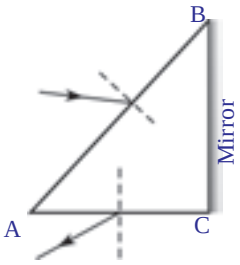


fig-Q-8:

11. How do you appreciate the working of Ciliary muscles in the eye? (AS 6)
12. Why does the sky sometimes appear white? (AS 7)
13. Glass is known to be transparent material. But ground glass is opaque and white in colour. Why? (AS 7)
14. If a white sheet of paper is stained with oil, the paper turns transparent. Why? (AS 7)
15. A light ray falls on one of the faces of prism at an angle 400 so that it suffers angle of minimum deviation of 300. Find the angle of prism and angle of refraction at the given surface. (Ans:500, 250) (AS 7)
16. The focal length of a lens suggested to a person with Hypermetropia is 100cm. Find the distance of near point and power of the lens. (Ans: 33.33cm, 1D) (AS 7)
17. A person is viewing an extended object. If a converging lens is placed in front of his eye. Will he feel that the size of object has increased? Why? (AS7)

Multiple Choice Questions

18. The size of an object as perceived by an eye depends primarily on
    (a) actual size of the object (b) distance of the object from the eye
    (c) aperture of the pupil (d) size if the image formed on the retina
19. When objects at different distances are seen by the eye which of the following remain constant?
    (a) focal length of eye-lens (b) object distance from eye-lens
    (c) the radii of curvature of eye-lens (d) image distance from eye-lens
20. During refraction, _____ will not change.
    a. wavelength b. frequency
    c. speed of light d. all the above (AS 1)

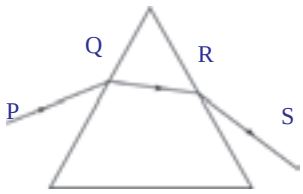


fig-Q-20:

21. A ray of light falls on one of the lateral surface an equilateral glass prism placed on horizontal surface of the table as shown in fig. Q-2. For the minimum deviation of ray which of the following is true?
    a. PQ is horizontal b. QR is horizontal
    c. RS is horizontal d. either PQ or RS is horizontal.

Chapter 5

Electricity

Electricity has become part of our everyday life. Electricity is a form of energy which helps us to operate almost everything that we use in our life such as fan, light, TV, fridge, water heater, cooler, AC, computer, laptop etc.

The conversion of chemical energy into electrical energy in a torch cell/battery was described in lower class books. Different parts of a cell and simple electric circuits were also studied. This chapter describes more about various circuit designs and gathers fundamental ideas about electric quantities and their measurement.

We know that the source of electricity is charge, it is of two kinds positive and negative. As charge is the basis of the all electric phenomena we often need to know the amount of charge on a body. It is measured in coulomb, its symbol is C.

An important thing about charged particles is that they can flow, i.e., they can move in particular direction. But they do not flow on their own. For flow of charges, there has to be a potential difference.

- What is a potential difference?



Charles-Augustin de Coulomb (14 June 1736 – 23 August 1806) was a French physicist. He was best known for developing Coulomb's law, the definition of the electrostatic force of attraction and repulsion. The SI unit of electric charge, the coulomb, was named after him.

Let us consider the analogy of flow of water. Water in a perfectly horizontal tube does not flow. If one end of the tube is connected to a tank of water kept at higher level, such that there is a pressure difference between the two ends of the tube, water flows out of the other end of tube. Charges do not flow in a copper wire by themselves. The flow of charges in a conducting metallic wire, the gravity, of course has no role to play, the charges move only if there is a difference of electric pressure called the potential difference along the conductor. This difference of potential may be produced by a battery consisting of one or more electric cells. The chemical action within the cell generates the potential difference across the terminals of the cell, even when no current is drawn from it. When the cell is connected to a conducting circuit element, the potential difference sets the charges in motion in the conductor and it produces an electric current. In order to maintain the current in a given electric circuit, the cell has to expend its chemical energy stored in it.

We define the electric potential difference between two points in an electric circuit carrying some current as the work done to move a unit charge from one point to other. We express this mathematically as

Potential difference (V) = Work Done (W)/Charge (q)

$$V = W/q$$

The SI unit of electric potential difference is Volt.

If one joule of work is done to move a charge of one coulomb from one point to the other, in a current carrying conductor then the potential difference between two points is said to be 1 volt.

Therefore,

1 volt = 1joule/ 1 coulomb

Noe 1: The potential difference measured across the terminals of an open cell is known as emf (electro motive force)

Note 2 : The potential difference is measured by a means of an instrument called the voltmeter. The voltmeter is always connected in parallel across the points between which the potential difference is to be measured.



Alessandro Giuseppe Antonio Anastasio Volta (18 February 1745 – 5 March 1827) was an Italian physicist known for the Invention of the electric cell and discovery of methane, Volt, Voltage, Voltmeter. Electric current

Electric current

We are familiar with air current and water current. We know that flowing water constitute water currents in rivers. Similarly, if electric charge flows through a conductor, we say that there is an electric current in the conductor.



André-Marie Ampère (20 January 1775 – 10 June 1836) was best known for developing Amperes circuital law, Amperes force law. He is a French physicist and mathematician who is generally regarded as one of the main founders of the science of classical electromagnetism, which he referred to as "electrodynamics". The SI unit of measurement of electric current, the ampere, is named after him.

- How do we express the electric current?

Electric current (I) is expressed by the amount of charge flowing through a particular area in unit time.

Mathematically, Electric current (I) = Charge (q) / Time (t)

The eclectic current is expressed by a unit called 'ampere' (A).

One ampere is constituted by the flow of one coulomb of charge per second.

$$1\ A = 1\ C/1\ s$$

Small quantities of currents are expressed in milli ampere ($1\ mA = 10^{-3}\ A$)

Or, in microampere ($1\ \mu A = 10^{-6}\ A$)

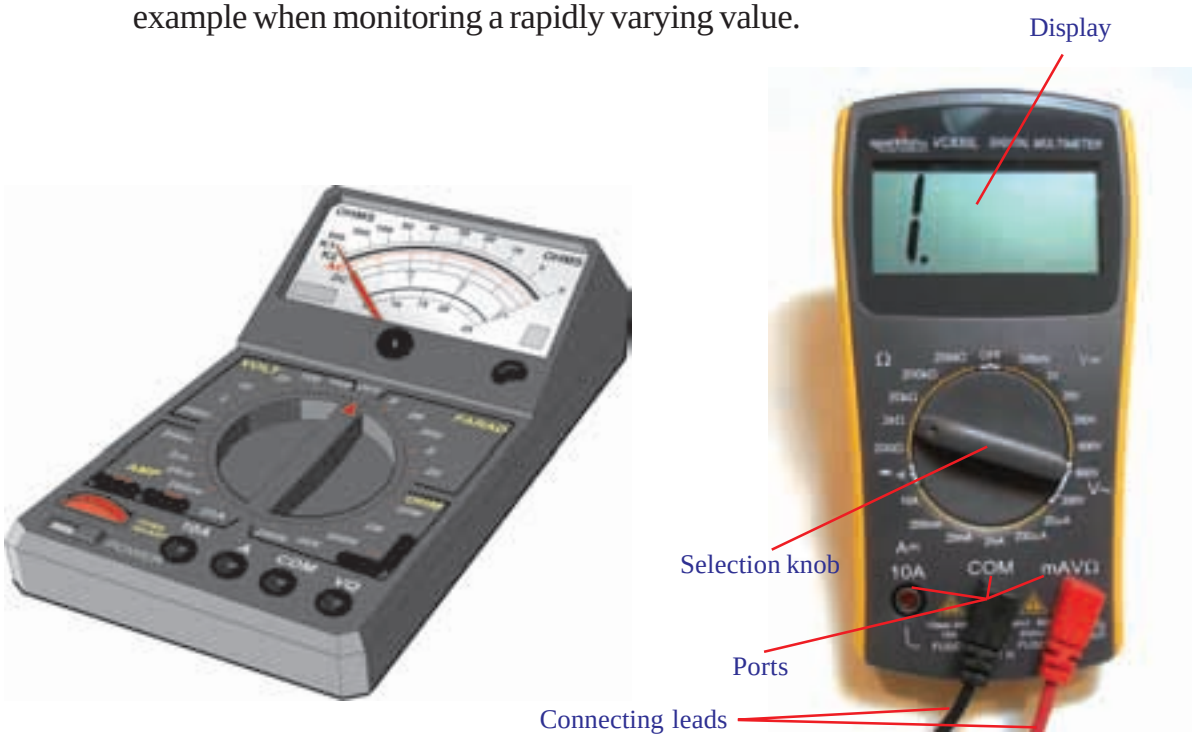
Measuring electric quantities and the multimeter

A voltmeter is commonly used to measure the potential difference between two points. An ammeter measures current. A multimeter is an electronic measuring instrument that combines several measurement functions in one unit. In this section we will learn how to measure some basic quantities of electricity such as potential difference, current and resistance.

Multimeters are two types

1. Analogue multimeter, which uses a micro-ammeter whose pointer moves over a scale calibrated for all the different measurements that can be made.

2. Digital multimeter displays the measured value in numerals. Digital multimeter is now far more commonly used than analogue one, but analogue multimeters are still preferable in some cases, for example when monitoring a rapidly varying value.



Example of analogue and digital multimeter

How to use a multimeter:

A multimeter has three parts:

1. Display
2. Selection knob
3. Ports

1. The display usually has four digits and the ability to display a negative sign.

2. The selection knob allows the user to set the multimeter to read different things such as milliamps (mA) of current, voltage (V) and resistance (Ω).

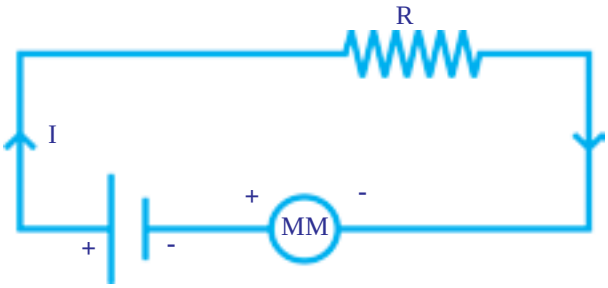
3. Multimeter generally have two ports. One is usually labelled as 'COM' (common or ground port). This is where black test lead is connected. The other is labelled as mAVΩ port where the red lead is conventionally plugged in.

WARNING: Most multimeters can measure AC system also, but AC circuits can be dangerous. So measure DC circuits only.

Measurement of current

Activity 1

Connect the battery and two resistors through a wire as shown in the Figure.



MM = Multimeter

fig- : Circuit diagram of a battery connected to a multimeter (as ammeter) and a resistor in series

To measure the current flowing through the circuit, break the circuit and connect the multimeter (set as an ammeter) in series. This ensures that all the current flowing in the circuit (I) must pass through the multimeter. The current consumption for many projects is under 200 mA. Make sure that the red probe is plugged into the 200 mA setting. 10A is the special probe used when measuring large current.

Measurement of potential difference

Activity 2

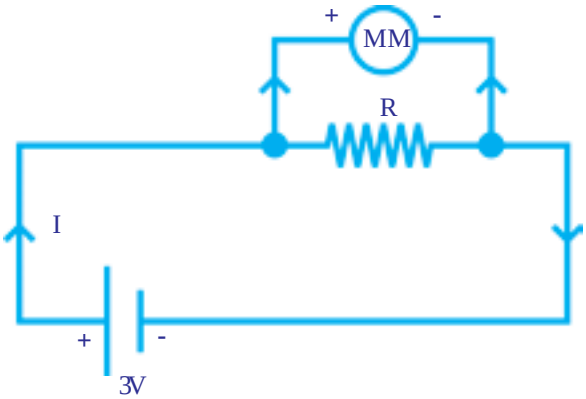


fig- : Circuit diagram of a battery connected to a resistor in series, and a voltmeter (V) in parallel to the resistor

Connect the battery (3V) and a resistor with a connecting wire as shown in Figure.

To measure the DC potential difference the circuit is not changed. Set the multimeter knob where V has a straight line (V-) is set as a voltmeter and the probes are connected in parallel across any resistor as shown.

Multimeters are generally not auto ranging. We have to set the multimeter to a range that it can measure. For example, 2V measures up to 2volt. 20V measures up to 20volt.so if you have measuring 12V battery use the 20V setting.

Measurement of resistance

Activity 3

Connect the battery and a resistor with a connecting wire as shown in the Figure.

The multimeter, set as an ohmmeter, does not function when a circuit connected to a source is ON. In order to measure the resistance of the resistors using an ohmmeter, there should not be any current in the circuit. Switch OFF the circuit and connect the probes in parallel across the resistors, one by one, and measure their resistances.

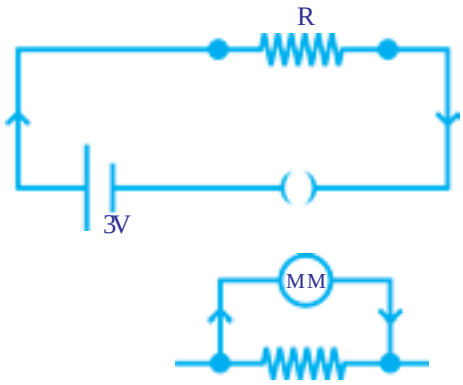


fig- : Multimeter as Ohm meter connected across the resistor

Pick out a random resistor and set the multimeter to the 20KΩ. Then hold the probe against the resistor legs the meter will read one of the following three things 0.00, 1, or the actual resistor value.

- If the meter reads 9.90, and then you have got the value as 9.9KΩ.
- If the multimeter reads 1, or displays OL, it's overloaded. You will need to try a higher mode such as 200KΩ or 2MΩ.
- If the multimeter reads 0.00 or nearly 0, then you need to lower the mode to 2KΩ or 200Ω.

Ohm's law

When a torch is used for several weeks, its light becomes dim. We say that cells have discharged. What does it mean? Let us find out.

Lab Activity

Set up a circuit as shown in figure. It consist of nichrome(Nichrome is an alloy of nickel, chromium, manganese and iron metals) wire AB of length say 0.5 metres, an ammeter, a voltmeter and four cells of 1.5V each.

- First use only one cell as the source in the circuit. Note the reading in the ammeter (I), for the current and reading of the voltmeter (V) for potential difference across the nichrome wire AB in the circuit. Tabulate them in the table given.

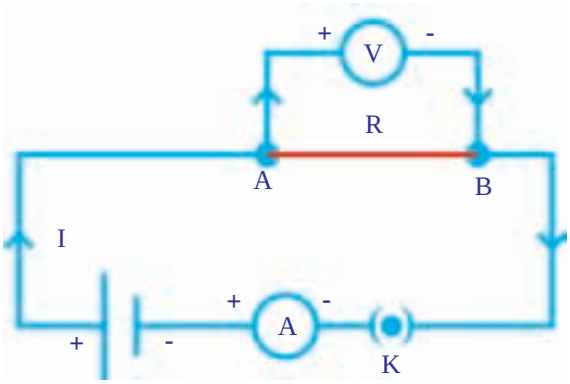


fig- : Circuit diagram of a battery connected to an ammeter (A), plug key (K) and nichrome wire (AB) in series, and a voltmeter (V) parallel to wire AB.

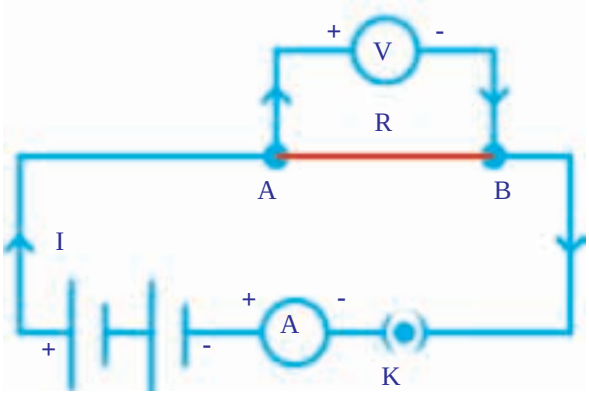


fig- : Circuit diagram of two battery cells connected to an ammeter (A), plug key (K) and nichrome wire (AB) in series, and a voltmeter (V) parallel to wire AB.

- Connect two cells in the circuit (as shown in the figure 12.7) and note the respective readings of the ammeter and voltmeter for the values of current and potential difference across the nichrome wire
- Repeat the above steps using three cells and then four cells in the circuit separately.
- Calculate the ratio of V to I for each pair of potential difference (V) and current (I).
- Plot the graph between V and I by taking I on X-axis and V on Y-axis. Observe the nature of the graph.

From the above activity you will find that the current (I) is proportional to the potential difference (V). The slope of the line gives the value of the resistance R. This relationship, between potential difference and current, was first established by the German Physicist, George Simon Ohm and is known as **Ohm's law.**

The current through a conductor element is proportional to the potential difference applied between its ends, provided the temperature remains constant.

If the voltage V is applied to an element and a current 'I' is passes through it,

$$V \propto I$$

$$V/I = \text{constant}$$

$$= R$$

Table 1

S.No	No of cells used in the circuit	Current throught the nichrome wire I (ampere)	Potential difference across the nichrome wire V (volt)	V/I
1.	1			
2.	2			
3.	3			
4.	4			

(Or) V = RI

Here R is a constant for the given metallic wire at a given temperature and is called its *resistance*.

Units of resistance:

R= V (volt) /I (ampere) = V/I (ohm)

The unit of resistance is called the *ohm* and its symbol is &Ω.



George Simon Ohm (16 March, 1787 - 6 July 1854), The German Physicist and mathematician. As a high school teacher, began his research.

Limitations of Ohm's Law

Ohm's law is valid for metallic conductors provided the temperature and other physical conditions remain constant. The resistance of the material changes with temperature. Hence for changing temperature the V-I graph for a conductor will be non-linear. Ohm's law is not applicable to gaseous conductors. It is also not applicable to semiconductors such as germanium, silicon.

Ohm's Law and Electric shock

Is it current or voltage, which is responsible for the electric shock in the human body- The damaging effects of shock are the result of current passing through the body. From Ohm's law, we can see that this current depends both on the voltage that is applied and on the electrical resistance of the human body. The resistance of one's body, which depends on its condition, ranges from about 100 ohm if it is soaked with salt water to about 100,000 ohm if the skin is very dry. We usually cannot feel the current produced by 12 volt, and 24 volt would just barely tingle. If our skin is moist, 24 volt could be quite uncomfortable. Table describes the effects of different amounts of current on the human body.

Table 2
Effect of Electric Currents on the Body

Current in ampere	Effect
0.001	Can be felt
0.005	Is painful
0.010	Causes involuntary muscle contractions (spasms)
0.015	Causes loss of muscle control
0.070	If through the heart, causes serious disruption ; probably fatal if current lasts for more than 1 s



Think and discuss

- The bird can stand harmlessly on one wire of high potential, but it had better not reach over and grab a neighbouring wire! Why not?

We have seen that for a given wire, the current is proportional to voltage applied across it.

- What if we take wires of different material of same dimensions?

Let us find

Activity 4

Take wires of different materials copper, aluminium, iron but of same cross-sectional area and with the same length. Connect to a circuit as shown in Figure in which AB represents a wire.

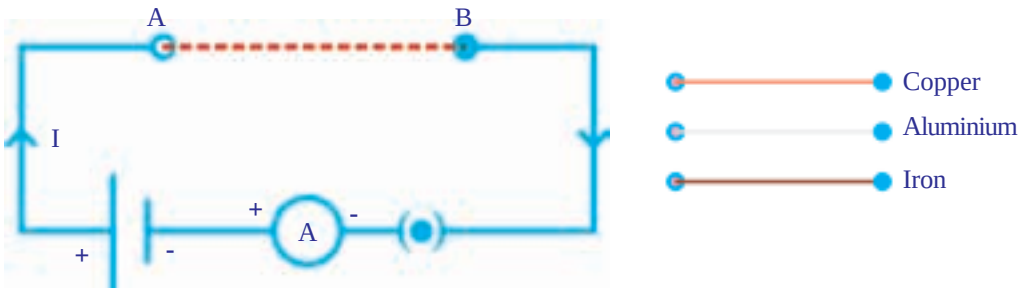


fig- :Diagram showing a circuit where a battery is connected to an ammeter (A), a plug key (K) and wire AB. AB is represents wires of different materials copper, aluminium, iron with same cross-sectional area and same length

Connect each wire one by one between A and B. After connecting a particular wire, insert the key into the plug and note the reading of the ammeter.

- What do you find?

You will find that the value of the current is different for different wires. Since the same cell is used every time, the potential difference (V) across the wires is same. (You can of course verify this by connecting a voltmeter across AB). This means that the different wires used in this experiment draw different currents, when the same potential difference is applied across them.

Hence the resistance of a wire of given length and cross-sectional area depends on the material of the wire, called its *resistivity* or *specific resistance* (ρ). $R \propto \rho$

Activity 5

Repeat the above experiment with wires of the same material and the same length but of different cross-sectional areas.

- What do you observe? List out your observations.

You will find that the thicker the wire, the greater the current. So, the thicker wires have less resistance than the thinner wires.

Resistance is inversely proportional to the area of cross-section (A)

$$R \propto 1/A$$

Activity 6

Take wires of the same material, say copper, and the same thickness but of different lengths. If the length of the wire is, let's say 'L', the other wires should be of length 2L, 3L and so on. Find the resistance V/I of the first wire and then compare it with that of the others.

- What do you find?

You will notice that when the length is doubled, the current is halved. In other words, the resistance is doubled. When the length becomes three times, the resistance also increases three times. Thus, *resistance is proportional to length*

$$R \propto L$$

Apart from these factors, resistance also depends slightly on temperature. In general, resistance increases with increase in temperature. Thus

$$R = \rho L/A$$

Here ñ is a constant for a given material at a given temperature. It is called the *resistivity* of the material (ρ).

The resistivity of the material is the resistance per unit length of a unit cross-section of the material. The SI unit is ohm-metre (Ω-m). The resistivities of some materials are listed in Table 12.1.

Table 3
Resistivity of various materials

Material	$\rho_{(\Omega\text{-m})}$ at 20 °C
Silver	1.59×10^{-8}
Copper	1.68×10^{-8}
Gold	2.44×10^{-8}
Aluminium	2.82×10^{-8}
Calcium	3.36×10^{-8}
Tungsten	5.60×10^{-8}
Zinc	5.90×10^{-8}
Nickel	6.99×10^{-8}
Iron	1.00×10^{-7}
Lead	2.20×10^{-7}
Nichrome	1.10×10^{-6}
Carbon (Graphite)	2.50×10^{-6}
Germanium	4.60×10^{-1}
Drinking water	2.00×10^{-1}
Silicon	6.40×10^{2}
Wet wood	1.00×10^{3}
Glass	10.0×10^{10}
Rubber	1.00×10^{13}
Air	1.30×10^{16}

The values of resistivity of material determine their conductivity. Metals with low resistivity behave as good conductors. Metals such as copper are therefore used for making electric wires. The filament of an electric bulb is usually made of tungsten, because of its higher resistivity values and the melting point (3422 ^{o}C).

The values of resistivity of insulators are very high of the order of 10^{14} to 10^{16} Ω-m. Alloys like Nichrome (Nickel, chromium and iron)and Manganese (86% copper, 12% manganese, 2% nickel) have 30-100 times larger values of resistivity than those of metals. This makes them suitable for use in the heating elements of electric irons, toasters, etc. These alloys also have the advantage that their resistance varies very little with temperature and they do not oxidise easily. The resistivity of materials such as silicon and germanium are 10^{5} to 10^{10} times more than that of metals, but 10^{15} to 10^{16} times less than that of insulators. Such materials are called semiconductors. Semiconductors are used to make diodes, transistors and integrated Circuits (ICs). ICs are used in all sorts of electronic devices, including computer, TV, mobile phones etc.

Colour code for resistors

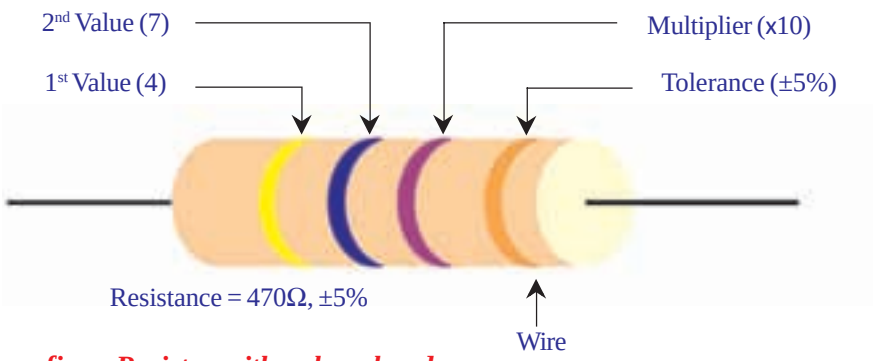


fig- : Resistor with colour bands

Resistors of different values are commercially available. To make a resistor; carbon with a suitable binding agent is moulded into a cylinder. Wire leads are attached to this cylinder and the entire resistor is encased in a ceramic or plastic jacket. The two leads are used to connect the resistor to a circuit.

To determine the value of given resistor, look for the gold or silver tolerance band and rotate the resistor keeping tolerance band to the right as shown in figure.

1. Look at the first colour band and determine its colour. Now look at the chart given below and match the colour to the digit it represents. Write

the number. In the above figure the first band colour is yellow. So the digit it represents is 4.

2. Look at the next colour in the resistor and identify its number from the chart. The resistor shown in the figure, the colour of second band is violet. So the digit for violet colour is 7. Write this number along with the first, (i.e.) 47.
3. The last colour band is the number to be multiplied to the result above. In our example the colour of third band is brown; its corresponding multiplier is 10.
4. Hence the total value of the above resistor is 47x10Ω=470Ω

The values indicated by the different colours are given the table below.

Table 4
Resistance Colour Codes

Colour	Digit	Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
White	9	10^9	
Gold	-	10^{-1}	± 5%
Silver	-	10^{-2}	± 10%

Resistors are never the exact value that the colour codes indicate. Therefore, manufacturers place a tolerance colour band as the fourth band on the resistor. This tells you how accurate are the resistor made.

As the chart indicates, gold means the tolerance value of the resistor is within 5%. Silver being within 10% and no colour band being within 20%.

For example, suppose the colours on the resistance are brown, yellow, green and gold as read from left to right. Using the above table the resistance is $14 \times 10^{-5} \pm 5\% = (1.4 \pm 0.07)$ MΩ.

Combination of resistors

A conducting material (e.g., wire) used in a circuit is called a resistor. A resistor is sometimes simply referred to as *resistance*. Two or more resistors can be connected in series, in parallel or in a manner that is a combination of those two.

Series connection of resistors

Two or more resistors are said to be connected in series if the current flowing through one also flows through the others.

Activity 6

We can use three torch bulbs as resistors in this activity. Connect the three bulbs to a battery of 2 torch cells, a plug key and an ammeter as shown in the Figure.

Close the key and note the ammeter reading. Now connect the ammeter between R_1 and R_2 and note the reading. Similarly place the ammeter between other circuit elements and measure the current.

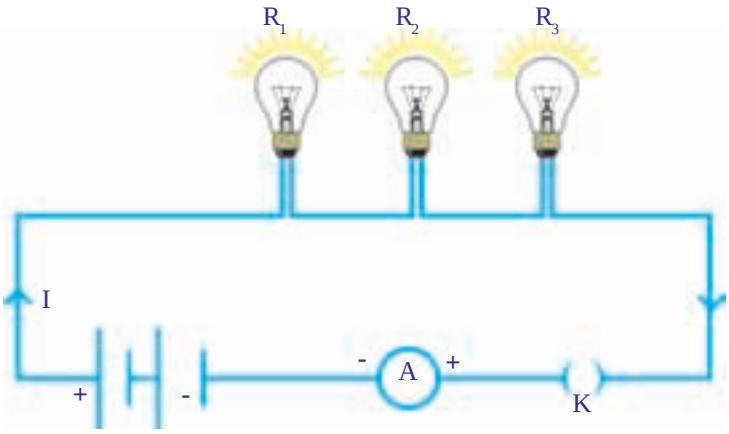


fig- : Diagram of a circuit where a battery is connected to an ammeter (A) and three bulbs in a series

- What do you find?

You will find that the value of the current is the same everywhere in the circuit. So, in a series connection, the same current passes through the resistors.

Activit 7

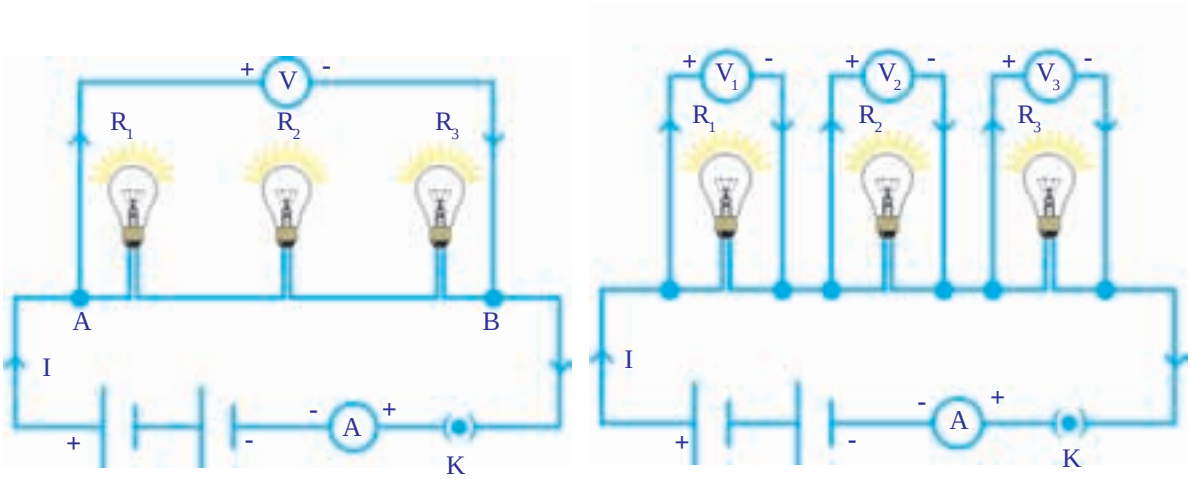
Now connect a voltmeter in the circuit across AB, close the key and note the voltage (V) across the series combination of resistors. Note the reading,

Similarly connect the voltmeter across the resistors, one at a time, and measure the voltage across them V_1, V_2, V_3

- What do you find?

You will find that $V = V_1 + V_2 + V_3$

The potential difference across a combination of resistors, connected in series, is equal to the sum of the voltages across the individual resistors.



(1) **(2)**

fig- : (1) Voltage was measured together (2) Voltages were measured separately

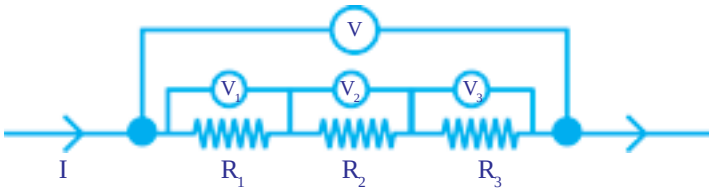
Equivalent resistance of a series connection

The cell connected across the series combination of 3 resistors maintains a potential difference (V) across the combination. The current through the combination is 'I'. Then same current flows through each resistor.

Let us replace the combination of 3 resistors by a single resistor R_{eq} such that the current does not change. This resistance is called the equivalent resistance of the combination, and its value is given by Ohm's law as

$$R_{eq} = V/I$$

Thus $V = I\ R_{eq}$



The potential differences V_1, V_2, and V_3 across the resistors R_1, R_2 and R_3 respectively are given by Ohm's law as

$$V_1 = I\ R_1,\ V_2 = I\ R_2 \text{ and } V_3 = I\ R_3$$

Since the resistors are connected in series,

$$V = V_1 + V_2 + V_3$$

Substituting the values of voltages in the above equation

$$I\ R_{eq} = I\ R_1 + I\ R_2 + I\ R_3$$

$$I\ R_{eq} = I\ (R_1 + R_2 + R_3)$$

$$R_{eq} = R_1 + R_2 + R_3$$

Similarly, for n resistors connected in series

$$R_{eq} = R_1 + R_2 + R_3 + \ldots\ldots\ldots\ldots + R_n$$

NOTE: If one resistance in a set of resistors, connected in series, breaks down, the circuit becomes open and the flow of current ceases. Normally household electrical appliances are not connected in series to avoid this problem.

Parallel connection of resistors

If resistors are connected in such a way that the same potential difference gets applied across each of them, they are said to be connected in parallel.

Activity 8

Connect three torch bulbs (R_1, R_2 and R_3), an ammeter, a cell and a plug key as shown in the figure. Close the key and note the ammeter reading. This is the current 'I' in the circuit.

Now connect the ammeter in the branch of the circuit that has R_1 and note the reading. This gives the current I_1 through the branch. Similarly, place the ammeter in the branches containing R_2 and R_3 and measure the currents I_2 and I_3 respectively

- What do you find?

You will find that the current i gets divided into the branches such that

$$I = I_1 + I_2 + I_3$$

The total current flowing into the combination is equal to the sum of the currents passing through the individual resistors.

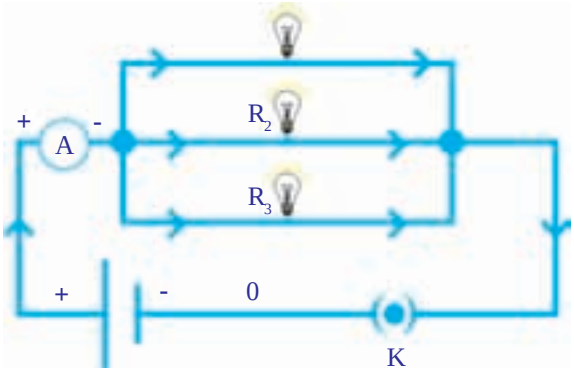


fig-: Diagram of a circuit where a battery and a plug key (K), and an ammeter (A) are connected to three resistors (R_1, R_2 and R_3) in parallel

Activity 8

In the above circuit measure the potential difference across the cell, let it be V. Now measure the potential difference across R_1, R_2, R_3 are V_1, V_2, V_3 What do you find?

You will find that potential difference remains constant in parallel combination of resistors.

$V = V_1 = V_2 = V_3$

Equivalent resistance of a parallel connection

The cell connected across 3 resistors maintains the same potential difference across each resistor. The current 'I' gets divided at A into three parts i_1, i_2 and i_3 which flow through R_1, R_2 and R_3 respectively.

Let us replace the combination of resistors by an equivalent resistance R_{eq} such that the p.d in the circuit does not change. The equivalent resistance is given by Ohm's law as,

$$R_{eq} = V/I$$

Thus, $$I = V/R_{eq}$$

The currents I_1, I_2 and I_3 through the resistors R_1, R_2 and R_3 respectively are given by Ohm's law as,

$$I_1 = V/R_1,\ I_2 = V/R_2 \text{ and } I_3 = V/R_3$$

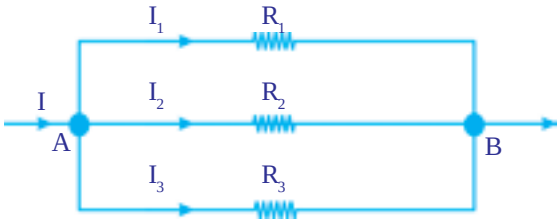


fig- : Diagram showing division of current (I_1, I_2 and I_3) through three resistors (R_1, R_2 and R_3)

Since the resistors are in parallel,

$$I = I_1 + I_2 + I_3$$

Substituting the value of currents in the above equation,

$$V/R_{eq} = V/R_1 + V/R_2 + V/R_3$$

Thus, $$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$$

Similarly, if there are n resistors connected in parallel their equivalent resistance Req is given by

$$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots\ldots\ldots + 1/R_n$$

For two resistances R_1 and R_2 connected in parallel

$$1/R_{eq} = 1/R_1 + 1/R_2 = (R_1+R_2)/R_1R_2$$

$$R_{eq} = R_1R_2/(R_1+R_2)$$

"The equivalent resistance of a parallel combination is less than the resistance of each of the resistors". Check the statement with an example.

You can use this result to explain why the resistance of a metallic wire is inversely proportional to its area of cross-section. You can think of a thick wire as a parallel combination of several thin wires. The resistance of the combination is less than that of each of the thin wires. In other words, the resistance of a thick wire is less than that of a thin wire.

Note: If a resistor connected in series with others is removed or fails, the current through each resistor becomes zero. On the contrary, if a resistor connected in parallel with others fails or is removed, the current continues to flow through the other resistors.

Distribution of current in two resistors in parallel

Consider the circuit as shown in figure. Two resistors are connected in parallel. The current I gets distributed between the two resistors.

- What is the relative magnitude of these currents?

Let, $$I = I_1 + I_2$$

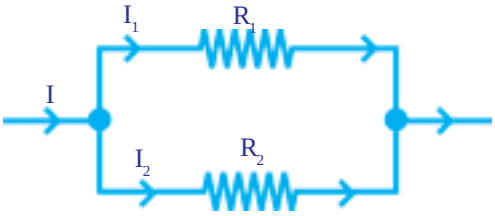


*fig-: **Diagram showing division of current I into I_1 and I_2***

Applying Ohm's law to resistor R_1 we get,

$$I_1 = V/R_1$$

i.e., $V = I_1R_1$

Similarly, $I_2 = V/R_2 = I_1R_1/R_2$

Substituting for I_2 in the first equation, we get

$$I = I_1 + I_1R_1/R_2 = I_1(1 + R_1/R_2) = I_1\{(R_1 + R_2)/R_2\}$$

or, $I_1 = IR_2/(R_1 + R_2)$

Similarly, $I_2 = IR_1/(R_1 + R_2)$

Thus, $I_1/I_2 = R_2/R_1$

Therefore, $I \alpha 1/R$

The current through each branch in a parallel combination of resistors is inversely proportional to the resistance of the branch

Kirchhoff's laws

Ohm's law is unable to give currents in complicated circuits. Kirchhoff, in 1842, gave two general laws which are extremely useful in analysing electric circuits. These are

1. The Junction law 2. The Loop law

The Junction Law

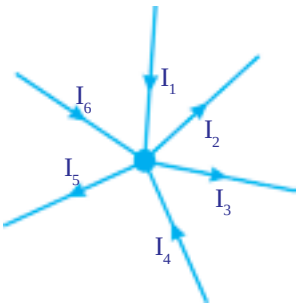


fig-: Diagram showing six electric currents passing at a junction

The algebraic sum of currents at any junction in a circuit is zero.

i.e., $\Sigma I = 0$

This means that there is no accumulation of electric charges at any point in a circuit. The currents which flow towards a point is taken as positive (I_1, I_4 and I_6) while those that flow away from the point is taken as negative (I_2, I_3 and I_5).

Therefore, $I_1 - I_2 - I_3 + I_4 - I_5 + I_6 = 0$

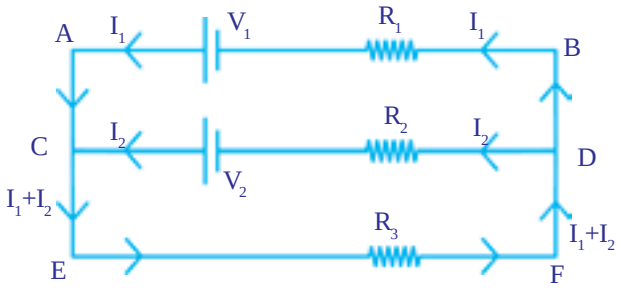
The Loop Law

In any closed circuit, the algebraic sum of the products of the current and resistances of each part of the circuit is equal to the total potential difference in the circuit.

i.e., $\Sigma I \times R = \Sigma V$

The product of the current and the resistance is taken as positive when it traverses in the direction of current. The voltage is taken as positive when it traverses from negative to positive electrode through the battery.

Let us apply Kirchhoff's second law to the above figure,



For the loop ACDBA,

$I_1 R_1 - I_2 R_2 = V_1 - V_2$

For the loop EFDCE,

$I_2 R_2 + (I_1 + I_2) R_3 = V_2$

For the loop EFBAE,

$I_1 R_1 + (I_1 + I_2) R_3 = V_1$

Electric power and energy

- A light bulb is marked 60 watt and 120 volt, what does it mean?

The practical electrical units the volt, ampere, coulomb and Ohm have been defined in such a way that it makes the calculation of work and power very simple.

In all resistances, through which a current flows, electrical energy is converted into heat energy. The filament of an ordinary light bulb is designed to be heated by the conversion of electrical energy into heat; the wires leading to the bulb are also slightly warmed by the passage of current.

By the definition of the volt, we know that two points differ by one volt if work done in moving one coulomb of charge from one point to the other is one joule. Also, we know that one ampere of current is a flow of one coulomb of charge for second, therefore we can write,

Power (Watt) = Current (Ampere) × Potential difference (Volt)

i.e., $P = V \times I$

Or, $P = V^2/R$

Or, $P = I^2 \times R$

It is important to remember that the wattage marked on the electrical appliance is not on inherent property of the device, but depends on the voltage supply to which it is connected.

For example, if a 60 watt light bulb is also marked 120 Volt, the meaning is that, if the bulb is connected to a source of 120 Volts of potential, it will convert electrical energy into heat and light at the rate of 60 Joules per second.

Let us find out what its power would be if it were connected to a 12 Volt battery. From the manufacturers' specification, we know that the bulb will have power of 60 Watt if it is connected to 120 Volt.

From the relation $P = V \times I$, $I = P/V = 60/120 = 0.5$ Amp

From Ohm's law, $R = V/I = 120/0.5 = 240$ ohm

Assuming the resistance remains same; we can see that the current that will flow when the bulb is connected to the 12 Volt batteries will be,

$$I = V/R = 12/240 = 0.05 \text{ Amp}$$

We can now calculate the power to be,

$$P = I \times V = 0.05 \times 12 = 0.6 \text{ Watt}$$

The value of power and voltage is taken together which is called the *rating* of an electrical appliance. We can easily calculate the resistance from the *rating* of an appliance by using the equation below,

$$R = V^2/P$$

Note: Higher the value of power rating smaller the value of resistance. So a 1000 W heater has less resistance than a 100 W bulb.

Since watt is a small unit of power, a bigger unit called kilowatt is used.

Thus, 1KW = 1000W = 1000A - V

Values of the power rating of various common electric appliances are tabulated in table 5. Find the current drawn in 1 hour in ampere by each appleance.

Table 5
List of common appliances and the values of their current drawn

Applications	Power Rating (Watt)	Current Drawn at 220V in one hour (Amp)
Fluorescent Lamp	40	0.2
Electric Fan	80	0.4
Washing mishion	800-1000	4-4.5
Water pump (1/2 HP)	500-1000	
Television (TV)	80-400	
Computer	80-150	
Refrigerator	200-300	

Electrical energy

Electric power measures the rate of consumption of energy. The total energy consumed during a contain interval of time is given by the product of the rate of consumption of energy (i.e., power) and time.

Thus, $E = P \times t = V \times I \times t$

It is clear from the above relation that the unit of electrical energy can be written as Watt-second, which is equivalent to joule. However, this is too small a unit for practical work. For commercial purposes, a bigger unit

known as kilowatt hour is found more convenient than watt second. A Kilowatt-hour (Kwh) is the amount of energy consumed by a 1kw electrical appliance in one hour and is known as Board of Trade Unit (or simply a *unit*). It is this unit which is used for expressing the domestic and commercial consumption of electrical energy.



Key words

Charge, Potential difference, Electric current, Multi-meter, Ohm's law, Resistance, Resistivity, Kirchhoff's laws, Electric power, Electric energy.



What we have learnt

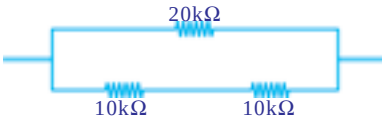
- The source of all electricity is charge. It's SI unit is coulomb (C).
- Electric potential difference between points in an electric circuit is the work done to move a unit charge from one point to other.
- SI unit of electric potential difference is volt (V).
- Electric current is expressed as the amount of charge flowing through a particular area in unit time.
- The SI unit of electric current is ampere (A).
- A multi-meter is an electronic measuring instrument the combines several measuring functions (electric potential difference, electric current and electric resistance) in one unit.
- To measure the current multi-meter is to connect in series to circuit.
- To measure potential difference across the element in the circuit, multi-meter is connected in parallel across that element.
- While measuring resistance in a circuit, switch off the source and measure.
- Ohms law: The current through a conductor element is proportional to the potential difference applied between it ends, provided the temperature remains constant. Mathematically V=IR.
- Ohm's law is valid for metallic conductors at constant temperature. It is not applicable for gaseous conductors and semiconductors.
- Resistance is the opposition that a substance offers to the flow of electric current.
- SI unit electric resistance is Ohm (Ω).
- Resistance of a wire depends on the material of the wire, its length and its area of cross section $R \alpha L/A$.

- The resistivity of the material is the resistance per unit length of a unit cross section of the material.
- SI unit of resistivity is Ωm.
- Colour code of resistors helps us to determine the value of given resistors.
- Two or more resistors are said to be connected in series if same current flows through them.
- Two or more resistors are said to be connected in parallel if same potential difference exist across them.
- Kirchhoff's first rule (The junction law): The algebraic sum of currents at junction in a circuit is zero. $\Sigma I=0$.
- Kirchhoff's second rule (The loop law): In any closer circuit, the algebraic sum of the products of current and resistances of each part of a circuit is equals to the total potential difference in the circuit. $\Sigma IR= \Sigma V$.
- The electric power is the product of potential difference and the current. SI unit of power is watt (W).
- The electrical energy is the product of power and time. Units of electrical energy W-s and KWH.



Improve your learning

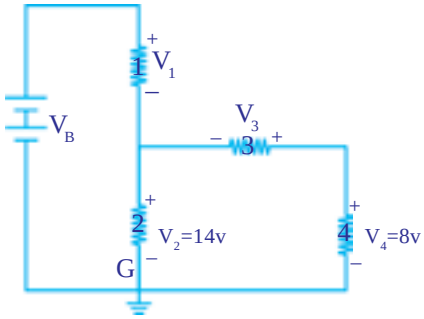
1. Deduce the expression for the equivalent resistance of the three resistors connected in series.(AS1)
2. Deduce the expression for the equivalent resistance of the three resistors connected in parallels. (AS1)
3. Silver is better conductor of electricity than copper. Why do we use copper wire for conduction electricity? (AS1)
4. Two bulbs have ratings 100 W, 220V and 60 W, 220 V. Which one has the greatest resistance? (AS1)
5. For 10 KÙ resistor with 5% tolerance mention the colours on the resistor? (AS1)
6. Name the instrument used to measure both electric current and potential difference?(AS1)
7. Consider the units volt, watt and ampere. One of them is the product of the other two. What is that? Write the relation. (AS1)
8. Why don't we use series arrangement of electrical appliances like bubl, Television, fan and other in domestic circuits? (AS1)
9. A wire of length 1m and radius 0.1 mm has a resistance of 100 ©. Find resistivity of the material. (AS1)
10. What is the equivalent resistance of the following combination of resistors? (AS1)



11. Why do we consider tungsten as a suitable material for making the filament of a bulb? (AS2)
12. Are the head lights of a car connected in series or parallel? Why? (AS2)
13. Why should we connect the electric appliances in parallel to household circuit? What happens if they are connected in series?
14. How should we connect the fuse in house wiring circuit? In series or in parallel? Why? (AS2)
15. Suppose that you have three resistors each of value 30 ©. How many resistors can you obtain by various combinations of these three resistors? Draw diagrams in support of yur predictions. (AS2)
16. State Ohm's law. Suggest an experiment to verify it and explain the procedure. (AS3)
17. a. Take a battery and measure the potential difference. Make a circuit and measure the potential difference when the battery is connected in the circuit. Is there any difference in potential difference of battery? (AS4)
    b. Measure the resistance of a bulb (filament) in open circuit with multi-meter. Make a circuit with elements such as bulb, battery of 12V and key in series. Close the key. Then again measure the resistance of the same bulb (filament) for every 30 seconds. Record the observations in a proper table. What can you conclude from the above results? (AS4)
18. Draw a graph between V and I where V is the potential difference between the ends of the wire and I is the current through it? What is the shape of he graph? (AS5)
19. Draw a circuit diagram for a circuit in which two resistors A and B are connected in series with a battery, and a voltmeter is connected to measure the potential difference across the resistor A. (AS5)
20. How can you appreciate the role of a small fuse in house wiring circuit ain preventing damage to various electrical appliances connected to the circuit?
21. In the figure below the potential at A is ———————— when the potential at B is zero. (AS7)



22. Observe the circuit and answer the questions given below. (AS7)



Q1. Are elements #3 and #4 in series?

Q2. Are elements #1 and #2 in series?

Q3. Is the battery in series with any element?

23. If the resistance of your body is 100000Ω what would be the current that flow in your body when you touch the terminals of a 12V battery? (AS7)
24. A uniform wire of resistance 100Ω is melted and recast into wire of length double that of the original. What would be resistance of the new wire formed?(AS7)

25. A house has 3 tube lights, two fans and a Television. Each tube light draws 40W. The fan draws 80W and the Television draws 60W. On the average, if all the tube lights are kept on for five hours, two fans for 12 hours and the television for five hours every day. Find the cost of electric energy used in 30 days at the rate of Rs. 3.oo per Kwh. (AS7)

26. A charge is moved from a point A to a point B. The work done to move unit charge during this process is called. [ ]

    a) potential at A b) potential at B

    c) potential difference between A and B d) current from A to B

27. Joule/ coulomb is the same as [ ]

    a) 1 - watt b) 1 - volt c) 1- ampere d) 1 - ohm

28. The current in the wire depends [ ]

    a) only on the potential difference applied b) only on the resistance of the wire

    c) on both of them d) none of them

29. Consider the following statements. [ ]

    A. In series connection, the same current flows through each element.

    B. In parallel connection, the same potential difference gets applied across each element.

    a) both A and B are correct b) A is correct but B is wrong

    c) A is wrong but B is correct d) both A and B are wrong

30. The kilowatt hour is the unit of.....

31. A thick wire has a ..... resistance than a thin wire.

32. An unknown circuit draws a current of 2A from a 12V battery its equivalent resistance is.....

33. A uniform wire of resistances 50 © is cut into five equal parts. These parts are now connected in parallel. Then the equivalent resistance of the combination is

    (a) 2 Ω (b) 12 Ω (c) 250 Ω (d) 6250 Ω

Chapter 6

Electromagnetism

In previous chapter on 'Electricity' you have learnt about the heating effects of electric current. We use many electric appliances in our daily life such as electric motor, electric generators, electric calling bells, electric cranes etc.,

- How do they work?
- How do electro magnets work?
- Is there any relation between electricity and magnetism?
- Can we produce magnetism by electricity?

In this chapter we will study electromagnetic effects. We also study electric motors which involve magnetic effects of electric current and electric generator which involves electric effects of moving magnets.



Hans Christian Oersted (1777 - 1851), one of the leading scientists of the 19th century, played a crucial role in understanding *electromagnetism*. He gave lectures which were quite popular among the public and also learnt a lot during the tours. During one such lecture in April 1820, Oersted carried out an experiment that was never performed before. He placed a compass underneath a wire and then turned on electric current. The needle of the magnetized compass showed movement.

Oersted recognized the significance of what he had just done. Earlier, it was

believed that electricity and magnetism were two different forces. Oersted had demonstrated that they were interconnected. Through this observation he showed that electricity and magnetism were related phenomena. Some scientists, influenced by this experiment, continued with the modern field of "electromagnetism". Their research resulted in several new scientific theories and various vital inventions like the dynamo and the electric motor, created technologies such as the radio, television, and fiber optics.

The unit of magnetic field strength is named the Oersted in his honour.

Oersted was made a foreign member of the Royal Swedish Academy of Sciences in 1822.

Activity 1

Oersted experiment

Take a thermacol sheet and fix two thin wooden sticks of height 1cm which have small slit at the top of their ends. Arrange the copper wire which passes through these slits and make a circuit in which the elements, a 3 volt battery, key and 24 gauge copper wire are connected in series as shown in figure 1. Now, keep a magnetic compass below the wire. Bring a bar magnet close to the compass.

- Does the needle get deflected by the bar magnet?
- Why does the needle get deflected by the magnet?

Take the bar magnet far away from the circuit and switch on the circuit observe for changes in position of the needle.

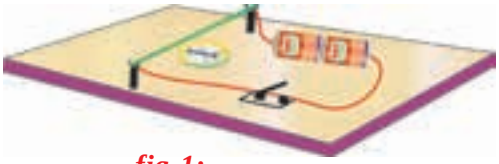


fig-1:

- What do you notice?
- Is there any change in the position of the compass needle?
- Which force is responsible for the deflection of compass needle?
- Does the current-carrying wire apply a force on the needle?
- What do we call this force? (Recall the idea of field forces in the class 8 chapter "Force").

In order to know reasons for deflection of compass needle with no bar magnet near to it we need to understand the idea of 'magnetic field' and influence of electric field on magnetic field.

Let us learn about it

Magnetic Field

We use the term field when a force is applied on the object by another object when there is no physical contact between them. You have observed this already in activity 1. Let us call this field which is responsible for deflection in compass needle as 'magnetic field'.

- How this field was produced?
- Could we observe this field of bar magnet?

Let us try.

Activity 2

Take a white sheet and place it on the horizontal table. Place a bar magnet in the middle of the sheet. Place a magnetic compass near to the magnet. It settles to a certain direction. Use pencil and put dots on the sheet on either side of the needle. Remove the compass. Draw a small line segment connecting the dots. Draw an arrow on it from South Pole of the needle to North Pole of the needle. Repeat the same by placing the compass at various positions on the paper. The magnetic compass settles to different directions at different positions.

- Why does this happen?

Remove the bar magnet and place magnetic compass on the paper. It comes to rest along north-south direction. Now place bar magnet in its previous place.

- Is there any change in the direction of needle of magnetic compass? Why?

The needle of magnetic compass is affected by the bar magnet without any physical contact. A force causes the needle to deflect and come to rest in a certain direction.

- What is the force that acts on the needle?

The force which is acting on the needle from a distance is due to the magnetic field of the bar magnet.

In activity 2, you have already seen that direction of needle is different at different places on paper. This gives us an idea that the magnetic field has direction and it varies from one point to other.

When you change place of the compass near bar magnet you can observe that its direction changes from point to point. Now take it too far places and observe the orientation of needle of compass.

- What do you observe?

Almost the needle of compass shows single direction pointing north at far places from bar magnet.

- What does it mean?

From this analysis, we conclude that the strength of field varies with distance from the bar magnet. Now hold compass little above the table and at the top of the bar magnet. You can observe that field exists in all directions around the bar magnet from the deflections of the magnetic compass. Hence we can say that the magnetic field is three dimensional i.e., magnetic field surrounds its source such as bar magnet. From the above discussion we can generalize that:

"The magnetic field that surrounded the source by which it has been produced at any point is characterised by the strength of the field and direction of field."

- How can you find the strength of the field and direction of the field?

You know that the direction of field can be determined by using the compass. Let us find out how to determine the strength of the field.

Activity 3

Place a white sheet on horizontal table. Place compass in the middle of it. Put two dots on either side of compass needle. Take it out. Draw a line connecting the dots, which shows the north and south of the earth. Now place bar magnet on the line drawn in such a way that its north pole points towards geographic north. Now place the compass at the edge of North Pole of the bar magnet. Put a dot on the north side of the compass needle. Now remove the compass and place it at the dot. It will point in other direction. Again put a dot on the north side of compass. Repeat the process till you reach the south of the bar magnet. Connect the dots from 'N' of the bar magnet to 'S' of the bar magnet. You will get a curved line. Now select another point from the North Pole of the bar magnet. Do the same for many points taken near North Pole. You will get different curves as shown in figure 2.

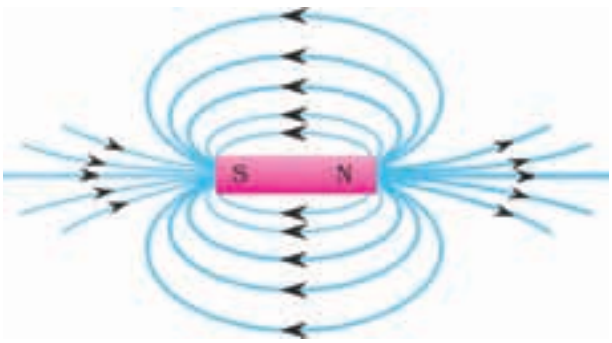


fig-2:

- What are these lines?

Technically those lines are called "magnetic field lines". Field lines are imaginary lines. These lines help us to understand the nature of the field. So these curved lines represent the field

lines. If you place a compass at any point on the line, the needle comes to rest along the tangent to the line. So we conclude that the tangent drawn to the field line at a point gives the direction of the field.

- Are these field lines are closed loops or open loops?

The field lines appear to be closed loops, but you can't conclude that lines as closed or open loops by looking at the picture of field lines because we do not know about alignment of lines that are passing through the bar magnet. We will come to this point later in this chapter.

Observe the spacing between lines. In some places field lines are crowded (near th poles of a bar magnet) and in some places field lines are spread apart (at far distances from bar magnet). From this picture we can conclude that field is strong when lines are crowded and field is weak when lines are spaced apart.

Thus, the field drawn is non uniform because the strength and direction both changes from point to point.

We may define the nature of the field with its characteristics such as its strength and direction. The field is said to be non uniform when any one of the characterstics of field i.e., strength or direction changes from point to point, similarly the field is said to be uniform if both strength and direction are constant throughout the field. Let us define the strength of uniform magnetic field.

- Can we give certain values to the field at every point in the magnetic field?

Consider a uniform magnetic field in space. Imagine a plane of certain area 'A' is placed perpendicular to the field at a certain point in the magnetic field as shown in figure 3(a). You notice that few field lines pass through this plane. This number gives the strength of the field at that point.

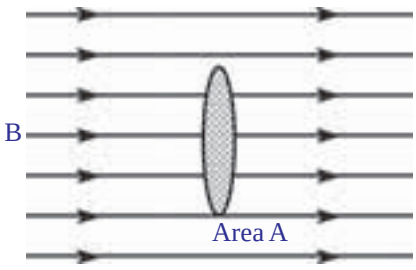


fig-3(a):

The number of lines passing through the plane of area 'A' perpendicular to the field is called magnetic flux. It is denoted by 'Φ'.

Magnetic flux represents the number of lines passing through the imagined plane in the field. Of course flux depends on the orientation of plane in the field. But here we are concerned only with perpendicular case. The S.I unit of magnetic flux is Weber. Now strength of the field is easily defined using the idea of flux. If your imagined plane is perpendicular to the field and has unit area, then the flux through this plane of unit area gives the strength of the field. The strength of the field

is technically called magnetic flux density (**B**). So, magnetic flux density is defined as the magnetic flux passing through unit area taken perpendicular to the field.

Let the flux through the area 'A' be Φ.

- What is the flux through unit area perpendicular to the field?

It is equal to Φ/A. The ratio of magnetic flux passing through plane perpendicular to the field and the area of the plane is called the magnetic flux density.

So magnetic flux density = magnetic flux/ area.

$$B = \Phi/A.$$

Units of magnetic flux density is Weber/ $(meter)^2$. It is also called as Tesla.

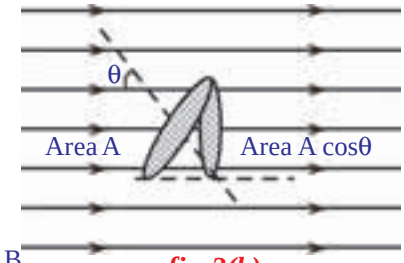


fig-3(b):

- Could we generalize the formula of flux for any orientation of the plane taken in the field?

Let 'θ' be the angle between magnetic field (B) and normal to the plane with area (A) as shown in figure 3(b). The effective area of the plane perpendicular to the field is a cosθ. Then magnetic flux density is given by,

B = magnetic flux /effective area

(this formula is used when plane is taken certain angle with field).

Then $B = \Phi/A \cos\theta$

The flux through the plane, is given by

$\Phi = BA \cos\theta$.

- What is the flux through the plane considered parallel to the field?
- What is the use of introducing the ideas of magnetic flux and magnetic flux density?

Later in this chapter, you will see how these ideas are used.

- Are there any sources of magnetic field rather than magnets?
- Do you know how electric calling bells (old) work?

Let us see

Magnetic field due to currents

In activity 1 we observed that the needle of compass is deflected when current flows through the circuit. This observation helps us to conclude that, "Current carrying wire produces magnetic field."

Let us know few of the magnetic fields produced by the current carrying wire.

(i) Magnetic field due to straight wire carrying current.

Activity 4

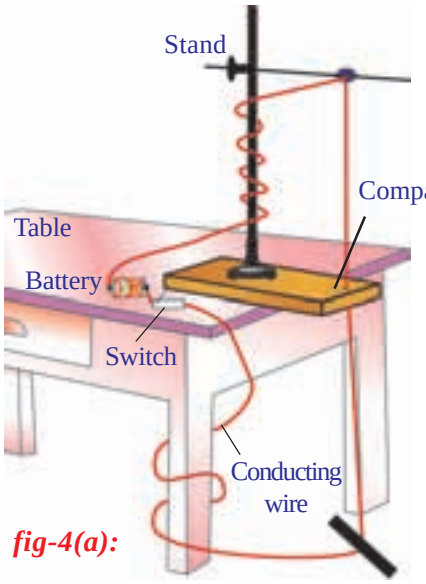
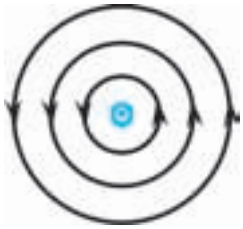


fig-4(a):

Take a plank and make a hole as shown in figure 4(a). Place this plank on the table. Now place a retort stand on the plank as shown in figure 4(a). Pass 24 gauge of copper wire through hole of the plank and rubber knob of the retort stand in such a way that the wire should be arranged in vertical position and it should not touch other material of the stand. Connect the two ends of the wire to a battery via switch. Place 6 to 10 magnetic compasses in circular path as its centre coincides the hole. Use 3- volt battery in circuit. Switch on. Current flows through wire.



Current out of the page

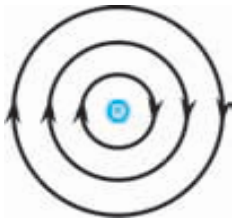
fig-4(b):

- How do the directions of the compasses change?

You may notice that they are directed as tangents to the circle.

- What is the shape of the magnetic line around wire?

It must be a circular line. So we conclude that magnetic lines are closed lines. The magnetic lines due to straight wire carrying the current is shown in figures 4(b) and 4(c). This can be verified by sprinkling iron filings around the wire when current exists in the circuit.



Current into the page

fig-4(c):

- What is the direction of magnetic field induction at any point on the field line?

If the current flow vertically upward direction from the page, the field lines are in anti clock wise direction, as shown in figure 4(b). If current flows into the page, in downward direction, the field lines are in clockwise direction as shown in figure 4(c). It can be easily demonstrated with right hand thumb rule. If you grab the current carrying wire with your right hand in such way that thumb is in the direction of current, then the curled fingers show the direction of the magnetic field as shown in figure 4(d).

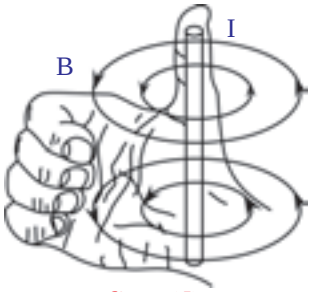


fig-4(d):

(ii) Magnetic field due to circular coil.

Activity 5

Take a thin wooden plank covered with white paper and make two holes on its surface as shown in figure 5(a). Pass insulated copper wire (24 gauge) through the holes and wind the wire 4 to 5 times through holes such that it looks like a coil as shown in figure 5(a). The ends of the wire are connected to terminals of the battery through a switch and switch on. Place a compass on the plank at the centre of the coil. Put dots on either side of the compass. Again place compass at one of the dots, put other dot further. Do the same till you reach the edge of the plank. Now do the other side of the coil from the centre. Then draw a line joining the dots, you will get a field line of the circular coil. Do the same for the other points taken in between the holes. Draw corresponding lines. You will get field lines of circular coil.

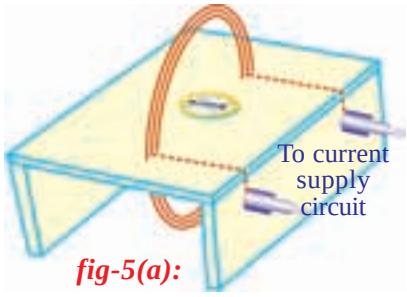


fig-5(a):

- Can you tell the direction of the field of the coil?

This could be answered from the orientation of compass. You can observe this when compass is kept at the centre of the coil. The direction in which the compass needle comes to rest indicates the direction of the field due to the coil. Thus the direction of the field is perpendicular to the plane of the coil.

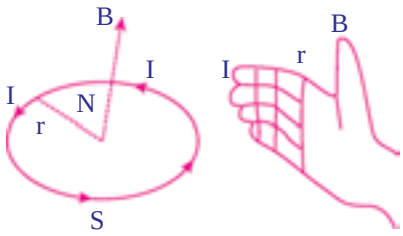


fig-5(b):

- Why does the compass points in the direction of field?

It is very easy to answer. Place the compass before the one of the faces of the coil and observe the orientation of the needle of the compass. Note the pole of the needle towards the face of the coil. We know that south pole is attracted to the north pole. The needle is oriented in such a way that its south pole points towards the north pole of the coil. So we can say that the direction of magnetic field due to coil points towards you when the current in the coil is in anticlockwise direction. Verified this in your experiment (do not touch the wires of the coil). When the current in the coil is in clock-wise direction, the direction of magnetic field due to the coil points away from you. The direction of the field due to coil or solenoid is determined by using right hand rule, which states that,

"When you curl your right hand fingers in the direction of current, thumb gives the direction of magnetic field."

Observe the direction of magnetic field in figure 5(b)

(iii) Magnetic field due to solenoid.

Activity 6

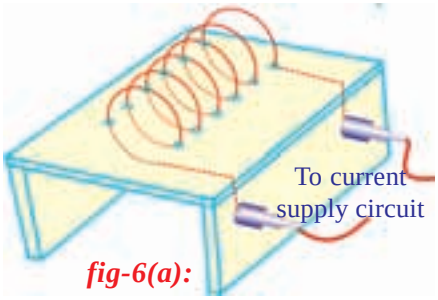


fig-6(a):

Take a wooden plank covered with white paper. Make holes on its surface as shown in figure 6(a). Pass copper wire through holes as shown in figure 6(a). Join the ends of the coil to a battery through a switch. Switch on the circuit. Current passes through the coil. Now sprinkle iron filings on the surface of the plank around the coil. Give a small jerk to it. An orderly pattern of iron filings is seen on the paper.

- How do they adjust in such an orderly pattern?

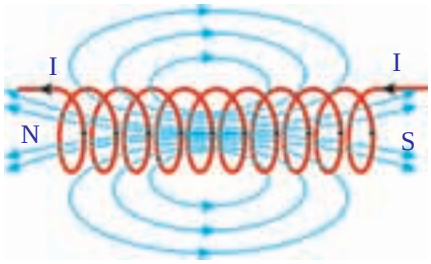


fig-6(b):

They nearly look like field lines of bar magnet. This long coil is called solenoid. A solenoid is a long wire wound in a close packed helix. The field of solenoid is shown in the figure 6(b). The direction of the field due to solenoid is determined by using right hand rule. One side of the solenoid behaves like a north pole and other behaves like a south pole. The field lines outside the solenoid are continuous with those inside. Outside the solenoid is the direction of the field lines from north to south while inside the direction it is from south to north. Thus the magnetic field lines are closed loops. This is so for the bar magnet too!

We have seen that current carrying wires produce magnetic field. So that electric charges in motion produce magnetic fields.

- What happens when a current carrying wire is kept in a magnetic field?

Let us see

Magnetic Force On Moving Charge And Current Carrying Wire

Activity 7

Stand near the TV screen. Switch on TV.

- Do you feel any sensation on your skin?
- What could be the reason for that?
- Take a bar magnet and bring it near to the TV screen.
- What do you observe?

You can observe that the picture on TV screen is distorted.

- Why doe sthe picture get distorted?

- Is the motion of electrons reaching the screen affected by the magnetic field of the bar magnet?

Move the bar magnet away from the screen. Now you will get a clear picture. Repeat this to conform that the motion of electrons is affected by the field produced by the bar magnet. This must be due to the fact that the magnetic field exerts a force on the moving charges. This force is called magnetic force.

- Can we calculate the force experienced by a charge moving in a magnetic field?

Let a charge 'q' move with a velocity 'v' perpendicular to the magnetic field 'B' as shown figure 7. The value of magnetic force on the moving charge found experimentally, is given by,

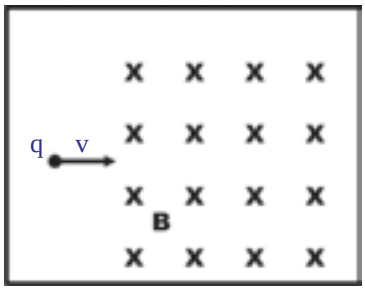


fig-7:

$$F = q\ v\ B$$

Magnetic force on the charge is the product of three quantities charge, speed and magnetic flux density. The equation for magnetic force acting on a charge 'q' is F = q v B and holds well only when the direction of velocity of charged particle 'v' is perpendicular to the direction of the magnetic field 'B'.

- Could you generalize the equation for magnetic force on charge when there is an angle 'θ' between the directions of field **B** and velocity **v**?

It is experimentally proved that when there is an angle between direction of field and velocity, the magnetic force experienced by the charge is given by,

$$F = q\ v\ B\ \sin\theta.$$

- What is the magnetic force on the charge moving parallel to magnetic field?

When charge moves parallel to the magnetic field (along field or against field) the value of θ becomes zero. In the above equations θ is 0^0 so that $\sin\theta = 0$.

Thus the charge experiences no force when it is moving parallel to magnetic field (along field direction or against field direction).

- Can you guess the direction of magnetic force acting on moving charge?

We have an easy method to find out the direction of magnetic force acting on a charge moving in a magnetic field. "Keep your right hand fore-finger along the direction of velocity of moving charge and next curl your fingers towards the direction of magnetic field then thumb gives the direction of magnetic force." This rule is applied for any case of angle

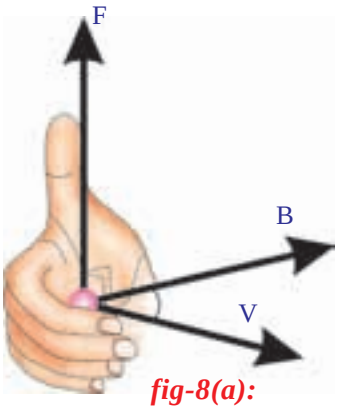


fig-8(a):

between directions of velocity and field. Observe figure 8(a). The direction of magnetic force is always perpendicular to the direction of both velocity and magnetic field.

Generally right hand rule is used when velocity and field are perpendicular to each other, this law states that,

If direction of fore-finger points velocity towards the direction of charge (current), middle finger points the direction of field (B) and thumb gives direction of force when the three fingers are stretched in such a way that they are perpendicular to each other as shown in figure 8(b).

This rule is applicable to positive charge.

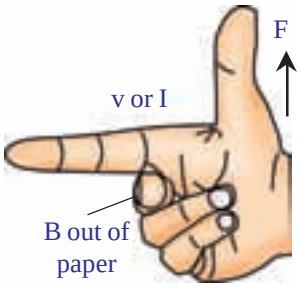


fig-8(b):Right hand rule for positive charge

• What could be direction of force acting on a negative charge moving in a field?

First find the direction of force acting on a positive charge. Next reverse its direction. This new direction is the direction of force acting on the negative charge.

Let us see an example of force acting on a charged particle.

Example 1

A charged particle 'q' is moving with a speed 'v' perpendicular to the magnetic field of induction B.

a) What is the path of the charged particle?

b) Find the radius of the path and time period of the particle.

Solution: Let us assume that the field is directed into the page as shown in figure E-1. Then the force experienced by the particle is F = q v B. We know that this force is directed always perpendicular to velocity. Hence the particle moves along a circular path and the magnetic force on charged particle acts like a centripetal force.

Let r be the radius of the circular path.

We know that centripetal force = mv^2 / r

$$q\,v\,B = mv^2 / r$$

Solving this equation, we get; $r = mv / Bq$

Time period of the particle; $T = 2\pi r / v$

Substituting r in above equation, we get

$$T = 2\pi m / Bq$$

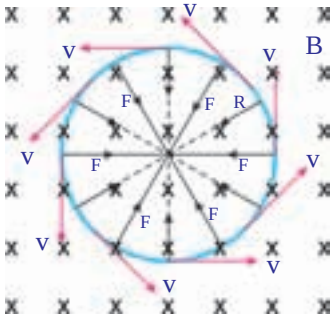


fig-E-1:

- What happens when a current carrying wire is placed in magnetic field?

Electric current is nothing but charges in motion. We know that each charge experiences a magnetic force. Thus the current carrying wire experiences magnetic force when it is kept in magnetic field.

- Can you guess the magnetic force on the current carrying wire which is placed along magnetic field?

We know that each charge experiences no magnetic force because they are moving parallel to direction of field along the field. So the force acting on wire is zero when it is kept along magnetic field.

Let us find the magnetic force on the straight wire carrying current which is kept perpendicular to the uniform field 'B'. This 'B' is directed into the page. It is represented by 'x' as shown in the figure 9. Let the field confines to the length L. So only the part of the wire of the length 'L' is inside the magnetic field. Remaining wire is outside the magnetic field. We know that the electric current means charges in motion hence they move with a certain velocity called drift velocity 'v'.

The magnetic force on single charge is given by,

$$F_0 = q\,v\,B$$

Let total charge inside the magnetic field be Q. So magnetic force on the current carrying wire is given by

$$F = Q\,v\,B \qquad \text{————(1)}$$

The time taken by the charge (Q) to cross the field is

$$t = L / v \qquad \text{————(2)}$$

we can write the equation 1 as,

$$F = (Q / t)\,(v\,t)\,B \qquad \text{————(3)}$$

From 2,

$$vt = L$$

substituting this in equation 3, we get,

$$F = (Q / t)\,LB$$

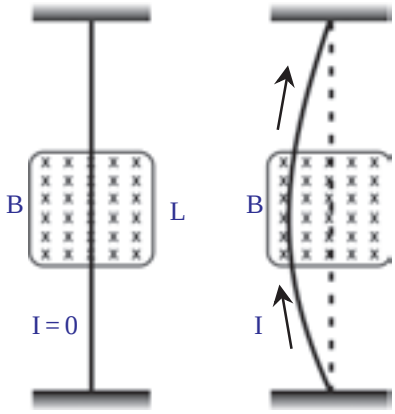


fig-9:

- To which is this value Q / t equal to?

We know that Q / t is equal to the electric current in the wire,

$$I = Q / t$$

Substituting 'I' in the equation 3, finally we get

$$F = ILB \qquad \text{———} (4)$$

Note: This equation holds well only when direction of electric current is perpendicular to magnetic field.

- What could be the force on the wire if its length makes an angle 'θ' with magnetic field?

Let 'θ' be the angle between direction of current and magnetic field, then the force acting on the current carrying wire is given by

$F = ILB \sin\theta$ (at any angle) ———(5)

- How could you find its direction?

You can use right hand rule to find out the direction of force on the current carrying wire.

- Could really magnetic field exert force on current carrying wire?

Let us see

Activity 8

Take a wooden plank. Fix two long wooden sticks on it. These wooden sticks have slits at the top of their ends.

A copper wire is passed through these slits and ends of the wire connected to the battery of 3 volt, through a switch. Close the switch to make the circuit. Current passes through wire. Now bring a horseshoe magnet nearer to the copper wire as shown in figure 10.

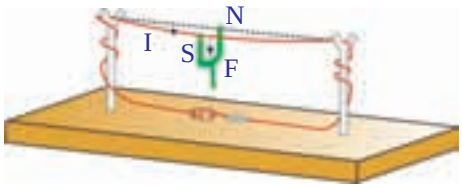


fig-10:

- What happens to the wire?
- In which way does it deflect?

Use the right thumb rule to find the direction of force.

- Is the direction of deflection observed experimentally same to that of theoretically learned one?

Change polarities of the horse shoe magnet. Again observe the deflection. Repeat this by changing the direction of current in the circuit.

- Does the right hand rule give the reason for magnetic force exerted by magnetic field on the wire?

Right hand rule helps you to find out the direction of magnetic force exerted by the magnetic field on current carrying wire. It does not help you to explain the reason for deflection of wire.

- Could you give reason for it?

Imagine there is no current in wire. Then there exists only magnetic field due to external source (horse shoe magnet). When there is a current in the wire, it also produces field. These fields overlap and give non-uniform field. Let us see this clearly with diagrams.

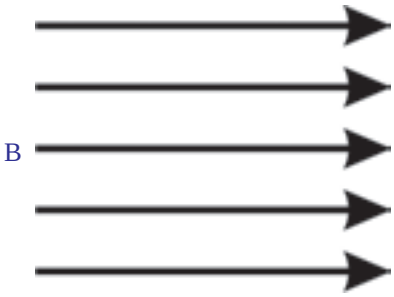


fig-11(a): Field lines due to horseshoe magnet between its poles

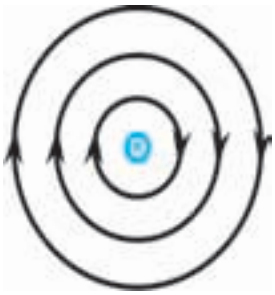


fig-11(b): Current into the page

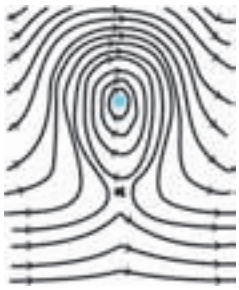


fig-11(c):

The field in between north and south pole of horse shoe magnet is seen in the figure 11 (a). Let us imagine a wire passing perpendicular to the paper. Let the current pass through it(flowing into the page). It produces field as shown in figure 11(b). Now let us try to sketch the resultant field by observing the field lines, we can understand that the direction of the field lines due to wire in upper part circular lines coincides with the direction of the field lines of horse shoe magnet and the direction of field lines by wire in lower part of circular lines is opposite to the direction of the field lines of horse shoe magnet. So that the net field in upper part is strong and in lower part it is weak. Hence a non-uniform field created around the wire. This non uniform field is shown in figure 11 (c). Therefore the wire tries to move to the weaker field region.

- Does this deflection fit with the direction of magnetic force found by right hand rule?
- What happens when a current carrying coil placed in uniform magnetic field?
- Can we use this knowledge to construct an electric motor?

Let us try to answer.

Electric Motor

To understand the working of an electric motor we need to understand the behaviour of current carrying coil kept in a magnetic field.

Consider that a rectangular coil is kept in a uniform magnetic field as shown in figure 12(a). Switch on, the circuit so that the current flows through the rectangular coil. The direction of current in the coil is shown in the figure 12(a).

- What is the angle made by AB, and CD with magnetic field?

You will notice that always they are at right angles to the field.

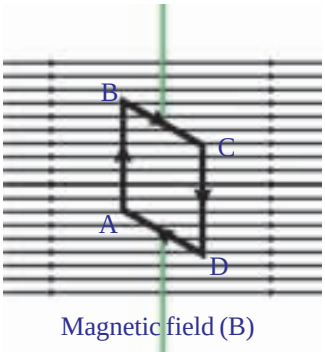


fig-12(a):

- Could you draw direction of magnetic force on sides AB and CD?

Use the method right hand rule to get the direction of magnetic force. At AB, magnetic force acts down perpendicular to field line by the magnet and on CD, it acts outward.

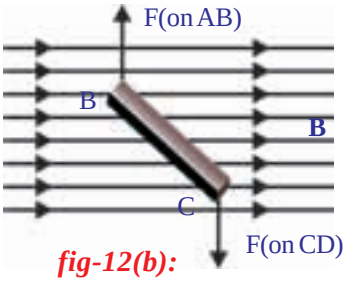


fig-12(b):

See the figure 12(b). This figure is drawn from top view. The force on these sides varies because they make different angles at different positions of the coil in the field.

- What are the direction of forces on BC and DA?

At BC, magnetic force pulls up and at DA magnetic force pulls down.

- What is the net force on the rectangular coil?

The force on AB is equal and opposite to the force on CD due to external magnetic field because they carry equal currents in the opposite direction and the length of them are equal. Sum of these forces is zero; similarly the sum of the forces on sides BC and DA is also zero for the same reason. So, net force on the coil is zero. But there is rotation in coil. How is it possible?

- Why does the coil rotate?

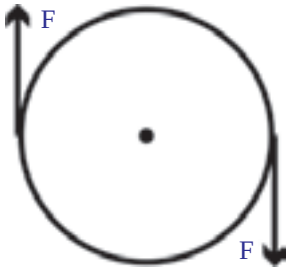


fig-12(c):

Let us consider opening a cap of the bottle as an example where two equal and opposite forces act on a body. Two forces equal in magnitude but opposite in direction must act on the either side of cap of the bottle as shown in figure 12 (c). These forces bring the cap into rotation. Similarly the rectangular coil comes into rotation in clockwise direction because the equal and opposite pair of force acting on the two edges of the coil.

- What happens to the rotation of coil if the direction of current in the coil is fixed?

If the direction of current in the coil is unchanged, it rotates up to a vertical position then due to its inertia it rotates further in clockwise. But now the edges of the coil experiences forces which are in opposite to the previous case. Hence these forces try to rotate it in anti clockwise direction. As a result of this coil comes to stop and rotate in anti clock wise direction, this will go in if the direction of current is fixed.

How could you make the coil to rotate continuously?

If the direction of current in coil, after the first half rotation, is reversed, the coil will continue to rotate in the same direction. Thus if the direction of current through the coil is reversed every half rotation, the coil will rotate continuously in one direction.

- How can we achieve this?

To achieve this, brushes B_1 and B_2 are used, as shown in figure 12 (d). These brushes are connected to the battery. The ends of the coil are connected to slip rings C_1 and C_2, which rotate along with the coil. Initially C_1 is in contact with B_1 and C_2 is in contact with B_2 .After half rotation, the brushes come into contact with the other slip rings in such a way that the direction of current through the coil is reversed. This happen every half rotation. Thus the direction of rotation of the coil remains the same. This is the principle used in "electric motor."

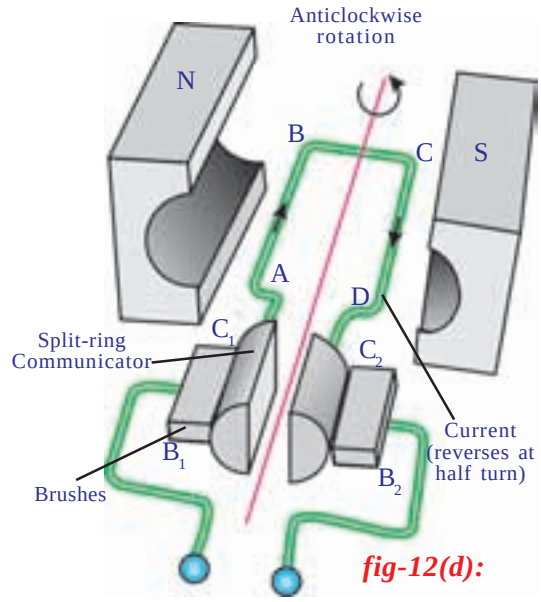


fig-12(d):

In electric motors, electrical energy is converted into mechanical energy.

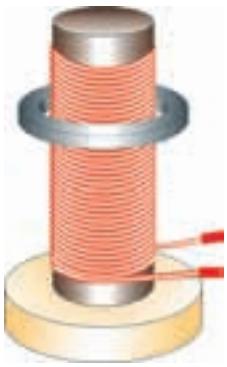
We have learned that the current carrying coil rotates when it is kept in uniform magnetic field.

- What happens when a coil without current is made to rotate in magnetic field?
- How is the current produced?

Electromagnetic induction - Faraday's law

Activity 9

Take a wooden base as shown in figure 13(a). Fix a soft iron cylinder on the wooden base vertically. Wind copper wire around the soft iron as shown in figure 13(a). Now take a metal ring which is slightly greater in radius than the radius of soft iron cylinder and insert it through the soft iron cylinder on the wooden base. Connect the ends of the coil to the AC source and switch on the current.


fig-13(a):

What do you notice?

You may notice that the metal ring is levitated on the coil.

Switch off the current, the ring will jump into the air very dramatically. Remove AC supply and connect DC supply. Observe what happens.

- Why is there a difference in behaviour in these two cases?
- What force supports the ring against gravity when it is being levitated?

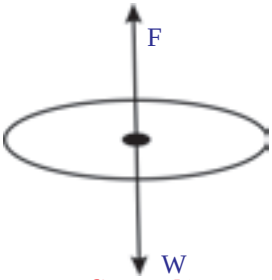


fig-13(b):

- Could the ring be levitated if DC current is used?

The metal ring levitates because the net force on it should be zero according to Newton's second law. The free body diagram of metal ring is shown in figure 13 (b). Weight acts down. To balance it a force equal in magnitude and opposite in direction should act as shown in figure 13 (b).

- What is this unknown force acting on the metal ring?

In this activity AC current is used. AC current changes both its magnitude and direction in regular time intervals. We know that the current through the coil, produce magnetic field so that one end of the coil behaves like north and other end behaves like south for a certain time interval. For the next interval, coil changes its polarities. Hence we can say that coil changes its poles in the same intervals of time. The levitation of metal ring is possible only when the metal ring should behave like a magnet and should change its polarities in the same time intervals but in a sense opposite to that of the solenoid (coil) as shown in figure 13(c). Assume that the current flows in anticlockwise direction in the solenoid as viewed from the top of it. Then upper end becomes north pole. An upward force is applied on the ring only when the upper side of the ring must be a south pole. It is only possible when there exists in current clockwise viewed from the top. After certain intervals solenoid changes its polarities, so that the ring should also change its polarities in the same intervals. This is the reason why the metal ring is levitated.

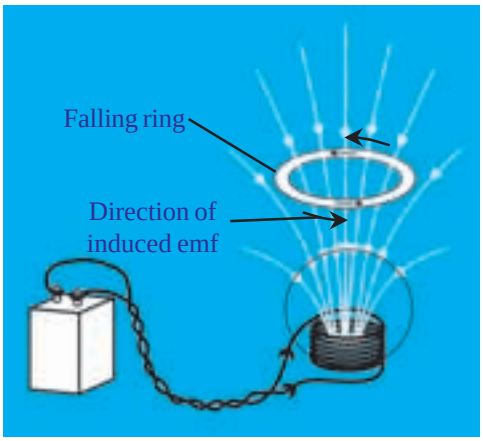


fig-13(c):

- Who is responsible for the current in metal ring?

AC current is not a constant current. So that, the magnetic induction changes in both magnitude and direction in the solenoid and in the ring.

Here the area of the metal ring is constant. But the field through the metal ring changes so that flux linked with the metal ring changes.

- If DC current is used, the metal ring lifts up and falls down immediately. Why?

The flux linked with metal ring is zero when no current flows through the solenoid. When the current is allowed to flow through solenoid, it behaves like bar magnet. So the flux links with metal ring when the switch is on. At that instant there should be a change in flux linked with ring.

Hence the ring rises up and falls down. If the switch is off, the metal ring again lifts up and falls down. In this case also, there is a change in flux linked with ring when the switch is off.

- What could you conclude from the above analysis?

Let us understand the results of the activity 9 by the following hypothetical activity.

Connect the terminals of a coil to a sensitive ammeter or a galvanometer as shown in the figure-14. Normally, we would not expect any deflections of needle in the galvanometer because there seems to be no electromotive force in this circuit. Now if we push a bar magnet toward the coil, with its north pole facing the coil, a remarkable thing happens. While the magnet is moving towards the coil, the needle in galvanometer deflects, showing that a current has been set up in the coil, the galvanometer does not deflects if the magnet is at rest. If the magnet is moved away from the coil, the needle in the galvanometer again deflects, but in the opposite direction, which means that a current is set up in the coil in the opposite direction.

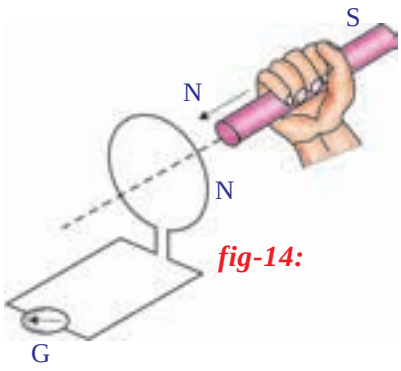


fig-14:

If we use the end of south pole of a magnet instead of north pole in the above activity, the experiment works just as described but the deflections are exactly reversed.

Further experimentation enables us to understood the relative motion of the magnet and coil set up a current in the coil. It makes no difference whether the magnet is moved toward the coil or the coil toward the magnet.

"Whenever there is a continuous change of magnetic flux linked with closed coil, the current is generated in the coil."

This is Faraday's law.

The current generated is called induced current and is set up by an induced electromotive force (induced EMF). This phenomenon of getting induced current is called electromagnetic induction.

Faraday observed that the changes in the magnetic flux through the coil are responsible for the generation of current in the coil. He also observed that the rapid changes in flux through coil generate greater induced current or induced EMF. After observing this important factor, he proposed a law of electromagnetic induction, which is as follow,

"The induced EMF generated in a closed loop is equal to the rate of change of magnetic flux passing through it."

In mathematical form, we can write this as

Induced EMF = change in flux/ time

$\varepsilon = \Delta\Phi/\Delta t$ ——————(6)

The equation is called faraday's law of induction where Φ (phi) is the flux linked with coil. Let Φ_0 is the flux linked with single turn. If there are N turns in the coil, the flux linked with the coil is $N\,\Phi_0$.

$\Phi = N\,\Phi_0$ ——————(7)

So far we have not specified the direction of the induced EMF or induced current. In the previous example, we have observed that an induced current is set up in the loop.

- What is its direction?
- Could you apply conservation of energy for electromagnetic induction?

When we are pushing the bar magnet towards the coils, current is generated, in other words in electromagnetic induction, mechanical energy is converted into electrical energy.

Let us discuss it in detail.

We know that when a bar magnet is pushed towards coil with its north pole facing the coil an induced current is set up in the coil. Let the direction of current in the coil be in clockwise direction with respect to north pole of the bar magnet. Then current carrying this loop behaves like a magnet, with its south pole facing the north pole of bar magnet. In such a case, the bar magnet attracts the coil. Then it gains kinetic energy. This is contradictory to the conservation of energy. So our assumed clockwise direction of induced current is wrong. Hence the correct direction of induced current to be in anticlockwise direction with respect to north pole of the bar magnet. In such a case, the north pole of the coil faces the north pole of the bar magnet as shown in figure 15. Then north pole of bar magnet repels by the north pole of the coil. Hence we need to do work to overcome this force. This work done on the magnet is converted into electrical energy in the coil. In this way conservation of energy takes place in electromagnetic induction.

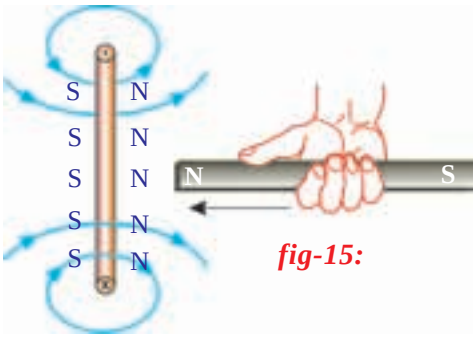


fig-15:

Let us see a case where the bar magnet pulled away from the coil, with north pole facing the coil. In such case, the coil opposes the motion of bar magnet to balance the conversion of mechanical energy into electric energy. This happens only when the north pole of the magnet faces the south pole of the coil.

- Can you guess what could be the direction of induced current in the coil in such case?

Invariably the direction of induced current in the coil must be in anti clock wise direction. In simple terms, when flux increases through coil, the coil opposes the increase in the flux and when flux decreases through coil, it opposes the decrease in the flux.

This is Lenz law.

Lenz law states that "the induced current will appear in such a direction that it opposes the changes in the flux in the coil."

- Could we get faraday's law of induction from conservation of energy?

Let us see

Let us arrange an apparatus as shown in figure 16. It consists of a pair of parallel bare conductors which are spaced *l* meters apart in uniform field of 'B'. We can hold another bare conductor makes in such a way that it contact with the two parallel wires(see figure-16). A galvano meter is connected to the ends of parallel conductors to complete an electric circuit. Now if the conductor placed across parallel conductors is moved to the left, galvanometer needle will deflect in one direction.

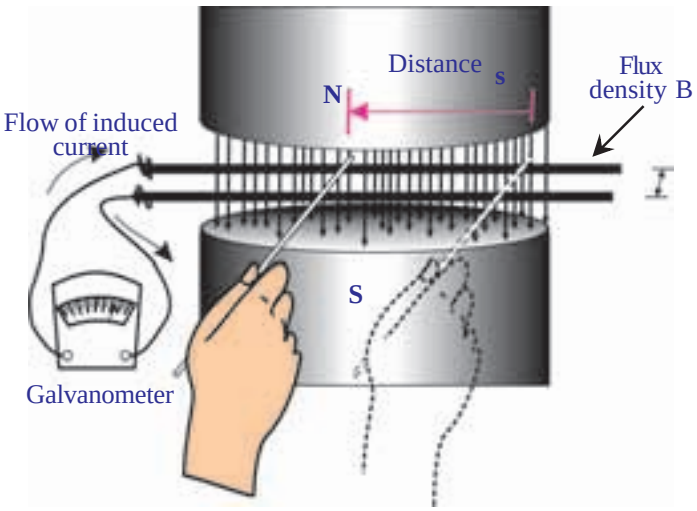


fig-16

If this cross wire is moved to the right, its needle deflects in opposite direction to the previous deflection.

Suppose that the crosswire is moved to the left to a distance of 's' meters in a time of 'Δ t' then the reading of galvanometer gives us an amount of current flow in the circuit. A current will be set up in the circuit only when there is an EMF in the circuit. Let this EMF be 'ε'.. The principle of conservation of energy tells us that this electric energy (associated with flow of current) must come from the work that we have done in moving the crosswire. If we ignore friction everywhere, in the arrangement the work done by this applied force = Fs. It is evident that there is a current of 'I' amperes is flowing through the length of *l* meters of the cross wire, and the cross wire is in a magnetic field. With this information,

- Can you derive an expression for the force applied on cross wire by the field B?

We know that it is equal to B*Il*, from equation-4 of previous discussion (see page ....)

i.e., $F = BIl$ ——————(8)

This force must oppose the applied force. The direction of appliedforce determines the direction of current through cross wire. Here we are doing positive work. The work done by us in moving cross wire converts into electric energy due to opposing force created by field. So the work done is given by,

$W = Fs = BIls$ ——————(9), using equation-8

When we put cross wire across parallel conductors it makes a complete electrical circuit which encloses a certain amount of magnetic flux. Now as we move the cross wire to the left, the area of the circuit decreases and the flux through the loop also decreases. The decrease in flux is given by,

$\Delta\Phi = Bls$ ——————(10)

Here B is perpendicular to the area (*l*s)

So, work done in moving the cross wire through a distance 's'

$W = BIls$, from equation (9)

But, $Bls = \Delta\Phi$, from equation (10)

$W = (\Delta\Phi) I$

Let us divide both sides of the equation by Δt

$W/\Delta t = I (\Delta\Phi/ \Delta t)$ ——————(11)

Electric power = $I\Delta\Phi/ \Delta t$

In the above equation, $W/\Delta t$, stands electric power. We know that electric power is the product of current and emf (or) voltage. $\varepsilon=\Delta\Phi/\Delta t$ stands for induced EMF. Thus the electric power generated in circuit is equal to product of induced EMF and the current. Thus the mechanical energy used to move cross wire to distance 's' in one second is converted into electric energy $(\Delta\Phi/\Delta t) I$ and leads conservation of energy.

A re-arrangement of above equation-11 gives us another statement that is often very useful, when single length conductor is moved across a magnetic field.

$W/\Delta t = Fs/\Delta t = BIl (s/\Delta t)$

Here $s/\Delta t$ gives the speed of the cross wire, let it be taken as v. Then

We know that, $W/\Delta t = \varepsilon I$

$\varepsilon I = BIlv$

We get,

$\varepsilon = Blv$

This is called motional EMF.

The above equation is not faraday's law of induction because it is not related to the loop. It is useful when a single length of conductor moved across a magnetic field which produce an induced EMF between its ends.

Let us see a few examples on induced emf.

Example 2

The magnetic flux inside a coil of 400 turns changes for each single turn with time as shown in figure

Determine the maximum induced emf generated in the coil. Is there any change in induced EMF from t = 0.1 second to 0.3 second?

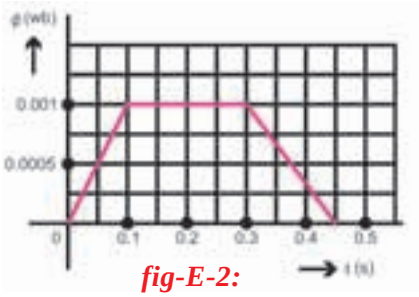


fig-E-2:

Solution: from the given graph, the increase or decrease in magnetic flux through one turn of coil in 0.1 second is 0.001 Weber. According to faraday's law the maximum induced emf generated in the coil is given by,

$\varepsilon = N \Delta \Phi / \Delta t$

Substituting the values, we get

$\varepsilon = 400(0.001/0.1) = 4V$

From graph, there is no change in magnetic flux through coil from t = 0.1s to 0.3s hence no emf is generated.

Example 3

Find the length of the active part of conductor which is moving with a speed of at 10 m/s in the direction perpendicular to the direction of magnetic field of induction 0.8T. If it induces an emf of 8V in the conductor.

Solution: given that B = 0.8T, v = 10 m/s and ε = 8V.

Using $\varepsilon = Blv$

$8 = 0.8(l)(10)$

l (length of the conductor) = 1m

Let us see some of the applications of faraday's law of induction.

Electromagnetic induction is all around us.

- You might have seen that, during security check, people are made to walk through a large upright coil of wire which produces a weak AC magnetic field. If we are carrying any significant quantities of iron, the magnetic flux linked with the large coil changes and the induced current generated in coil triggers an alarm.

- The tape recorder which we use to listen songs (or) record the voices works on the principle of electromagnetic induction. It consists a piece of plastic tape coated with iron oxide is magnetised more in some parts than in others. When the tape is moved past as a small coil of wire (which we call as head of the tape recorder), the magnetic field produced by the tape changes which leads to generation of current in the small coil of wire.
- How could we use the principle of electromagnetic induction in the case of using ATM card when its magnetic strip is swiped through a scanner? Discuss with your friends and your teacher.
- An induction stove works on the principle of electromagnetic induction. A metal coil is kept just beneath the cooling surface. It carries AC current so that AC current produces an alternating magnetic field. When you keep a metal pan with water on it, the varying magnetic field beneath it crosses the bottom surface of the pan and an EMF is induced in it. Because the pan is metal the induced EMF generates an induced current in it. Since the pan has a finite resistance, the flow induced current in it produces heat in it and this heat is conducted to the water. That's why we call this stove as induction stove.

Have you ever thought,

From where are we getting energy?

Let us learn about it.

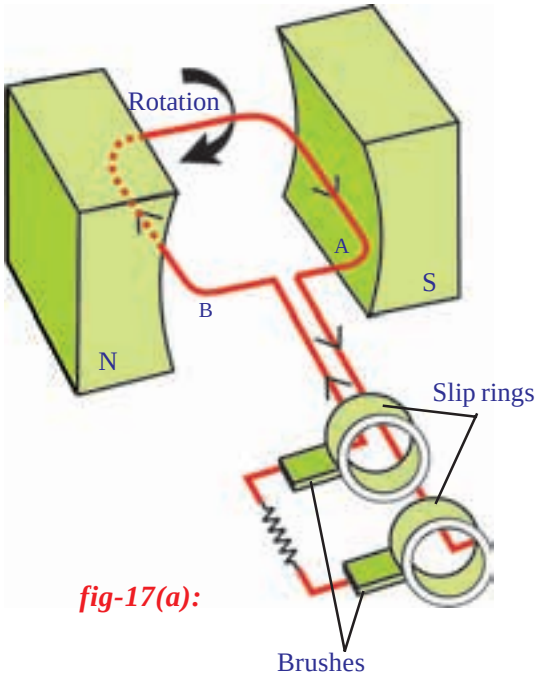


fig-17(a):

Electric Generator and AC-DC Currents

- What happens when a coil is continuously rotated in a uniform magnetic field?
- Does it help us to generate the electric current?

Let us see:

Consider a rectangular coil that is rotated in which is fixed between the poles of U- shaped permanent magnet as shown in figure 17(a). As the coil rotates, the magnetic flux passing through the coil changes. According to the law of electro magnetic induction an induced current generates in the coil.

- Is the direction of current induced in the coil constant? Does it change?

Consider initially the coil, positioned in such a way that magnetic flux passes through it. When the coil is at rest in vertical position, with side (A) of coil at top position and side (B) at bottom position, no current will be induced in it. Thus current in the coil is zero at this position. When the coil is rotated in clockwise direction, current will be induced in it and it flows from A to B. During the first quarter of rotation, the current increases from zero to a maximum and reaches peak value when the coil is in horizontal position. If we continue the rotation of coil, current decreases during the second quarter of the rotation and once again becomes zero when coil comes to vertical position with side B at top side (A) at bottom position. During the second of the rotation, current generated follows the same pattern as that in the first half, except that the direction of current is reversed. (see figure-17(b))

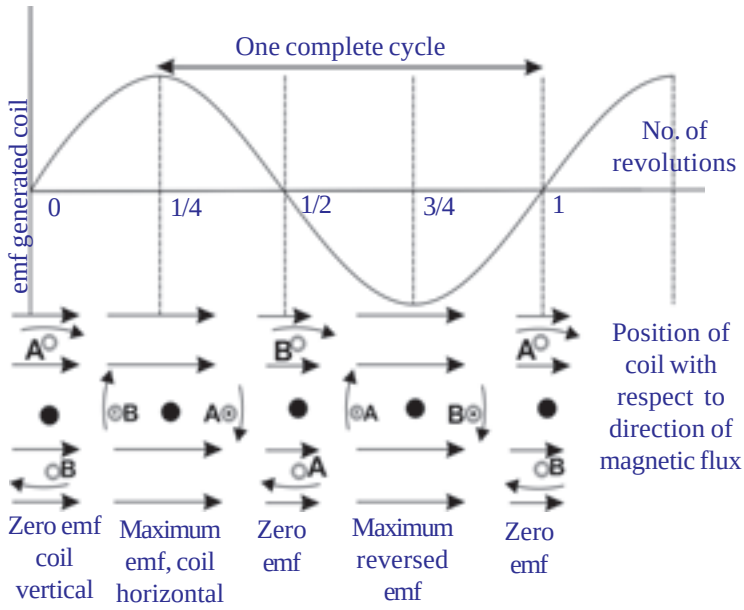


fig-17(b):

- Do you guess the reason for variation of current from zero to maximum and vice-versa during the rotation of coil?
- Can we make use of this current? If so, how?

Let us find:

As shown in figure17(a) the ends of the coil are connected to two slip rings. Two carbon brushes arranged in such a way that they press the slip rings to obtain current from the coil. When these brushes are connected to external devices like TV, radio, we can make them to work with current supplied from ends of carbon brushes.

The current obtained by this process alternatively changes its direction for each half cycle as shown in figure 17(b).

This current is called Alternative Current (AC) in which, the direction of charge flow reverses periodically. So AC current possess certain

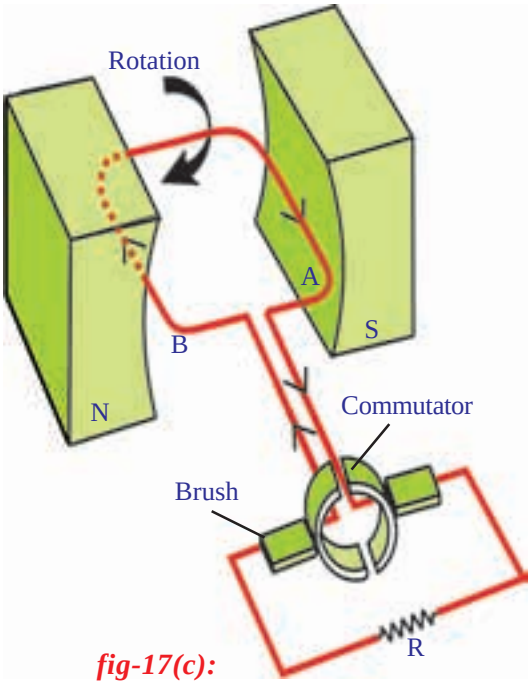


fig-17(c):

frequency. The generator that we discussed here is called AC generator. These AC- EMF and AC current are expressed in terms of *rms* values.

Let I_0 and v_0 not be the peak values of AC current and AC EMF.

$I_{rms} = I_0/\sqrt{2}$ and $v_{rms} = v_0/\sqrt{2}$

- How can we get DC current using a generator?
- What changes do we need to make an AC generator into a DC generator?

Let us find:

If two half slip rings are connected to ends of the coil as shown in figure 17(c). The AC generator works as DC generator to produce DC current.

Let us see how it works.

When the coil in the vertical position the induced current generated during the first half rotation which rises from zero to maximum and then falls to zero again. As the coil moves further from this position, the ends of the coil go to other slip rings. Hence during the second half rotation, the current is reversed in the coil itself, the current generated in the second half rotation of the coil is identical with that during the first half DC current is shown in figure 17(d)for one revolution.

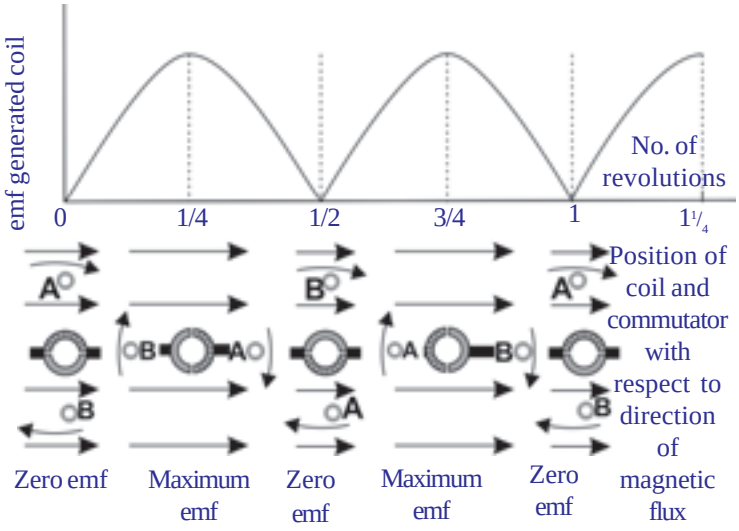


fig-17(d):

In generators, mechanical energy is converted into the electric energy.

Thanks to the scientists who gave us electrical energy by discovering generators

Key words

Magnetic flux, Magnetic flux density, Electric motor, Slip rings, Induced current, Induced EMF, Electric generator, DC and AC currents, rms values etc.

What we have learnt

- Magnetic flux density (B) is defined as the ratio of flux passing through the plane perpendicular to field and area of the plane.
- Current carrying wire produces magnetic field.
- F=qvB and F=BIL
- In electric motor, electrical energy is converted to mechanical energy.
- Faraday's law: the induced EMF generated in the closed loop is equal to the rate of change of magnetic flux passing through it.
- Lenz's law: the induced current will set up in the coil in such a direction that it opposes the changes in the flux.
- When a conductor of length '*l*' moves perpendicular to field B with a speed v then potential difference (voltage) developed between the ends of conductor is B*l*v. This EMF is called motional EMF.
- In generators, mechanical energy is converted into electrical energy.

Improve your learning

1. Are the magnetic lines closed? Explain. (AS1)
2. See fig. Q-2, magnetic lines are shown. In what direction does the current through wire flow?(AS1)
3. A bar magnet with North Pole facing towards coil moves as shown in fig.Q-3. What happens to magnetic flux passing through the coil? (AS1)
4. A coil is kept perpendicular to page. At P, current flows into the page and at Q it comes out of the page as shown in figure Q-4. What is the direction of magnetic field due to coil? (AS1)



fig- Q2

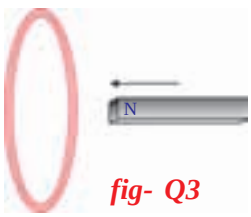


fig- Q3



fig- Q4

5. The direction of current flowing in a coil is shown in fig.Q-5. What type of magnetic pole is formed at the face that has flow of current as shown in fig.Q-5? (AS1)



fig- Q5

6. Why do the picture appear distorted when a bar magnet is brought close to the screen of a television? Explain (AS1)
7. X indicates the direction of a magnetic field into the page. A straight long wire carrying current along its length is kept perpendicular to the magnetic field. What is the magnitude of force experienced by the wire by the magnetic field? In what direction does it act? (AS1)

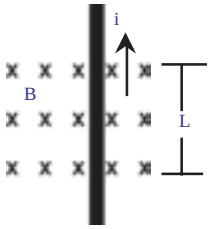


fig- Q7

8. Explain the working of electric motor with a neat diagram. (AS1)
9. Derive faraday's law of induction from conservation of energy. (AS1)
10. The value of magnetic induction of uniform field is 2T. What is the flux passing through the surface of area 1.5 m2 perpendicular to field? (AS1)
11. An 8N force acts on a rectilinear conductor 20cm long placed perpendicular to magnetic field. Determine the magnetic field induction if the current in the conductor is 40A. (Ans: 1tesla) (AS1)
12. Rajkumar said to you that the magnetic field lines are open and they start at north pole of bar magnet and end at south pole. What questions do you ask Rajkumar to correct him by saying "field lines are closed"? (AS2)

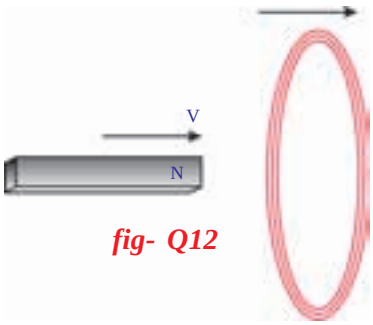


fig- Q12

13. As shown in figure Q-12 both coil and bar magnet moves in the same direction. Your friend is arguing that there is no change in flux. Do you agree with his statement? If not what doubts you have? Frame questions about doubts you have regarding change in flux. (AS2)
14. What experiment do you suggest to understand faraday's law? What material is required? What suggestions do you give to get good results of the experiment? Give precautions. (AS3)
15. How can you verify that current carrying wire produces magnetic field with the help of experiment? (AS3)
16. Collect information about generation of current by using faraday's law. (AS4)
17. Collect information about material required and procedure making simple electric motor from internet and make a simple motor on your own. (AS4)
18. Draw a neat diagram of electric motor. Name the parts. (AS5)
19. Draw a neat diagram of AC generator. (AS5)
20. How do you appreciate the faraday's law, which is the consequence of conservation of energy? (AS6)
21. How do you appreciate the relation between magnetic field and electricity that changed the life style of mankind? (AS6)
22. Give a few applications of faraday's law of induction in daily life. (AS7)
23. Which of the various methods of current generation protects the nature well? Give examples to support your answer. (AS7)

Chapter 7

Heat

Recall the experiments you did in Class 7 with the glasses of cold water, lukewarm water and hot water. We understood that 'hot' and 'cold' are relative terms and that heat was a form of energy. We use the word "Temperature and Heat" to describe these observations. These words, technically, have special meanings. In order to understand their meanings let us do some activities

Activity 1

Take a piece of wood and a piece of metal and keep them in a fridge or ice box. After 15 minutes, take them out and ask your friend to touch them.

- Which is colder? Why?

When we keep materials in a fridge, they become cold i.e., they lose heat energy. The iron and wooden pieces were kept in the fridge for the same period of time but, we feel that the metal piece colder than the wooden piece.

- What could be the reason for this change in coldness?
- Does it has any relation to the transfer of heat energy from our body to object?

When you touch the metal or wooden piece, you feel that they are cold. This means that heat energy is being transferred from your finger to the pieces. When you remove your finger, you don't get a feeling of 'coldness'. This means that when heat energy flows out of your body you get the feeling of 'coldness' and when heat energy enters your body you get a feeling of 'hotness'. You can test this by bringing your finger near the flame of a matchstick!

So, if you feel that the metal piece 'colder' than the wooden piece, it must mean that more heat energy flows out of your body when you touch the metal piece as compared to the wooden piece. In other words, the 'degree of coldness' of the metal piece is greater than that of the wooden piece.

The conventional definition of temperature is "the degree of hotness or coldness".

We say that the metal piece is at a lower 'temperature' as compared to the wooden piece when they are taken out of the fridge.

- Why transfer of heat energy takes place between systems?
- Does transfer of heat happen in all situation?
- What are the conditions for occurrence of transfer of heat energy?

Let us find

Thermal equilibrium-heat and temperature

When two bodies are placed in thermal contact, heat energy will be transferred from the 'hotter' body to the 'colder' body. This transfer of heat energy is continued till both bodies attain same degree of hotness (or) coldness. At this stage, we say that the bodies have achieved 'thermal equilibrium'. Thus, the state of thermal equilibrium denotes a state of a body where it neither receives nor gives out heat energy.

If you are not feeling either hotness or coldness in your surroundings, then your body is said to be in thermal equilibrium with the surrounding atmosphere. Similarly, the furniture in the room is in thermal equilibrium with air in the room. So we can say that the furniture and the air in the room are at same temperature.

Heat

- What is temperature?
- How can you differentiate it from heat?

Let us find

Activity 2

Take two cups and filled one of them with hot water and another with cold water. Now take a laboratory thermometer, observe the mercury level in it and note it in your note book. Keep it in hot water. Observe changes in mercury level. Note the reading.

- What change did you notice in mercury level?

- Did mercury level increase or decrease?

Now place the thermometer in cold water and observe changes in mercury level.

Did mercury level decrease or increase?

We know that bodies in contact achieve thermal equilibrium due to transfer of heat energy. When you kept thermometer in hot water you will observe that there is raise in mercury level. This happens because heat has transferred from hotter body (hot water) to cold body (mercury in thermometer). Similarly I second case you will observe that mercury level comes down from its level because of the transfer of heat from mercury (hotter body) to water (colder body). Thus we define heat as follows:

"Heat is a form of energy in transist that is transferred from body at higher temperature to body at lower temperature."

The steadiness of the mercury column of the thermometer indicates that flow of heat, between the thermometer liquid (mercury) and water, has stopped *thermal equilibrium* has been attained between the water and thermometer liquid (mercury). The thermometer reading at thermal equilibrium state gives the "temperature". Thus 'temperature' is a measure of thermal equilibrium.

If two different systems, A and B in thermal contact, are in thermal equilibrium individually with another system C(thermal contact with A and B), will the systems A and B be in thermal equilibrium with each other?

We know that if A is in thermal equilibrium with C, they both have the same temperature. Similarly, B and C have the same temperature. Thus A and B will have the same temperature and would therefore be in thermal equilibrium with each other. (A,B and C are in thermal contact).

The SI unit of heat is Joule (J) and CGS unit is calorie (cal).The amount of heat required to increase the temperature of 1gram of water by 1^0C is called calorie.

1cal = 4.186 joules

The SI unit of temperature is Kelvin (K). It can also be expressed as degree Celsius (^{0}C).

0^0C = 273K

- How would you convert degree Celsius to Kelvin?

Temperature in Kelvin =273+Temperature in Celsius

Add 273 to the value of temperature in degree Celsius to get the temperature in the Kelvin scale.

Note: Temperature measured in Kelvin scale is called absolute temperature.

Temperature and Kinetic energy

Activity 3

Take two bowls one with hot water and second with cold water. Gently sprinkle food colour on the surface of the water in both bowls .Observe the motion of the small grains of food colour.

- How do they move?
- Why do they move randomly?
- Why do the grains in hot water move more rapidly than the grains in cold water?

You will notice that the grains of food colour jiggle (move randomly). This happens because the molecules of the water in both bowls are in random motion. We observe that the jiggling of the grains of food colour in hot water is more when compared to the jiggling in cold water.

We know that bodies possess kinetic energy when they are in the motion.

As the speed of motion particles (grain of food) in the water of both bowls is different, we can say that they have different kinetic energies.Thus we conclude that the average kinetic energy of molecules / particles of the hotter body is larger than that of a colder body. So we can say that the temperature of a body is an indicator of the average kinetic energy of molecule of that body.

"The average kinetic energy of the molecules is directly proportional to the absolute temperature"

Activity 4

Take water in a jar and heat it to 60°C. Take a cylindrical transparent glass jar and fill half of it with the hot water. Very gently pour coconut oil over the surface of the water. (Take care that the water and oil do not mix). Put a lid with two holes on the top of the glass jar. Take two thermometers and insert them through holes of the lid in such a way that bulb of the one thermometer lies inside the water and other lies inside the coconut oil as shown in the figure 1.

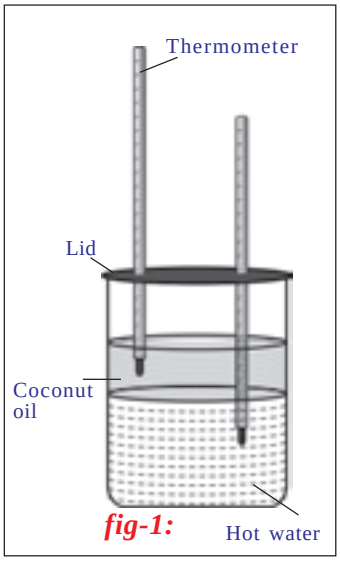


fig-1:

Now observe the readings of the two thermometers. The reading of the thermometer kept in water decreases, while,

at the same time, the reading of the thermometer kept in oil increases.

- Why does this happen?

Because the average kinetic energy of the molecules of oil increases, while the average kinetic energy of the molecules of water decreases. In other words, the temperature of oil increases while the temperature of water decreases.

- Can you say that the water loses energy?

From the above discussion it is clear that, water loses energy while oil gains energy; because of the temperature difference between the water and oil. Thus some heat energy flows from water to oil. This means, the kinetic energy of the molecules of the water decreases while the kinetic energy of the molecules of oil increases.

- Can you now differentiate between heat and temperature with discussion we have in above activities?

With activities 2, 3 and 4 we can differentiate heat and temperature as follows:

Heat is the energy that is transferred from hotter to colder body. Temperature is a quantity that decides which body is hotter and which is colder. So temperature decides direction of heat (energy) flow, whereas heat is the energy itself that flow.

SPECIFIC HEAT

Activity 5

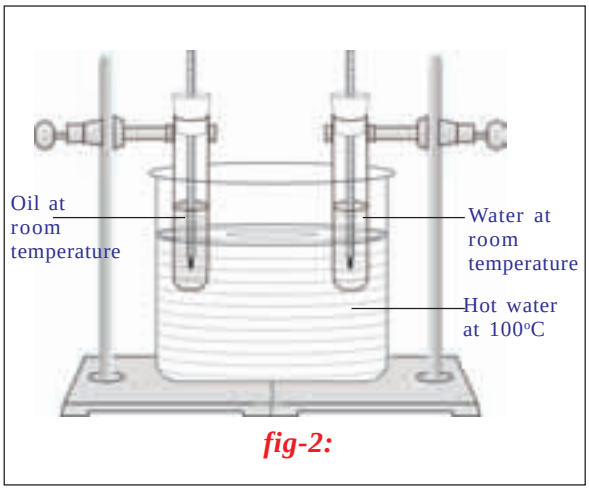


fig-2:

Take a large jar with water and heat it up to 100°.Take two identical boiling test tubes with single-holed corks and fill them, one with 50gm of water and the other with 50gm of oil. Insert two thermometers through holes of the corks, one each in two test tubes. Now clamp them to a retort stand and place them in the jar of hot water as shown in the figure 2.

Observe the readings of thermometers every three minutes .Note the readings in your notebook.

- In which material does the temperature rise quickly?
- Are the amounts of heat given to the water and oil same? How can you assume this?

We believe that the same amount of heat is supplied to water and oil because they kept in the water of same temperature for the same interval of time.

We observe that the rise in temperature of the oil is faster than the rise in temperature of the water.

- Why does this happen?

We conclude that the *rise in temperature depends on the nature of the material.*

Activity 6

Take 250 ml of water in one beaker (a small beaker) and 1 litre of water in another beaker (a large beaker), and note down their initial temperature using a thermometer (initial temperatures of them should be equal). Now heat both beakers till their temperature of water in two beakers rises by 90 ^{0}C from their initial temperatures. Note down the heating times required to rise temperature of water by 90 ^{0}C in each beaker.

- When do you need more time?

You will notice that you need more time to rise temperature by 90 ^{0}C for water in larger beaker when compared to water in small beaker that means you need to supply more heat energy for water in larger beaker than water in small beaker for same change in temperature.

For same change in temperature the amount of heat absorbed by a body is directrly proportional to its mass (m)

⇨ $Q \propto m$ (when ΔT is constant) ……..(1)

Now take 1 litre of water in a beaker and heat it. Note the temperature changes (ΔT) for every two minutes.

- What do you notice?

You will notice that the change in temperature rise with time, that means, for the same mass (m) of water the change in temperature is proportional to amount of heat (Q) absorbed by it.

⇨ $Q \propto \Delta T$ (when 'm' is constant) …….(2)

From equation (1) and (2), we get

$Q \propto m\Delta T$ (as $Q = ms\Delta T$)

Where 's' is a constant for a given material. This constant is called "Specific heat" of substance.

$$S = \frac{Q}{m\Delta T}$$

Substance	Specific heat	
	In cal/g-0C	In J/kg-K
Lead	0.031	130
Mercury	0.033	139
Brass	0.092	380
Zinc	0.093	391
Copper	0.095	399
Iron	0.115	483
Glass(flint)	0.12	504
Aluminum	0.21	882
Kerosene oil	0.50	2100
Ice	0.50	2100
Water	1	4180
Sea water	0.95	3900

The specific heat of a material is the amount of heat required to rise the temperature of unit mass of the material by a unit.

- How much heat energy is required to raise the temperature of unit mass of material by 1°C ?

CGS unit of specific is cal / g -°C and SI unit of it is J / kg - K

1 cal/g- = 1 kcal /kg-K
= 4.2 x J/kg-K
= 4.2 KJ/kg-K (Here $K=10^3$)

We have seen that the rise in temperature depends on nature of the material; hence the specific heat of the material depends on its nature. If the specific heat is high the rise in temperature is low. It gives us an idea of degree of 'reluctant' of a material to rise in temperature.

- Why is the specific heat different for different materials?

Let us find.

We know that the temperature of the body is directly proportional to the average kinetic energy of particle of the body.The molecules of the system (body or material) have different energies such as linear kinetic energy, rotational kinetic energy, vibrational energy and potential (binding) energy between molecules. The total energy of the system (body or material) is called *internal energy* of the system (body or material). When we supply heat energy to the system (body or material) the heat energy given to it will be shared in various forms.

This sharing will vary from material to material. The rise in temperature is high for a material, if the maximum share of heat energy is spent in increasing its linear kinetic energy. This sharing of heat energy of the system (body or material) also varies with temperature .That is why the specific heat is different for different material.

If we know the specific heat of a substance, we can determine how much heat (Q) is needed to raise the temperature of a certain mass of substance to a certain level by using the equation $Q = ms\Delta T$

Applications of Specific heat capacity:

1. The sun delivers a large amount of energy to the Earth daily. The water masses on Earth, particularly the oceans, absorb this energy for maintaining a relatively constant temperature. The oceans behave like heat "store houses" for the earth. They can absorb large amounts of heat at the equator without much rise in temperature due to high specific heat capacity of water.. Therefore, oceans moderate the surrounding temperature near the equator. Ocean water transports the heat away from the equator to areas closer to the north and south poles. This transported heat helps moderate the climates in parts of the Earth that are far from the equator.

2. Water melon brought out from the refrigerator retains its coolness for a longer time than any other fruit because it contains large percentage of water. (water has greater specific heat).

3. The samosa seems to be cool but it is hot when we eat it because the curry inside samosa contains ingredients with higher specific heats.

Method of mixtures

Activity - 7

Situation – 1: Take two beakers of the same size and pour 200 ml of water in each of them. Now heat the water in both beakers till they reach to the same temperature. If you pour the water from these two beakers into a larger beaker, what do you expect the temperature of the mixture to be? Measure the temperature of mixture.

- What do you notice?
- What could be the reason for the fact you noticed?

Situation – 2: Now heat the water in one beaker to 90°C and the other to 60 . Mix the water from these beakers in large beaker.

- What will be the temperature of the mixture?
- Measure temperature of mixture. What did you notice?
- Can you give reason for the change in temperature?

Situation – 3: Now take 100 ml of water at 90 and 200 ml of water at 60 and mix the two.

- What is the temperature of the mixture?
- What difference do you notice in change of temperature?

Let us find.

Let the initial temperatures of the samples of masses m_1 and m_2 be T_1 and T_2 (the higher of the two temperatures is called T_1, the lower is called T_2). Let T be the final temperature of the mixture.

The temperature of the mixture is lower than the temperature of the hotter sample, but higher than the temperature of the colder sample. This means that the hot sample has lost heat, and the cold sample has gained heat.

The amount of heat lost by the hotter sample Q_1 is $m_1S(T_1 - T)$.

The amount of heat gained by the cooler sample, Q_2, is $m_2S(T - T_2)$.

Since heat lost by the first sample is equal to the heat gained by the other sample i.e $Q_1 = Q_2$,

which can be written as $m_1S(T_1 - T) = m_2S(T - T_2)$

Which can be simplified to $T = (m_1T_1 + m_2T_2)/(m_1 + m_2)$

You will notice the temperatures of mixtures in situation – 2 and situation – 3 are not equal.

- Can you guess the reason for this?
- Can we find temperature of mixture using a thermometer?

Principle of method of mixtures:

When two bodies or more bodies at different temperatures are brought into thermal contact, then net heat is lost by the hot bodies is equal to net heat gain by the cold bodies until they attain thermal equilibrium. (If heat is not lost by any other process)

Net heat lost= Net heat gain

This is known as principle of method of mixtures.

Determination of Specific heat of solid:

Lab Activity 1

Aim: To find the specific heat of given solid.

Apparatus: calorimeter, thermometer, stirrer, water, steam heater, wooden box and lead shots.

Procedure: The mass of the calorimeter along with stirrer is determine by common balance. One third of the volume of the calorimeter is filled with water and its mass is measured as .

The calorimeter is placed in the wooden box and temperature is measured using thermometer.

Lead pieces is placed in steam heater they are heated to a temperature is quickly transferred in to calorimeter, with minimum loss of heat. Contents in the calorimeter are stirred well and then resultant temperature is noted .

Since there is no loss of heat to surroundings, we can assume that the entire heat lost by the solid is transferred to the calorimeter and water to reach the final temperature. The mass of the calorimeter along with contents is measured as m_3.If , and are the specific heats of the calorimeter, solid pieces and water respectively.

Heat lost by the solid = Heat gain by the calorimeter + Heat gain by the water

$$(m_3 - m_1)\, S_s(T_2-T_3) = m_1\, S_c(T_3-T_1)+(m_2-m_1)\, S_w(T_3-T_1)$$

$$S_s = \frac{[m_1S_c+(m_2-m_1)S_w]\,(T_3-T_1)}{(m_3-m_1)(T_2-T_3)}$$

Knowing the specific heat capacities of we can calculate the specific heat of the solid pieces.

EVAPORATION

When wet clothes dry, you will notice the water in clothes disappear.

- Where does the water go?

Similarly, when floor of the room is washed with water, the water on the floor dries within minutes.

- Why does water on the floor disappear after some time?

Let us see.

Activity 8

Take a small amount of spirit in a cup (make sure there is no flame near it). Pour a few drops on your palm.

- Why does your skin become colder?

Take a few drops of spirit (say 1 ml) in two petri dishes (a shallow glass or plastic cylindrical lidded dish used in the laboratory) separately. Keep the one of the dishes containing spirit under a ceiling fan and switch on the fan . Keep another dish with its lid closed. Observe the quantity of spirit in both dishes after 5 minutes.

- What do you notice?

You will notice that spirit in the dish that kept under the ceiling fan disappear. Where as you will find some spirit in the dish that kept in closed room?

- What could be the reason for this change?

To answer above questions you need to understand the process of evaporation. Let us consider second situation activity – 8. The molecules of spirit that kept in petri dish continuously move with random speeds in

various directions. As a result these molecules collide with others molecules.

During the collision they transfer energy to other molecules. When the molecules inside of the liquid collide with molecules at the surface, the molecules at the surface acquire energy and fly off from the surface.

Some of these escaped molecules may be directed back into liquid when they collide the particles of air the surface of liquid, but number of escaped molecules is always greater than the number returned. Thus when a liquid exposed to air, the particle at the surface keep on escaping from the surface till the entire liquid disappears. This process is called *evaporation.*

During the process of evaporation the energy of the molecules inside the liquid slows down. They transfer this energy to escaping molecules during the collisions.

"The process of escaping of molecules from the surface of a liquid at any temperature is called evaporation"

Let us see the reason for faster evaporation of spirit under the fan. If air is blown over the liquid surface in an open pan the number of returning molecules is reduced to a large extent. This is because any molecule escaping from the surface is blown away from the vicinity of the liquid. This increases the rate of evaporation. This is the reason for the spirit in petri dish that kept under ceiling fan evaporates quickly when compared to that kept in closed room. You will notice clothes dry faster when a wind is blowing.

It means that the temperature of the system falls during evaporation.

Evaporation is a surface phenomenon.

We can also define evaporation "as the change of phase from liquid to gas that occurs at the surface of the liquid". It is a cooling process, because the particles of liquid continuously give up their energy to the particles that are escaping from the surface.

Let us look at the following example.

- Why do we sweat while doing a work?

When we work our bodies produce heat. As a result the temperature of the skin becomes higher and the water in the sweat glands starts evaporating. This evaporation cools the body.

Rate of evaporation of a liquid depends on its surface area, temperature and amount of vapour already present in the surrounding air.

- Does the reverse process of evaporation take place?
- When and how does it take place?

Let us find.

CONDENSATION

Activity 9

Place a glass tumbler on the table. Pour cold water up to half its height.

- What do you observe?
- Why do water droplets form on the outer side of the glass?

We know that the temperature of surrounding air is higher than the temperature of the cold water.

Air contains water molecules in the form of vapour.

When the molecules of water in air, during their motion, strike the surface of glass tumbler which is cool; then the molecules of air lose their kinetic energy which leads to lower the temperature and they get converted into droplets.

The energy lost by the water molecule in air will be given to the molecules of glass tumbler. Hence the average kinetic energy of the glass molecules increases. In turn the energy is transferred from glass molecules to the water molecules in the glass.

In this way the average kinetic energy of water molecules in the tumbler rises. Hence we can conclude that the temperature of the water in glass increases. This process is called '*condensation*'. It is warming process.

"Condensation" can also be defined as the phase change from gas to liquid that at the surface of the liquid".

Let us examine a situation:

You feel warm after you finish your bath under the shower on hot day. In the bathroom, the number of vapour molecules per unit volume is greater than number of vapour molecules per unit volume outside the room. When you try to dry yourself with a towel, the vapour molecules surrounding you condense on your skin and this condensation makes you feel warm.

HUMIDITY

Some vapour is always present in air. This vapour may come from evaporation of water from the surfaces of rivers, lakes, ponds and from the drying of wet clothes, sweat and so on. The presence vapour molecules in air is humid. The amount of water vapour present in air is called the *humidity* of air.

DEW AND FOG

In early morning time during winter you might have noticed that water droplets form on window panes, flowers, grass etc.

- How these water droplets are formed?

Let us find.

During winter nights, the atmospheric temperature goes down. The surfaces of window-panes, flower grass etc, become still colder. The air near them becomes saturates and condensation begins. The water droplets condensed on such surface are known as *dew*.

If the temperature falls further, the whole atmosphere in that region contain maximum amount of vapour. So the water molecules present in vapour condense on the dust particles in air and form small droplets of water. These droplets keep on floating in the air and form a thick mist which restricts visibility. This thick mist is called *fog*.

- Does the temperature of the water rise continuously if heat is supplied continuously?

BOILING

Activity 10

Take a beaker of water, keep it on the burner .Note the readings of thermometer every 2 minutes

- Did you see any rise or fall in level of the surface of the water, taken in a transparent glass beaker? Why?
- Does the temperature rise continuously?
- When does the rise in temperature of water stop?

You will notice that, the temperature of the water rises continuously, till it reaches 100°C. At 100°C no further rise of temperature of water is seen. At 100 ^{0}C, though supply heat continues we can observe a lot of bubbling at the surface of water at this 100°C temperature. This is what we call *boiling* of water

- Why does this happen?

Water is a solution, there are many impurities dissolved in it including some gases. When water or any liquid is heated, the solubility of gases it contains reduces. As a result, bubbles of gas are formed in the liquid (on the bottom and walls of the vessel). Evaporation of water molecules from surrounding liquid occurs in to these bubbles, and they become filled with saturated vapour, whose pressure increase as we increase temperature of

the liquid by heating. At a certain temperature, the pressure of the saturated vapour inside the bubbles becomes equal to the pressure exerted on the bubbles from the outside (this pressure is equal to the atmospheric pressure plus the pressure of the layer of water above the bubble). As a result of these bubbles rise rapidly to the surface and collaps at the surface releasing vapour present in bubbles into air at the surface. This process of converting the liquid into vapour (gas) continues as long as you supply heat. This appears as boiling of water for us.

"The process in which the liquid phase changes to gaseous phase at a constant temperature ". This temperature is called boiling point of the liquid.

- Are the process of evaporation and boiling the same?

As you have seen in activity – 8 and 10, the boiling of a liquid differs essentially from evaporation. Note that evaporation takes place at any temperature, while boiling occurs at a definite temperature called the boiling point. Let us recall your observation in activity – 10 that, when boiling process starts, the temperature of the liquid cannot be raised, no matter how long we continue to heat it. The temperature remains at the boiling point until all of the liquid has boiled away.

In activity – 10, you have noticed that, while heating the water in the beaker, the temperature of water rises continuously till it reaches 100 ^{0}C. But once boiling was started, no further rise temperature seen though supply of heat continues.

- Where does the supplied heat energy go?

This heat energy is used to change the state of water from liquid to vapour (gas). This is called *latent heat of vapourization.*

The heat energy is required to change 1gr of liquid to gas at constant temperature is called latent heat of vapourization.

Consider a liquid of mass 'm' requires heat energy 'Q' calories to change from its state liquid phase to gas phase. Then ***Latent heat of vapourization*** is **Q/m**. Latent heat of vaporization is denoted by '**L**'.

CGSunit and SI unit of latent heat of vaporization is cal/gm and J/kg respectively.

The boiling point of water at constant atmospheric pressure (1atm) is 100°C or 373K and Latent heat of vaporization of water is 540 cal/gm.

- Why does the ice cube get converted into water?

MELTING

Activity 11

Take small ice cubes in a beaker. Insert the thermometer into ice cubes in the beaker. Observe the reading of thermometer. Now start heating the beaker keeping on a burner. Observe changes in the reading of thermometer for every 1 minute till the ice completely melts and gets converted into water.

- What changes, do you notice in reading of thermometer as time lapses?
- Does the temperature of the ice change during the process of melting?

You will observe that the temperature at beginning is below $0\ ^0$Cand it goes on changing till it reaches 0^0C. When ice starts melting, you will notice no change in temperature though you are supplying heat continuously.

- Why does this happen?

The heat energy supplied to the ice increases the internal energy of the molecules of the ice. This increase in internal energy of molecules weakens the bonds as well as breaks the bonds between the molecules (H_2O) in the ice. That is why the ice (in solid phase) becomes water (in liquid phase).This process takes place at a constant temperature 0°C or 273K. This temperature is called *melting point.* This process of converting solid into a liquid is called "***Melting***".

The temperature of the ice does not change during melting because the heat energy given to the ice is totally utilized in breaking the bonds between the water molecules.

The process in which solid phase changes to liquid phase at a constant temperature is called melting. This temperature is called melting point.

- How much energy is required to convert 1gm of ice to liquid?

The Heat energy required to convert 1gm of solid completely into liquid at a constant temperature is called *Latent heat of fusion.*

Consider a solid of mass m which requires heat energy Q to change from the solid phase to liquid phase. The heat required to change 1gm of solid into liquid is Q/m.

Latent heat of fusion L = Q/m. The value of Latent heat of fusion of ice is 80cal/gm

FREEZING:

You might have observed coconut oil, ghee converts from liquid state to solid state during winter season.

- What could be the reason for this change?
- What happens to water kept in a refrigerator?
- How it converts from liquid phase to solid phase?

We know that the water that is kept in a refrigerator converts in to solid ice. You know that temperature of water is more compared to the temperature of ice. It means that during the process of conversion from liquid to solid the internal energy of the water decreases so that it becomes a solid ice. This process is called *freezing*.

"The process in which the a substance in liquid phase changes to solid phase by losingsome energy from it is called *freezing*."

Freezing of water takes place at 0°C temperature and at one atmospheric pressure.

- Are the volumes of water and ice formed with same amount of water equal? Why?

Let us find.

Activity 12

Take small glass bottle with a tight lid .Fill it with water completely without any gaps and fix the lid tightly in such a way that water should not come out of it. Put the bottle into the deep freezer for a few hours. Take it out from the fridge and you will observe the glass bottle after a few hours.

- What do you observe?
- Why did the glass bottle break?

We know that the volume of the water poured into the glass bottle is equal to the volume of the bottle. When the water freezes to ice, the bottle is broken .This means that the volume of the ice should be greater than the volume of the water filled in bottle.

In short, we say that water 'expands' (increases in volume) on freezing!

Thus the density of ice is less than that of water and this explains why ice floats on water.

Key words

Temperature, Heat, Thermal equilibrium, Specific heat, Evaporation, Humidity, Dew, Fog, Boiling, Latent heat of vaporization, Melting, Freezing.

What we have learnt

- If two different systems, A and B, (thermal contact) are in thermal equilibrium individually with another system C. then the systems A and B are in thermal equilibrium with each other.
- The average kinetic energy of the molecules is directly proportional to the absolute temperature.
- The specific heat capacity of a material is the amount of heat required to rise the temperature of unit mass of the material by or unit.

  $S=Q/m\Delta t$
- Principle is the process of escaping of molecules from the surface of a liquid at any temperature and it is a cooling process.
- Condensation is the reverse process of evaporation.
- Boiling is the process in which the liquid phase changes to gaseous phase at a constant temperature.

Improve your learning

1. What would be the final temperature of a mixture of 50g of water at 200C temperature and 50g of water at 400C temperature? (AS1)
2. Explain why dogs pant during hot summer days using the concept of evaporation? (AS1)
3. Why do we get dew on the surface of a cold soft drink bottle kept in open air? (AS1)
4. Write the differences between evaporation and boiling? (AS1)
5. Does the surrounding air become warm or cool when vapour phase of H2O condenses? Explain. 6. Answer these. (AS1)
   a) How much energy is transferred when 1gm of boiling water at 1000C condenses to water 1000C?
   b) How much energy is transferred when 1gm of boiling water at 1000C cools twice water 00C?
   c) How much energy is transferred when 1gm of water at 00C freezes to ice at 00C?
   d) How much energy is transferred when 1gm of steam at 1000C turns to ice 00C?
7. Explain the procedure of finding specific heat of solid experimentally. (AS1)
8. Covert 200C into Kelvin scale.(AS1)

9. Your friend is notable to differentiate between evaporation and boiling. What questions do you ask to make him know the differences between evaporation and boiling? (AS2)
10. What happens to the water when wet clothes dry? (AS3)
11. Equal amounts of water are kept in a cap and in a dish. Which will evaporate faster? Why? (AS3)
12. Suggest an experiment to prove that rate of evaporation of liquid depends on its surface area and vapour already present in surrounding air. (AS3)
13. Place a Pyrex funnel with its mouth-down in a sauce pan with full of water, in such a way that the stem tube of the funnel is above the water or pointing upward into air. Rest the edge of the bottom portion of the funnel on a nail or on a coin so that water can get under it. Place the pan on a stove and heat it till it begins to boil. Where do the bubbles form first? Why? Can you explain how a geyser works using above experience. (AS4)
14. Collect the information about working of geyser and prepare a report. (AS4)
15. How do you appreciate the role higher specific capacity value of water in stabilising atmospheric temperature during winter and summer seasons? (AS6)
16. Suppose that to 1l of water is heated for a certain time to rise and its temperature by 20C. If 2l of water for the same time, by how much will its temperature rises? (AS7)
17. What role does specific heat capacity play in a watermelon to keep it cool for long time after removing it from a fridge on a hot day? (AS7)
18. If you are chilly outside the shower stall, why do you feel warm after the bath if you stay in bathroom? (AS7)
19. Assume that heat is being supplied continuously to the ice at -50C. You know that ice melts at 00C and boils at 1000C. Continue the heating till it starts boiling. Note the temperature for every minute. Draw a graph between temperature and heat using the values you get. What do you understand from the graph. Write the conclusions. (AS5)

Fill in the blanks

1. The SI unit of specific heat is_____
2. _____ flows from a body at higher temperature to a body at lower temperature.
3. _____ is a cooling process.
4. An object 'A' at 10 ^{0}C and another object 'B' at 10K are kept in contact, then heat will flow from _____ to _____.
5. The latent heat of fusion of ice is _____.
6. Temperature of a body is directly proportional to _____.
7. According to the principle of method of mixtures, the net heat lost by the hot bodies is equal to _____ by the cold bodies.

8. The suffocation in summer days is due to _____.
9. _____ is used as a coolant.
10. Ice floats on water because _____.

Multiple choice questions

1. Which of the following is a warming process [ ]
   a) Evaporation b) condensation c) boiling d) all the above
2. Melting is a process in which solid phase changes to [ ]
   a) liquid phase b) liquid phase at constant temperature
   c) gaseous phase d) any phase
3. Three bodies A, B and C are in thermal equilibrium. The temperature of B is 450C. then the temperature of C is _____ [ ]
   a) 450C b) 500C c) 400C d) any temperature
4. The temperature of a steel rod is 330K. Its temperature in 0C is _____ [ ]
   a) 550C b) 570C c) 590C d) 530C
5. Specific heat S = [ ]
   a) $Q/\Delta t$ b) $Q\Delta t$ c) $Q/m\Delta t$ d) $m\Delta t/Q$
6. Boiling point of water at normal atmospheric pressure is _____ [ ]
   a) 00C b) 1000C c) 1100C d) -50C
7. When ice melts, its temperature [ ]
   a) remains constant b) increases c) decreases d) cannot say