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Chapter Ten

RECTILINEAR PROPAGATION OF LIGHT AND REFLECTION AT PLANE SURFACES

Introduction

- **O**ptics is a branch of physics which studies the behaviour of light as it traverses various media.
- Optical instruments such as cameras, microscopes, periscopes and laws governing their working form a major part of this branch of physics.
- Light is a form of energy. Light regulates your daily life. You need light to see the size, shape and colour of things around you.

Sources of Light

- There are two : **luminous (incandescent)** and **non-luminous**
- ***Luminous objects*** are those which produce their own light e.g. sun, candles, electric lamps, glowing worms etc.
- ***Non-luminous*** objects are those which don't give their own light but reflect light that comes from a luminous object. These are objects. Examples are: the moon, paper, you ***etc.***
- You can see an object clearly if light from it enters your eyes.

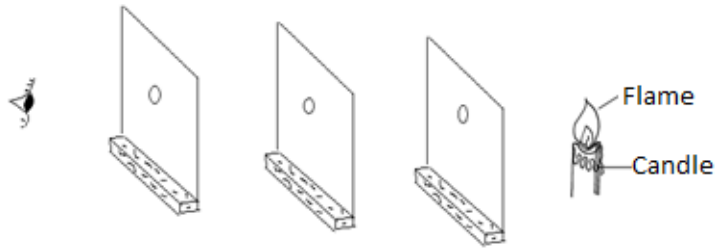
Transparent, Translucent and Opaque Objects

- *Transparent objects* are those which allow light to pass through them e.g. a glass window, clear water, the air around you. All these substances let light pass through them.
- *Opaque objects* are those which cannot allow light to pass through them e.g. wool, steel, Brick.
- *Translucent bodies* are those which let light pass through them, but scatter in all directions e.g. lamp shades, frosted glass, some plastic etc.

Rectilinear Propagation of Light

- This is the property of light to travel in a straight line in a medium of homogeneous propagation density.
- Light does not travel around corners. The formation of shadows shows that light travels in a straight line. When an opaque body is placed in a beam of light, a shadow is formed.

Demonstrating Rectilinear Propagation of Light



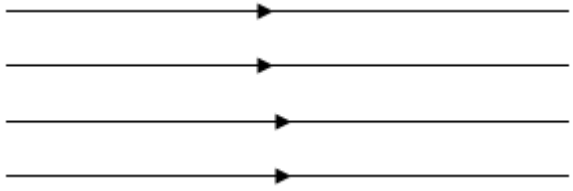
- Make a small hole in each of the three card boards ensuring that all the holes are at the same height.
- The lamps positioned in such a way that a ray of light passes through all the holes.
- When the cardboard is displaced by moving it slightly to the one side, the eye will not see the lamp. This shows that light travels in a straight line.

Rays of Light and Beam of Light

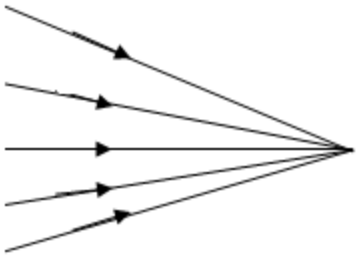
- ***A ray*** is a narrow stream of light of negligible thickness while a ***beam of light*** is a collection of rays of light.

Types of beams

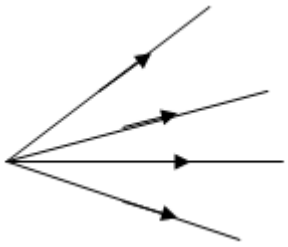
- A beam in which rays are parallel to each other is called ***parallel beam***.



- A beam in which the rays converge at a point is called a ***convergent beam***.



- A beam in which the rays spreads out from a point is a ***divergent beam***



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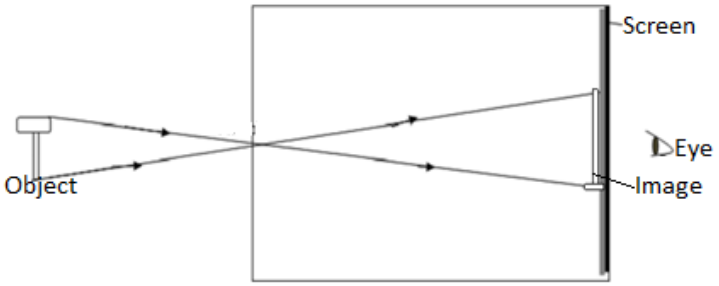
The Pinhole Camera

- A pin-hole camera is made using a small rectangular box with a pin hole at one end, a large rectangular hole at one end, a large rectangular hole at the other end.
- The rectangular hole at the back is covered with a screen of special paper like grease proof paper which lets some light pass through it (i.e. it is translucent).

Advantage

- It is able to form focused images on the film of objects both near and far from the camera.

Image Formation by a Pinhole Camera



The Length (Size) Of Image

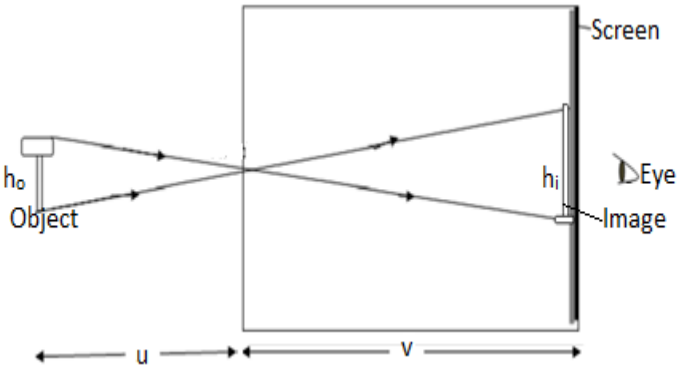
- The length of the image formed depends on:
  a) The distance of the object from the pinhole
  b) The length of the camera box

MAGNIFICATION

- This is the ratio of the image size to the object size or the ratio of the image distance to the object distance.

$$Magnification = \frac{Image\ size}{object\ size}$$

$$Magnification = \frac{image\ distance}{object\ distance}$$



h_o=object height
h_i=image height
u=object distance
v=image distance from pinhole
Given that magnification is m, then

$m = \frac{h_i}{h_o}$ or $m = \frac{v}{u}$ and so $\frac{h_i}{h_o} = \frac{v}{u}$

Examples

1. ***A pinhole camera of length 15 cm forms an image 3cm high of a man standing 9m in front of the camera what is the height of the man?***

$$\frac{h_i}{h_o} = \frac{v}{u}$$

$$\frac{0.03\ m}{h_o} = \frac{0.15\ m}{9\ m}$$

$$h_o = \frac{0.03\ m \times 9\ m}{0.15\ m} = 1.8\ m$$

2. ***Lamp A of height 6cm stands in front of a pinhole camera at a distance of 24 cm. The camera screen is 8cm from the pinhole. What is the height of the image?***

$$\frac{h_i}{h_o} = \frac{v}{u}$$

$$\frac{h_i}{0.06\ m} = \frac{0.08\ m}{0.24\ m}$$

$$h_i = \frac{0.08\ m}{0.24\ m} \times 0.06\ m$$

$$h_i = 2\ m$$

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Exercise

1. ***An image 100mm long of a man 2m tall is pinned on top of a pin-hole camera. The distance of pin hole from the screen if the man is standing 6cm from the pinhole.***
2. ***An object 1m tall forms an image 5 cm tall from the screen of a pinhole camera. Find the distance of the object from the pin hole of the object if the length of the camera box is 40 cm.***

Effect on the Image Formed by the Pinhole Camera On:

(a) Many pin holes

- Each pinhole will form its image resulting into brighter but blurred image.

(b) Large pinhole

- A large hole is equivalent to several holes and will produce brighter but blurred image.
- However, a sharp image can be produced where a wide hole or several holes have been used by simply placing a converging lens in front of the many holes and in contact with the box. The convex lens brings all rays from a point on object to unique point on the screen.

The pin-hole camera can be modified as follows in order to take photographs:

- Should be painted black on the inside to eliminate reflection of light.
- Translucent screen to be replaced by light-tight lid with photographic film fitted on the inside.
- Should be covered with a thin black card which acts as a shutter.

The exposure time of a pin-hole camera depends on:

- Size of the pin-hole
- Lighting conditions
- Sensitivity of the film
- Length of the camera

Advantage of the Pinhole Camera over the Lens Camera

- The pinhole camera is preferred to the lens camera because it does not produce distortion.

The disadvantages of using a pin hole camera:

a) It takes a long time for image to be formed since the amount of light passing through the hole is small.
b) It cannot be used to take photographs of moving objects.

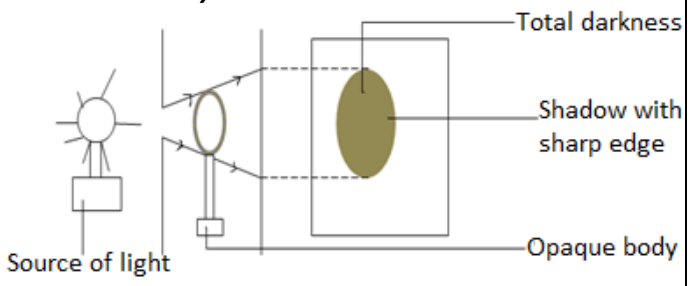
Shadows

- A shadow is a shade cast by an object blocking direct rays of light. The formation of shadows depends on the fact that light travels in a straight line

The size of the shadow formed depends on:

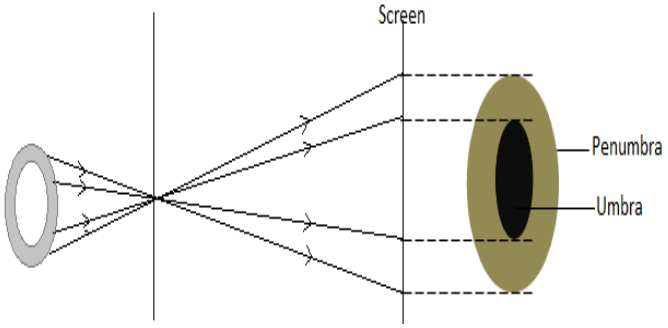
a) Size of sources of light.
b) Size of opaque object.
c) Distance between the object and source of light.

Shadow Formed by a Point Source



- A point source of light is one which is small enough for all the rays of light to come effectively from a single point.
- The shadow is uniformly and totally dark all over and is called ***<u>umbra.</u>*** The umbrella shape edges on the shadow shows that light travels on a straight line.

Shadows Formed by an Extended Source of Light.



- An extended source of light is large enough for rays to be seen to come from many points.
- The shadow is larger and has a central dark region called <u>*umbra*</u> surrounded a ring of partial shadow called <u>*penumbra*</u>.

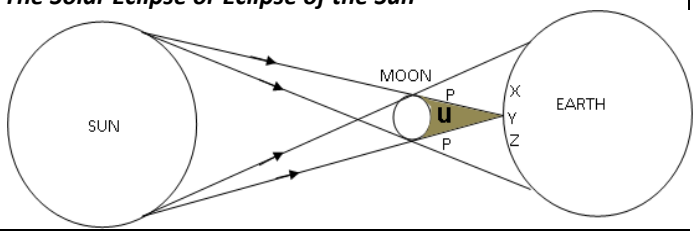
Application of extended light sources

a) Lampshades are used at home to provide a more pleasant kind of lightning.
b) Fluorescent tubes are usually surrounded by a frosted diffuse to scatter the light & reduce shadow sharpness.

Eclipses

An eclipse is the total or partial disappearance of sun rays as seen from the earth.

The Solar Eclipse or Eclipse of the Sun



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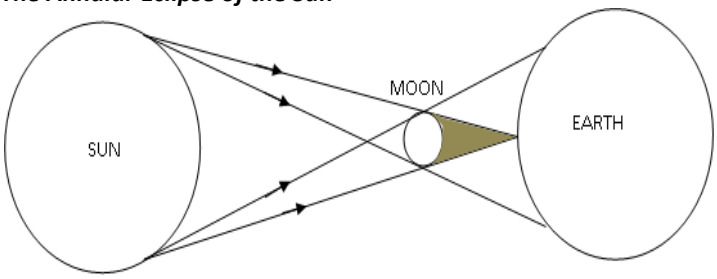
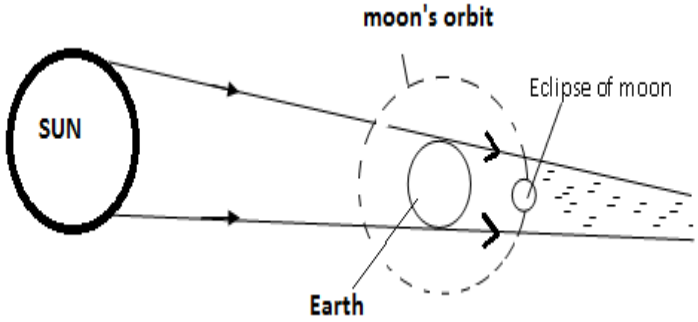
- The solar eclipse occurs when the moon comes between the sun and the earth

The Annular Eclipse of the Sun



- It occurs when the distance of separation between the earth and the moon is great. The umbra of the moon does not totally cover the sun edge of the dark disk of the moon.

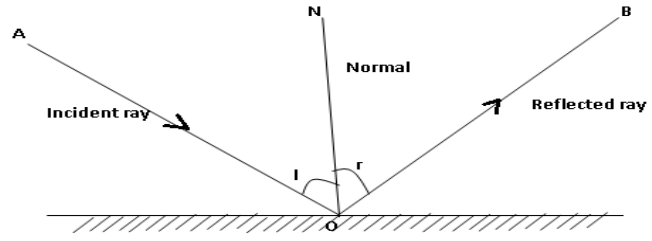
Lunar Eclipse or Eclipse of the Moon



- The eclipse of the moon occurs when the earth comes between the sun and the moon.
- When the lunar eclipse occurs, it lasts longer (about 1hr) than the solar eclipse because the moon is much smaller than the earth.
- During a total lunar eclipse some light reaches the moon due to refraction by the earth's atmosphere& make it look a coppery colour.

REFLECTION BY PLANE MIRRORS.

- When a ray of light meets a plane mirror it is reflection.
- An ordinary mirror is made by depositing a thin layer of metal, often silver paint at the back of the glass which acts as the reflecting surface.



- The ray from the source AO is called the ***incident ray***. The ray that bounces off from the Mirror O is called the ***reflected ray.*** ON is the ***normal.***
- The angle between incident ray and the normal is called ***Angle of incident angle, I*** between the normal and the Reflected ray is called ***angle of reflection***.

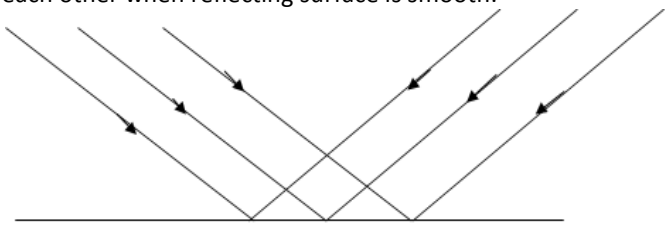
The Laws of Reflection

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

Types of Reflection

a) ***Regular or Specular Reflection***

It occurs when parallel incident rays are reflected parallel to each other when reflecting surface is smooth.



b) Irregular or Diffuse Reflection

Parallel incident rays are reflected in different directions for

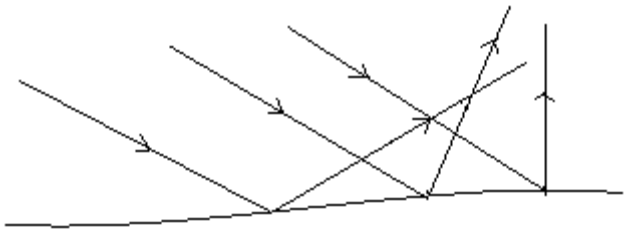
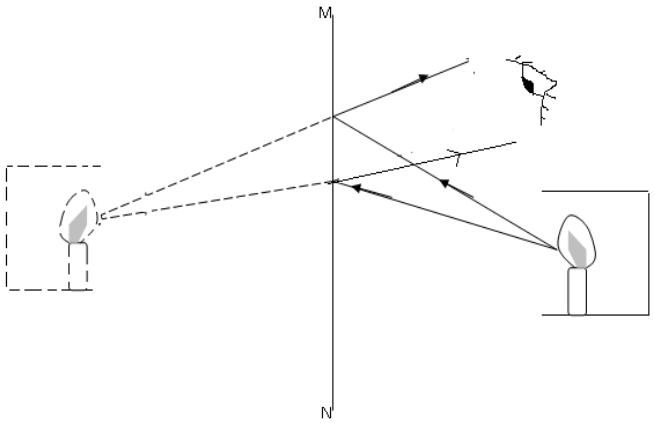


Image Formation by a Plane Mirror.

- The image of an object seen in a plane mirror is formed by rays of light travelling in straight lines which are reflected according to the laws of reflection.



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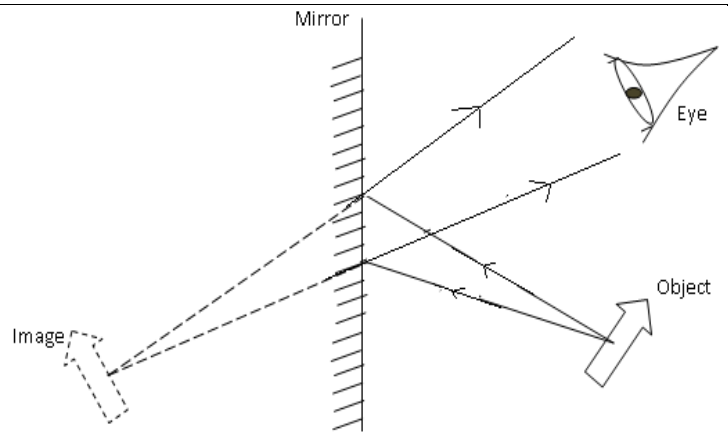


From the above diagram one can see that ***the image formed in a plane mirror is always:***

a) Erect (Upright)

b) As far behind the mirror as object is in front of it.

c) Virtual.

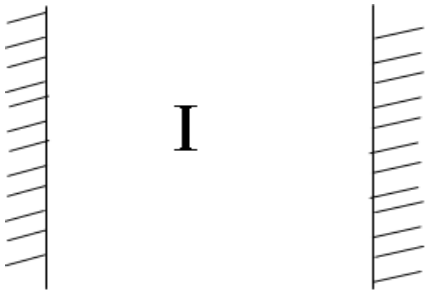
A virtual image is one:

- *which cannot be received on the screen*
- *which is formed by the intersection of virtual rays.*

c) Laterally inverted i.e. left appears on the right & vice versa

d) The same size as the object.

Image Formation in Parallel in Mirrors



- ❖ When an object is placed between two parallel mirrors as shown above an ***<u>infinite number of images</u>*** are formed.
- ❖ Each image seen in one mirror acts as a virtual object which in turn forms an image in the other mirror.
- ❖ The image becomes fainter because light energy is absorbed by the mirror at each successive reflection.
- ❖ The number of images formed by two mirrors inclined at an angle is given by the formula.

$$n = \frac{360}{\theta} - 1$$

Exercise

1. ***Find the number of images formed when mirrors are inclined at 20^o***
2. ***Find the angle between two mirrors if 35 images are formed***
3. ***At what angle would two mirrors be inclined if the number of images formed are (i) 17 (ii) 29?***

Rotation of a Mirror

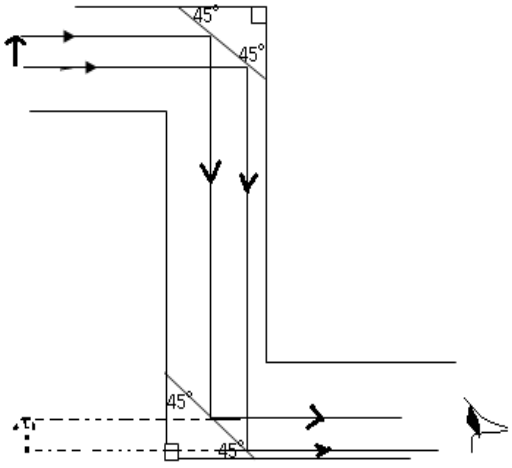
- ❖ When a mirror is rotated through an angle θ the reflected ray turns through 2θ.
- ❖ Hence, the reflected ray always turns through twice the angle through which the mirror is rotated.

Exercise

1. ***A mirror is rotated through an angle of 15^o through what angle does the reflected ray turn?***
2. ***A mirror is rotated through a certain angle and the reflected ray turned through 40^o what angle had the mirror been turned?***
3. ***An incident ray makes an angle of 25^o with the normal. If the mirror is turned through 9^o in the anticlockwise direction from the horizontal, through what angle is the reflected ray rotated?***

Application of Plane Mirrors

(a) The Periscope



- ❖ A periscope consists of a plane mirrors parallel to one another and inclined at angle of 45^o to the horizontal.
- ❖ They are used to help one see over an obstacle.

- Periscopes in submarines use prisms instead of plane mirrors because.
  1. *The silver part of the mirror easily gets damaged*
  2. *Thick mirrors produce multiple refractions*
  3. *There is no lateral inversion with prisms.*

(b) Use of plane mirrors in instrument scales

- Plane mirrors are often used behind pointers as instruments to improve the reading accuracy.
- When the pointer is viewed at an angle its image will be seen through the plane mirror.
- The image seen will enable the reader to know that reading being taken will have an error due to parallax. The reader will therefore position the eye vertically so that the image of the pointer is not seen and hence a correct reading will be taken.
- The sports galvanometer uses a ray of light as a pointer instead.

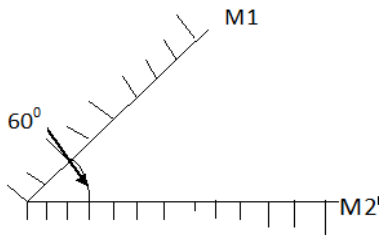
(c) The kaleidoscope

- It applies the principle of mirrors inclined at an angle.
- It consists of two mirrors M_1 and M_2 placed to each other at 60^0 to each other inside a tube.
- The instrument is used by designers to obtain ideas on systematic patterns.

Revision Exercise

1. (a) Sally went to Mary salon to have her hair dressed. The salon had two parallel mirrors placed on the walls which are 3 meters apart. While waiting to be attended to, she sat at a distance of 1 meter from one of the walls and noticed that there were multiple of her in each mirror. Determine the distance between the two nearest images formed in the two mirrors.

(b) Two plane mirrors are placed at an angle of 60^0 as shown below. A ray of light makes an angle of 40^0 with mirror m1 and goes to strike mirror M_2. Find the angle of reflection of Mirror M_2



2. What is rectilinear propagation of light?

3. Draw a ray diagram to show how a pinhole camera forms an image.

4. State the changes that would occur in the size and brightness of the image formed if

a) ***The object distance is made large.***

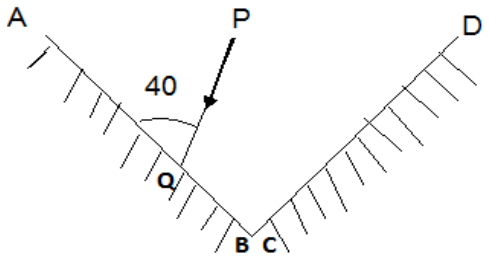
b) The length of the camera is made longer.

c) The single hole is replaced by four pinholes close together.

5. Define the term reflection of light.

6. State the Laws of reflection of light.

7. The mirror AB and CD are at right angles to each other.



a) What is the value of the angle of incidence of the ray PQ on the mirror AB?

b) Complete the diagram to show the path taken by the ray PQ after reflection at both mirrors.

c) Determine:

I. Angle of reflection on AB.

II. Angle incidence on CD.

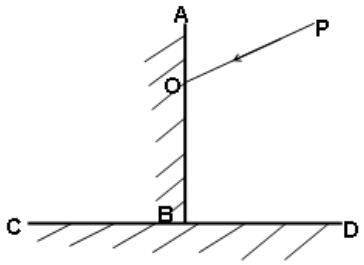
III. Angle of reflection on CD.

8. If a girl walks away from a plane mirror at a speed of 2m per second,

I. In what direction does her image move?

II. With what speed does her image move?

9. The figure below shows mirrors AB and CD inclined at right angles. A ray PO makes an angle of 30^o with mirror AB has as shown.



(i) Show the path of the ray after reflection from both mirrors.

(ii) What is the angle of incidence on the mirror CD?