Refraction and total internal reflection of light rays at different angles of incidence

Fig 4.46 shows the refraction of light rays from a point source A kept in a denser medium to a rarer medium at different increasing angles of incidence.

For the ray AO, the angle of incidence is zero, it is refracted as OA'.

For the ray AP, the angle of incidence i is less than the critical angle C (*i.e.*, $i < C$), it is partly reflected as PB and partly refracted as PC at an angle of refraction $r > i$.

For the ray AQ, the angle of incidence is equal to the critical angle for the pair of media (*i.e.*, $i = C$), so it is partly reflected as QB′ and partly refracted as QC′ at the angle of refraction r equal to 90°.

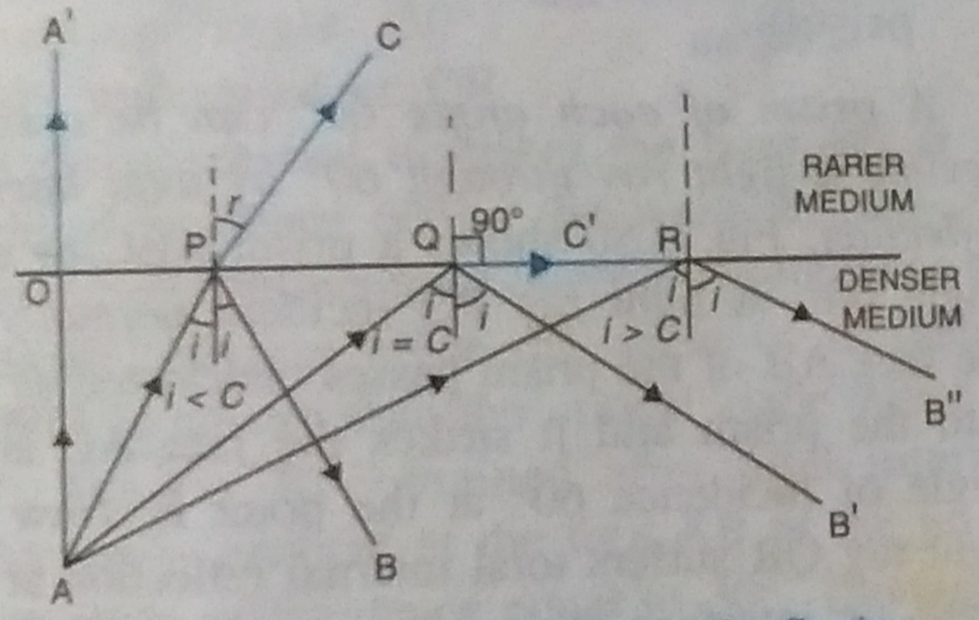

Fig 4.46 Refraction and total internal reflection

For the ray AR, the angle of incidence is greater than the critical angle (*i.e.*, $i > C$), so it is totally reflected as RB″ at an angle of reflection $r = i$, and *no refraction occurs*.

> *Note :* The above phenomenon of refraction and total internal reflection can easily be demonstrated with the help of a laser pen source. The main precaution is taken that the laser source is not seen directly as it may damage the eyes.

4.17 TOTAL INTERNAL REFLECTION IN A PRISM

Now we shall consider the phenomenon of total internal reflection in *three* different prisms : (1) 45°, 90°, 45° prism (*i.e.*, right angled isosceles prism or total reflecting prism), (2) prism of each angle 60° (*i.e.*, equilateral prism), and (3) 30°, 90°, 60° prism (*i.e.*, a right-angled prism).

(1) Total internal reflection through a 45°, 90°, 45° prism (or right-angled isosceles prism)

Total reflecting prism : *A prism having an angle of 90° between its two refracting surfaces and the other two angles each equal to 45°, is called a total reflecting prism* because *the light incident normally on any of its faces, suffers total internal reflection inside the prism.* Due to this behaviour, a total reflecting prism is used for the following *three* purposes :

(a) *to deviate a ray of light through 90°,*

(b) *to deviate a ray of light through 180°,* and

(c) *to erect the inverted image without producing deviation in its path.*

(a) *To deviate a ray of light through 90°*

In Fig. 4.47, ABC is a total reflecting prism. A beam of light is incident *normally* at the face AB. It passes undeviated into the prism and strikes at the face AC at an angle of incidence equal to 45°. For glass-air interface, the critical angle is about 42°, therefore the beam of light *suffers total internal reflection* at the face AC because the angle of incidence is greater than the critical angle. The reflected beam inside the prism then strikes the face BC, where it is incident normally and therefore passes undeviated. As a result, the incident beam gets deviated through 90° emerging out through the prism. Fig. 4.47 shows the path of two rays PQ and P′Q′ through the prism and then out of it.

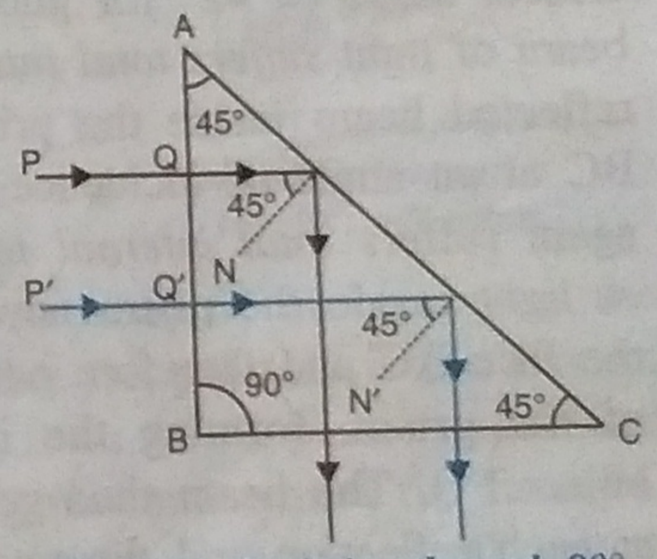

Fig. 4.47 Deviation through 90°

> *Note :* By the principle of reversibility of path of light, if light is incident *normally* on the face BC of the prism, it will emerge out from the face AB after suffering total internal reflection at the face AC.

Use : This action of prism is used in a *periscope* where a total reflecting prism is preferred over a plane mirror.

(b) To deviate a ray of light through 180°

In Fig. 4.48, the beam of light from the object PQ falls *normally* on the face AC (*i.e.*, hypotenuse) of the prism, so it enters undeviated inside the prism and strikes the glass-air interface AB of the prism. Since the beam of light is travelling from glass to air at an angle of incidence equal to 45° which is greater than the critical angle (= 42° for glass-air), therefore the beam of light *suffers total internal reflection.* The reflected beam inside the prism strikes the face BC at an angle of incidence equal to 45°, so it again suffers *total internal reflection.* The beam of light inside the prism now falls normally on the face AC and therefore passes undeviated out of the prism, forming the image P′Q′ of the object PQ. The beam thus gets deviated by 90° at each reflection and the total deviation due to two reflections becomes 180°.

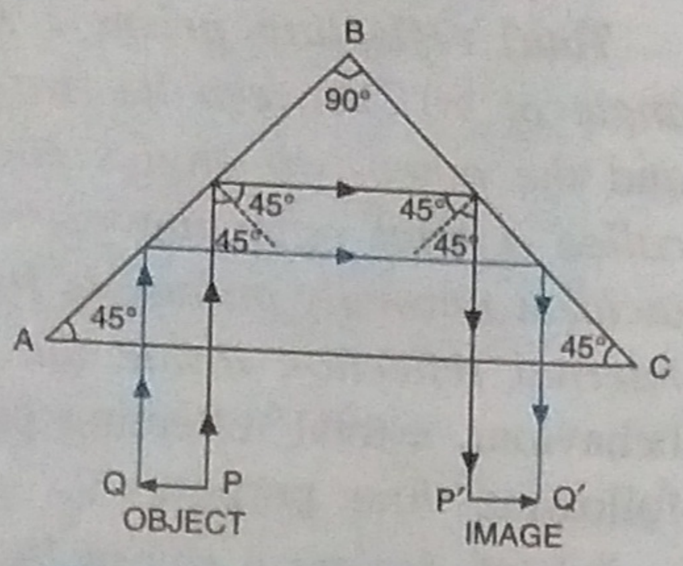

Fig. 4.48 Deviation through 180°

Use : This action of prism is used in a *binocular* and *camera to invert the image without the loss of intensity.*

(c) To erect the inverted image without deviation

In Fig 4.49, the beam of light from the object PQ is incident *parallel* to the face AC (*i.e.*, hypotenuse) of the prism and strikes the face AB of the prism. It suffers refraction from air to glass and strikes the face AC of the prism travelling from glass to air at an angle of incidence greater than the critical angle (= 42°), therefore it suffers *total internal reflection.* The beam inside the prism now strikes the face BC at an angle of incidence less than the critical angle hence it suffers refraction from glass to air and bends away from the normal. *The beam emerges parallel to the face* AC. As a result of refraction, on emergence the rays are inverted and for the inverted object PQ, the erect image P′Q′ is obtained. A prism when used in this manner is called the *erecting prism.*

Use : This action of prism is used in *a slide projector.*

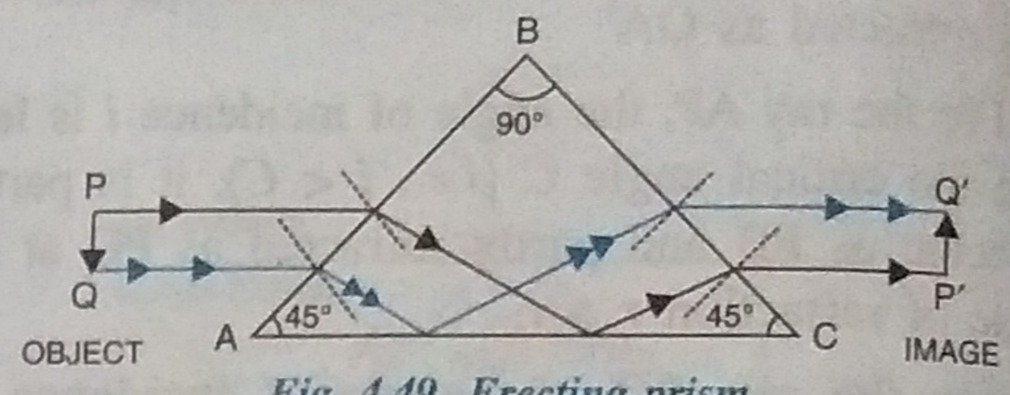

Fig. 4.49 Erecting prism

(2) Total internal reflection through a prism where each angle is 60° (*i.e.*, equilateral prism)

A prism of each angle 60° can be used to deviate a light ray through 60° by total internal reflection. Fig. 4.50 shows a prism ABC of each angle 60°. A light ray PQ incident *normally* on the face AB of the prism passes undeviated as QR into the prism and it strikes the face AC at an angle of incidence 60° at the point R. Now the light ray QR suffers total internal reflection at the glass-air interface, since the angle of incidence (= 60°) is greater than the critical angle which is 42°, such that ∠QRS is 120°. The ray RS obtained after total internal reflection falls normally on the face BC of the prism and so it passes out undeviated through the face BC. Thus

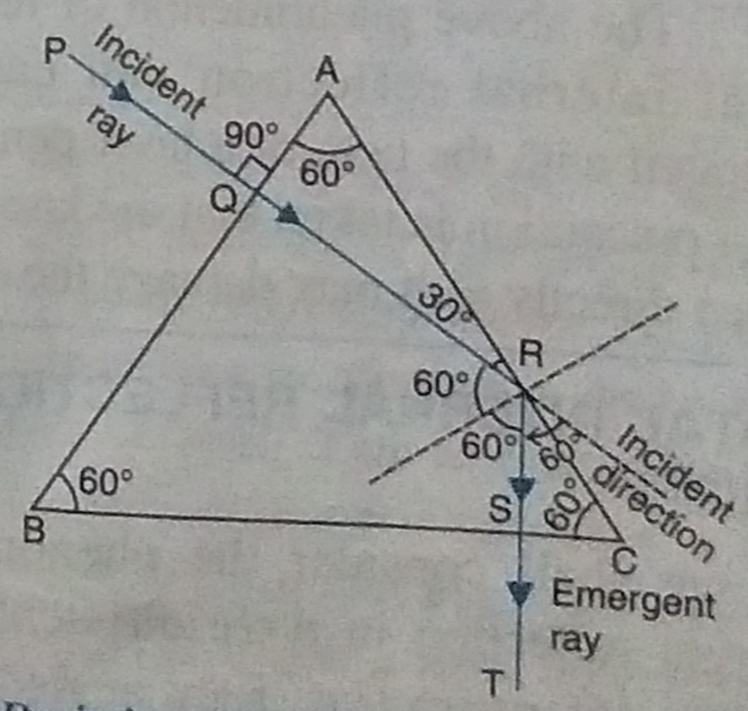

Fig. 4.50 Deviation through 60° by an equilateral prism

ST is the emergent ray. From Fig. 4.50, it is clear that the incident ray PQ has turned through an angle of 60° towards the base from its initial direction and it emerges out as ST.

(3) Total internal reflection and refraction of light through a 30°, 90°, 60° prism (or right angled prism)

A 30°, 90°, 60° prism can be used to deviate a light ray through an angle less than 60° by total internal reflection. Fig. 4.51 shows a prism ABC of angles 30°, 90° and 60°. A light ray PQ incident *normally* on the face BC of the prism (opposite to the refracting angle 30°) passes undeviated as QR into the prism and it strikes the face AC at an angle of incidence 60° at the point R. Now the light ray QR suffers *total internal reflection* at the glass-air interface since the angle of incidence (= 60°) is greater than the critical angle which is 42°. The ray RS obtained after total internal reflection is incident at the face AB of the prism at an angle of incidence equal to 30°. This angle of incidence at glass-air interface is less than the critical angle, so the ray RS is refracted from glass to air as ST with an angle of refraction greater than 30°. Thus the emergent ray ST has turned through an angle δ (which is less than 60°) from the direction of incident ray PQ.

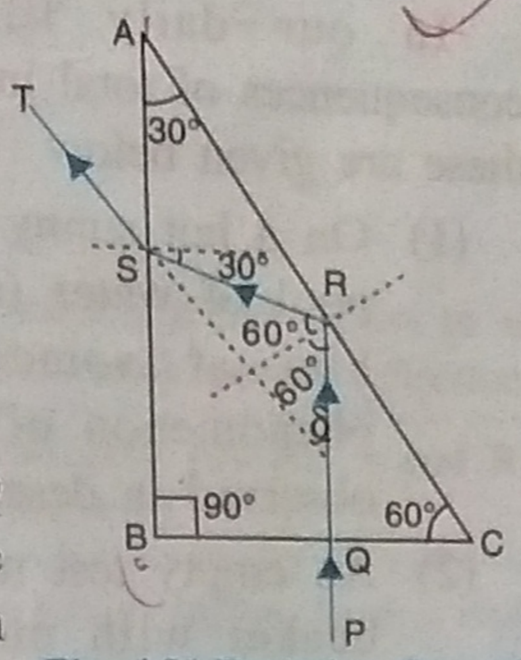

Fig. 4.51 Deviation through less than 60° by a 30°, 90°, 60° prism

Non occurance of total internal reflection through a 30°, 90°, 60° prism : *In Fig. 4.52 (a) a light ray* PQ *is incident normally on the face* AB of the prism ABC while in Fig. 4.52 (b) an light ray PQ is incident on *a part of face* AC *of the prism* ABC. *In both the cases, the light ray does not suffer total internal reflection inside the prism and gets refracted as* RS *obeying the laws of refraction.* In each case, the angle of incidence at the other face inside the prism is 30° which is less than the critical angle (*i.e.*, 42°).

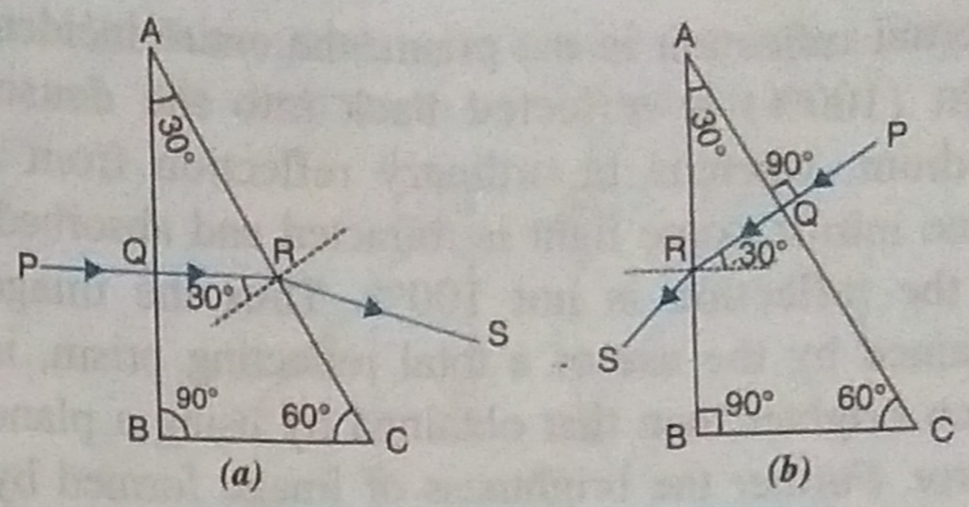

Fig. 4.52 No total internal reflection through a 30°, 90°, 60° prism

Exception : *A ray of light incident normally on hypotenuse of prism below the foot of perpendicular on it from its opposite corner, suffers total internal reflection and gets deviated by an angle greater than 60°.* In Fig. 4.53, a light ray PQ is incident *normally* on the face AC (hypotenuse) of the prism in the portion DC such that the point D is the foot of perpendicular from B on AC. It passes undeviated as QR inside the prism and strikes the face BC of the prism at an angle of incidence 60° which is greater than the critical angle (= 42°). The ray suffers *total internal reflection* inside the prism as RS. The reflected ray RS then strikes the face AB at an angle of incidence 30°, so it suffers refraction from glass to air and emerges out of the prism as ST, bending away from the normal at the face AB. Thus the incident ray PQ gets deviated through an angle greater than 60°.

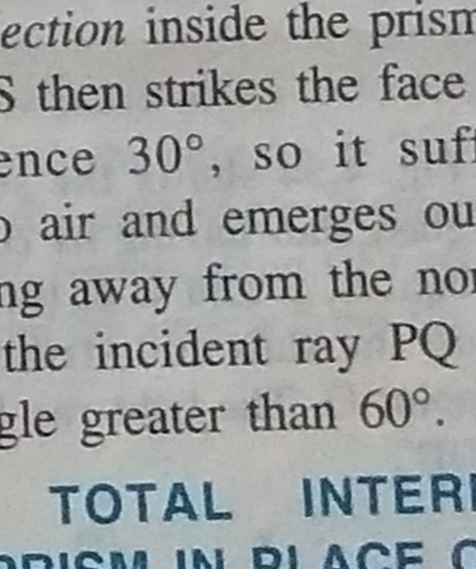

Fig. 4.53 Total internal reflection through a 30°, 90°, 60° prism

4.18 USE OF A TOTAL INTERNAL REFLECTING PRISM IN PLACE OF A PLANE MIRROR

A total reflecting prism is used in place of a plane mirror to deviate the light ray by 90° in a periscope and by 180° in a binocular as well as in a camera. The reason is that due to total

internal reflection in the prism, the entire incident light (100%) is reflected back into the denser medium, whereas in ordinary reflection from a plane mirror, some light is refracted and absorbed, so the reflection is not 100%. Thus the image obtained by the use of a total reflecting prism, is much brighter than that obtained by using a plane mirror. Further the brightness of image formed by a total reflecting prism always remains unchanged, while due to deterioration of silvering of the plane mirror after a long use, the image formed by it becomes faint.

Distinction between the total internal reflection and reflection from a plane mirror

Total internal reflection	Reflection from a plane mirror
1. It takes place only when light passes from a denser medium to a rarer medium at an angle of incidence greater than the critical angle for that pair of media.	1. It takes place when light is incident on a plane mirror from any medium at any angle of incidence.
2. The entire light is reflected.	2. Only a part of light is reflected while rest is refracted and absorbed.
3. There is no loss of energy. The energy of reflected ray is same as that of the incident ray.	3. There is a loss of energy. The energy of the reflected ray is always less than that of the incident ray.
4. The image is much brighter and the brightness remains unchanged even after the long use of the total reflecting device.	4. The image is less bright and the brightness gradually decreases as the silvering on mirror becomes old and rough.

4.19 SOME CONSEQUENCES OF TOTAL INTERNAL REFLECTION

In our daily life, we observe many consequences of total internal reflection. Some of these are given below :

(1) On a hot sunny day, a driver may see a pool of water (or wet road) in front of him at some distance. It is the phenomenon of *mirage* which is often observed in desert.

(2) An empty test tube placed in water in a beaker with mouth outside the water surface, shines like a mirror when seen at certain angles.

(3) A crack in a glass vessel often shines like a mirror.

(4) A piece of diamond sparkles when viewed from certain directions.

(5) An optical fibre is used to transmit a light signal over a long distance without any loss of energy.