

(D) CRITICAL ANGLE AND TOTAL INTERNAL REFLECTION

4.13 TRANSMISSION OF LIGHT FROM A DENSER MEDIUM (GLASS OR WATER) TO A RARER MEDIUM (AIR) AT DIFFERENT ANGLES OF INCIDENCE

Consider the refraction of light from a denser medium to a rarer medium. When a light ray travelling in a denser medium falls on the surface separating it from a rarer medium, it is partly reflected back into the denser medium and partly refracted in the rarer medium. The refracted ray bends away from the normal on the surface at the point of incidence obeying the laws of refraction. Now we shall consider this process of reflection and refraction at different angles of incidence.

Case (i) when the angle of incidence is small ($i < C$) : In Fig 4.42, a light ray AO

travelling in glass is incident at the glass-air interface at a small angle of incidence i . It is partly reflected and partly refracted. We get a weak reflected ray OC and a strong refracted ray OB. Since the incident ray bends away from the normal when it suffers refraction from glass to

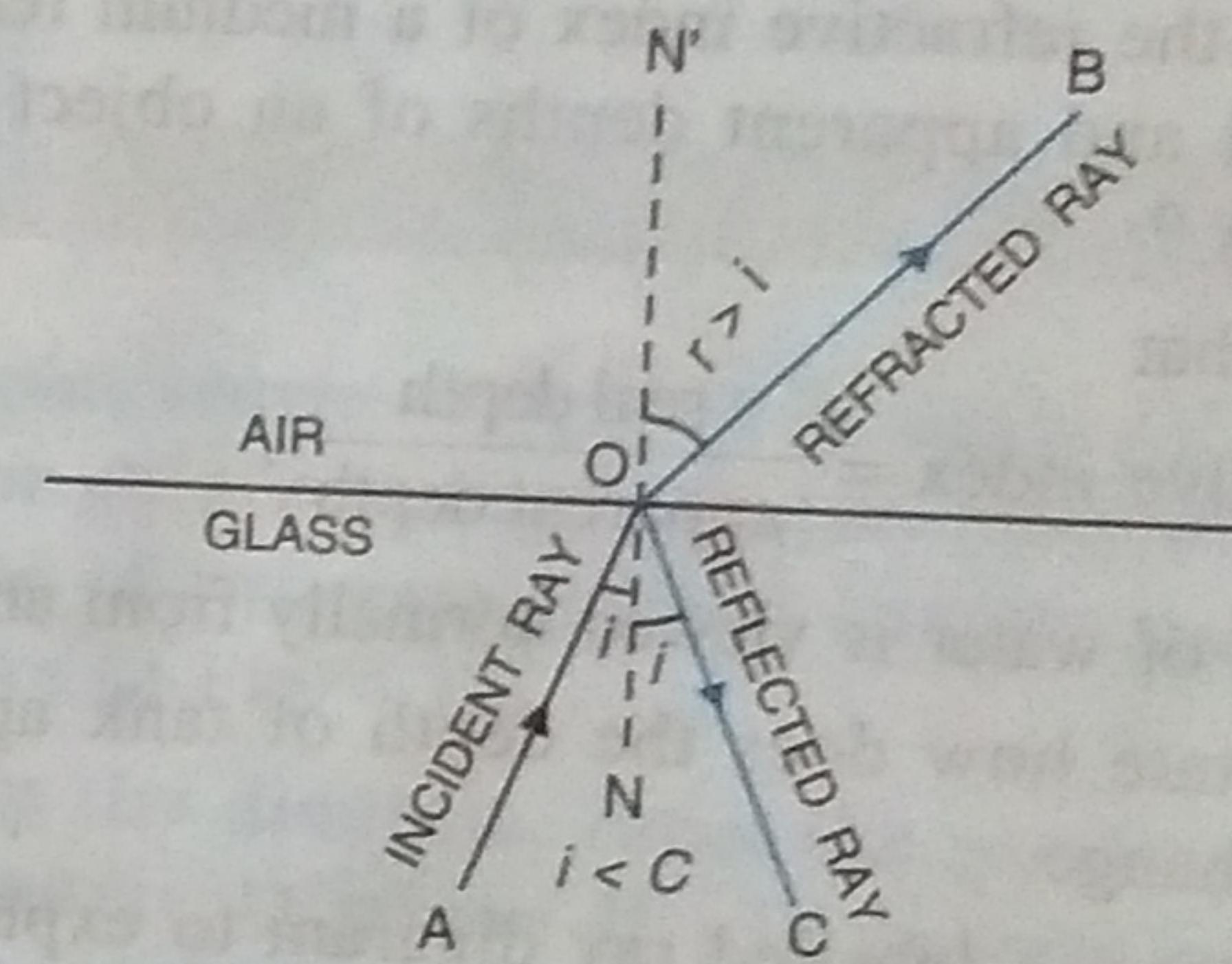


Fig. 4.42 Refraction from glass to air when $i < C$

air, therefore the angle of refraction r is greater than the angle of incidence i .

Now if the angle of incidence i is gradually increased, the angle of refraction r also increases, but the intensity of refracted ray keeps on decreasing. Finally the angle of refraction r reaches its maximum possible value equal to 90° at a certain angle of incidence $i = C$. Here C is called the *critical angle**.

Case (ii) when the angle of incidence is equal to the critical angle ($i = C$) : At angle of incidence equal to the critical angle ($i = C$), the angle of refraction becomes 90° as shown in Fig. 4.43. The refracted ray is along the glass-air interface and it is very weak.

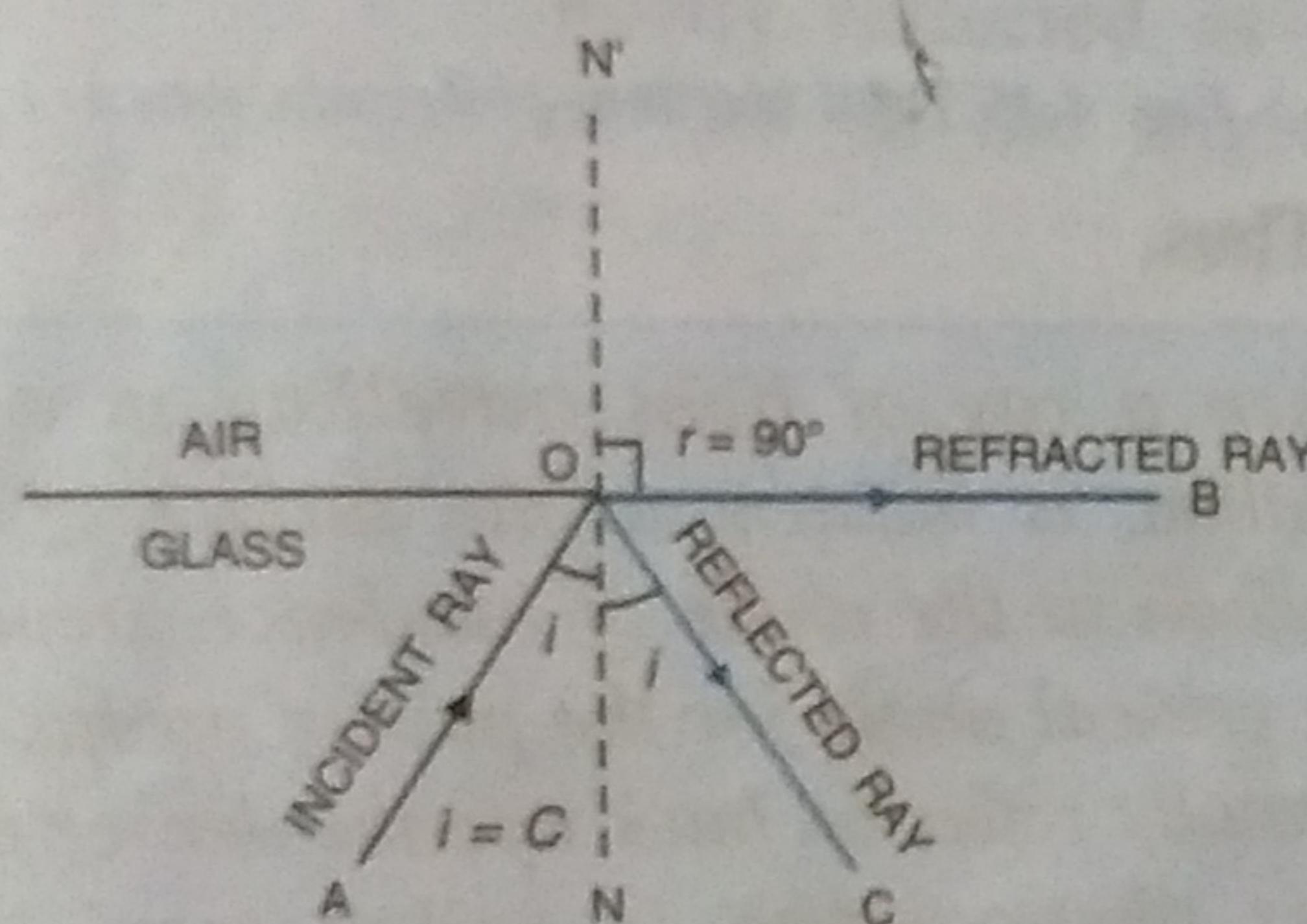


Fig. 4.43 Refraction from glass to air when $i = C$

In Fig. 4.43, for the incident ray AO at $i = C$, the refracted ray is OB and the reflected ray is OC.

Case (iii) when the angle of incidence is greater than the critical angle ($i > C$) : Fig. 4.44 shows that for the incident ray AO at an angle of incidence i greater than the critical angle C , no refracted ray is obtained and the incident ray is totally reflected as OC. Such that $\angle AON = \angle CON$.

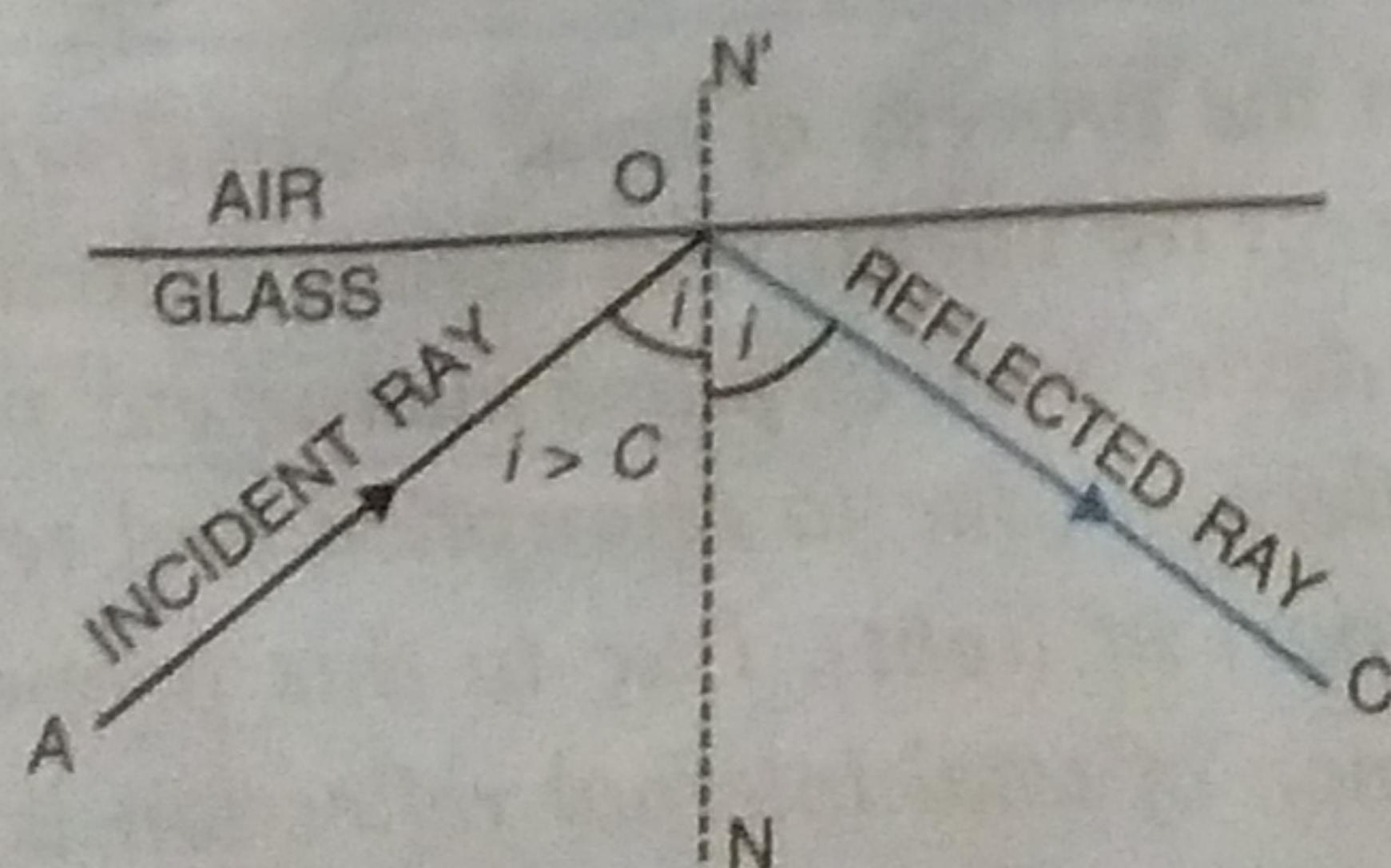


Fig. 4.43 Total reflection when $i > C$ (no refraction)

4.14 CRITICAL ANGLE

We have read that when a ray of light passes from a denser medium to a rarer medium, at a certain angle of incidence $i = C$, the angle of refraction becomes 90° , i.e., at $i = C$, $r = 90^\circ$. The angle C is called the *critical angle*. Thus,

Critical angle is the angle of incidence in the denser medium corresponding to which the angle of refraction in the rarer medium is 90° .

4.15 RELATIONSHIP BETWEEN THE CRITICAL ANGLE AND THE REFRACTIVE INDEX ($\mu = 1/\sin C$)

In Fig. 4.43, AO is an incident ray from glass to air at an angle of incidence $i = C$ (critical angle) for which the angle of refraction r is 90° . Therefore, the refractive index of air with respect to glass is

$$g\mu_a = \frac{\sin C}{\sin 90^\circ}$$

$$\text{But } \sin 90^\circ = 1 \quad \therefore g\mu_a = \sin C$$

But refractive index of glass with respect to air is

$$a\mu_g = \frac{1}{g\mu_a}$$

$$\therefore a\mu_g = \frac{1}{\sin C} = \operatorname{cosec} C \quad \dots(4.16)$$

Thus, knowing the refractive index of the denser medium with respect to the rarer medium, we can calculate the critical angle C for that pair of media.

Examples :

(1) For glass, refractive index $a\mu_g = \frac{3}{2}$

$$\therefore \sin C = \frac{1}{a\mu_g} = \frac{2}{3}$$

$$\text{But } \sin 42^\circ = \frac{2}{3}, \quad \therefore C = 42^\circ$$

(2) For water, refractive index $a\mu_w = \frac{4}{3}$

$$\therefore \sin C = \frac{1}{a\mu_w} = \frac{3}{4}$$

$$\text{But } \sin 49^\circ = \frac{3}{4}, \quad \therefore C = 49^\circ$$

* Symbol i_c is also used to denote the critical angle.

The table below gives the critical angle for some substances with respect to air.

Critical angle for some substances with respect to air

Substance	μ	Critical angle C
Water	1.33	$48^\circ 45' \approx 49^\circ$
Turpentine	1.47	$42^\circ 54' \approx 43^\circ$
Glass	1.5	$41^\circ 48' \approx 42^\circ$
Flint glass	1.57	$39^\circ 28' \approx 39^\circ$
Diamond	2.41	$24^\circ 30' \approx 25^\circ$

Factors affecting the critical angle

The critical angle for a given pair of media depends on their refractive indices. But the refractive index of a medium is affected by the following two factors :

- (1) the colour (or wavelength) of light, and
- (2) the temperature.

Therefore the critical angle depends on the two factors : (1) the colour of light and (2) the temperature.

(1) **Dependence on the colour of light** : The refractive index of a transparent medium decreases with the increase of wavelength of light (it is most for the violet light and least for the red light), therefore the critical angle for a pair of media is least for the violet light and most for the red light i.e. *the critical angle increases with the increase in wavelength of light*.

(2) **Dependence on temperature** : On increasing the temperature of medium, its refractive index decreases, so the critical angle for that pair of media increases. Thus *critical angle increases with the increase in temperature*.

4.16 TOTAL INTERNAL REFLECTION

When light travels from a *rarer* to a *denser* medium, at all angles of incidence a part of it is reflected and the rest of it is refracted at the boundary surface. Thus both the reflection and refraction occur simultaneously. On the other hand, when light travels from a *denser* to a *rarer*

medium, under certain condition (when the angle of incidence is greater than the critical angle), no part of light is refracted, but the entire light is reflected back in the same medium. In Fig. 4.45, the light ray AO gets entirely reflected as OC obeying the laws of reflection and it does not suffer refraction. This phenomenon is called *total internal reflection*.

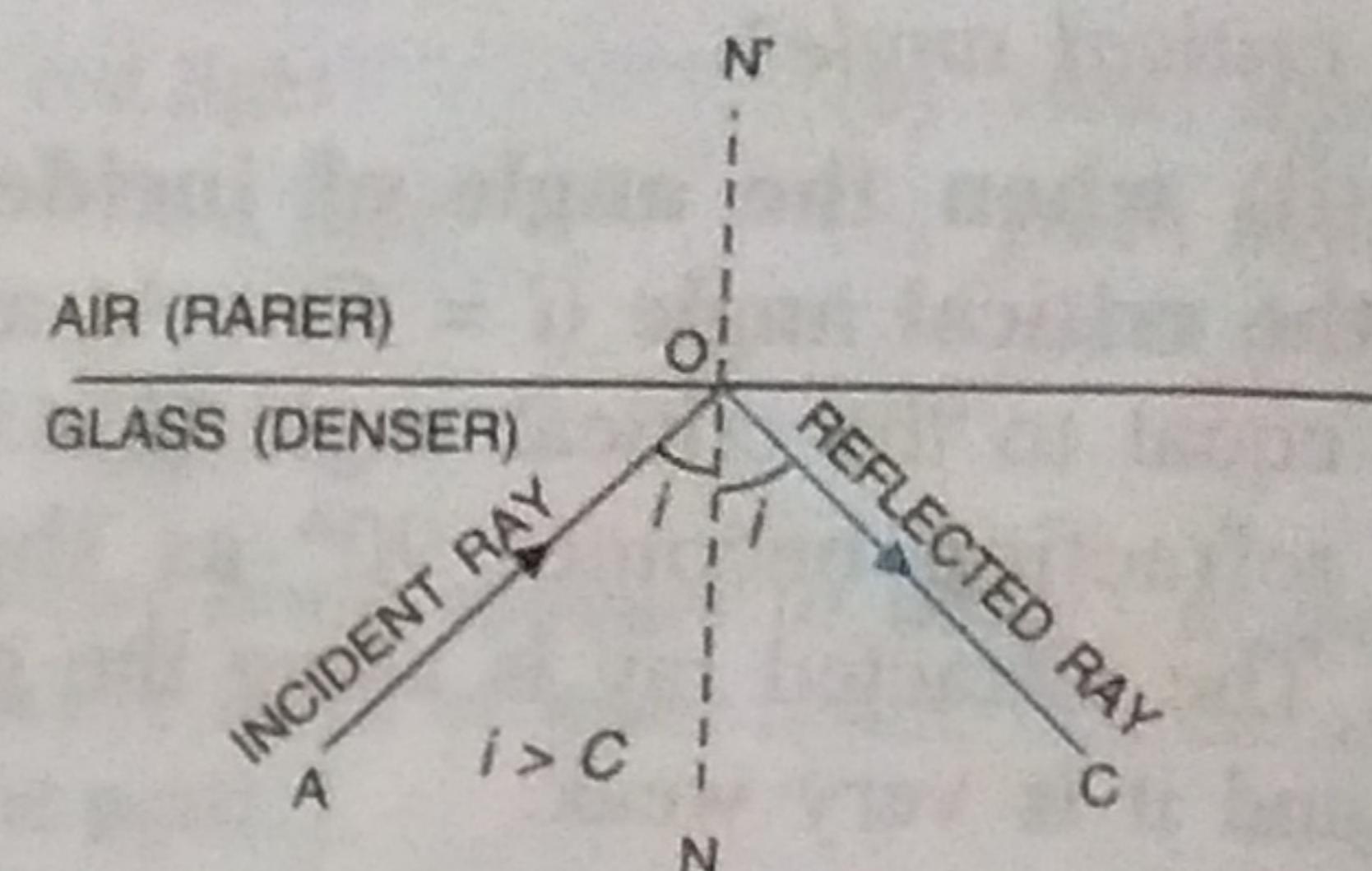


Fig. 4.45 Total internal reflection when $i > C$

Thus,

When a ray of light travelling in a denser medium, is incident at the surface of a rarer medium at the angle of incidence greater than the critical angle for the pair of media, the ray is totally reflected back into the denser medium. This phenomenon is called *total internal reflection*.

Essential conditions for the total internal reflection

There are following two necessary conditions for the total internal reflection :

- (1) *The light must travel from a denser to a rarer medium.*
- (2) *The angle of incidence must be greater than the critical angle for the pair of media.*

Note : In the process of total internal reflection, 100% energy (or intensity) of light is reflected back. No other device such as plane mirror, etc. produces 100% reflection (due to absorption and refraction of some part of light). Due to this property, the phenomenon of total internal reflection is used in the construction of periscope, binocular and certain types of camera in which a total reflecting prism replaces a plane mirror for the reflection of light.