TOPIC 13 Light

Objectives

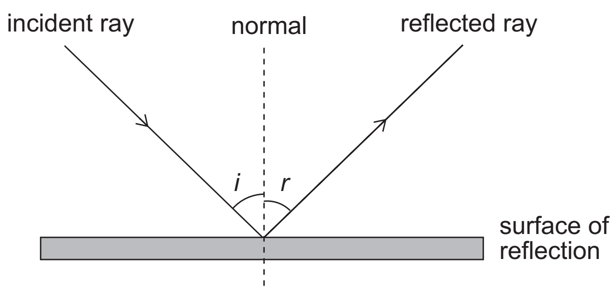
Candidates should be able to:

(a) recall and use the terms for reflection, including *normal*, *angle of incidence* and *angle of reflection*
(b) state that, for reflection, the angle of incidence is equal to the angle of reflection and use this principle in constructions, measurements and calculations
(c) recall and use the terms for refraction, including *normal*, *angle of incidence* and *angle of refraction*
(d) recall and apply the relationship $\frac{\sin i}{\sin r}$ = *constant* to new situations or to solve related problems
(e) define *refractive index* of a medium in terms of the ratio of speed of light in vacuum and in the medium
(f) explain the terms *critical angle* and *total internal reflection*
(g) identify the main ideas in total internal reflection and apply them to the use of optical fibres in telecommunication and state the advantages of their use
(h) describe the action of a thin lens (both converging and diverging) on a beam of light
(i) define the term *focal length* for a converging lens
(j) draw ray diagrams to illustrate the formation of real and virtual images of an object by a thin converging lens

NOTES

13.1 Reflection

1. The diagram below shows a ray of light being reflected from a plane surface.



2. The following terms are commonly used in the reflection of light:

Term	Definition
Normal	Imaginary line perpendicular to the surface of reflection
Angle of incidence, *i*	Angle between the incident ray and the normal
Angle of reflection, *r*	Angle between the reflected ray and the normal

3. Laws of reflection:
   (a) Angle *i* = Angle *r*
   (b) The incident ray, reflected ray and the normal at the point of incidence all lie on the same plane.

4. Characteristics of an image formed in a plane mirror:
   (a) Upright
   (b) Virtual (Cannot be captured on a screen)
   (c) Laterally inverted
   (d) Same size as the object
   (e) Image distance from the other side of the surface of reflection is the same as the object's distance from the surface of reflection.

13.2 Refraction

1. The diagrams below show a ray of light refracted as it passes from air into glass and from glass into air. Note how the light ray bends in each case.

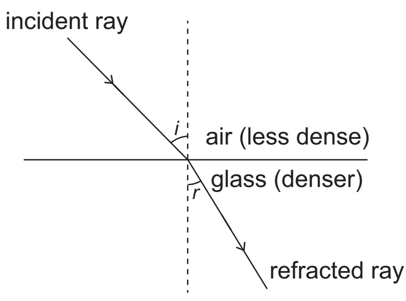


Fig. (a)

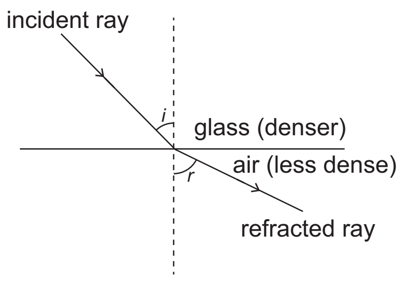


Fig. (b)

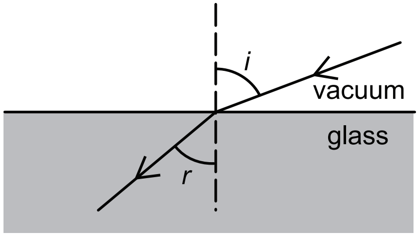
2. The following terms are commonly used in refraction:

Term	Definition
Normal	Imaginary line perpendicular to the surface of reflection
Angle of incidence, *i*	Angle between incident ray & normal
Angle of refraction, *r*	Angle between refracted ray & normal
Refractive index of a medium, *n*	Ratio of the speed of light in vacuum to the speed of light in medium
Critical angle	Angle of incidence in a denser medium for which the angle of refraction in the less dense medium is 90°
Total internal reflection	Complete reflection of an incident ray of light within a denser medium surrounded by a less dense medium when the incident angle is greater than the critical angle

3. Refractive index of vacuum is taken as 1.
   Air has a refractive index of 1.0003 which is very close to 1, but is not equal to 1.

4. Laws of refraction:
   (a) The incident ray, refracted ray and the normal at the point of incidence all lie on the same plane.
   (b) Snell's Law: $\frac{\sin i}{\sin r}$ = constant, for two given media.

***E.g.* 1**: For the light ray passing from a **less dense** medium to a **denser** medium (such as vacuum to glass),

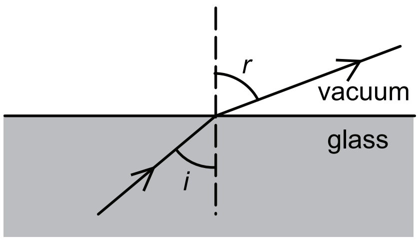


$$\frac{\sin i}{\sin r} = \frac{n_{\text{denser medium}}}{n_{\text{vacuum}}} = \frac{n}{1}$$

$$\frac{\sin i}{\sin r} = n$$

where n is the refractive index of the denser medium.

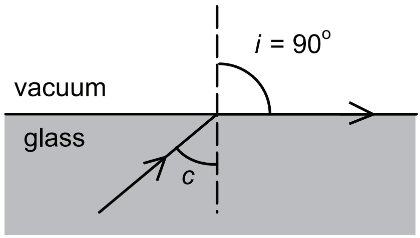
***E.g.* 2**: For the light ray passing from a **denser** medium (such as glass to vacuum) to a **less dense** medium,



$$\frac{\sin i}{\sin r} = \frac{n_{\text{vacuum}}}{n_{\text{denser medium}}} = \frac{1}{n}$$

where n is the refractive index of the denser medium.

***E.g.* 3**: For light ray passing from a denser medium into a less dense medium at a critical angle, $i = c$,



$$\frac{\sin i}{\sin r} = \frac{n_{vacuum}}{n_{glass}}$$

$$\frac{n_{vacuum}}{n_{glass}} = \frac{\sin c}{\sin 90^\circ} \text{ where } i = c \text{ and } r = 90^\circ$$

$$n_{glass} = \frac{1}{\sin c}$$

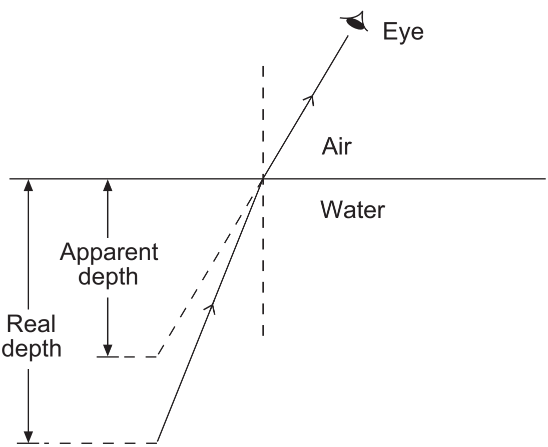
$$\Rightarrow n = \frac{1}{\sin c}$$

where n is the refractive index of the denser medium.

When other incident angles $i > c$, the incident ray will undergo total internal reflection.
Note that $n_{vacuum} = 1$ and $n_{air} = 1.0003$.

5. Refractive index, n, of a medium (i.e. water) can also be calculated as follows:

$$\frac{\text{real depth}}{\text{apparent depth}} = n$$



6. The speed of light is slower in a denser medium as compared to that in a less dense medium.

Example 13.1

A ray of light travels from within a piece of glass into air. The incident angle is 10° and the refractive index of glass is 1.61. Calculate the angle of refraction.

Solution

Refractive index of glass, $n_{\text{glass}} = 1.61$

Refractive index of air, $n_{\text{air}} = 1.0003$

$$\frac{\sin i}{\sin r} = \frac{n_{air}}{n_{glass}} \quad (\textit{Common mistake}: \frac{\sin i}{\sin r} = n_{glass})$$

$$\frac{\sin 10^{\circ}}{\sin r} = \frac{1.0003}{1.61}$$

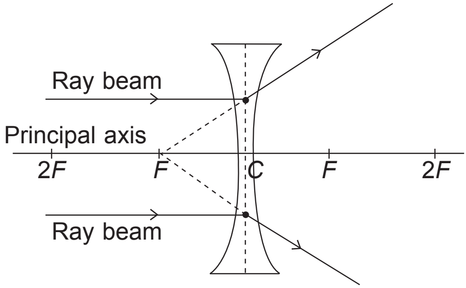
$$\sin r = \frac{1.61 \sin 10^{\circ}}{1.0003}$$

Angle $r = 16.2^{\circ}$ (to 1 d.p.)

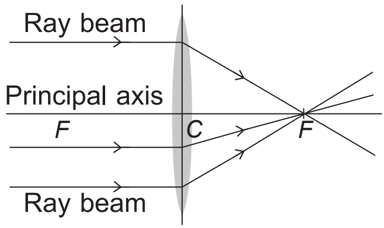
7. An application of total internal reflection: optical fibres to transmit data.
   Principle: The polished surfaces of the fibres are made of a material of suitable refractive index for total internal reflection of light.
   Advantages:
   1. Optical fibres have high electrical resistance, so it can be used near high-voltage equipment safely.
   2. Since optical fibres have lower density than copper, the mass is lower for the same volume of wires. Hence optical fibres are suitable for mobile vehicle applications such as aircrafts where mass and space are concerns.
   3. Optical fibres are resistant to chemical corrosion
   4. Optical fibres do not emit electric fields or magnetic fields since they carry light instead of electrical currents, hence they will not interfere with nearby electronic equipment or themselves be subject to electromagnetic interference.
   5. Since optical fibres are secured, it is difficult to intercept signals without disrupting them, unlike conventional current carrying copper cables.

13.3 Lenses

1. Actions of a thin lens: As shown in the following diagrams, a converging lens converges a beam of light whereas a diverging lens diverges a beam of light.



Diverging lens

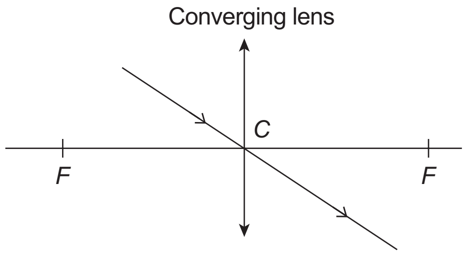
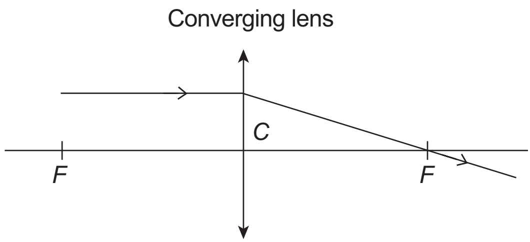
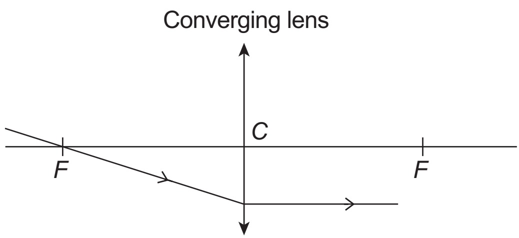


Converging lens

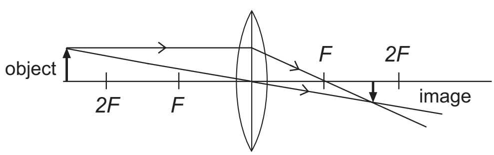
2. The following table summarises the main features of a lens:

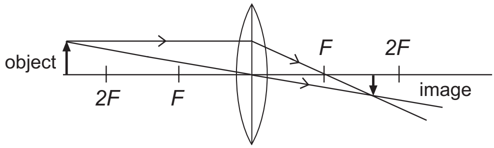
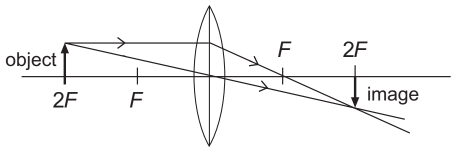
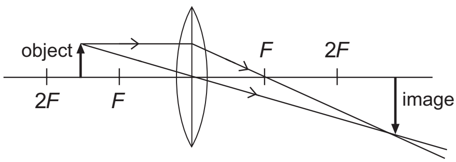
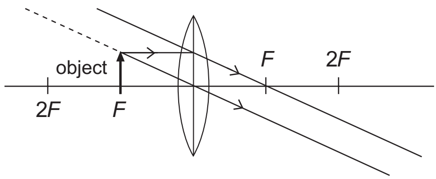
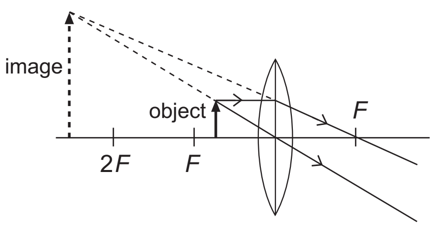
Term	Definition
Focal length, f	Distance between the optical centre, C and the principal focus F.
Optical centre, C	Midpoint between the lens' surface on the principal axis. Rays passing through optical centre are not deviated.
Principal axis	Line passing symmetrically through the optical centre of the lens.
Principal focus or Focal point, F	Point of convergence for all light rays refracted by the lens.
Focal plane	Plane which passes through F and perpendicular to the principal axis.

3. Ray diagrams are drawn to locate the position and the size of an image.

Action of incident ray	Diagram
Ray passing through *C* passes straight through without a change in direction.	
Ray parallel to principal axis passes through lens and changes direction and passes through *F*.	
Ray passing through *F* initially reaches lens and passes out parallel to principal axis.	

4. Types of images formed by a **thin** converging lens

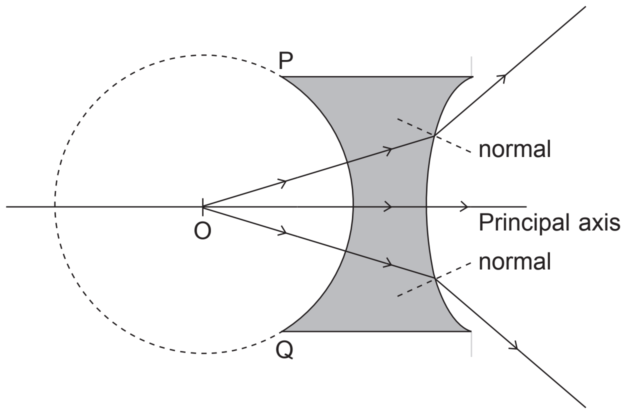
Object distance	Ray diagram	Image characteristics	Application
At infinity		• Real • At *F*	Telescope lens

Object distance	**Ray diagram**	**Image characteristics**	**Application**
Greater than 2*F*		• Inverted • Real • Diminished • Between *F* and 2*F*	Camera lens
At 2*F*		• Inverted • Real • Same size as object • At 2F	Photocopier
Between *F* and 2*F*		• Inverted • Real • Magnified	Projector
At *F*		• Image formed at infinity. (Light rays travel parallel to each other.)	
Less than *F*		• Upright • Enlarged • Virtual (On the same side of the lens as the object.)	Magnifying glass

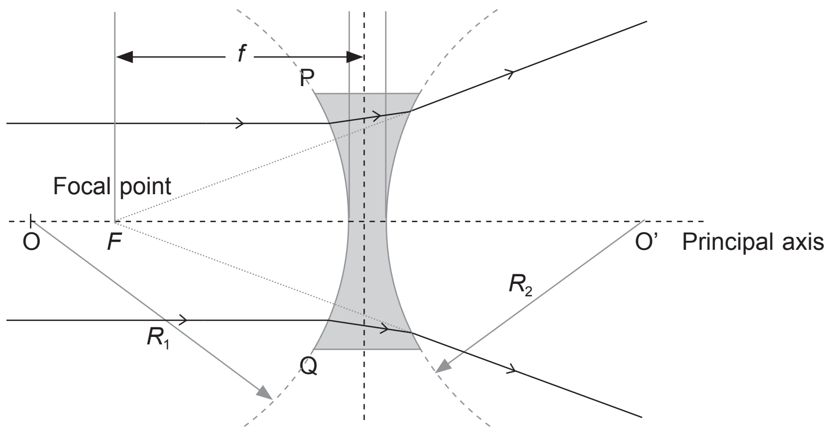
Note: Ray diagrams must ALWAYS have arrows to indicate direction of the ray.

5. Special cases

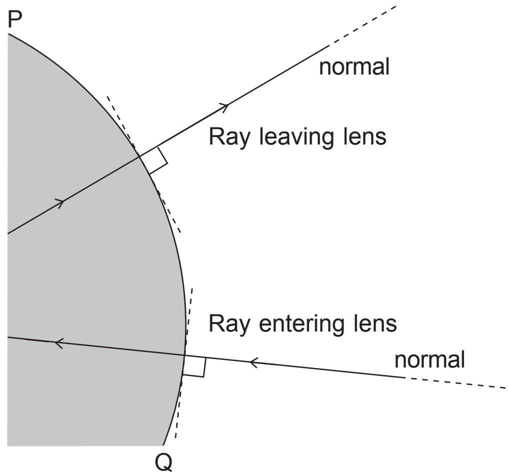
- Diverging lens: Light source from O, centre of curvature of the lens.
  The figure shows part of a diverging lens where one of the faces of the lens PQ is part of a circle with centre O.



Any light rays drawn from O to PQ will be normal (90°) to the surface PQ because they are moving along the normal line.
Hence any light ray originated from O and entering into the lens PQ will be moving into the lens without changing direction.
A complete diverging lens is shown in the figure below, where O and O' are the centre of the circles (dotted), F is the focal point and f is the focal length. R_1 and R_2 are the radii of the circles with centres O and O' respectively.



- Converging lens: Light rays entering or leaving the lens will travel along the path of the normal to the lens surface which is a part of a circle. The figure shows part of a converging lens where PQ is part of a circle.



The rays will not change direction because they are moving along the path of the normal line. The path forms an angle of 90° to the surface of the lens.
A complete converging lens is shown in the figure below, where O and O' are the centre of the circles (dotted), F is the focal point and f is the focal length. R_1 and R_2 are the radii of the circles with centres O and O' respectively.