5 Ray Model of Light

By learning about properties of light, we can understand the universe, monitor climate change and even develop machines to save lives. Scientists and engineers use the knowledge of how light behaves under different conditions to develop new technologies that make our world a better place to live in.

- Representing Light (5.1)
- Reflection of Light and its Applications (5.2)
- Refraction of Light and its Effects (5.3) **Optional** for N(A)
- Impact of Applications of Radiation (5.4)

5.1 Representing Light

Scientists and engineers have always relied on models to explain and predict the behaviour of the physical world. People who first studied and described the behaviour of visual light created the Ray Model of Light. This model can be used to describe how telescopes work, explain how we see rainbows, and why we can see our reflection on smooth surfaces.

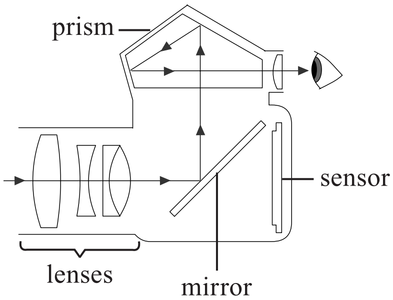


Fig 5.1 Ray models help us to understand how light travels in a DSLR camera.

1. Luminous objects emit visible light. They are referred to as light sources.
   Examples: stars (the Sun), the Bunsen flame, the filament lamp, the fluorescent lamp, laser.
2. Non-luminous objects do not emit light. We are able to see non-luminous objects because their surfaces reflect light into our eyes.
   Examples: the moon, all planets and most living things.
3. Light travels in straight lines. When there is an obstruction to the straight path of the light, light is blocked and cannot reach our eyes.

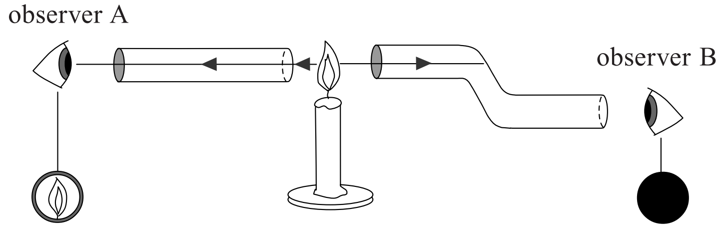


Figure 5.2 Observer A is able to see the candle flame through the tube while Observer B is unable to do so as light is blocked.

4. The Ray Model of Light is used to represent the path taken by light. Some objects may emit light in all directions but we only show the most important paths.
5. Hence, the path taken by a ray of light can be represented by a solid straight line on a ray diagram, with an arrow showing its direction.
6. A beam of light is a bundle of light rays.

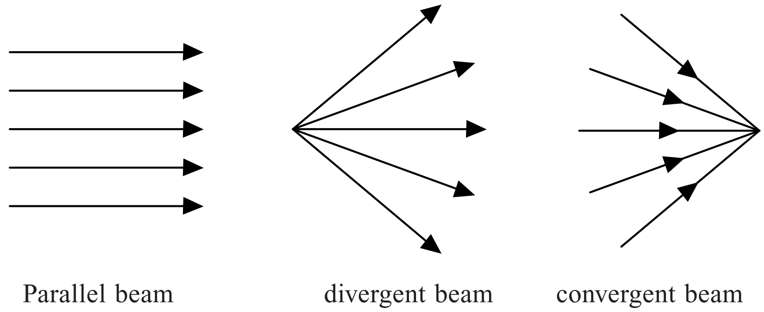
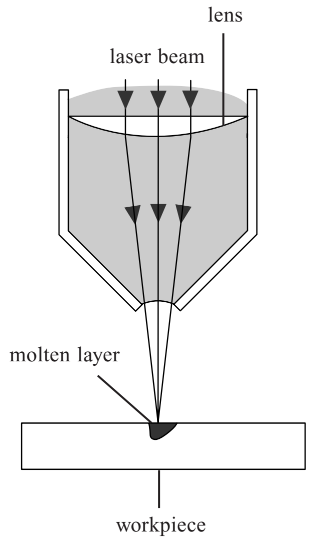


Fig 5.3 A beam of light can be parallel, divergent or convergent.

Extra

Unlike flashlights, laser beams are focused and do not spread out much. They can travel long distances, and concentrate a lot of energy in a small spot causing rapid heating. High-power laser beams can be used to cut a vast range of materials of different thicknesses.



Note

Light from a distant source or reflected light from a distant non-luminous object is a parallel beam of light.

5.2 Reflection of Light and its Applications

The moon is a non-luminous object. However, we are able to see the moon because sunlight bounces off its surface and into our eyes, just like how we are able to see objects around us. When light bounces off the moon, we can say that light is reflected. As the moon orbits the Earth, it is lit from different angles, making it seem as if the moon is changing shape every night.

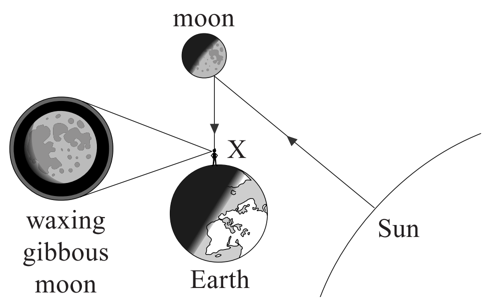


Fig 5.4 If you are at position X of the Earth viewing the Moon as shown, you will see waxing gibbous moon.

Law of Reflection

1. **Optional** for N(A)

   The Law of Reflection states that the angle of incidence *i* equals the angle of reflection *r*. When a ray of light is incident at a point on a smooth, reflective surface (e.g. polished metal, mirror), it bounces off the surface at an angle that is equal to the angle of incidence.

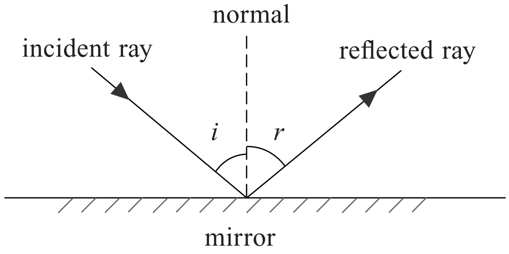


Fig 5.5 A ray of light reflects when it bounces off a smooth surface.

Key

- Normal – Imaginary line perpendicular to the reflecting surface
- *i* – Angle between the incident ray and the normal
- *r* – Angle between the reflected ray and the normal

2. When a beam of light is incident on a smooth surface (e.g., mirror, highly polished surfaces), each ray is reflected in the same direction. We call this regular reflection.
3. If a beam of light is incident on a rough surface (e.g., paper surface, wall), the rays will be reflected in many different angles depending on the angle of the surface it reflects off, but still obeying the law of reflection. We call this diffused reflection.

Note

In a regular reflection, all the normals are parallel.
In a diffused reflection, the normals are not parallel.

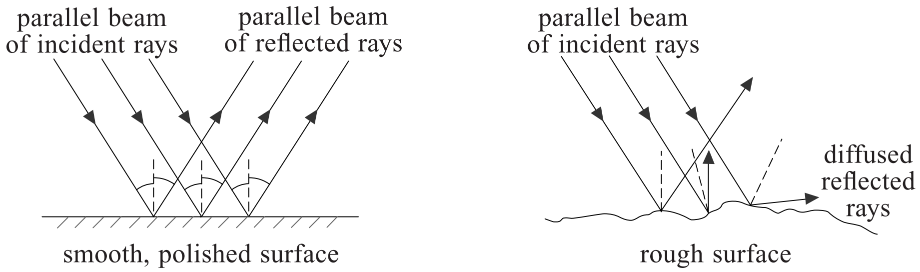


Fig 5.6 How rays reflect off smooth and rough surfaces

Reflection on a Plane Mirror

1. Optional for N(A)

   We can use a mirror to check and observe our image. The image due to reflection on a plane mirror appears to come from behind the mirror. To explain this phenomenon, we can draw a ray diagram.

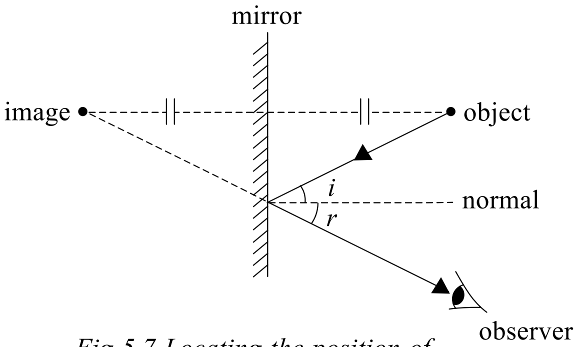


Fig 5.7 Locating the position of image by constructing a ray diagram

   Step 1: Draw an incident ray from the object to the mirror.
   Step 2: Draw the normal at the surface of the mirror where the incident ray meets the surface. Measure the angle of incidence.
   Step 3: Measure the angle of reflection and draw the reflected ray towards the eye.
   Step 4: Extend the reflected ray backward into the mirror using a broken line. It will reach the position of the image.

2. We can observe the following characteristics of an image formed by a plane mirror.
   - Size of object = size of image
   - Distance of object from the mirror = Distance of image from the mirror
   - Image is laterally inverted. When you look into the mirror and close your left eye, your image will appear to have closed its right eye.
   - Image is upright.
   - Image is virtual.
3. A **virtual image** is an image which is not formed by actual rays meeting one another on a physical object. That is why virtual images cannot be formed on a screen (e.g., plane mirror images).
4. A **real image** is an image which is formed by actual rays meeting one another. That is why real images can be formed on a screen.
   Example: The use of the convex lens in an overhead projector produces a real image which is formed on the screen.

Note
Use broken lines behind the mirror to locate the position of a virtual image.

Note
The aim of the ray diagram of the overhead projector is to show that light rays meet together to form a real image on the screen.

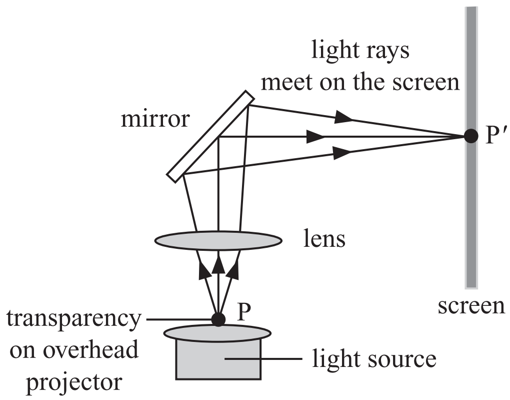


Fig 5.8 Formation of a real image by an overhead projector

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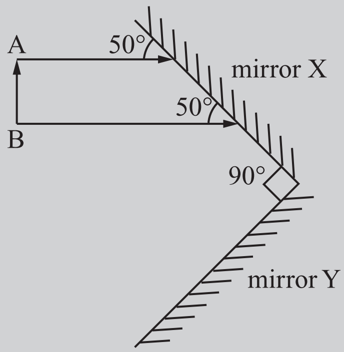
Optional for N(A)

Two mirrors X and Y are placed perpendicular to each other. Two parallel rays from object AB are incident on one of the mirrors as shown below.



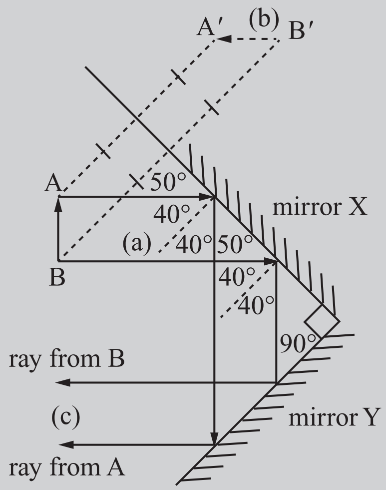
(a) Draw the normals and write down the angles of incidence. [2]

(b) Draw lines to find the position of the image A'B' formed behind mirror X. [2]

(c) Continue the paths of the two rays that would incident on mirror Y before reflecting from it. [2]

(d) What effect do the two perpendicular mirrors X and Y have on the two rays from A and B? [1]

ANSWER



(a) *Both angles of incidence = 40°*

(b) *Distance of object to mirror is equal to distance of image to mirror.*

(d) *The perpendicular mirrors X and Y invert the two parallel rays.*

Applications of Reflection

1. We use different types of mirror (e.g., plane mirrors, curved mirrors) for many purposes. There are two types of curved mirrors—convex mirrors and concave mirrors.
2. Plane mirrors are used in optical shops to create space in a room, microscopes and for making a physical space look wider than it actually is.

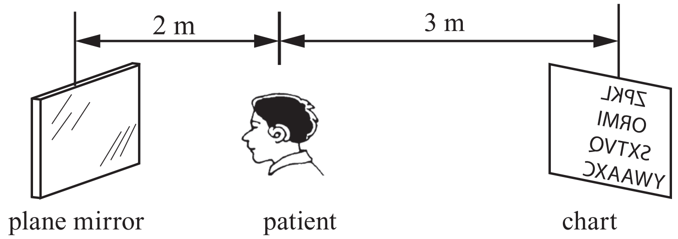


Fig 5.9 Plane mirrors help to create space in a room. A small eye-testing room that is only 5 m long allows the patient to see an image that is 7 m away from him by using a plane mirror.

3. Mirrors that curve outward are convex mirrors. A convex mirror diverges a parallel beam of light. Images formed in convex mirrors are virtual, upright and diminished (smaller than objects). They are used when a large area is to be seen from the mirror.
4. Uses of convex mirrors: used at corners of bends to check for cars not in view, corners of retail stores to monitor security in the shop, rear-view mirrors of cars to check traffic condition behind the car.
5. Mirrors that curve inward are concave mirrors. A concave mirror converges a parallel beam of light. Images formed in concave mirrors are virtual, upright and magnified (bigger than objects). They are used when a magnified image is to be seen from the mirror.
6. Uses of concave mirrors: beauty mirrors that magnify faces, astronomical telescopes, headlights of a car.

Note

Always draw the normal at each incident point when drawing rays reflecting and refracting off surfaces. Refraction will be covered in the next section.

Note

Notice that the letters in Fig 5.9 are deliberately laterally inverted so that the patient sees the letters in their correct form.

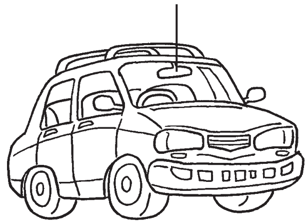


Fig 5.10 Convex mirrors are used as rear-view mirrors in vehicles to provide a wider view.

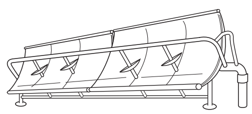


Fig 5.11 The solar panels use a concave mirror to focus the light rays from the Sun.

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An object is placed at a distance in front of a curved mirror. Three rays of light from tip A of the object are drawn incident on points B, C and D. The rays at B and C are reflected and meet at E.

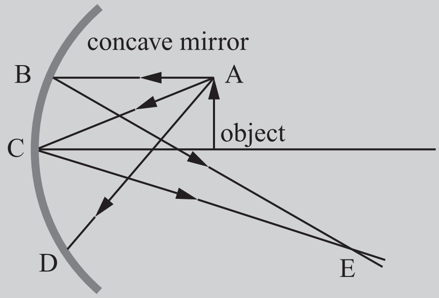
(a) Draw, on the diagram, the position of the image. [1]

(b) Indicate the angle of incidence *i* and angle of reflection *r* at C. [1]

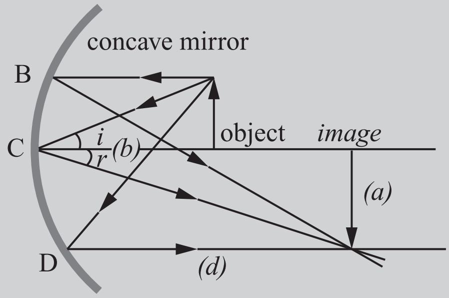
(c) (i) Explain whether the image is real or virtual. [1]

(ii) Deduce two other characteristics of the image. [2]

(d) On the diagram complete the path of the light ray that is incident at D. [1]



ANSWER



(c) (i) The image is real because the rays meet to form the image.

(ii) The image is magnified and inverted (upside down).

5.3 Refraction of Light and Its Effects

Optional for N(A)

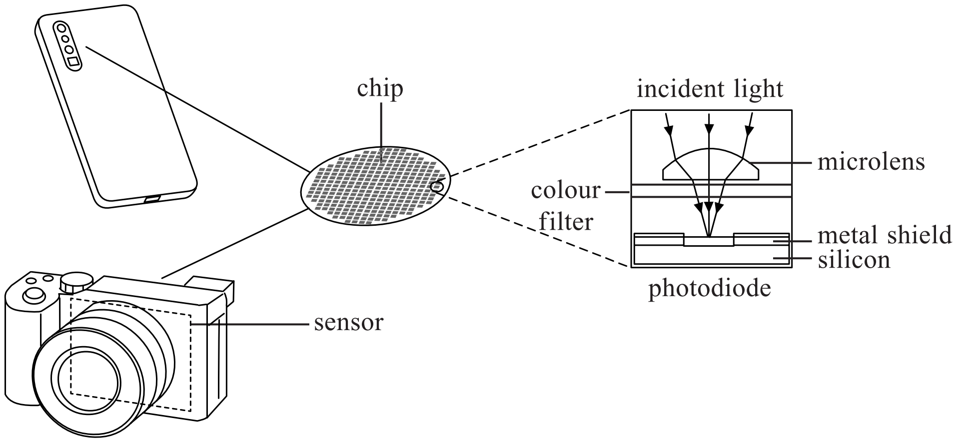


Fig 5.12 To increase the sensitivity of a light sensor, many tiny microlenses are used to concentrate more light on a unit area of photodiode.

Refraction of Light

1. When light passes through transparent materials of different optical densities, its speed changes and it changes direction or bends. This is called the refraction of light.
2. Refraction is the bending of light at the boundary between two different transparent materials, as it passes from one material into another.
3. Light travels faster in air than in glass. The speed of light in air is 3.0×10^8 m/s. A light ray travelling from air (optically less dense) into glass (optically denser) slows down and bends towards the normal. (See A $\longrightarrow$ B $\longrightarrow$ C in Fig 5.13)
4. When the light ray travels through the glass block, there is no change in optical density and it continues to travel in a straight line.
5. When the light ray emerges from the glass block (optically denser) into air (optically less dense), it speeds up and bends away from the normal. (See B $\longrightarrow$ C $\longrightarrow$ D in Fig 5.13)

6. If the light ray is incident at right angle (angle of incidence = 0º) to the surface of the optically denser material, it passes into the material without bending. (See E ⟶ F ⟶ G in Fig 5.13)

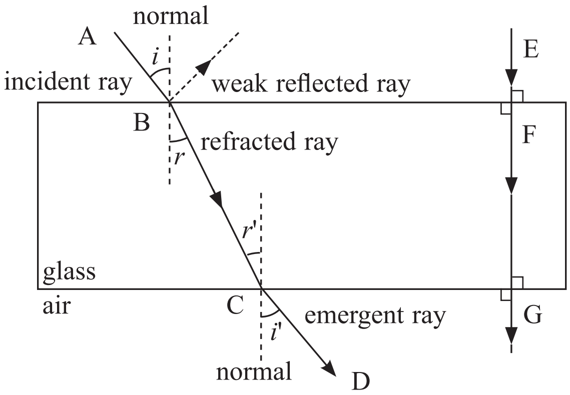


Fig 5.13 Refraction in a rectangular glass block

Note

The angle of incidence and angle of refraction of light ray E ⟶ F ⟶ G are 0°, not 90°.

$\angle r' = \angle r$

$\angle i' = \angle i$

Refractive index

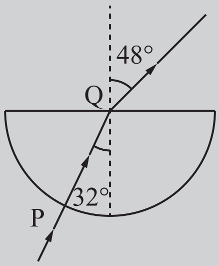
Extension Knowledge

1. The refractive index, n, of a transparent material (an optical medium) is the ratio of the speed of light in air, c, to the speed of light in the material, v.
2. Because light travels faster in air than in the medium concerned, the refractive index is always greater than 1.
3. The greater the refractive index of the medium (or the more optically dense the medium is), the more light is bent.
4. The refractive index, n, of a medium can also be found using the formula $n = \frac{\sin i}{\sin r}$, where i is the

SCIENCE AROUND US

Extension Knowledge

A ray of light incident on the curved side P of a semi-circular glass block is shown below. The refracted ray exits from flat side Q.



(a) The ray of light enters the glass block from curved side P along the broken lines drawn. State the angle of incidence and angle of refraction at P. [1]

(b) The ray of light is incident at the flat side Q of the semi-cicular glass block and undergoes refraction. Calculate the refractive index of the glass. [2]

(c) The speed of light in air is 3.0×10^8 m/s. Calculate the speed of the light in the glass block. [2]

ANSWER

(a) Angle of incidence = angle of refraction = 0°

(b) $n = \frac{\sin 48^\circ}{\sin 32^\circ} = 1.11$

The refractive index will not change for the same material used, hence we could use the information given in the ray drawn above to calcualte the refractive index even though it enters from the flat side.

(c) n = speed of light in air ÷ speed of light in glass

$1.11 = 3.0 \times 10^8$ m/s ÷ speed of light in glass

Speed of light in glass = 2.7×10^8 m/s

Note

(b) and (c) require additional knowledge from upper secondary Physics regarding Laws of Refraction.

Effects and Applications of Refraction

Optional for N(A)

1. Effect of refraction: Objects in water are perceived to be shallower than their actual depth.

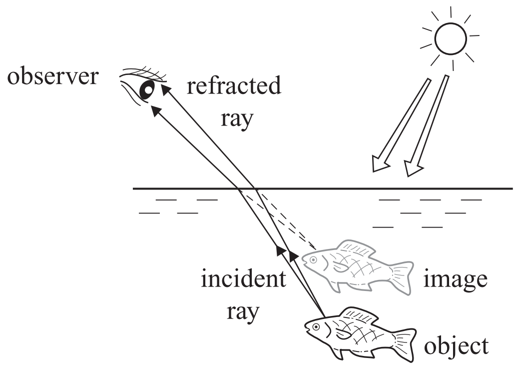


Fig 5.14 A ray from a body in the water emerges out of the water. It bends away from the normal before it reaches our eyes. This makes the object appear at a shallower position.

2. Effect of refraction: Formation of rainbows due to dispersion of white light
   - Dispersion of white light can be observed using a prism, where the prism disperses white light into a continuous spectrum of colours (i.e. red, orange, yellow, green, blue, indigo and violet).

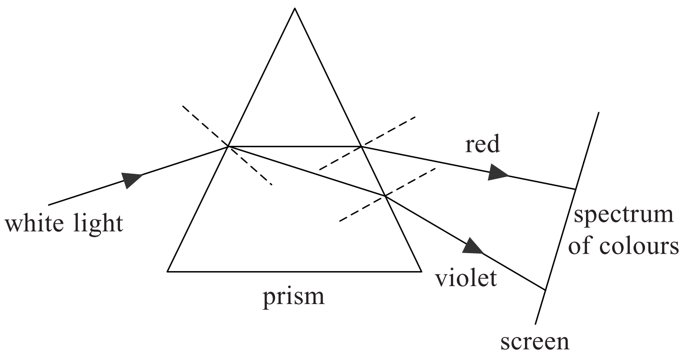


Fig 5.15 White light is dispersed into a spectrum of colours.

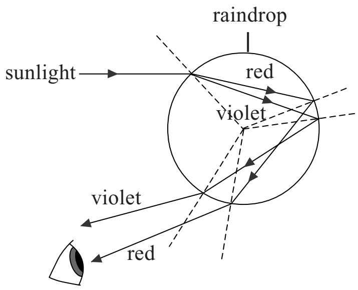
   - The dispersion of white light is due to the fact that different colours in the white light travel at different speeds in the prism.

- Red light travels the fastest in the prism and so it is bent the least. Violet light travels the slowest in the prism and so it is bent the most.
- Another effect of refraction we can observe is the formation of a rainbow. Dispersion of light can be observed in the sky when a rainbow is formed. Visible light from the Sun passes through many tiny (optically denser) raindrops, and are dispersed by raindrops in the air.

3. Application of refraction: Spectacles
A lens is a piece of glass with curved sides. Light passing through a lens undergoes refraction. Converging lenses are used in microscopes and spectacles for long-sightedness while diverging lenses are used in spectacles for short-sightedness.

Extra

When a ray of white light passes through a raindrop, it refracts and disperses as it enters, and reflects off the inner surface of the raindrop. The different colours of light then refract and disperse further apart as they exit the droplet.



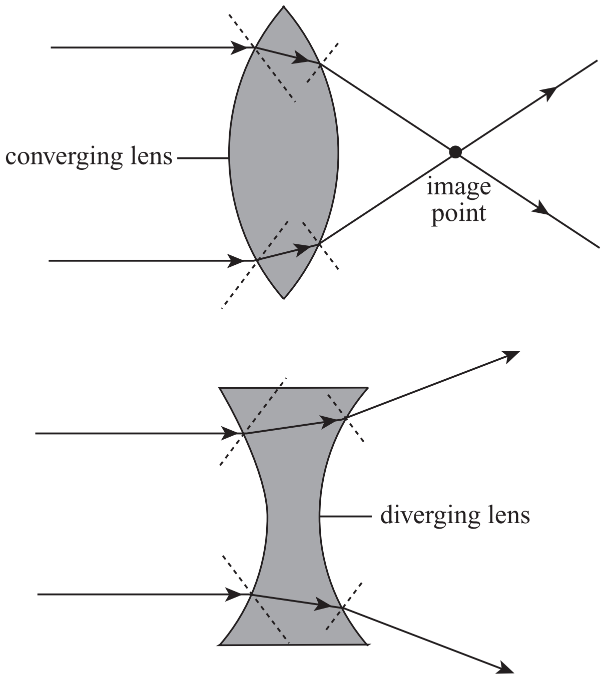
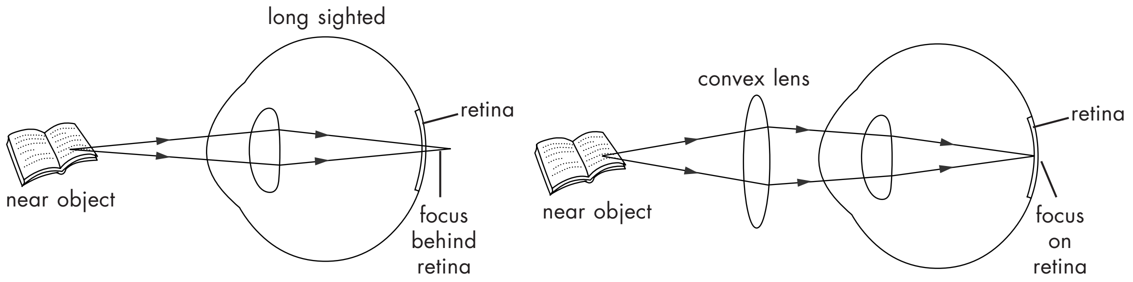


Fig 5.16 Refraction in a converging lens and in a diverging lens

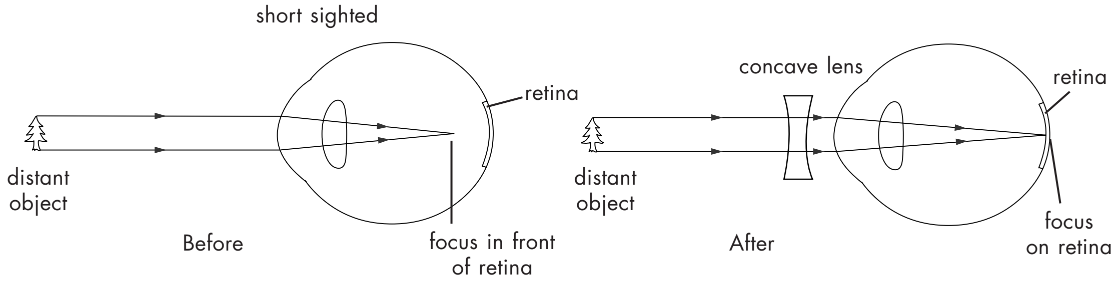
Extra

A long-sighted person can see distant objects clearly but cannot see nearby objects clearly. The eyes of a long-sighted person focus light rays from a nearby object behind the retina. A converging lens is used to bring the focus nearer to the lens.



Before After

A short-sighted person can see nearby objects clearly but cannot see distant objects clearly. The eyes of a short-sighted person focus light rays from distant objects in front of the retina. A diverging lens is used to bring the focus farther away from the lens.



Before After

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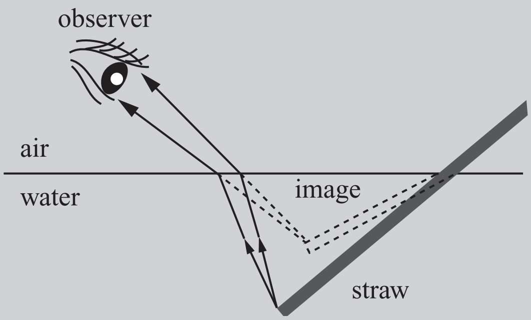
A straw half immersed in water appears bent due to refraction.

(a) Draw a ray diagram which explains how this occurs. Your diagram should show two rays from the tip of the straw. [3]

(b) Explain whether the image formed is real or virtual. [2]

ANSWER

(a)



(b) *The image is virtual because no rays actually meet to form the image.*

5.4 Impact of Applications of Radiation

The electromagnetic (EM) spectrum is the range of all types of EM radiation. EM radiation is everywhere around us—the visible light that comes from a lamp in your classroom, the infrared radiation we feel as heat, the ultraviolet waves that cause sunburn.

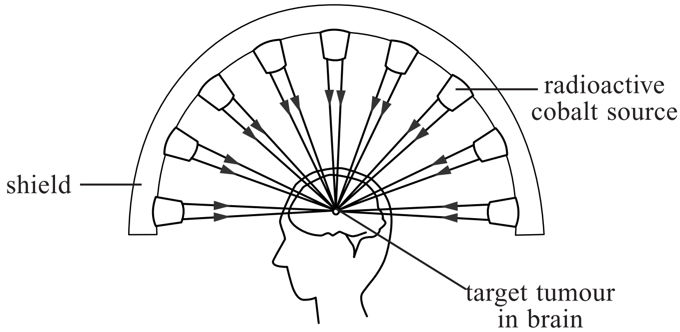


Fig 5.17 Gamma knife surgery focuses low-dose beams of gamma rays from different directions to destroy all cancer cells in a tumour without damaging nearby healthy cells.

EM radiation is the basis for the technologies of electrical and computer engineering. An example would be the study of how light propagates and interacts with biological tissues and cells. This novel technology could provide diagnostic information about structure and function, based on these EM principles. However, EM radiation can also be harmful to the environment, if not used with care and awareness.

Extra

Gamma rays have the shortest wavelength and highest frequency followed by X-ray, ultraviolet, visible light, infrared, microwaves and radio waves which have the longest wavelength and lowest frequency. You will learn about wavelength and frequency in upper secondary Physics.

Electromagnetic (EM) Radiation

1. The electromagnetic (EM) spectrum is the range of different types of EM radiation, arranged in order of radio waves, microwaves, infrared (IR), visible light, ultraviolet (UV), X-rays and gamma rays.
2. Sunlight is also a form of EM radiation, but visible light is only a small portion of the EM spectrum. A radio detects a different portion of the spectrum, and an X-ray machine uses yet another portion. Scientific instruments used by scientists to study the Earth, the solar system and universe use the full range of the electromagnetic spectrum.

3. Uses of EM radiation around us:

EM radiation	Use
Gamma rays	PET is an imaging test that allows a doctor to diagnose and monitor diseases.
X-rays	Airport security uses X-ray machines to see through luggage.
Ultraviolet	UV lamps are used to sterilise surgical equipment in hospitals.
Visible light	We use light to see things. Laser light is also used in aircraft weapon aiming systems.
Infrared	Thermal scanners detect infrared light emitted by our skin and objects with heat to tell us the temperature of objects.
Microwaves	Used to cook food as it can cause molecules to vibrate, allowing food to be heated up.
Radio waves	Radios capture radio waves emitted by radio stations, allowing you to tune to your favourite station.

Table 5.1 Uses of EM radiation

Impact of Light produced by Technology, on Society and the Environment

1. Plants rely on visible light to make food during photosynthesis. Visible light also helps us to see in the dark, enabling us to carry on with daily activities at night.
2. Too much visible light in the cities causes light pollution. This affects living things (e.g., migratory birds) that depend on Earth's day and night cycle to carry out their daily activities for survival, such as migration, reproduction or finding shelter and food.

Extra

Bright artificial lights can suppress the production of melatonin, a hormone that regulates sleep-wake cycle in our body. The chronic suppression of melatonin has been hypothesised to increase the risk of some types of cancer.