Brien Holden Vision Institute

OPTICS

THINK

Have you ever looked through a magnifying glass? Have you ever seen a mirror that makes things look smaller than they really are? Have you ever seen a crystal make a rainbow of light on a wall?

All of these things use optics to change light and make you see images differently.

AIM

This unit will introduce you to the study of optics. You will learn how light travels and how some surfaces reflect light while others allow light to pass through.

LEARNING OUTCOMES

When you have worked through this unit you should be able to:

- explain how light travels
- explain how light rays can be reflected, refracted or absorbed
- describe different optical media and how their refractive indices affect light
- discuss how a prism bends light
- describe how a lens focuses light
- explain what happens to light rays that travel through the optical centre of a lens
- define what a plano lens is.

LIGHT

We are able to see when the eyes receive light from an object, and the brain interprets the light messages that are received by the eyes. Light contains a lot of information about the object it comes from including its colour, its shape and its movement. The brain interprets this information, which helps us to identify the object.

To see clearly, the eyes must receive light and correctly focus it on the retina at the back of the eye. If an eye does not focus light correctly, spectacles may be required to give clear vision.

BEHAVIOUR OF LIGHT

Light travels from an object into our eyes by moving in straight lines. These lines are called light rays.

Light rays can be drawn on diagrams, so that we can predict the path that the light will take. These diagrams are called ray diagrams. Light rays on ray diagrams are drawn as straight lines with arrowheads which point in the direction that the light is travelling.

Light rays can travel in different directions or in the same direction. Types of light rays include:

- parallel light rays
- convergent light rays
- divergent light rays.

PARALLEL LIGHT RAYS

Light travels from an object into our eyes by moving in straight lines. These lines are called light rays.

Light rays can be drawn on diagrams, so that we can predict the path that the light will take. These diagrams are called ray diagrams. Light rays on ray diagrams are drawn as straight lines with arrowheads which point in the direction that the light is travelling.

Light rays can travel in different directions or in the same direction. Types of light rays include:

- parallel light rays
- convergent light rays
- divergent light rays.

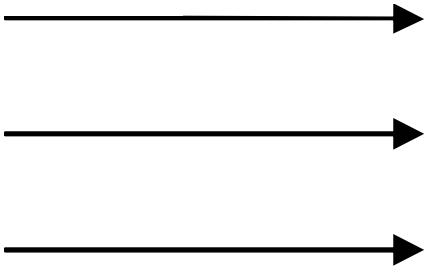


Figure 2.1: *Parallel light rays*

Parallel light rays come from all objects that are distant (far away).

In optics, all objects that are 6 metres (m) or more away are considered distant.

This means that parallel light rays come from all objects that are 6 m away or further.

BEHAVIOUR OF LIGHT (cont.)

CONVERGENT LIGHT RAYS

These light rays travel towards each other.
Convergent light rays will meet at a focal point.

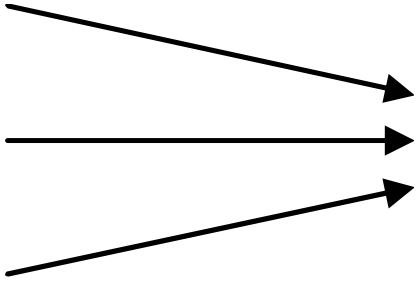


Figure 2.2: *Convergent light rays* ***and***

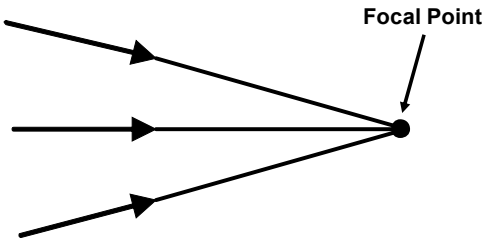


Figure 2.3: *Convergent light rays converge to a focal point*

DIVERGENT LIGHT RAYS

These light rays travel away from each other.
Divergent light rays come from an object closer than 6 m from the eye.

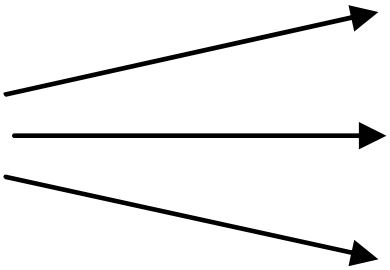


Figure 2.4: *Divergent light rays* ***and***

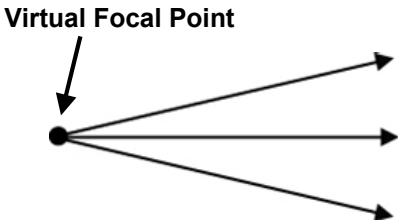


Figure 2.5: *Divergent light rays diverge from an object closer than 6 m away*

Light rays will travel in straight lines until they reach an object. When they reach an object they can be:

- reflected by the object - this is called **reflection** of light; or
- refracted by (travel through) the object – this is called **refraction** of light; or
- absorbed by the object.

Reflection and refraction can change the direction that light rays are travelling in.

Light rays will stop if an object absorbs them. If an object absorbs all light rays, it will appear black in colour.

BEHAVIOUR OF LIGHT (cont.)

OPTICAL MEDIUM	Light rays can travel through any transparent (clear) material. A transparent material that lets light travel through it is called an optical medium (or simply a medium). An optical medium can be a: • gas (like air) • liquid (like water) • solid (like glass or clear plastic).
REFRACTIVE INDEX	Every optical medium has a specific refractive index. The refractive index tells us how much faster light travels through air than it does through the medium. So, it is a comparison of the speed of light in air to the speed of light in the medium. Light travels faster in a medium that has a low refractive index (like air), and slower in a medium that has a high refractive index (like glass). *Example:* Air has a refractive index of 1 and glass has a refractive index of 1.5. This means that light travels 1.5 times faster in air than it does in glass.

REFLECTION

A light ray will bounce off a surface (like a ball that bounces off the ground) when it reaches a smooth reflecting surface, such as a mirror. This is called reflection of light.

When an incoming light ray (also called an incident light ray) hits a reflecting surface, it is reflected. This means it then travels away from that surface as a reflected light ray.

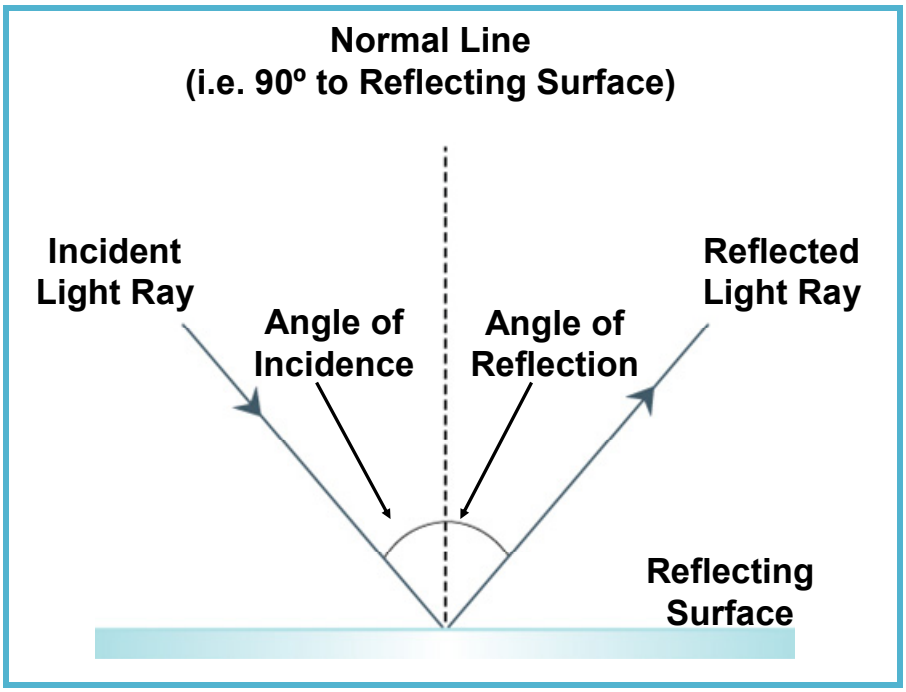


Figure 2.6: *Reflection*

At the point where the light ray hits the reflecting surface, we can draw a dotted line perpendicular (at an angle of 90°) to the reflecting surface. This dotted line is called the normal line (or simply, the normal).

The angle between the incident ray and the normal is called the *angle of incidence*. **The angle between the reflected ray and the normal is called the *angle of reflection*.**
 **Law of reflection:** **Angle of incidence = angle of reflection**

REFRACTION

Sometimes, instead of light being absorbed or reflected from a surface, the light will continue to travel into the new medium. An incident light ray will hit a refracting surface and then travel through that surface as a refracted ray. The refracted ray changes direction when it travels through the new medium.

At the point where the light ray hits the refracting surface, we can draw a dotted line perpendicular (at an angle of 90°) to the refracting surface. This is the normal line (or normal). The angle between the normal line and the incident light ray is called the angle of incidence (*i*). The angle between the refracted ray and the normal is called the angle of refraction (*i'*).

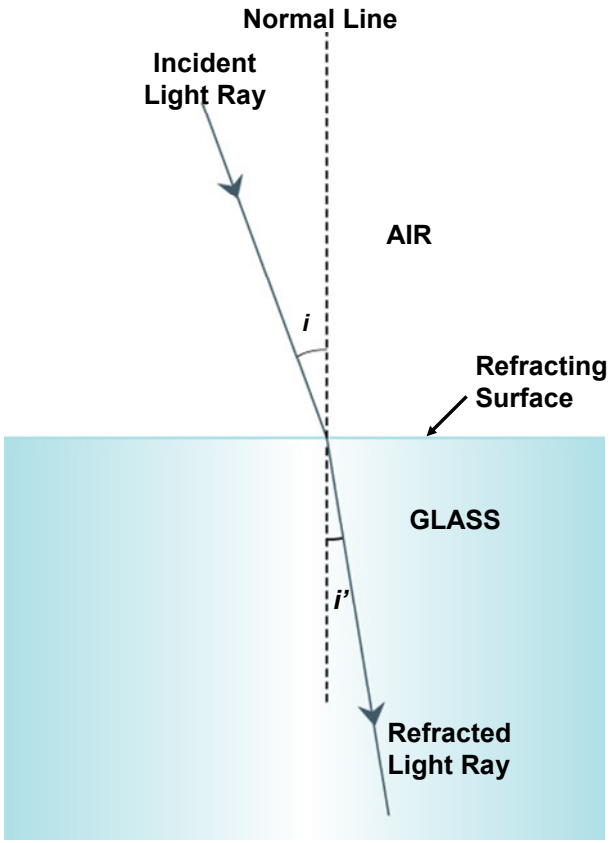


Figure 2.7: *Refraction*

Exception:
If the light ray enters a new medium perpendicularly (along the same line as the normal), the light ray will pass into the new medium without changing direction.

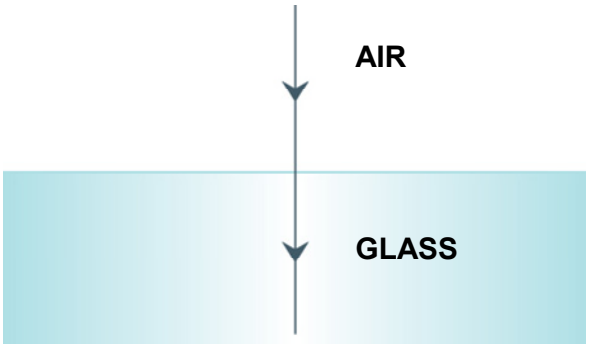


Figure 2.8: *A light ray that travels along the same line as the normal will not change direction*

When a light ray travels from one medium into another medium (such as from air into glass), the direction that the light ray is travelling in will change – the path of the light ray will be bent. This is called refraction of light.

The amount of light refraction (the amount that a light ray is bent) depends on the refractive index of the medium that the light ray is coming from and the refractive index of the medium that it is entering.

A light ray will be refracted *more* if there is a greater difference between the refractive index of the original medium and the refractive index of the new medium.

A light ray will be refracted *less* if there is a smaller difference between the refractive index of the original medium and the refractive index of the new medium.

REFRACTION (cont.)

When a light ray travels from a medium with a lower refractive index into a medium with a higher refractive index, the light ray is bent towards the normal.

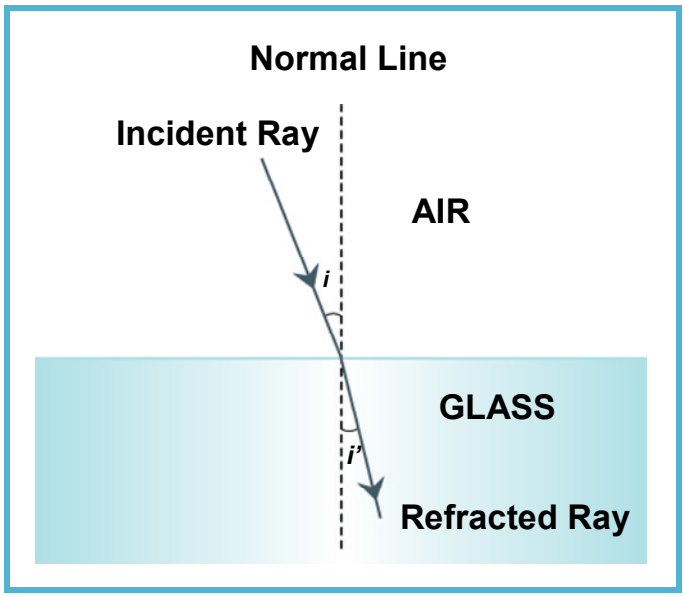


Figure 2.9: *Light travelling from a medium with lower refractive index to a medium with higher refractive index*

When a light ray travels from a medium with a higher refractive index into a medium with a lower refractive index, the light ray is bent away from the normal.

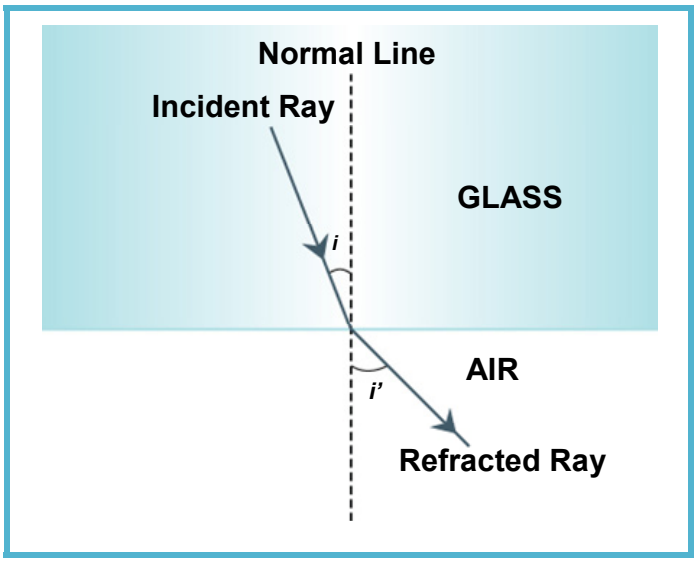


Figure 2.10: *Light travelling from a medium with higher refractive index to a medium with lower refractive index*

- If a light ray travels into a medium with a **higher refractive index**: the angle of refraction (*i'*) **is smaller than the** angle of incidence (*i*).
- If a light ray travels into a medium with a **lower refractive index**: the angle of refraction (*i'*) **is greater than the** angle of incidence (*i*).

PRISMS

Prisms bend light. An optical prism is made of transparent material (like glass or plastic) that has a higher refractive index than air.

A prism is shaped like a triangle. One side of this triangle is the base of the prism, and the corner opposite the base is called the apex. The angle of the apex is called the apical angle and its size will affect how much the prism will bend light.

At the point where the light ray hits the refracting surface, we can draw a dotted line perpendicular (at an angle of 90°) to the refracting surface. This is the normal line (or normal). When a light ray travels through the new medium, in this case a prism, it will change the angle between the normal line and the refracted ray.

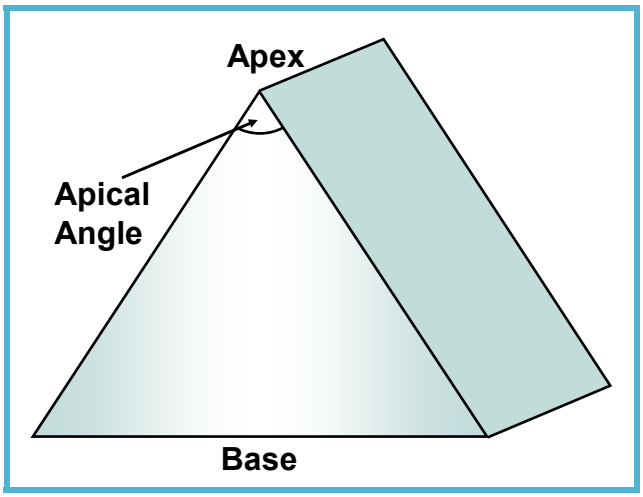
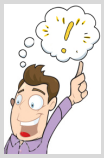


Figure 2.11: *An optical prism*



REMEMBER:

- If a light ray travels into a medium with a **higher refractive index**: the angle of refraction is **smaller** than the angle of incidence.
- If a light ray travels into a medium with a **lower refractive index: the** angle of refraction is **greater** than the angle of incidence.

PRISMS (cont.)

REFRACTIVE INDEX AND PRISMS

A glass or plastic prism has a higher refractive index than air (and air has a lower refractive index than glass or plastic). When an incident light ray enters a prism, the light ray will be bent towards the normal inside the prism and away from the normal when it leaves the prism.

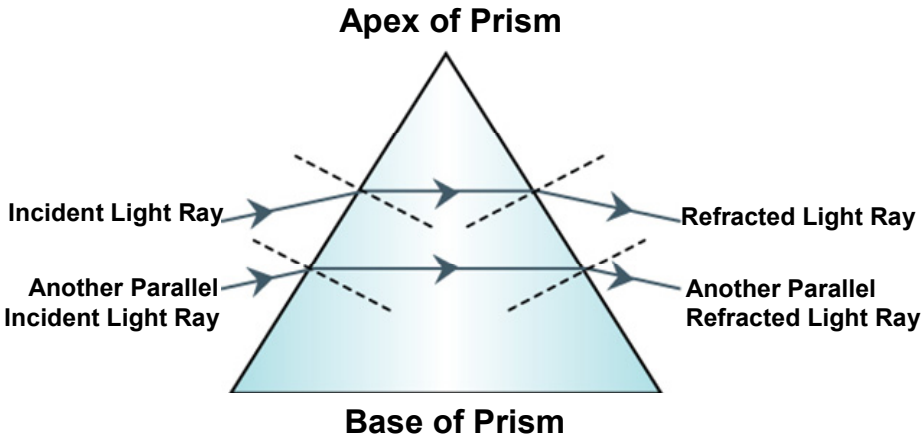


Figure 2.12: *A prism will bend all light rays by the same amount, no matter where the light ray enters the prism. All parallel light rays that enter a prism will exit the prism travelling in the same new direction*

Light entering a prism will always bend away from the apex of the prism.

APPARENT DEVIATION

A prism does **not** focus light. If parallel light goes in to the prism, then parallel light will come out the other side.

When we look at an object through a prism, the object will look like it is closer to the apex of the prism than it really is. This is called the apparent deviation of the object.

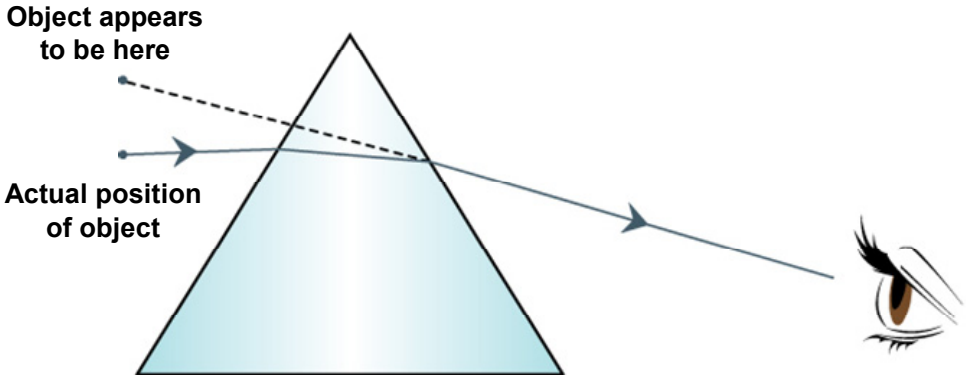


Figure 2.13: *Apparent deviation: Light from an object bends towards the base of a prism, but the object appears to move towards the apex*

LENSES

An optical lens (or simply a lens) is a piece of transparent material that is shaped so that it refracts light rays to focus at a certain point – called the focal point. While prisms just bend light, lenses focus light. Lenses are used for spectacles, magnifying glasses, microscopes and slide projectors.

A slide projector has lenses that can focus an image onto a screen. Spectacle lenses can change the focus of the eyes, so that sight becomes clearer.

If an eye has a refractive error (like hyperopia, myopia, astigmatism or presbyopia), a spectacle lens can be used to correctly focus the light coming into the eye so that the vision becomes clear.

All lenses have two surfaces: a front surface and a back surface. A lens must have at least one curved surface so that it can focus light.

Lenses are usually made of glass or plastic, and they come in many shapes. The most common lens shapes are:

- **Spherical**: plus and minus lenses
- **Astigmatic**: cylindrical and sphero-cylindrical lenses.

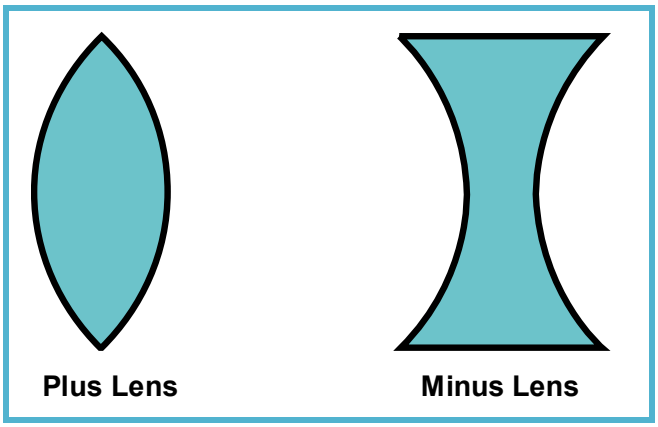


Figure 2.14: *Plus and minus lenses*

A plus lens has a focal point where all of the refracted light rays converge and meet.
A minus lens makes light rays diverge as though the light rays are coming from one point.

A lens will bend light rays by different amounts depending on the refractive index of the lens material, and where on the lens surface the incident light ray enters.

Although prisms can only bend light and cannot focus light, a lens can be thought of as prisms that are joined together.

A plus lens can be thought of as two prisms that are joined base to base.

A minus lens can be thought of as two prisms that are joined apex to apex.

LENSES (cont.)

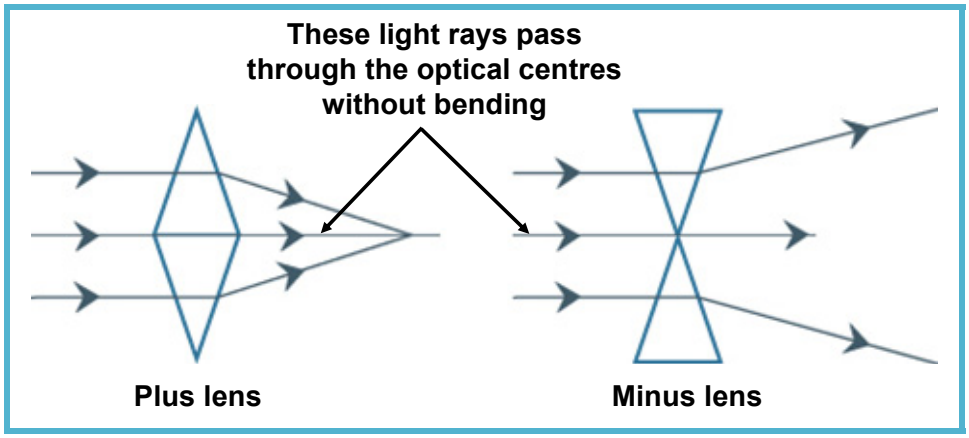


Figure 2.15: *Lenses can be thought of as prisms that are joined together*

This basic description of a lens helps us to understand how plus and minus lenses bend light – but it is not perfectly accurate. We can see the problem with this explanation if we add some more light rays to the diagram, as seen below. Here we can see that two prisms by themselves cannot focus light to a single point, they can only bend light.

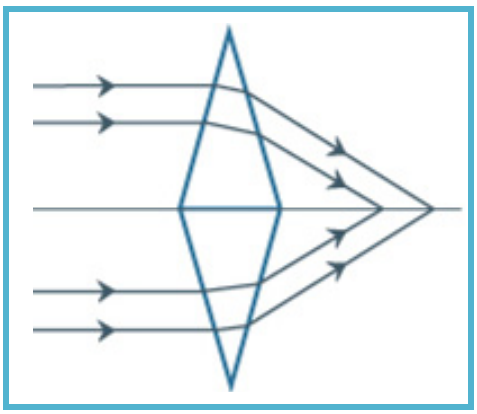


Figure 2.16: *Light rays passing through two prisms*

A lens is really like a large number of prisms that get stronger towards the edge. We can see from Diagram A below how this might work if we add just two extra prisms to the figure above. If we add more and more light rays you would need more and more prisms to bend the light to one focus (see Diagram B below).

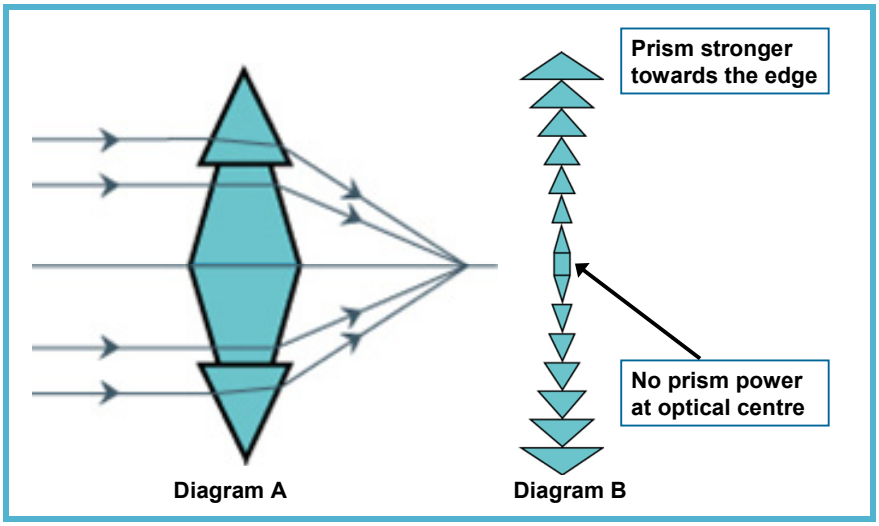


Figure 2.17: *A lens is like a large number of prisms getting gradually stronger towards the edge of the lens*

LENSES (cont.)

Another way of bending the light to focus at one point is to make at least one of the lens surfaces curved. This is just like a much larger number of prisms getting gradually stronger towards the edge of the lens. Most spectacle lenses have both surfaces curved.

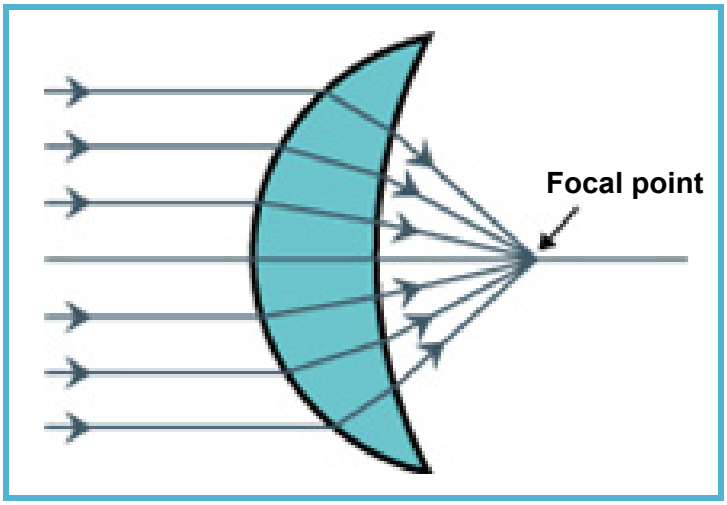


Figure 2.18: *A spectacle lens has two surfaces curved. A curved surface lets the lens focus light*

OPTICAL CENTRE

Notice that the light ray that travels through at the place where the two prisms join is not bent at all. This point is called the optical centre of the lens.

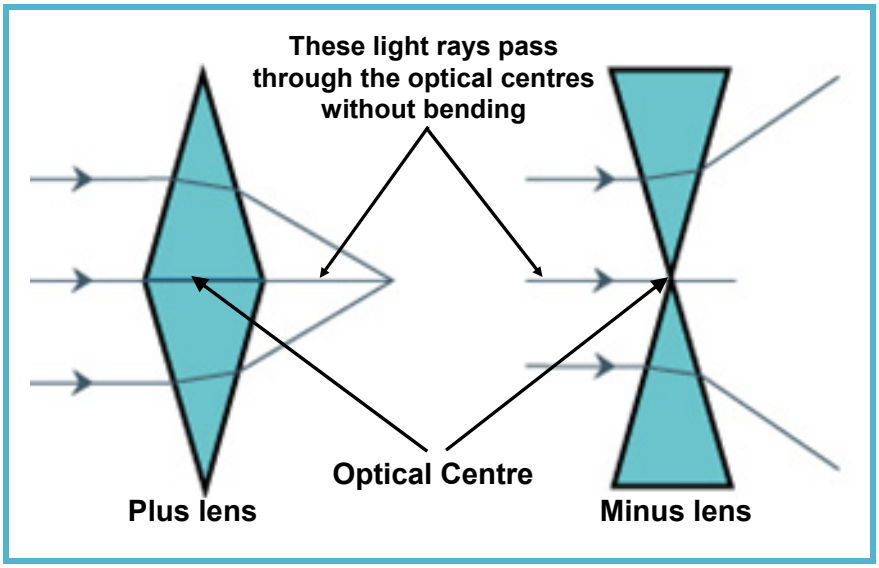


Figure 2.19: *Optical centres of a plus and minus lens*

The optical centre is the only part of a lens that a light ray can travel through without being refracted. It is the optical centre of a lens that we line up with a person's eyes when making spectacles.

The optical centre for a plus lens is the point where the lens is thickest. The optical centre for a minus lens is the point where the lens is thinnest.

LENSES (cont.)

PLANO LENSES

A lens that is neither plus nor minus is called a plano (or non-prescription) lens.

A plano lens has no focusing power – it cannot bend or refract light. Light will travel through a plano lens without being bent or focused, like light that travels through a glass window.

A plano lens can have two flat surfaces or two (equal and opposite) curved surfaces.

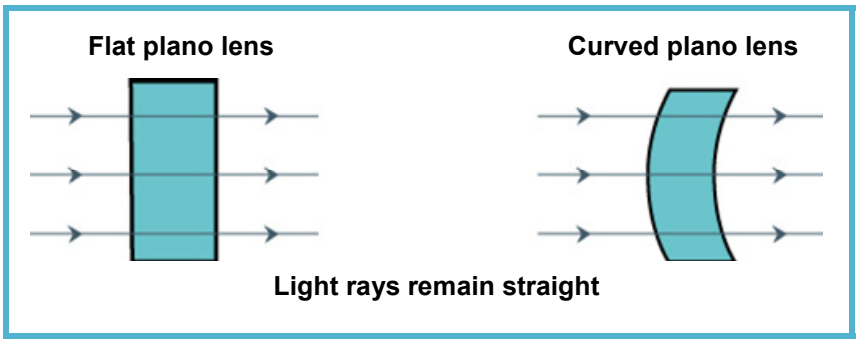


Figure 2.20: *Plano lenses can be flat or curved.*
Light rays that pass through a plano lens do not bend

SUMMARY: OPTICS

LIGHT AND SEEING

- Seeing is a result of the eyes receiving light from an object and the brain interpreting these light messages.
- To see clearly, the eyes must receive the light and correctly focus the light on the retina at the back of the eye.

BEHAVIOUR OF LIGHT

- Light travels in straight lines.
- Light rays can be parallel, convergent, divergent, or scattered.
- Parallel light rays come from distant objects (6 m or further away).
- Light can be reflected, refracted or absorbed when it reaches an object.

OPTICAL MEDIUM

- An optical medium will let light travel through it.
- An optical medium can be gas, liquid or solid.

REFRACTIVE INDEX

- Every optical medium has a specific refractive index.
- Light travels faster in media that have a low refractive index, and slower in media that have a high refractive index.

REFLECTION AND REFRACTION

- Reflection occurs when light bounces off an object.
- Refraction describes the change in direction of a light ray as it passes from one medium to another.
- The incident ray is the light ray that travels towards a surface. If it is not absorbed, it will become a reflected ray or a refracted ray once it touches the surface.

PRISMS

- A prism is a piece of glass or plastic in the shape of a triangle.
- A prism has a base and an apex
  → A prism bends light away from its apex.
- An object viewed through a prism looks like it is closer to the apex of the prism than it really is → this is called apparent deviation.

LENSES

- Light rays that enter lenses can be bent or refracted.
- Spherical lenses can be plus or minus lenses.
- Plus lenses converge light rays, while minus lenses diverge them.
- Astigmatic lenses can be cylindrical or sphero-cylindrical lenses.
- A lens can be thought of as a large number of prisms that get stronger towards the edge of the lens
  → A plus lens is like prisms joined base to base
  → A minus lens is like prisms joined apex to apex.

OPTICAL CENTRE

- A light ray will not be refracted or bent if it travels through the optical centre of a lens.

PLANO LENSES

- A plano lens has zero focusing power.
- Light rays will pass through a plano lens without bending or focusing.

SUMMARY: OPTICS (cont.)

AQUEOUS

- Watery liquid in the anterior chamber.
- Provides nutrients to the cornea and the lens.

LENS

- Transparent in a normal eye.
- Suspended behind the pupil.
- Changes in the lens' shape change the eye's focus from distance to near.

CILIARY MUSCLE

- Changes the focusing ability of the eye by changing the shape of the lens.

VITREOUS BODY

- Transparent gel between the lens and the retina.
- Helps give shape to the eyeball.

FUNDUS

- The fundus is the inside of the eye that can be seen when looking through the pupil with a special instrument (such as an ophthalmoscope).
- It includes the retina, optic disc and blood vessels.

RETINA

- Catches the light that comes into the eye and changes it into nerve messages that are sent to the brain.
- The central portion of the retina is the macula.

OPTIC NERVE

- Sends messages to the brain.
- The visible part of the optic nerve (when looking through the pupil) is called the optic disc.

EXTRAOCULAR MUSCLES (OEMs)

- Six muscles are attached to each eye.
- EOMs move the eyeballs in various directions.

THREE KEY REQUIREMENTS FOR GOOD VISION

- The cornea, lens and vitreous must be transparent.
- Light is focused by the cornea and the crystalline lens to form a clear image on the retina.
- The optic nerve sends information received by the retina to the brain.

ANATOMICAL TERMS OF LOCATION

- **Anterior** = In front of
- **Posterior** = Behind
- **Superior** = Above
- **Inferior** = Below
- **Nasal** = Closer to the nose; further away from the ear
- **Temporal** = Further away from the nose; closer to the ear.

TEST YOURSELF QUESTIONS

1. **Name the three different types of light rays (in terms of their direction of travel).**

_____

_____

_____

2. **Name the only two ways in which light rays can change direction.**

_____

3. **What do we call a light ray travelling towards a surface?**

_____

4. **What is refractive index a measure of?**

_____

_____

5. **What is a prism? In what direction is light bent as it passes through a prism?**

_____

_____

6. **When a light ray travels from a medium of a lower refractive index into a medium of a higher refractive index, is it bent *away from* or *towards* the normal?**

_____

7. **When a light ray travels from a medium of a higher refractive index into a medium of a lower refractive index, is it bent *away from* or *towards* the normal?**

_____

8. **Will a light ray be refracted more if there is a *greater* difference between the refractive index of the original medium and the refractive index of the new medium, or if there is a *smaller* difference*?***

_____