SPHERICAL LENSES

THINK

A man from another village comes to you for an eye examination. He tells you that he wears spectacles but that he does not know the name of his eye problem. Knowing whether the lenses in his spectacles are minus or plus powers will help you find out what his spectacles are for.

AIM

This unit will help you understand how plus and minus spherical lenses focus light.

LEARNING OUTCOMES

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

- describe the types of refractive errors that spherical lenses can correct
- explain the differences between plus and minus lenses
- recognise the shapes of spherical lenses
- understand how spherical lenses focus light
- define a dioptre (D)
- write the power of a spherical lens
- understand how lens power (F) and focal length (f) are related.

REVIEW: SPHERICAL LENSES

BEHAVIOUR OF LIGHT	• Light always travels in straight lines. • Light rays can be parallel, convergent, or divergent. • Parallel light rays come from distant objects (6 metres or further away). • Light can be reflected, refracted or absorbed when it reaches an object.
LENSES	• Lenses refract light to form a focus. • Spherical lenses can be plus or minus lenses. • Astigmatic lenses can be cylindrical or sphero-cylindrical lenses.
PRISMS	• A prism bends light away from its apex. • Prism power is measured in prism dioptres (Δ).
OPTICAL CENTRE	• A light ray will not bend if it travels through the optical centre of a lens.
PLANO LENS	• A plano lens has zero focusing power.
REFRACTIVE ERROR	• A person who has a refractive error will need to wear spectacles (glasses) or contact lenses so that they can see clearly and comfortably. This is because their eye is not the correct size and shape. • There are four main types of refractive error: myopia, hyperopia, astigmatism and presbyopia.

SPHERICAL LENS SHAPES

The thickness of a spherical lens is different in the centre of the lens compared with the edge of the lens.

Plus lenses are always **thicker in the middle** and thinner at the edge.
Minus lenses are always **thinner in the middle** and thicker at the edge.

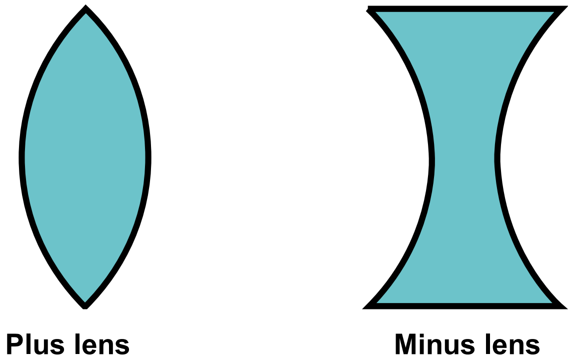


Figure 4.1: *Plus and minus lenses*

A good way to think about the shape of a spherical lens is to imagine the space between two spheres (balls) that are either overlapping (in the case of a plus lens) or are next to each other (in the case of a minus lens).

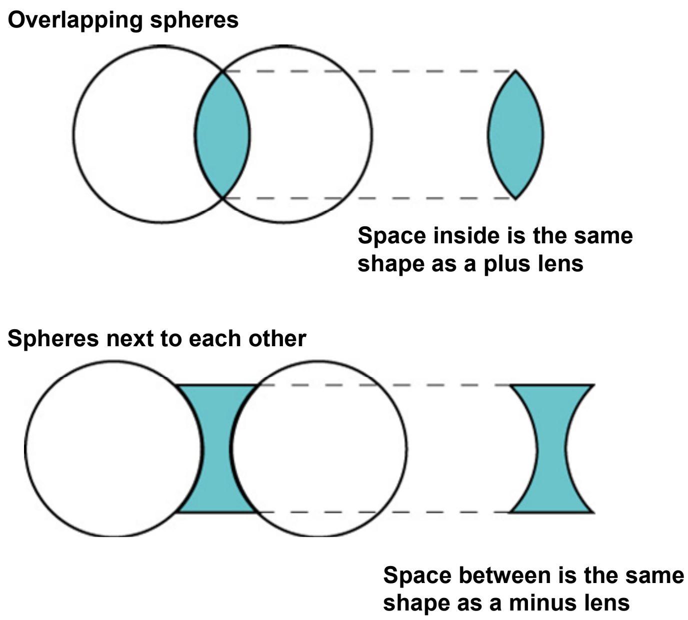


Figure 4.2: *The shape of a spherical lens is the same as the space between two spheres*

Spectacle lenses can be different shapes.
They do not always look like the symmetrical shapes above.

SPECTACLE LENS SHAPES

Spherical spectacle lens surfaces can be:

- Plano (flat)
- Convex (curved like the outside of a ball)
- Concave (curved like the inside of a ball).

If you have a sphere (like a soccer ball) and you cut it in half, each of these halves has two surfaces: the outside surface and the inside surface.

→ The outside surface of the sphere is convex.
→ The inside surface of a sphere is concave.

A convex surface converges light and a concave surface diverges light.

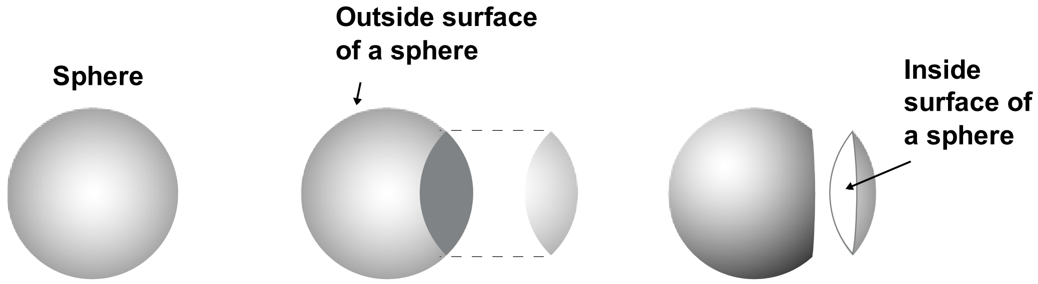


Figure 4.3: *Looking at the outside and the inside surfaces of a sphere*

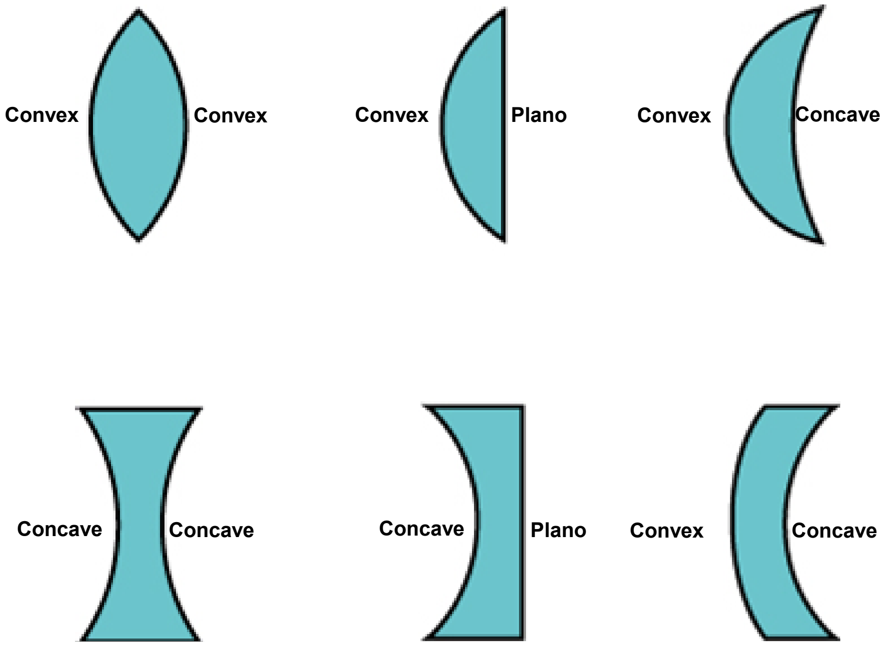


Figure 4.4: *Some of the ways that plano, convex and concave surfaces can form lenses*

SPECTACLE LENS SHAPES (cont.)

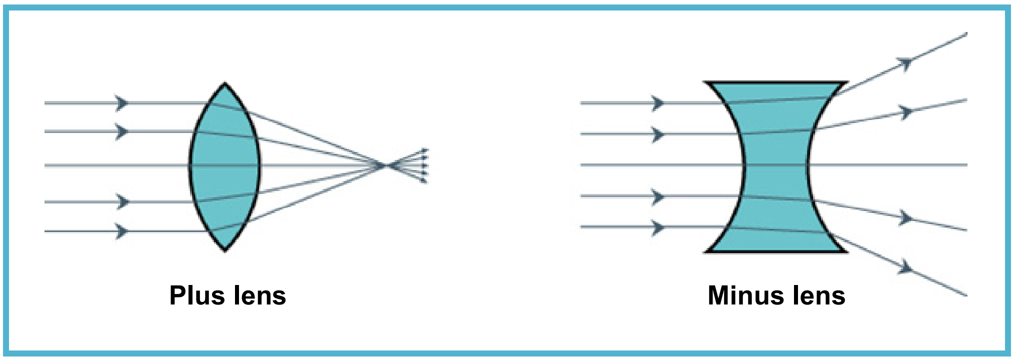
<table>
<tr><td>PLUS LENS</td><td>At least one surface of a plus lens is convex (like the outside of a ball).
Plus lenses have other names too:
Positive lenses
Convex lenses
Converging lenses.</td></tr>
<tr><td>MINUS LENS</td><td>At least one surface of a minus lens is concave (like the inside of a ball).
Minus lenses have other names too:
Negative lenses
Concave lenses
Diverging lenses.


Figure 4.5: Light rays travelling through plus and minus lenses.
The plus lens is converging light and the minus lens is diverging light.</td></tr>
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SPHERICAL LENSES AND REFRACTIVE ERROR

Spherical lenses are used to correct some types of refractive errors by correcting the focus of the eye.

Spherical lenses can be put into spectacles to help people with hyperopia, myopia and presbyopia see clearly.

Plus lenses are used to correct hyperopia and presbyopia.
Minus lenses are used to correct myopia.

SPHERICAL REFRACTIVE POWER

LENS POWER (DIOPTRES)

The refractive power (or strength) of a lens tells us how much focussing power the lens has.

A lens has two surfaces – a back surface and a front surface. Each surface has certain refractive power, but the total refractive power of the lens is the total of its two surfaces added together.

A convex surface converges light and has a plus (+) power.

A concave surface diverges light and has a minus (–) power.

A convex or concave surface which is more curved (a “steeper” curve) will be more powerful than a surface which is less curved (a “flatter” curve).

Spherical refractive power is measured in dioptres**.** This is usually written as “D”. A dioptre is a measure of how much a convex or a concave surface makes light converge or diverge.

Spectacle refractive powers are written with two decimal places (with two numbers after the decimal point).

For example:

A spectacle lens that has a power of plus two dioptres would be written as +2.00 D.

Spectacle refractive powers usually increase in quarter dioptre steps (0.25 D steps).

For example:

+0.25 D, +0.50 D, +0.75 D, +1.00 D, +1.25 D, +1.50 D…

–0.25 D, –0.50 D, –0.75 D, –1.00 D, –1.25 D, –1.50 D…

SPHERICAL REFRACTIVE POWER (cont.)

FOCAL LENGTH

Parallel light rays that travel through a plus lens will converge. These converging light rays will meet at a focal point behind the plus lens.

The distance between the lens and its focal point is called the focal length. The focal length is a positive number for a plus lens, because the focal point is behind the lens.

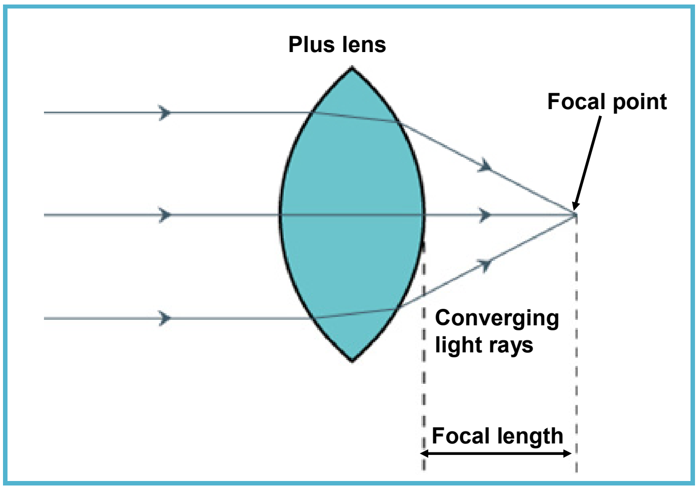


Figure 4.6: *Parallel light rays travelling through a plus lens converge to a focal point*

A parallel light ray that travels though a minus lens will diverge. These diverging light rays will not meet behind the minus lens – diverging light rays will travel away from each other.

A minus lens has a virtual focal point in front of the minus lens. A virtual focal point is an imaginary point where diverging light rays seem to be coming from.

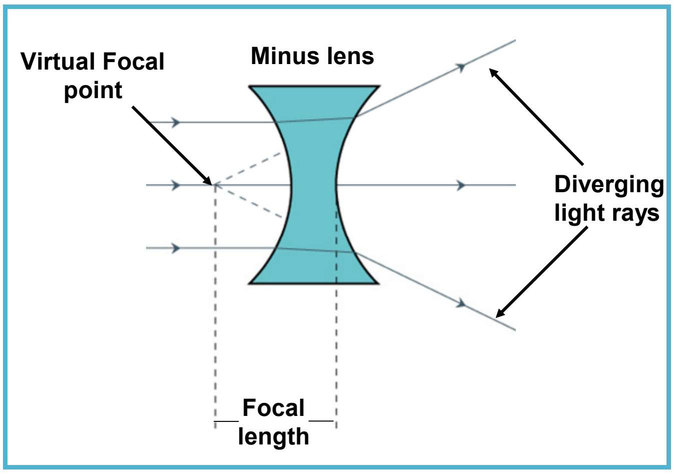


Figure 4.7: *Parallel light rays travelling through a minus lens diverge. These diverging light rays look like they are coming from a virtual focal point.*

For a minus lens, the distance between the lens and the virtual focal point is also called the focal length. The focal length is a negative number for a minus lens, because the virtual focal point is in front of the lens.

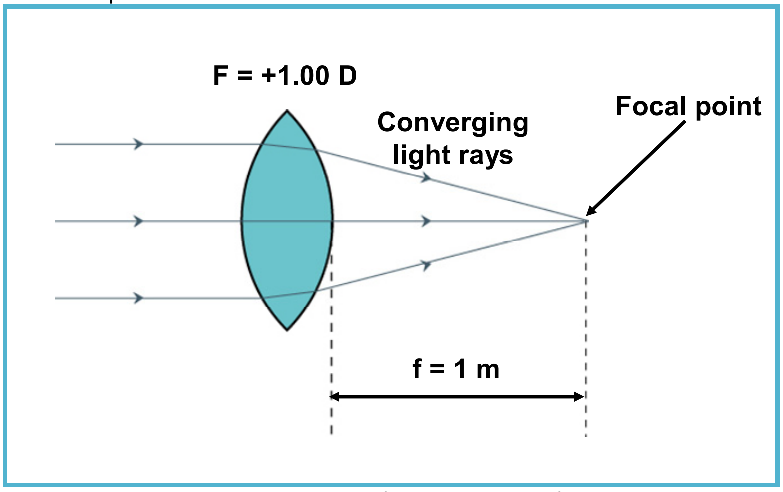
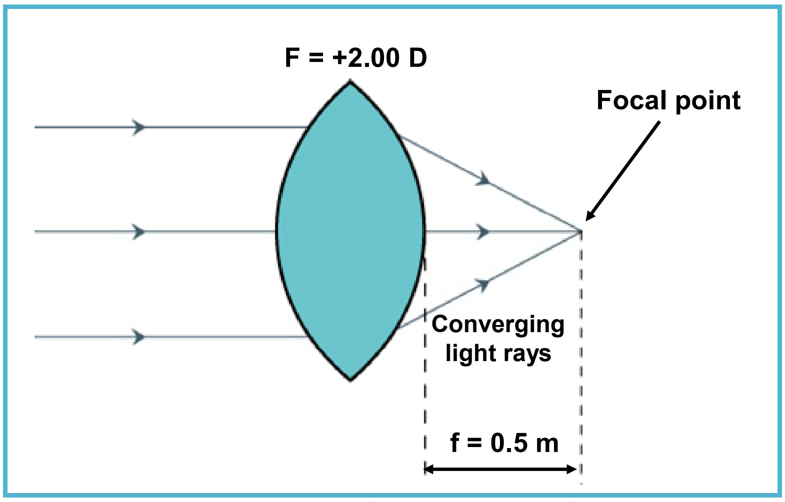
To find the focal length of any lens there is a formula:

f = 1/F or F = 1/f

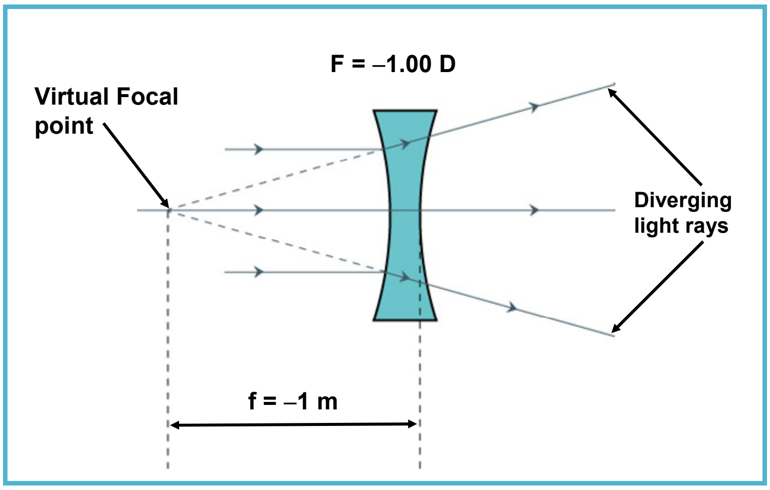
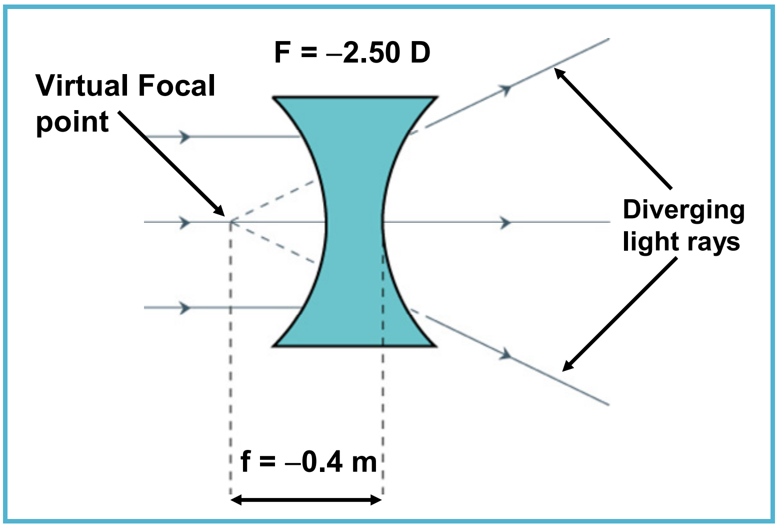
Where:	f = focal length	in metres (m)
	F = lens power	in dioptres (D)

We can therefore say that the refractive power of a lens, measured in dioptres, is equal to the reciprocal of the focal length of the lens measured in metres.

SPHERICAL REFRACTIVE POWER (cont.)

EXAMPLE 1	If parallel light rays enter a +1.00 D lens, how far away from the lens will the focal point be? f = 1/F = 1/+1.00 = +1 m Therefore, the focal point of a +1.00 D lens will be 1 m behind the lens.  ***Figure 4.8:*** *Parallel light rays will focus 1 m away from a +1.00 D lens*
EXAMPLE 2	If parallel light rays enter a +2.00 D lens, how far away from the lens will the focal point be? f = 1/F = 1/+2.00 = +0.5 m = +50 centimetres (cm) Therefore, the focal point of a +2.00 D lens will be 50 cm behind the lens.  ***Figure 4.9:*** *Parallel light rays will focus 50 cm away from a +2.00 D lens*

SPHERICAL REFRACTIVE POWER (cont.)

EXAMPLE 3	If parallel light rays enter a –1.00 D lens, how far away from the lens will the virtual focal point be? $f = 1/F = 1/(-1.00) = -1$ m Therefore, the virtual focal point of a –1.00 D lens will be 1 m in front of the lens.  ***Figure 4.10:*** *Parallel light rays travelling through a –1.00 D lens will form a virtual focal point 1 m in front of it*
EXAMPLE 4	If parallel light rays enter a –2.50 D lens, how far away from the lens will the virtual focal point be? $f = 1/F = 1/(-2.50) = -0.4$ m $= -40$ cm Therefore, the virtual focal point of a –2.50 D lens will be 40 cm in front of the lens.  ***Figure 4.11:*** *Parallel light rays travelling through a –2.50 D lens will form a virtual focal point 40 cm in front of it*

SPHERICAL REFRACTIVE POWER (cont.)

LENS SHAPE AND LENS POWER

Lenses that have different shapes can still have the same power.

Example 1:
All the lenses below have the same power, even though they have different shapes. They are all +4.00 D lenses, so all of them will bend (converge) light by the same amount.

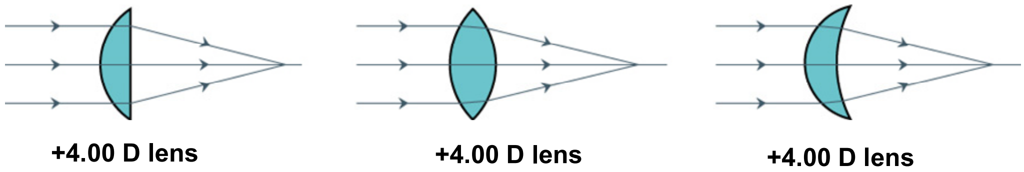


Figure 4.12: *+4.00 D lenses can come in different shapes*

Example 2:
All the lenses below have different shapes, but the same power. They are all –4.00 D lenses, so all of them will bend (diverge) light by the same amount.

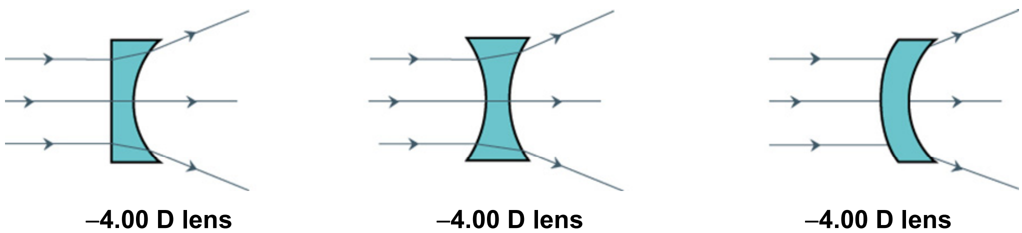


Figure 4.13: *–4.00 D lenses can come in different shapes*

SPHERICAL REFRACTIVE POWER (cont.)

PLUS LENSES

- **Lens Thickness**
  It is usually easy to recognise a plus lens because it is thicker in the middle than it is at the edge. The optical centre is at the thickest part of a plus lens.

- **Lens Image Size**
  Another way to know if a lens has plus power is to look at objects through the lens. When you look through a plus lens the objects viewed will appear bigger and closer. A magnifying glass is an example of a plus lens.

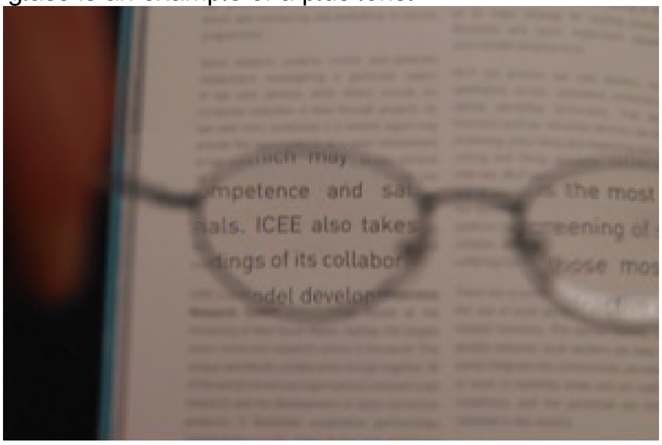
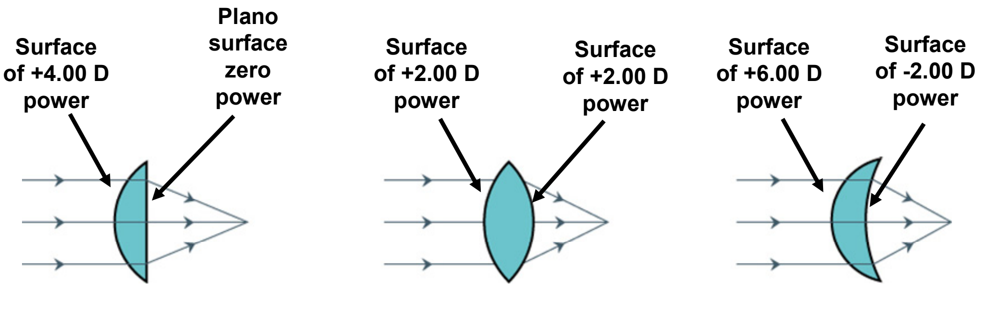


Figure 4.14: *Objects seen through plus lenses look bigger and closer*

- **Writing Plus Prescriptions**
  People with hyperopia and presbyopia need positive lenses in their spectacles and you will often see something like this written in the spectacle prescription: +2.50 D.

  - The "+" sign tells us it is a plus lens
  - The "2.50 D" tells us the power is two and one-half dioptres.

- **Plus Lens Surface Powers**



All of these have a power of +4.00 D

Figure 4.15: *Plus lenses converge light.*
A plus lens may have:
- *one flat and one convex surface; or*
- *both surfaces convex; or*
- *one convex and one concave surface, where the power of the convex surface is greater than the power of the concave surface.*

The three lenses shown in Figure 4.15 all have a power of +4.00 D. This is because for each lens the total of the powers of the two surfaces equals +4.00.

SPHERICAL REFRACTIVE POWER (cont.)

MINUS LENSES

- **Lens Thickness**
  It is usually easy to recognise a minus or negative lens, because it is thinner in the middle than it is at the edge. The optical centre is at the thinnest part of a minus lens.

- **Lens Image Size**
  Another way to know if a lens has minus power is to look at objects through the lens. If you look through a minus lens, the objects viewed will appear smaller and farther away.

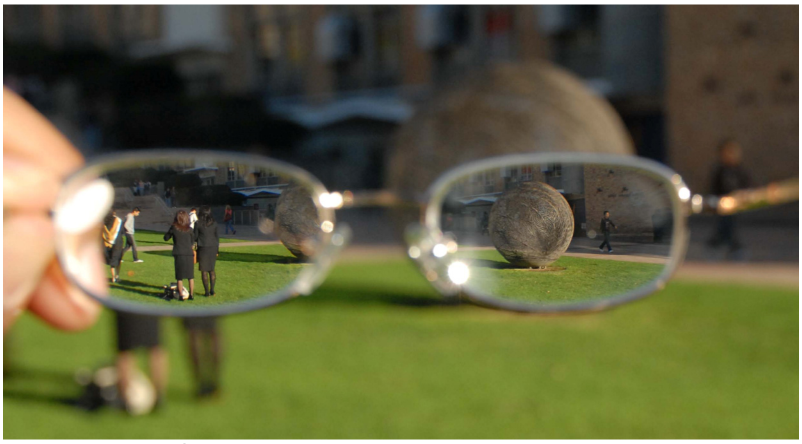
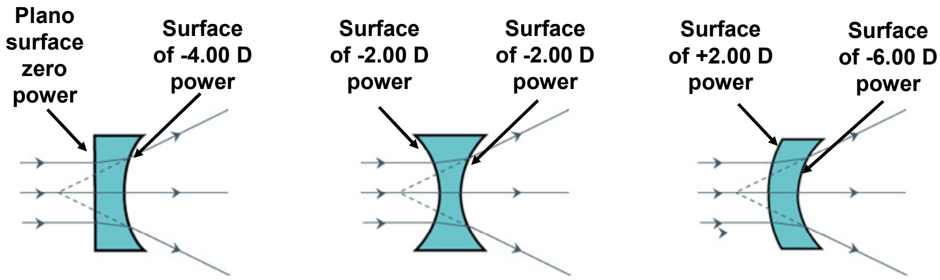


Figure 4.16: *Objects seen through plus lenses look bigger and closer*

- **Writing Minus Prescriptions**
  People with myopia need minus lenses in their spectacles and you will often see something like this written in the spectacle prescription: –3.75 D.

  - The "–" sign tells us it is a minus lens
  - The "3.75 D" tells us the power is three and three-quarter dioptres.

- **Minus Lens Surface Powers**



All of these lenses have a power of –4.00 D

Figure 4.17: *Minus lenses diverge light.*
A minus lens may have:
- *one flat and one concave surface; or*
- *two concave surfaces; or*
- *one convex and one concave surface, where the power of the concave surface is greater than the power of the convex surface.*

The three lenses shown in Figure 4.17 all have a power of –4.00 D.
This is because, for each lens, the total power of the two surfaces equals –4.00.

SPHERICAL REFRACTIVE POWER (cont.)

LENS THICKNESS AND LENS POWER

Lenses that are of different thicknesses usually have different powers.

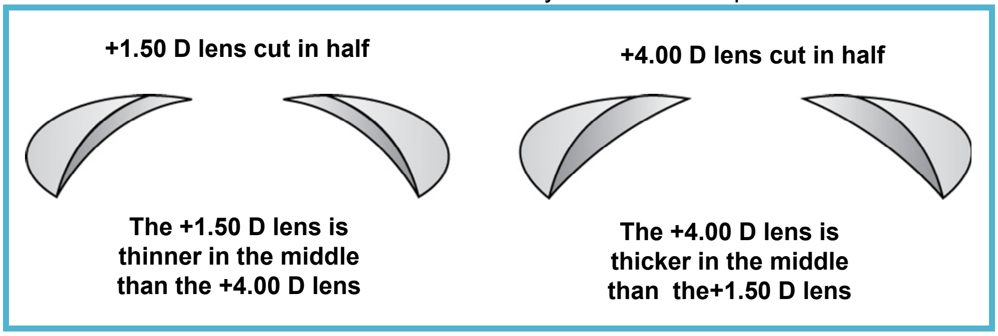


Figure 4.18: *Plus lenses that have a stronger power are thicker in the middle*

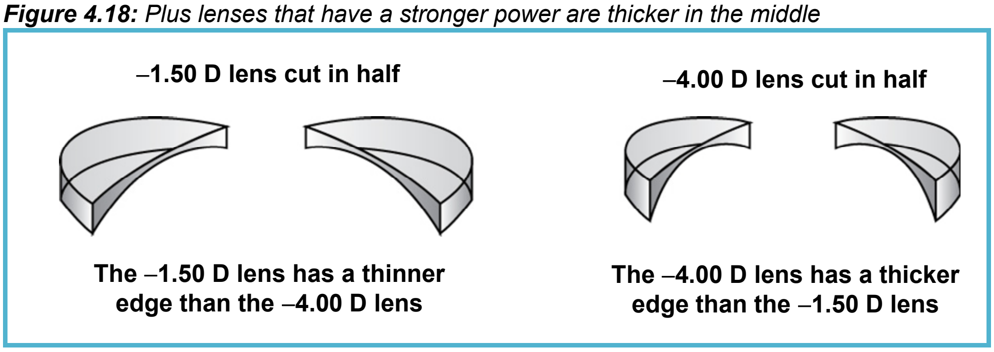


Figure 4.19: *Minus lenses that have a stronger power are thicker on the edge*

The more curved a surface is (the steeper the curve of a surface), the greater the power of that surface.

PLANO LENSES

Sometimes lenses with no power are needed. Lenses with no power are called plano lenses or "non-prescription" lenses.

A person with good vision who spends a lot of time outdoors may need sunglasses with plano lenses. A factory worker with good vision might need plano safety spectacles. Some people need a lens with power for one eye, but the other eye may be perfect. In that case, a plano spectacle lens would be used for the good eye.

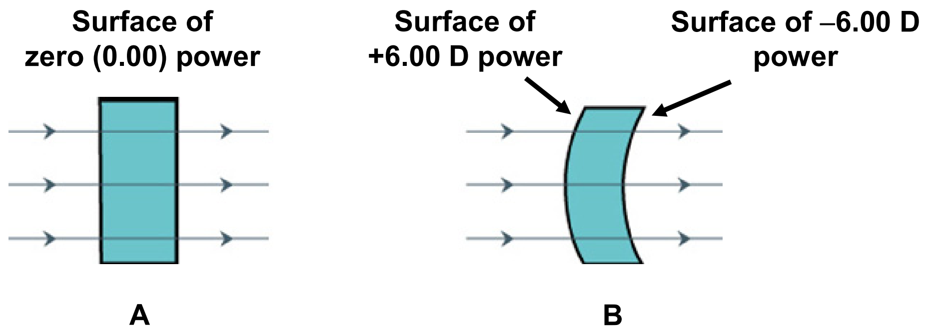


Figure 4.20*: Plano lenses may be flat or curved.*
Light rays that pass through a plano lens do not bend.

Like all lenses the power of a plano lens is the total of the powers of the two surfaces.

- The first lens in Figure 4.20 has a front surface that is flat (plano or zero power) and a back surface that is flat (plano or zero power). The lens power is 0.00 + 0.00 = 0.00 D.
- The second lens in Figure 4.20 has a convex front surface of +6.00 D and a concave back surface of –6.00 D. The lens power is +6.00 + (–6.00) = 0.00 D.

You can see that for a curved lens to be of plano power, the curvature of both surfaces must be the same, but one must be convex and one concave. This means that the thickness of a plano lens is the same in the centre as it is at the edges.

When plano lenses are used as safety spectacles the lenses are usually made thicker, so that they are harder to break.

SUMMARY: SPHERICAL LENSES

SPHERICAL LENSES AND REFRACTIVE ERROR

- Spherical lenses correct hyperopia, myopia and presbyopia.
- Plus lenses correct hyperopia and presbyopia.
- Minus lenses correct myopia.

SPHERICAL LENS SHAPE

- Plus lenses are thicker in the middle than at the edge.
- Minus lenses are thinner in the middle than at the edge.
- Spherical lenses have at least one convex or concave surface.
- A convex surface converges light, it has plus (+) power.
- A concave surface diverges light, it has minus (–) power.

SPHERICAL LENS POWER

- Spherical refractive power is measured in dioptres (often written as "D").
- Spherical refractive power is written with two decimal places (e.g. –2.75 D).
- Spectacle refractive powers usually increase in 0.25 D steps.
- Thicker lenses usually have stronger powers.
- The focal point of a plus lens is where the converging light rays meet (behind the lens).
- The virtual focal point of a minus lens is where the diverging light rays seem to be coming from (in front of the lens).
- Focal length is the distance between the lens and the focal point.
- Focal length (f) is related to the power (F) of the lens:

  $f = 1/F$ *or* $F = 1/f$.
- The refractive power of a lens, measured in dioptres, is equal to the reciprocal of the focal length of the lens measured in metres.

Lens Type	Lens Thickness	Lens Image Size	Writing a Lens Prescription	Total of Lens Surface Powers
Plus lens	Thickest in centre, thinnest at edges	Objects viewed through lens look larger and closer	"+"	Plus
Minus lens	Thickest at edges, thinnest in centre	Objects viewed through lens look smaller and further away	" – "	Minus
Plano lens	Equal thickness at edge and centre	Objects viewed through lens look the same	Plano	Zero

TEST YOURSELF QUESTIONS

1. **Does light bend when it passes through the optical centre of a lens?** (*tick one*)
   ☐ Yes ☐ No

2. **Does a convex lens surface converge or diverge light?**

   ____

3. **How would you write the power of a plus lens of one and three-quarter dioptres?**

   ____

4. **Give two other names for a minus lens.**

   a. ____

   b. ____

5. **If a lens has one surface with a power of +3.00 D, and a second surface of power –6.00 D, what is its total power?**

   ____

6. **List two different uses for plano lenses.**

   ____

7. **List three differences between plus and minus lenses.**

   ____

8. **What is the focal length of a +2.50 D lens?**

   ____

9. **What type of refractive error can be corrected with minus lenses?**

   ____

10. **Name two types of refractive error that can be corrected with plus lenses:**

    a. ____

    b. ____

NOTES