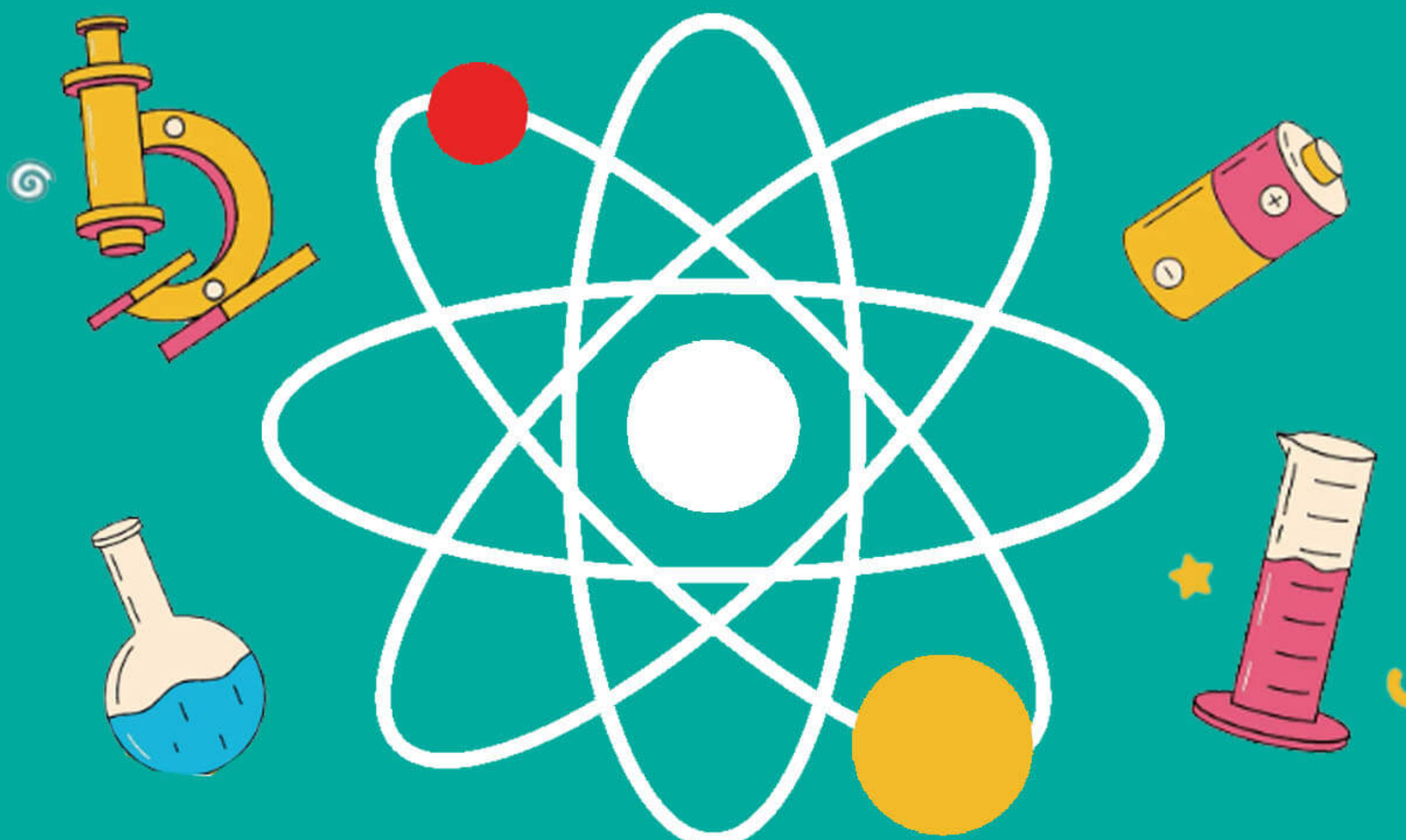
Exam Papers Practice

10.1 Physics of the Eye



AQA A Level Physics Revision Notes

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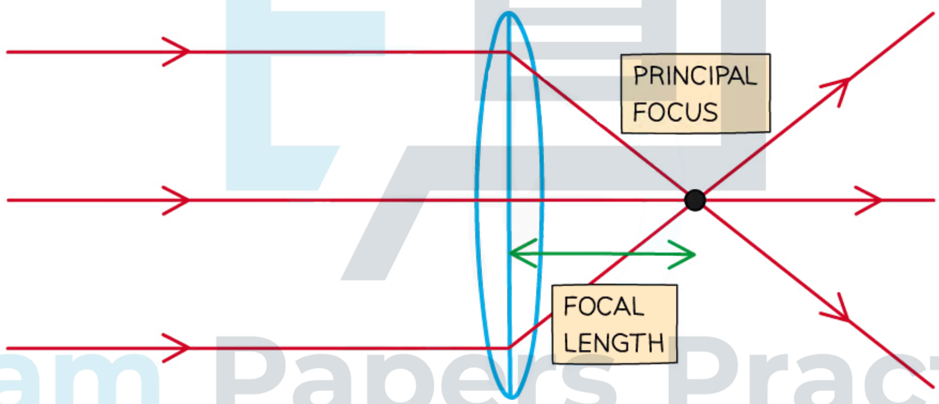
10.1.1 Converging & Diverging Lenses

Converging Lenses

- A lens is a piece of equipment that forms an image by **refracting** light
- There are two types of lenses:
  - A convex, or **converging** lens
  - A concave, or **diverging** lens

- In a converging lens, parallel rays of light are brought to a focus along the principal axis
  - This point is called the focal point

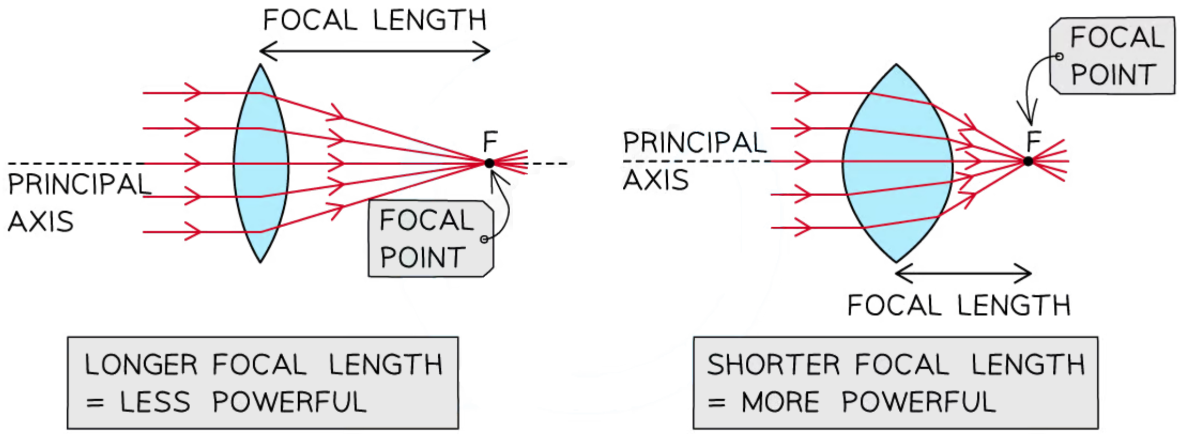
The Ray Diagram of a Converging Lens



A converging lens brings parallel rays of light to a focus

- The distance from the centre of the lens to the focal point is called the **focal length**, f
  - This length depends on how **curved**, or how **thick**, the lens is
  - The **more** curved (**thicker**) the lens, the **shorter** the focal length
  - The **shorter** the focal length, the more **powerful** the lens
  - f is **positive** for a converging lens because it is in front of the lens

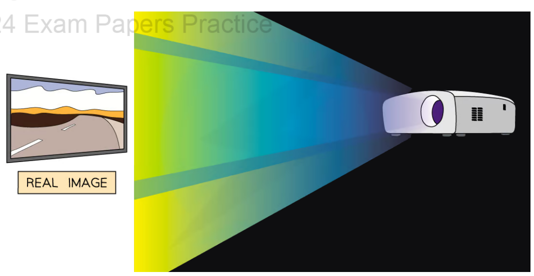
The Different Shapes of Lenses with Long and Short Focal Lengths



The focal length is shorter in a lens that is thicker and more curved. This makes for a more powerful lens

Real & Virtual Images

- Images produced by lenses can be either **real** or **virtual**

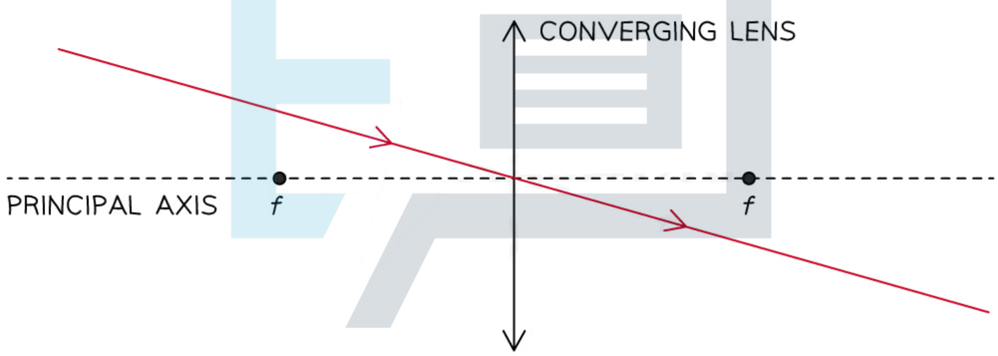
Real image	Virtual image
light converges towards a focal point	light diverges away from a focal point
always inverted	always upright
can be projected onto a screen	cannot be projected onto a screen
intersection of two solid lines	intersection of two dashed lines (or a dashed and a solid line)
 example: image from a projector onto a screen	 example: image in a mirror

Constructing Ray Diagrams

- When constructing ray diagrams of refractors, it is generally assumed that the lenses used are **very thin**
  - This simplifies the situation by reducing the amount the incident rays of light refract
- As a result, the three main rules for constructing ray diagrams are as follows:

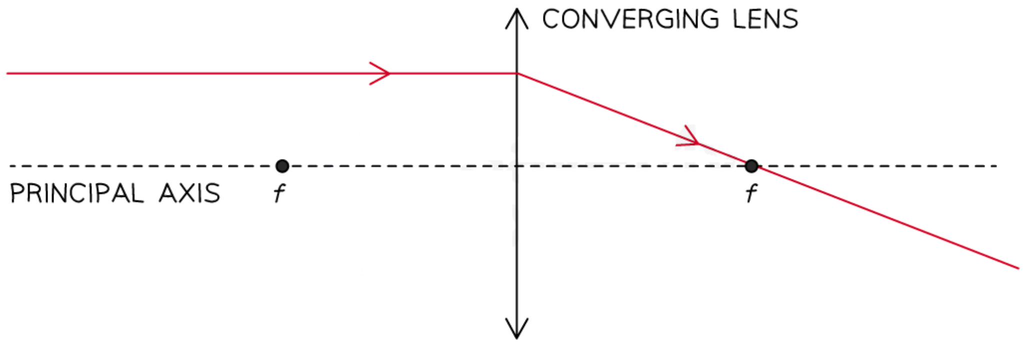
  1. Rays passing through the principal axis will pass through the optical centre of the lens undeviated

Converging Lens Ray Diagram Construction Rule 1



2. Rays that are parallel to the principal axis will be refracted and pass through the focal point *f*

Converging Lens Ray Diagram Construction Rule 2



3. Rays passing through the focal point *f* will emerge parallel to the principal axis

Converging Lens Ray Diagram Construction Rule 3

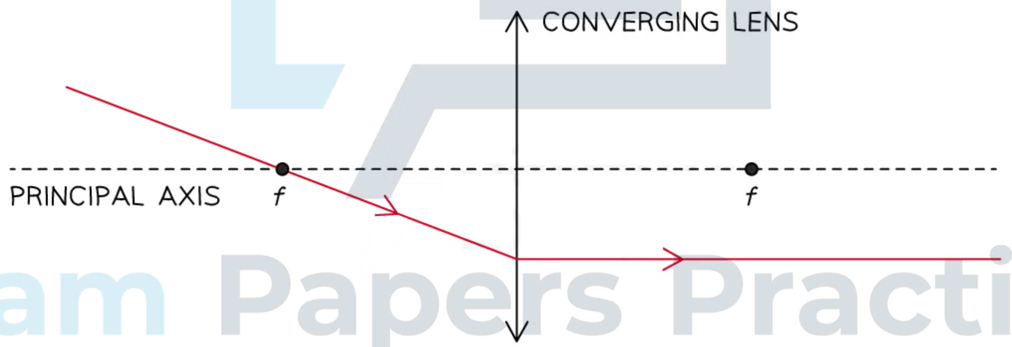


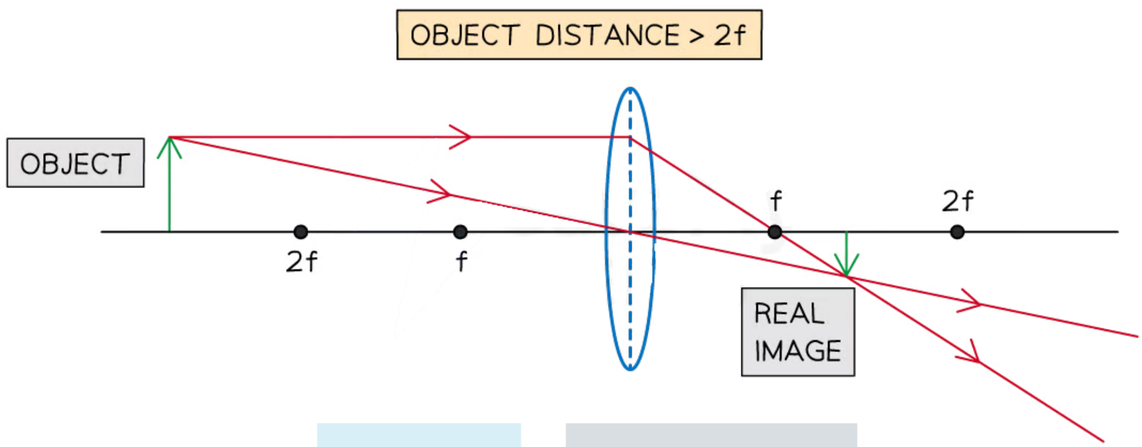
Image Formation by a Converging Lens

- Images formed by lenses can be described by their
  - **Nature:** Real or virtual
  - **Orientation:** Inverted or upright (compared to the object)
  - **Size:** Magnified (larger), diminished (smaller), or the same size (compared to the object)

Drawing ray diagrams of real images

- For an object placed at a distance **greater than** 2 focal lengths...

A Converging Lens Ray Diagram for an Object Placed Further than 2f

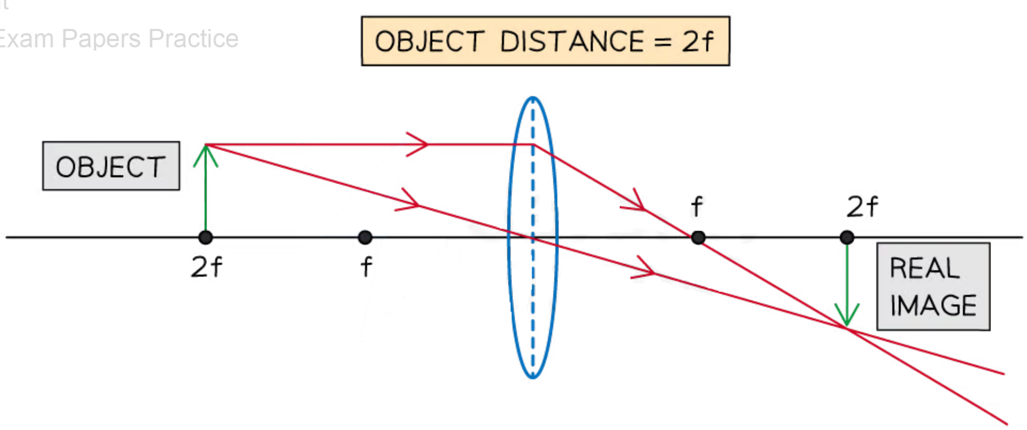


- The image that forms will have the following properties:

The image forms...	between *f* and 2*f*
The nature of the image is...	real
The orientation of the image is...	inverted
The size of the image is...	diminished

- For an object placed at a distance **equal to** 2 focal lengths...

A Converging Lens Ray Diagram for an Object Placed at 2f

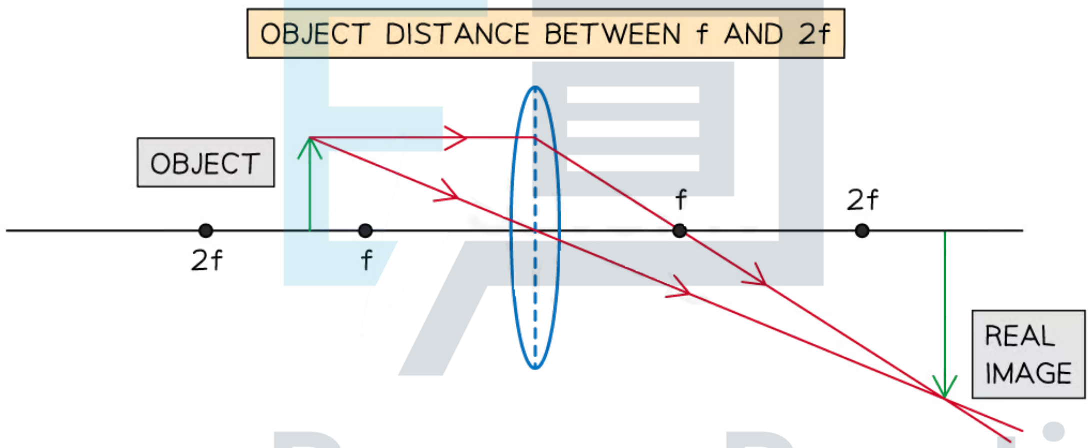


- The image that forms will have the following properties:

The image forms...	at $2f$
The nature of the image is...	real
The orientation of the image is...	inverted
The size of the image is...	the same

- For an object placed at a distance **between** 1 and 2 focal lengths

A Converging Lens Ray Diagram for an Object Placed Between f and 2f



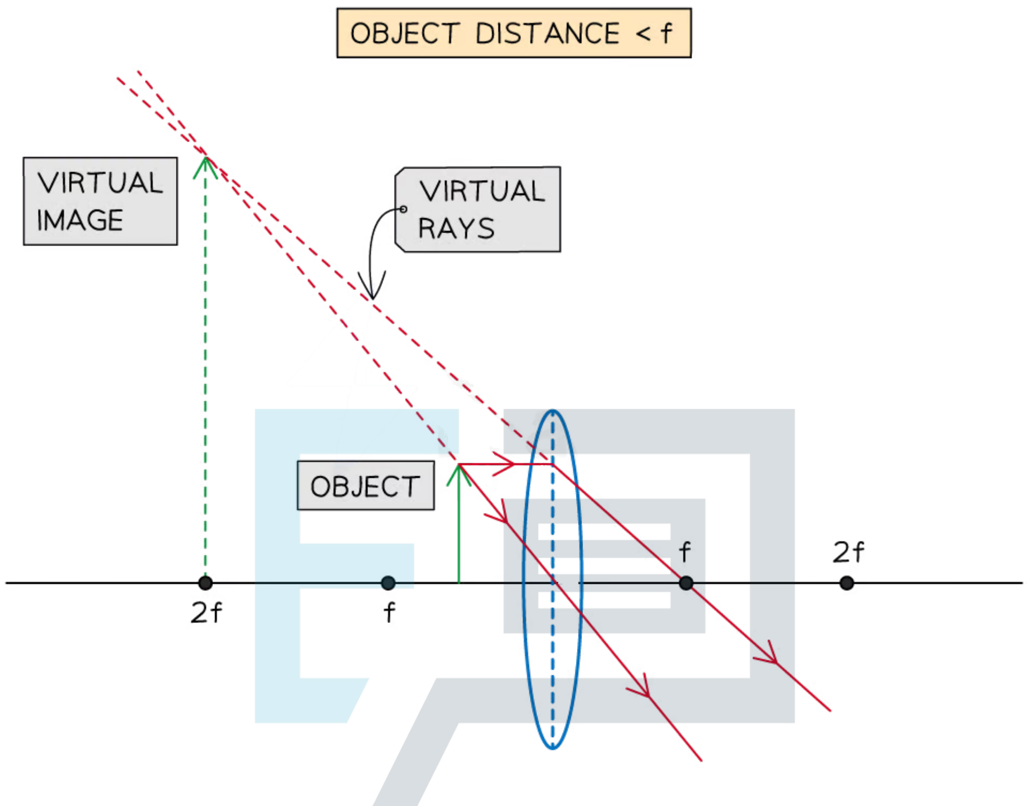
- The image that forms will have the following properties:

The image forms...	beyond $2f$
The nature of the image is...	real
The orientation of the image is...	inverted
The size of the image is...	magnified

Drawing ray diagrams of virtual images

- For an object placed at a distance **less than** the focal length (i.e. a **magnifying glass**):

A Converging Lens Ray Diagram for an Object Placed Less than f



- The image that forms will have the following properties:

The image forms...	at $2f$ (on the same side as the object)
The nature of the image is...	virtual
The orientation of the image is...	upright
The size of the image is...	magnified

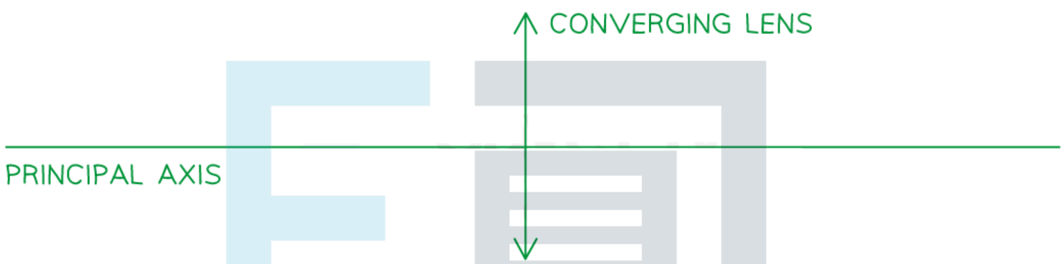
Worked example

Draw a ray diagram to show how a converging lens can be used to form a diminished image of a real object.

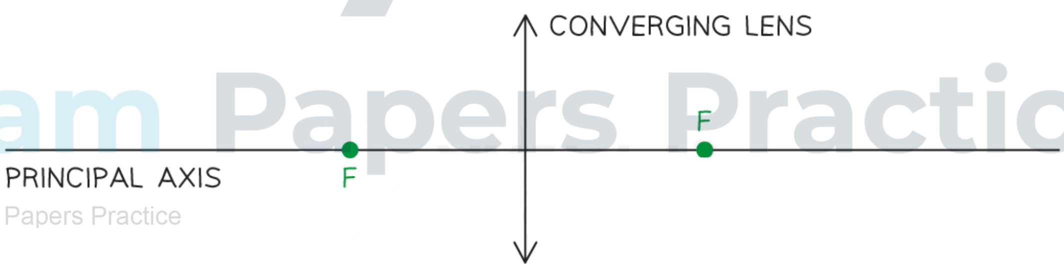
Label the object, image and principal foci of the lens on your diagram.

Answer:

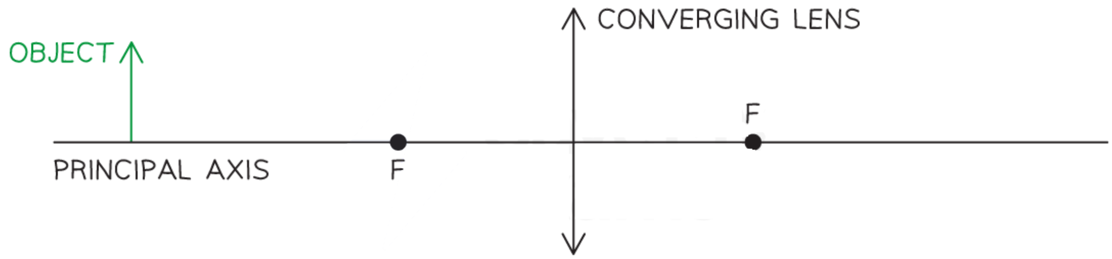
Step 1: Start by drawing and labelling a principal axis and the lens as a line or a very thin ellipse



Step 2: Mark and label the focal points on each side of the lens

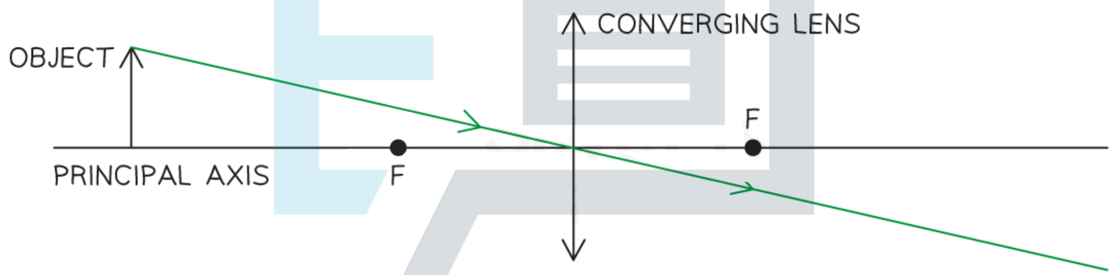


Step 3: Draw and label the object at a distance greater than the focal length on the left side of the lens

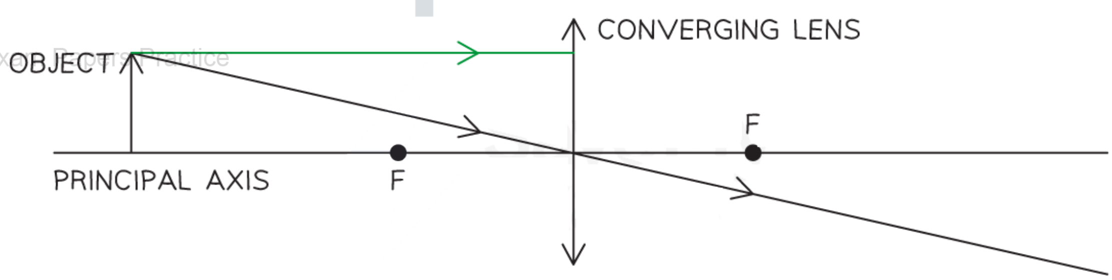


- Tip: For a diminished image the object should be placed a distance of at least 2F away from the lens

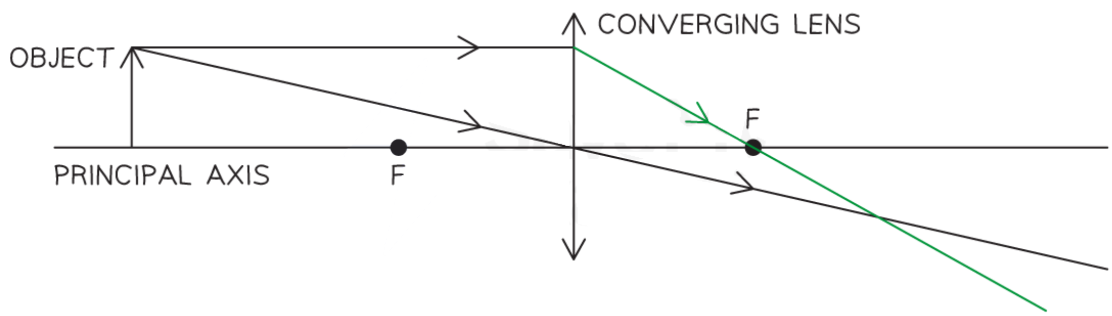
Step 4: Draw a ray through the optical centre of the lens



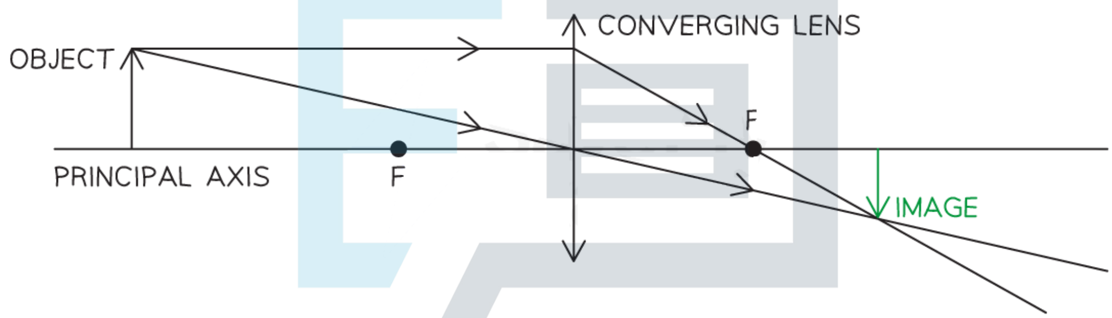
Step 5: Draw a second ray from the object to the lens which is parallel to the principal axis



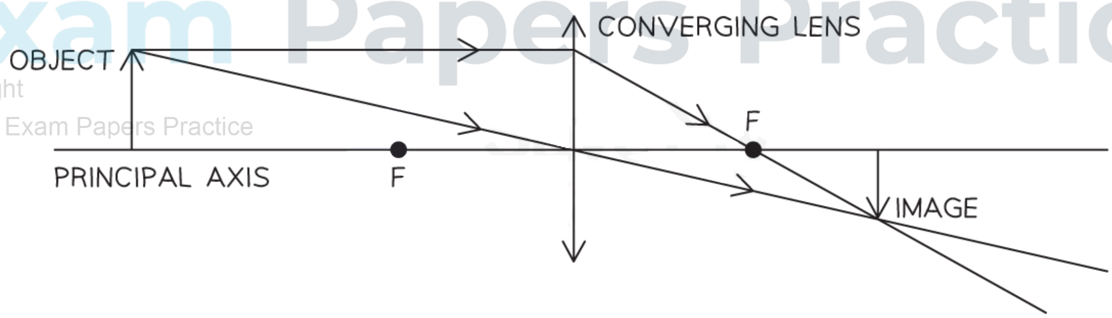
Step 6: Draw the continuation of the ray passing through the focal point on the right side of the lens



Step 7: Draw and label the image at the point where the rays meet



Step 8: Check your final image and make sure everything is included to gain the marks

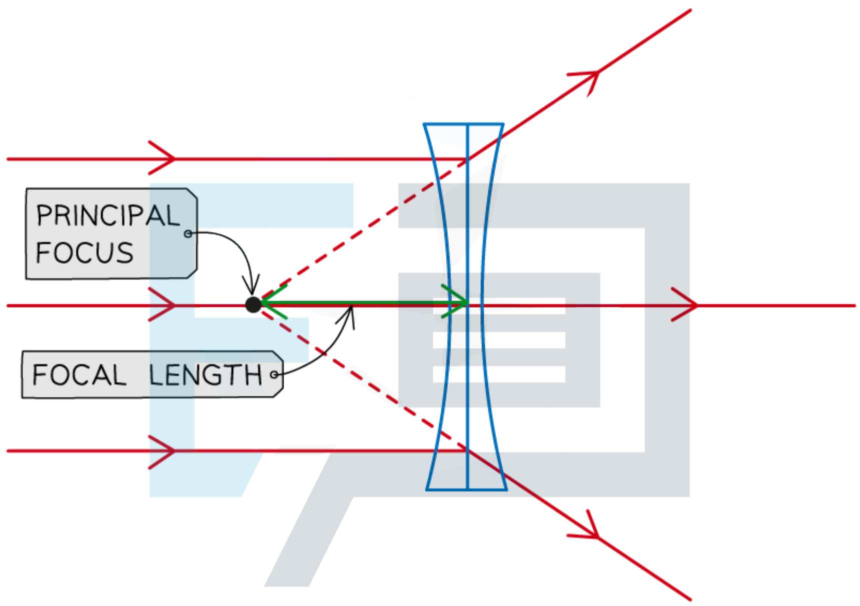


- For a three-mark question, examiners will be looking for:
  - One ray drawn through the optical centre of the lens
  - A second ray drawn which produces a diminished (smaller) image (which must pass through a labelled focal point)
  - Both the object and the image must be drawn and labelled correctly

Diverging Lenses

- In a diverging lens, parallel rays of light are made to diverge (spread out) from the **principal focus** on the principal axis
  - This lens is sometimes referred to as a **concave** lens

The Ray Diagram of a Diverging Lens



Parallel rays from a diverging lens appear to come from the principal focus

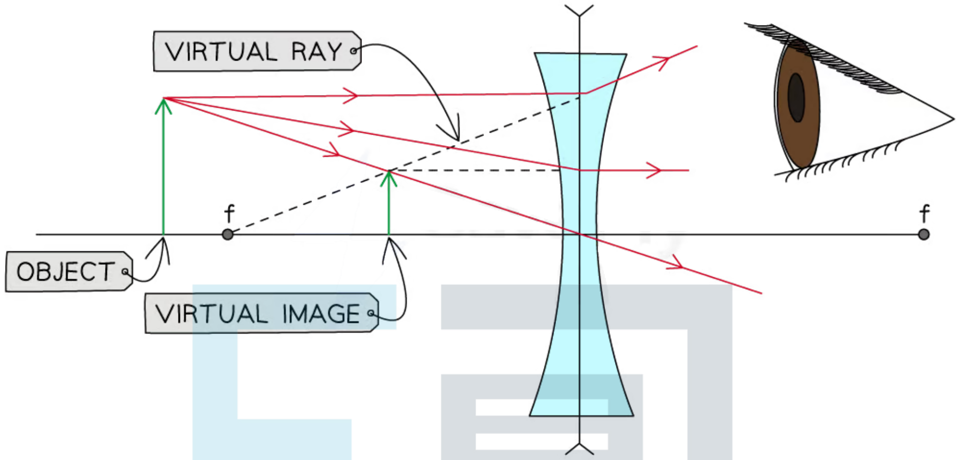
- Just like for converging lenses, the distance from the centre of the lens to the focal point is called the **focal length**, *f*
  - This length also depends on how **curved**, or how **thick**, the lens is
  - The **more** curved (**thicker**) the lens, the **shorter** the focal length
  - The **shorter** the focal length, the more **powerful** the lens
  - However, *f* is **negative** for a diverging lens because it is behind the lens

Image Formation by a Diverging Lens

- No matter the position of the object all images formed by diverging lenses are:
  - **Nature: Virtual** (and not real)
  - **Orientation: Upright** (the same as the object)
  - **Size: Diminished** (smaller than the object)
  - **Position:** On the **same side** of the lens as the object

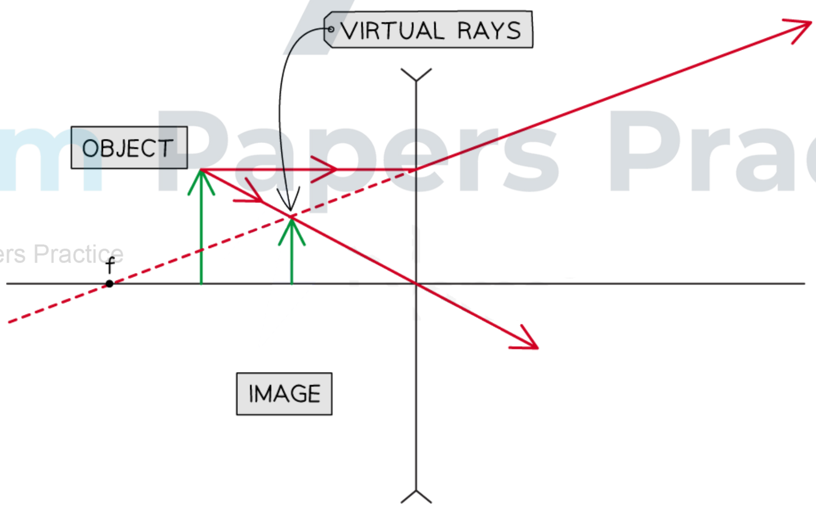
- For an object placed at any distance away from the lens (further than the focal point or closer than):
  - The ray of light incident on the centre of the lens does not change direction
  - The rays of light parallel to the principal axis are refracted
    - It appears that they come from a **virtual focus**

Virtual Image Produced by a Diverging Lens with Object Beyond f



A diverging lens always produces a virtual image no matter the position of the object in relation to the focal point or the lens. Here the object is further away from the lens than the focal point.

Virtual Image Produced by a Diverging Lens with Object Closer than f

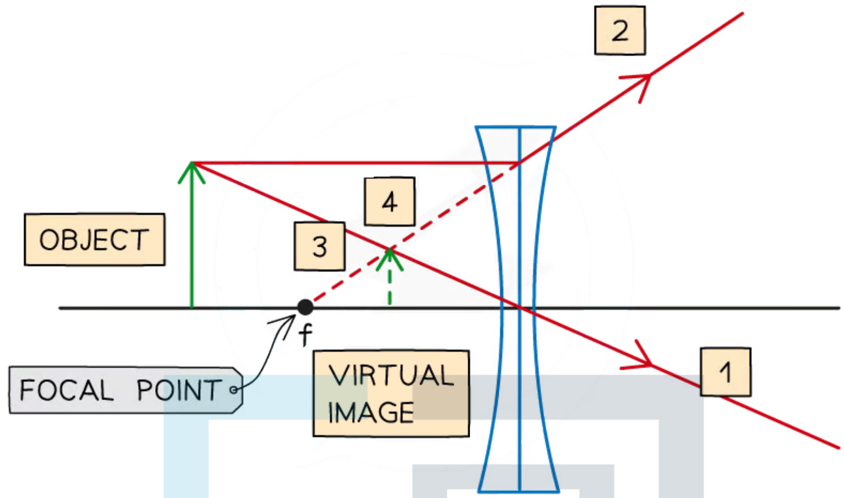


A diverging lens always produces a virtual image no matter the position of the object in relation to the focal point or the lens. Here the object is closer to the lens than the focal point.

Constructing Ray Diagrams for Diverging Lenses

- Follow the steps below to produce a ray diagram for a diverging lens:

Step By Step To Constructing a Virtual Image from a Diverging Lens



The step-by-step procedure for drawing accurate diverging lens ray diagrams

1. Start by drawing a ray going from the top of the object through the **centre** of the lens. This ray will continue to travel in a straight line
2. Next draw a ray going from the top of the object, travelling parallel to the axis to the lens. When this ray emerges from the lens it will move in a line as if coming from the **focal point**
3. Draw a dashed line continuing this ray downwards to the focal point, *f*
4. The image is the line drawn from the axis to the point where the above two rays **meet**

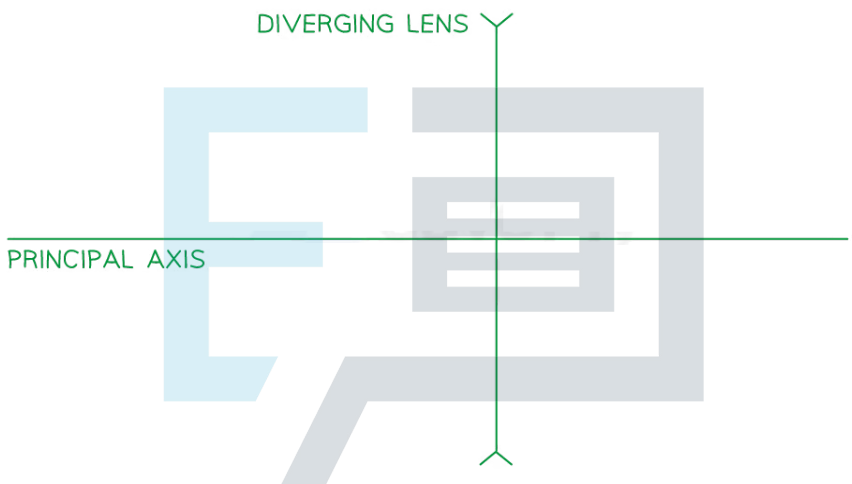
Worked example

Draw a ray diagram to show how an image is formed of an object placed at the focal point of a diverging lens.

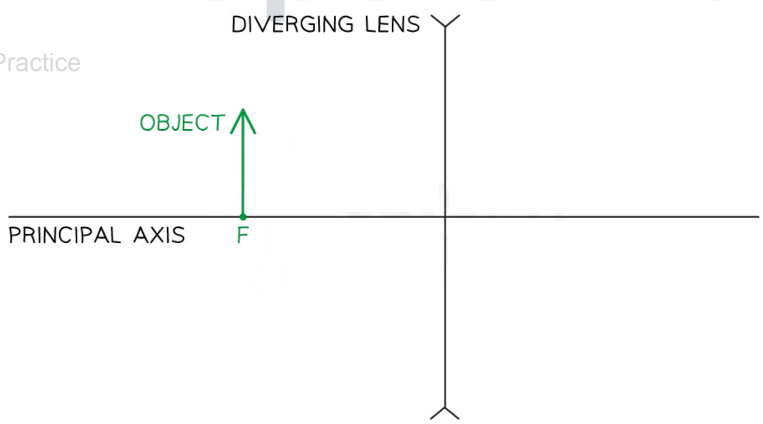
Label the object, image and principal focus of the lens on your diagram.

Answer:

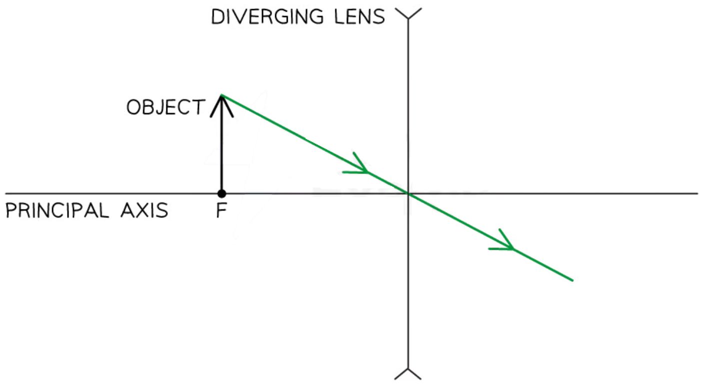
Step 1: Start by drawing and labelling a principal axis and the lens as a line



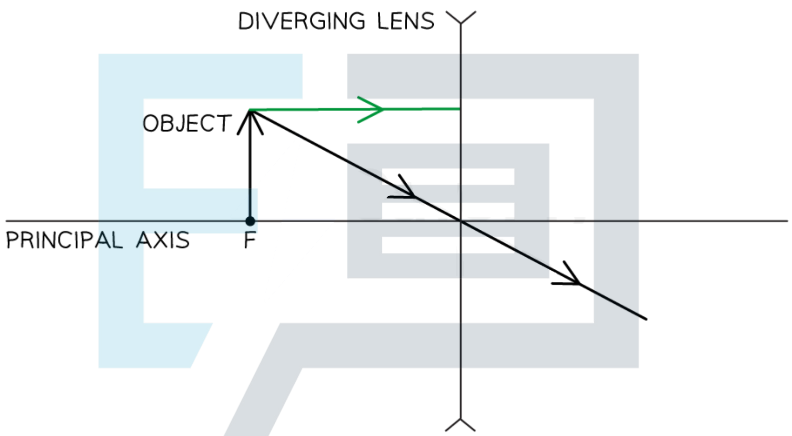
Step 2: Mark and label the principal focus and the object in the same place on one side of the lens



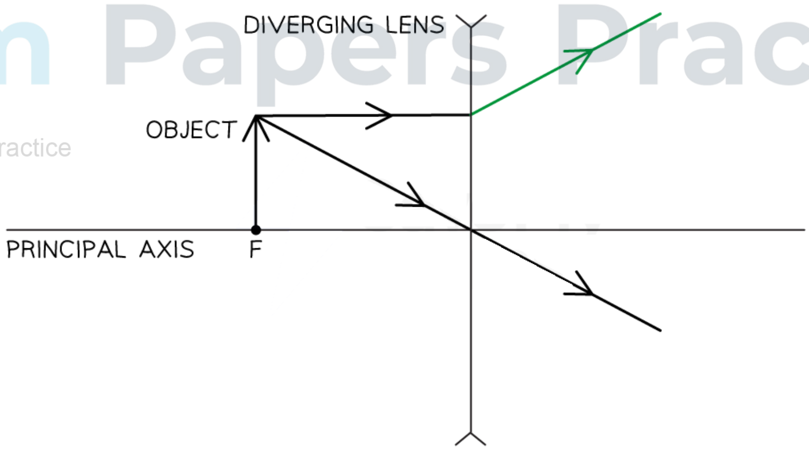
Step 3: Draw a ray from the top of the object through the centre of the lens



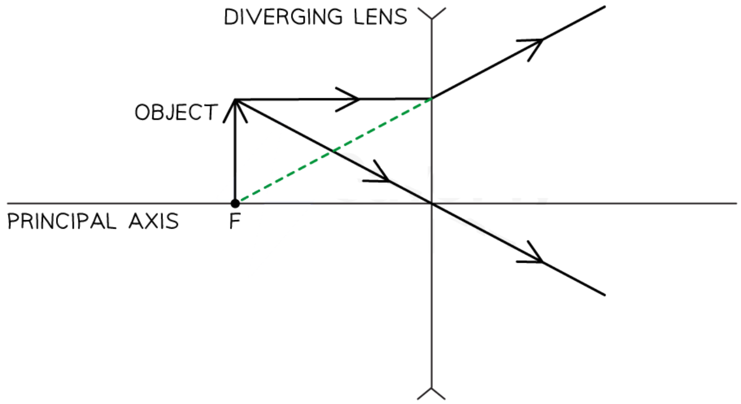
Step 4: Draw a ray from the top of the object travelling parallel to the axis of the lens



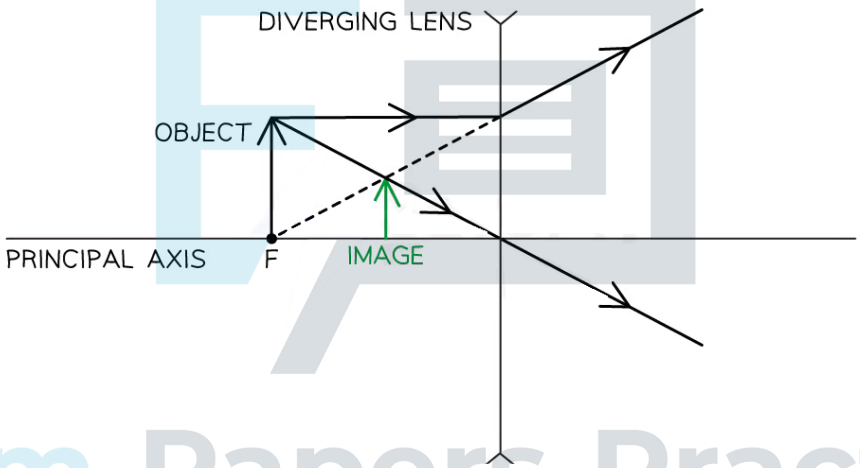
Step 5: Draw the continuation of the ray diverging away from the principal focus



Step 6: Draw a dashed line continuing this ray downwards to the principal focus

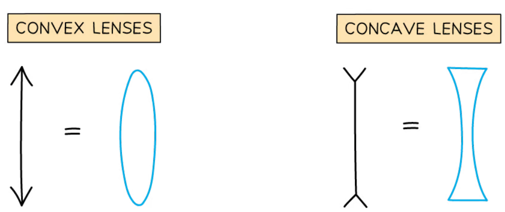


Step 7: Draw an arrow up from the principal axis to the point where the two rays meet and label it image



Exam Tip

When drawing ray diagrams, convex (converging) and concave (diverging) lenses can be simplified using the following symbols:



Exam Papers Practice

10.1.2 Lens Calculations

Lens Calculations

Power

- The power of a lens, P is calculated using the following equation:

$$P = \frac{1}{f}$$

- Where:
  - P = power (dioptres, D)
  - f = focal length of the lens (m)
- The focal length is measured from the centre of the lens
- **Power** is **inversely proportional** to **focal length**
  - So the more powerful the lens the shorter the focal length
- For a **diverging** (concave) **lens**, where the focal length is negative, power has a negative value

Worked example

A diverging lens has a focal length of –1.5 cm.

Calculate the power of the lens.

Answer:

Step 1: Write the known values

- Focal length, f = –1.5 cm

Step 2: Convert the focal length into m

- 1 m = 100 cm
- So, –1.5 cm = –1.5 ÷ 100 = –0.015 m

Step 3: Recall the equation for power and focal length

$$P = \frac{1}{f}$$

Step 4: Substitute for focal length into the equation

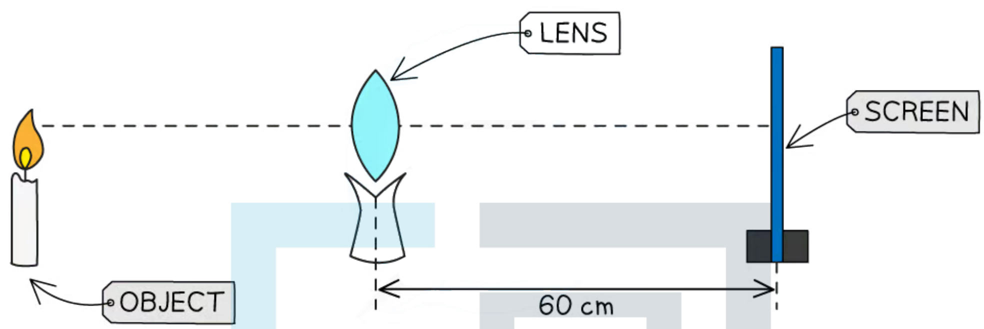
$$P = \frac{1}{-0.015}$$

Step 5: Calculate the power of the lens, P

$$P = -66.6 \text{ D}$$

Worked example

A lens is set up between an object candle and a screen. All the equipment is arranged perpendicular to the desk. The image of the candle is in focus when the screen is positioned 60 cm from the lens.



Determine the power of the lens.

Answer:

Step 1: Write the known quantities in S.I. units

- Image is in focus, so the screen is at the focal point
- Focal length, f = 60 cm = 0.6 m

Step 2: Write the equation for power and substitute the values

$$P = \frac{1}{f} = \frac{1}{0.6} = 1.67$$

Step 3: Give the full answer, to correct significant figures and with units

The power of the lens, P = 1.7 D

Exam Tip

The explanations above relate to life in a common sense way. Stronger, more powerful reading glasses are used by people who have the weakest eye sight. They need lenses to do more of the focusing for them.

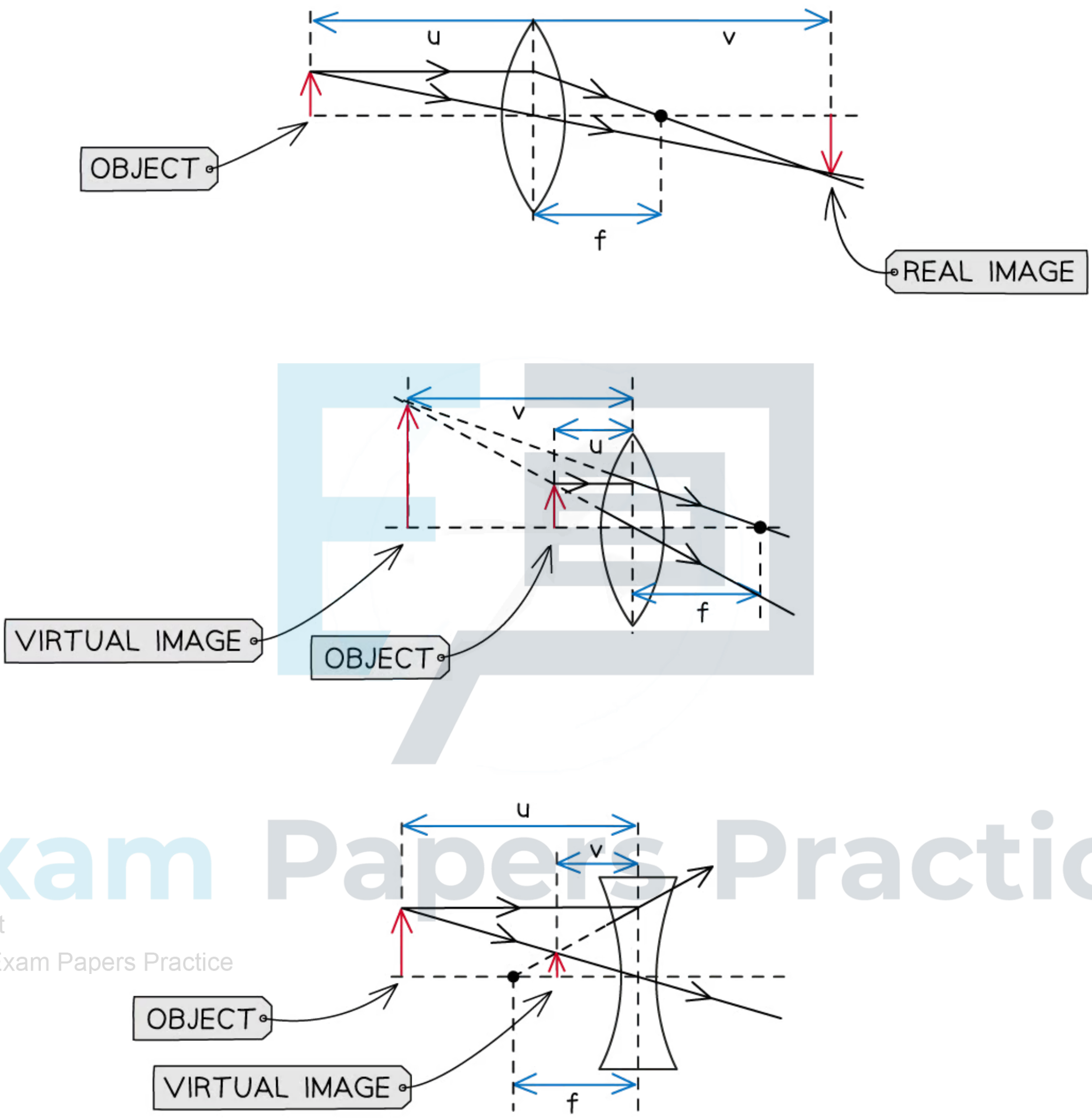
The Lens Equation

- This equation can be applied to all **thin converging** and **diverging** lenses
- The equation relates the **focal length** of the lens to the **distances** from the **lens** to the **image** and the **object**

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

- Where:
  - f = focal length (m)
  - v = image distance from lens (m)
  - u = object distance from lens (m)
- f, v and u do not all have to be in meters but they do have to be in the **same units**
  - They are measured from the centre of the lens

Labels of *f*, *u* and *v* on Converging and Diverging Ray Diagrams



Examples of where the lens equation can be used

- Remember that:

- The values are **positive** if the image is **real**
- v is negative if the image is **virtual**
- f is negative if the lens is diverging

Worked example

A student investigates the focal length of a thin lens by using it to project and image onto a screen.

The object is set 50.0 cm from the centre of the lens and the screen moved back and forth until the inverted image is sharp. This position is found to be 75.0 cm from the lens.

Determine the focal length of the lens.

Answer:

Step 1: Write the known values

- Distance from object to lens, u = 50.0 cm
- Distance from image to lens, v = 75.0 cm

Step 2: Write the equation and substitute in the values

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{50} + \frac{1}{75} = \frac{1}{30}$$

***f* = 30 cm**

Exam Tip

It is easy to forget the last step in a calculation like this one. Remember that you are calculating $\frac{1}{f}$ not f, and that you need to take the **reciprocal** of your answer.

Linear Magnification

Magnification as a Ratio of Heights

- Magnification means how much larger the image is than the object
  - This is the ratio of the image/object height

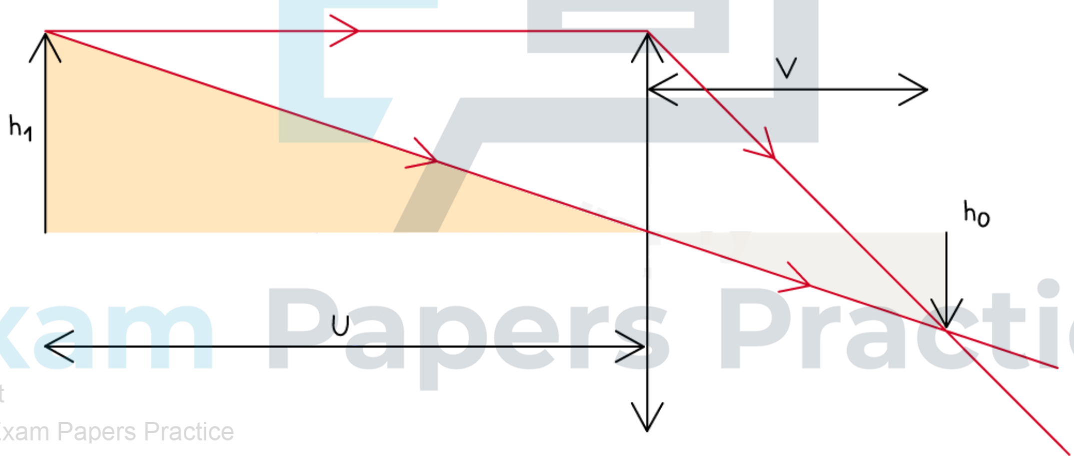
$$m = \frac{h_i}{h_o}$$

- Where:
  - m = magnification
  - h_i = image height (m)
  - h_o = object height (m)

Magnification as a Ratio of Distances

- A diagram of an object and its **real image** will produce similar triangles
  - Therefore, the ratio of magnification is also represented by comparing the distance from the lens to the object and the image

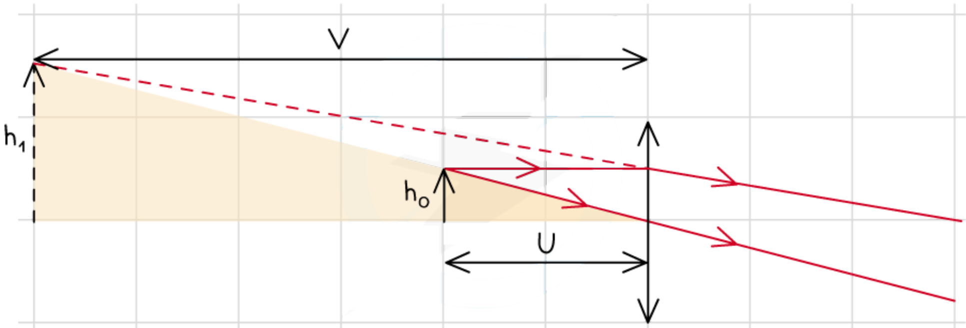
Real Image Magnification as a Ratio of Image and Object Distances



The ratio of object distance u to image distance v is the same as object height h_1 to image height h_0 for a real image

- This also works for virtual images

Virtual Image Magnification as a Ratio of Image and Object Distances



The ratio of object distance u to image distance v is the same as object height h_1 to image height h_0 for a virtual image

$$m = \frac{v}{u}$$

- Where:
  - m = magnification
  - v = distance from lens to image (m)
  - u = distance from lens to object (m)
- Since magnification is a **ratio**, it has **no units**

Worked example

A magnifying glass has a focal length of 15 cm. It is held 5 cm away from a component which is being examined.

Determine the magnification of the image.

Answer:

Step 1: Write the known values

- Focal length, f = 15 cm
- Distance between object and lens, u = 5 cm

Step 2: Use the lens formula and rearrange to make v the subject

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$v = \left(\frac{1}{f} - \frac{1}{u}\right)^{-1} = \left(\frac{1}{15} - \frac{1}{5}\right)^{-1} = -7.5 \text{ cm}$$

- The negative sign indicates a virtual image (expected for a magnifying glass) and is ignored for the next step

Step 3: Use the magnification formula to find the magnification of the image

$$m = \frac{v}{u} = \frac{7.5}{5} = 1.5$$

Exam Tip

The most common mistake with magnification calculations is to get the formula upside down.

Do a 'sanity check' by looking at the answer to make sure that magnified objects have got bigger ($m > 1$) and diminished ones smaller ($m < 1$).

Since we are working with ratios (so the units get cancelled out) this is one of those rare times when you don't need to convert everything to SI units, but do check that your units are all the same - for example all distances in cm.

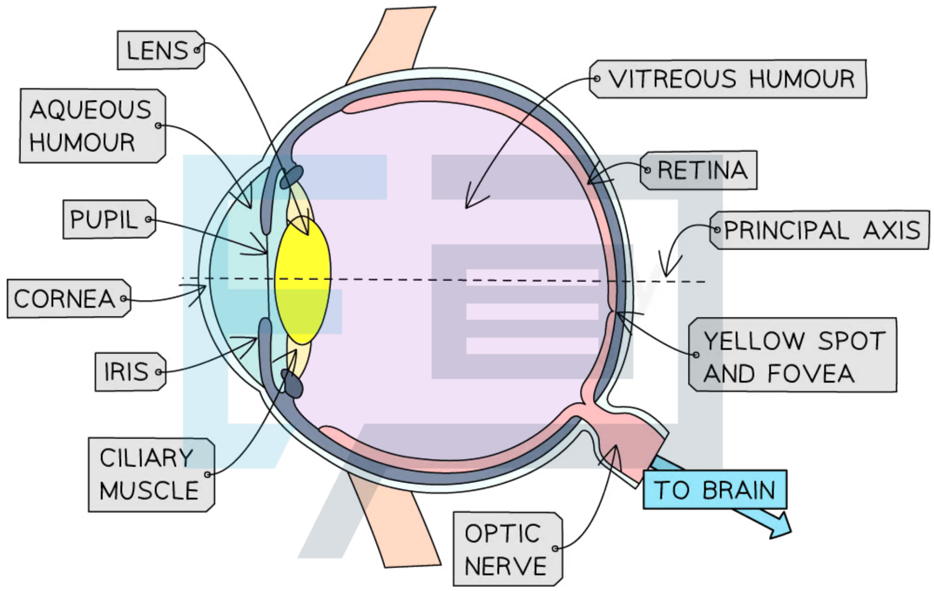
10.1.3 Structure of the Eye

Structure of the Eye

The Main Structure of the Eye

- Our eyes contain **converging lenses** that focus light onto the **retina** at the back of the eye
- Each component the light passes through has a **different refractive index** causing a different amount of refraction to the light entering the eye

The Main Features of the Eye



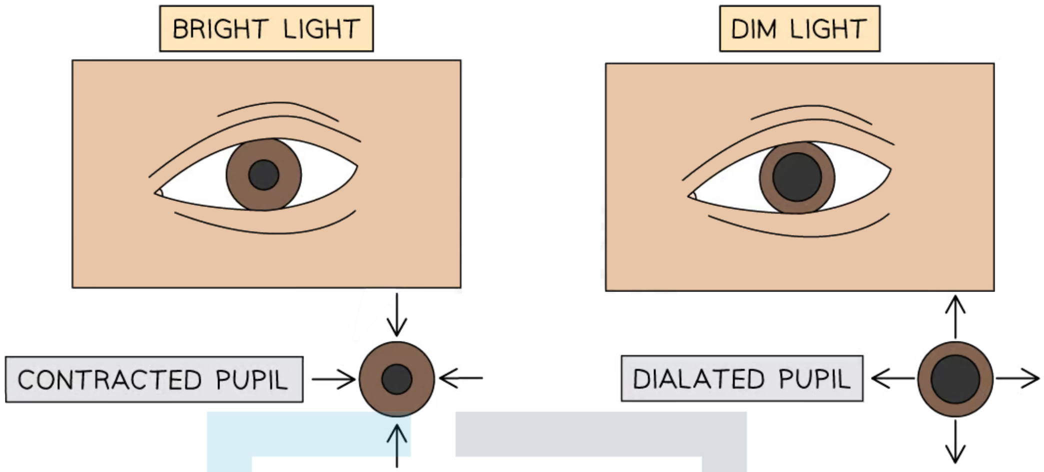
The basic structure of the eye

- Light rays enter the eye through the **cornea**
  - A transparent convex membrane that covers the front of the eye
  - Variations and defects in its shape lead to problems in focussing the light onto the **retina** at the back of the eyeball
  - The **cornea** has a high refractive index, compared to air, so light entering the eye is initially refracted by a large angle

The Pupil

- The **pupil** is surrounded by muscles called the **iris**
- They control the amount of light entering the eye
  - When in a **dark** room the **iris expands** allowing the **pupil** to **dilate** (widen) so more light can enter the eye
  - When in bright sunlight the **iris contracts** causing the pupil to get smaller, so less light can enter the eye

Contracted and Dilated Pupils



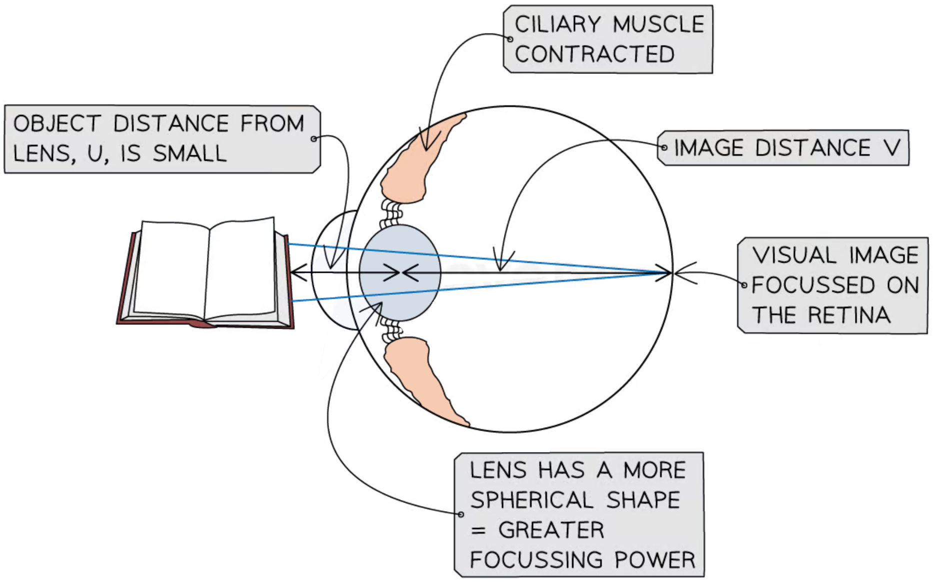
Pupils dilate when too little light is incident on the eye and contract when there is too much light incident on the eye

- After passing through the **cornea** light rays move through the clear liquid of the **aqueous humour** before they reach the **lens**

The Lens

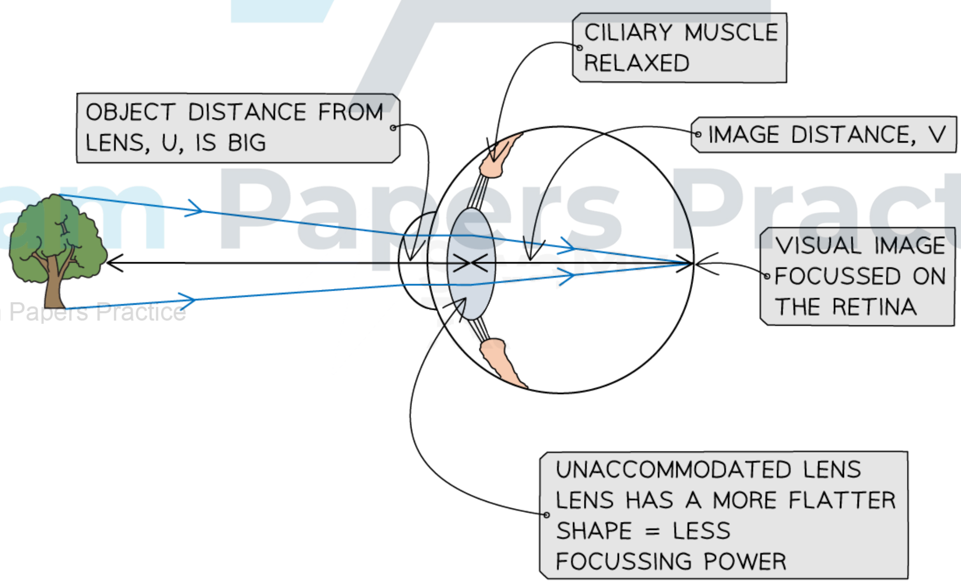
- The eye can focus light from a range of distances
  - The **near point** is the closest distance the eye can focus on
    - For 'normal sighted' people this is 25 cm
  - The **far point** is the furthest distance the eye can focus comfortably
    - For 'normal sighted' people this is infinity
- The **lens** is controlled by the **ciliary muscles** which changes the **focal length** of the eye
  - When the muscles **contract** the lens becomes wider / **more spherical** and **more powerful**
    - This occurs when the eye is focussing on an image close to the **near point**
  - When the muscles relax the lens becomes thinner / **less spherical** and **less powerful**
    - This is called an **unaccommodated** lens
    - It occurs when the eye is focussing on an image close to the **far point**
- Remember from 10.1.2 Lens Calculations:
  - *u* is the distance from the object to the centre of the lens
  - *v* is the distance from the image to the centre of the lens
    - In an adult human, this is around 2 cm
- Lens diagrams for the eye should be drawn **refracting** once only to show the total amount of refraction from all parts of the eye.
  - This is normally at the **lens only** but can sometimes be at the **cornea only**
- **Adding together** the powers of the **cornea** and the **lens** gives the **total power** of the eye

A Wider Lens Has a Stronger Focussing Power



A wider more spherical lens is created when the ciliary muscles contract and it has a stronger focusing power. This means the lens can refract rays by a greater angle to focus light rays from nearby objects when u is small

A Narrower Lens Has a Smaller Focussing Power



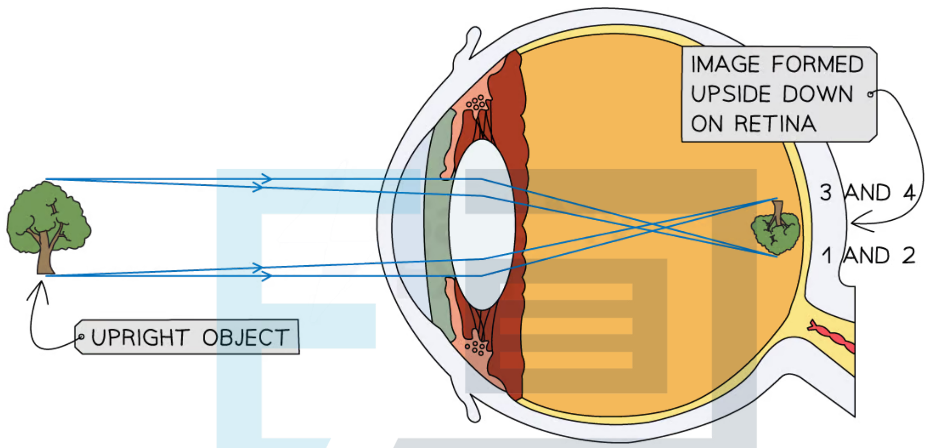
A thinner less spherical lens is created when the ciliary muscles relax so the focussing power is less. This happens when the eye focuses light rays from far away objects, when u is big, as the angle of refraction needed is less.

The Retina

- After passing through the **lens** the light is focussed on the **retina**

- The image formed on the **retina** is **upside down** but is interpreted by the brain as being the correct way up
- The light rays are refracted through the **cornea** and **lens** so that they cross within the **vitreous humour** and arrive at the **retina** the opposite way around
  - Rays from the top of the object are now at the bottom of the **retina** and vice versa

The Inverted Image on the Retina

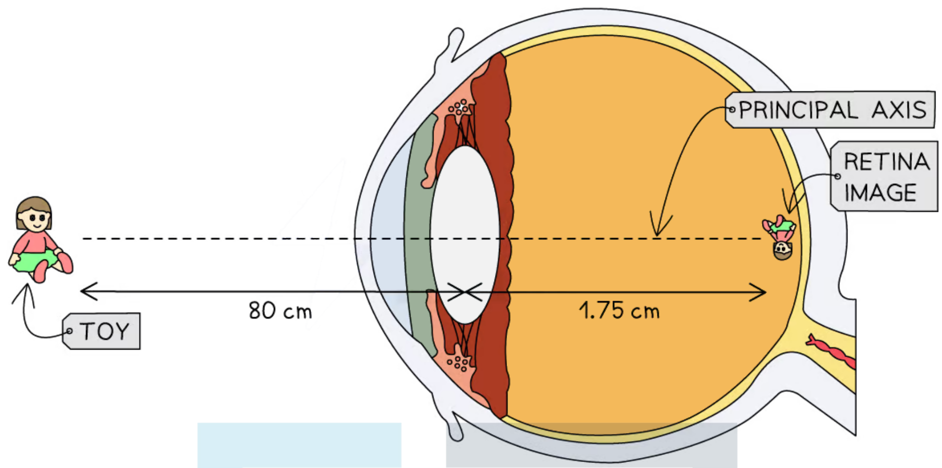


Rays 1 and 2 from the top of the object are now focussed onto the bottom of the retina. Rays 3 and 4 from the bottom of the object are now focussed on the top of the retina.

- The **retina** contains light-sensitive cells called **rods** and **cones**
- The **optic nerve** carries signals from the **rods** and **cones** to the **brain**

Worked example

A boy is looking at a toy 80 cm away. The diameter of his eye from the centre of the lens to the fovea is 1.75 cm.



(a) Complete the diagram to show the passage of the rays to the retina.

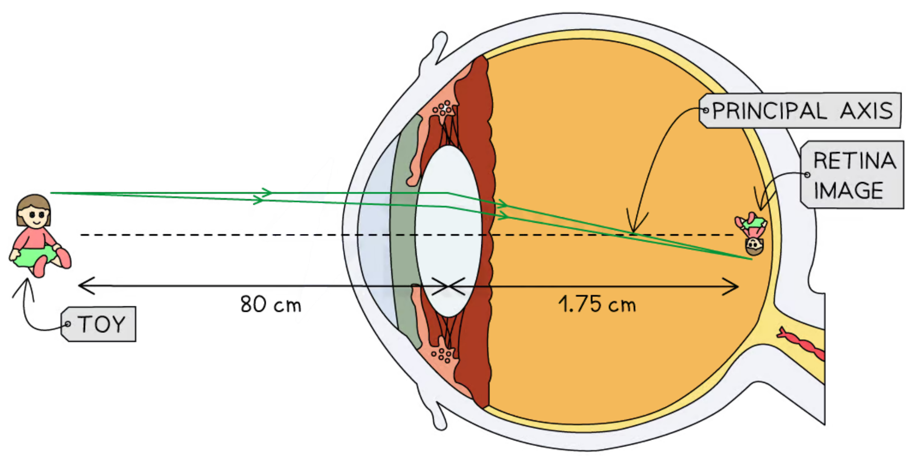
(b) Calculate the power needed by the boy's eye for him to be able to see a focused image of the toy.

Answer:

(a) Complete the diagram to show the passage of the rays to the retina:

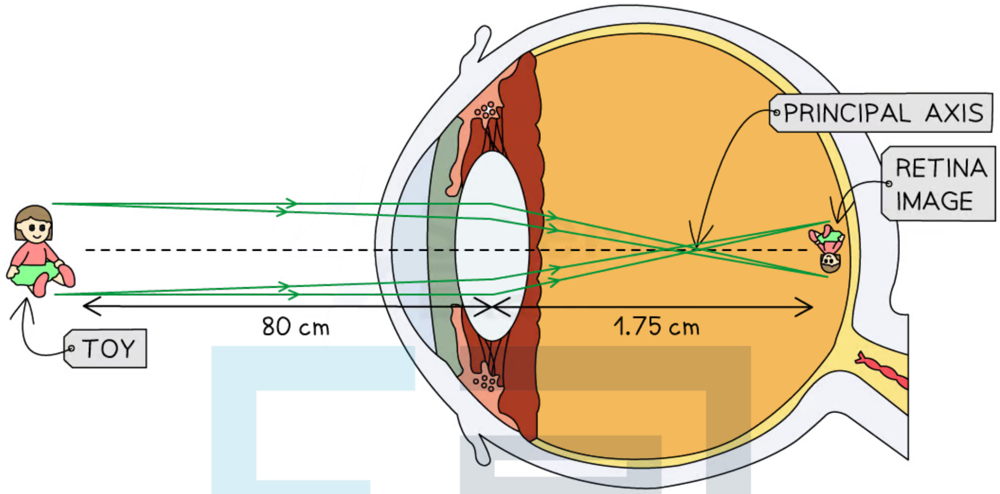
Step 1: Start by sketching the two rays coming from the top of the toy

- The two rays separate as they pass towards the cornea
- At the cornea, they are both refracted towards the bottom of the image of the toy on the retina (which is now the toy's head)
- Arrows indicating the direction of the rays should be drawn both before and after the cornea



Step 2: Now sketch the two rays coming from the bottom of the toy

- The two rays also separate as they pass towards the cornea
- At the cornea they are both refracted towards the top of the image of the toy on the retina (which is now the toy's feet)
- Arrows indicating the direction of the rays should be draw both before and after the cornea



(b) Calculate the power of the boy's eye for an object in this position:

Step 1: Write the known values in meters

- Image distance from the lens, v = 1.75 cm = 0.0175 m
- Object distance from the lens, u = 80 cm = 0.8 m

Step 2: Recall the lens equation

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Step 3: Substitute the known quantities into the equation

$$\frac{1}{f} = \frac{1}{0.8} + \frac{1}{0.0175}$$

Step 4: Calculate $\frac{1}{f}$

$$\frac{1}{f} = 58.4$$

Step 5: Recall the equation for focal length and power

$$P = \frac{1}{f}$$

Step 6: State the power of the lens

P = 58.4 D (3 s.f.)

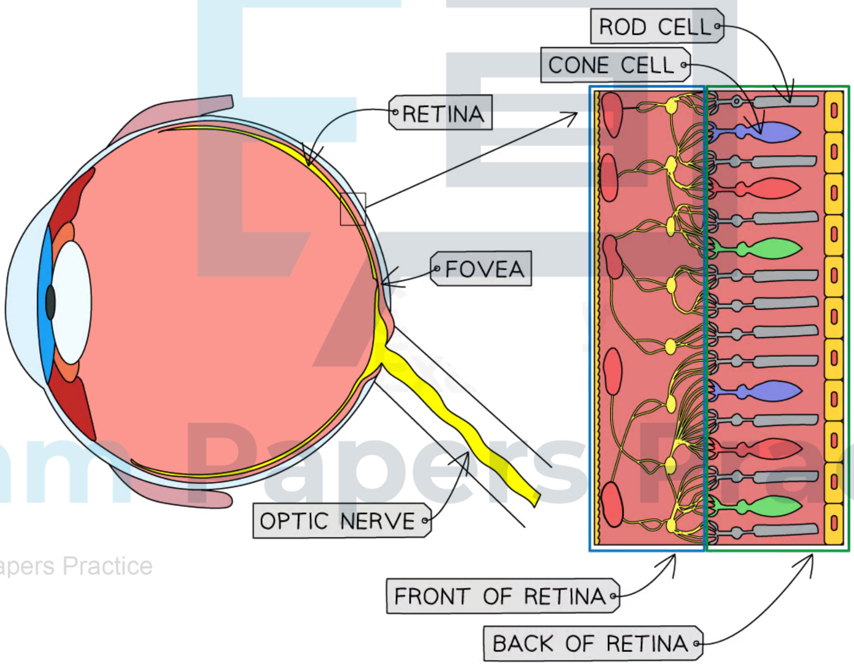
10.1.4 Sensitivity of the Eye

Sensitivity of the Eye

Rods and Cones

- Light travels through the front of the **retina** to the **rods** and **cones** at the back
- **Rods** and **cones** are light-sensitive cells called **photoreceptors**
  - They detect light and convert it into an electrical signal which allows the brain to visualise the image
- When light falls on the chemical pigments in the **rods** and **cones** they are **bleached**
- This **stimulates** the cell to send signals to the brain via the **optic nerve**
- The cells are reset / **unbleached** by vitamin A from the blood

A Diagram to Show the Position of the Rods and Cones in the Retina

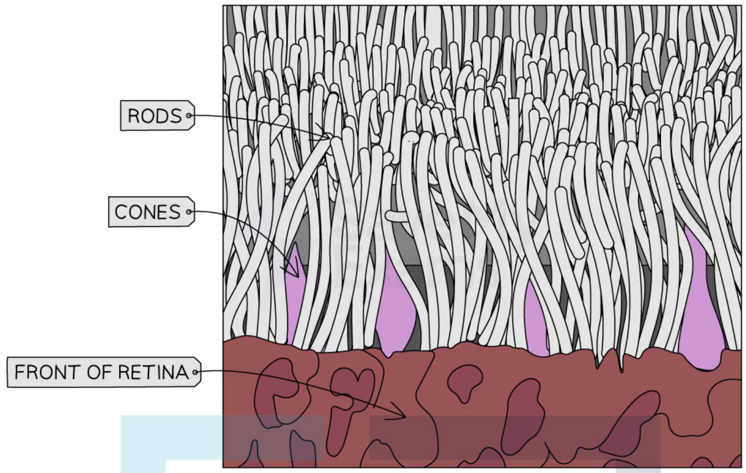


The rods and cones are found at the back of the retina

- There are about twenty times more **rods** than **cones** in the retina
  - **Rods** detect varying **amounts of light**
    - They work well with **low-intensity** light levels
    - Contribute **little detail** to the image
    - Are not sensitive to different colours / wavelengths of light
  - **Cones** can detect different **colours**
    - Each cone is connected to the brain via **one nerve fibre**
    - They are sensitive to **high-intensity** light but do not function well in low-intensity light
    - They contribute **greater detail** to the image

- They provide information to the brain on the **colours** in the image

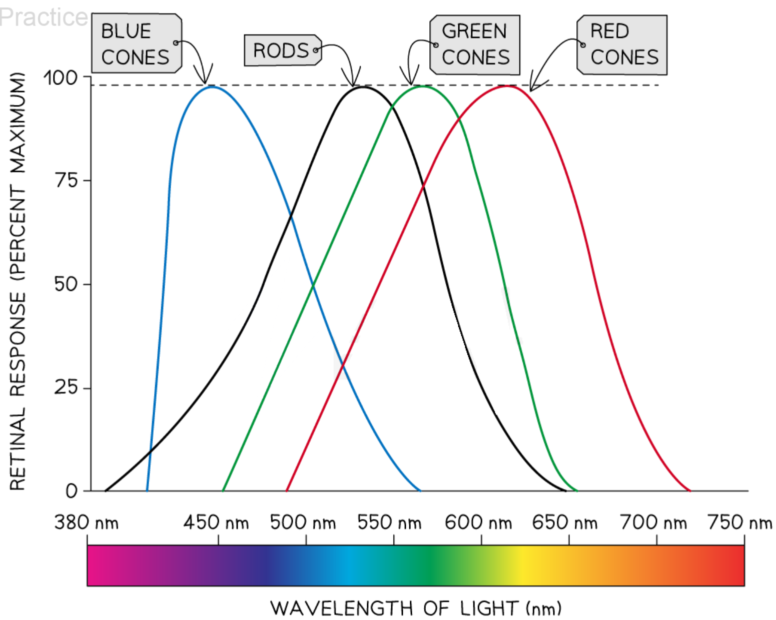
An Image Showing the Difference in Size and Number between the Rods and the Cones



The image shows that there are many more rods than cones found in the retina. The rods that detect light intensity are much longer than the cones that detect colour.

- There is **one type** of **rod**
- There are **three types** of **cone**
  - Each type is sensitive to a **different wavelength range** of light:
    - Red
    - Green
    - Blue

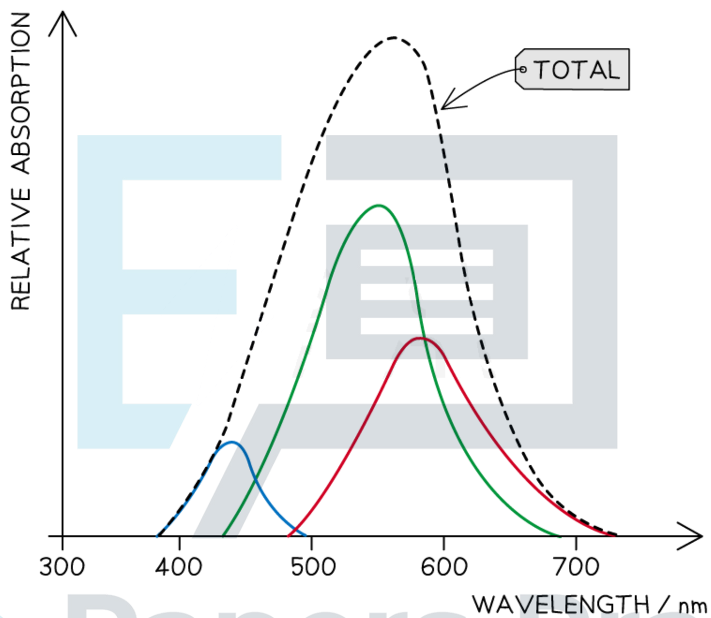
The Graph Shows the Colours Detected by the Rods and Different Types of Cone



The black peak on the graph shows that rods detect 100% of all wavelengths of light from 380 to 650 nm. When all the colours of the spectrum are not dispersed as their separate colours then they are all detected as white light. Blue cones detect 100% of blue wavelengths, green cones 100% of green wavelengths and red cones 100% of red wavelengths

- The eye responds to each colour **differently**:
  - It is less responsive to blue light than red or green
  - So **blue** light looks **dimmer**
- The brain processes signals from the three types of **cone** and interprets their **weighted relative strengths** as colour

The Graph Shows the Relative Absorption by the Brain of Each Colour



The sum of the relative absorption of blue, red and green wavelengths gives the total relative absorption of all the colours

- Any colour can be produced by **combining** different intensities of red, green and blue light
- For example, **yellow** light can be obtained by **combining** signals from the red and green cones

Worked example

Explain what types of cones are used by the brain to detect purple light.

Answer:

- Purple is made by mixing red and blue
- So the brain uses red and blue cones to detect purple light

Exam Tip

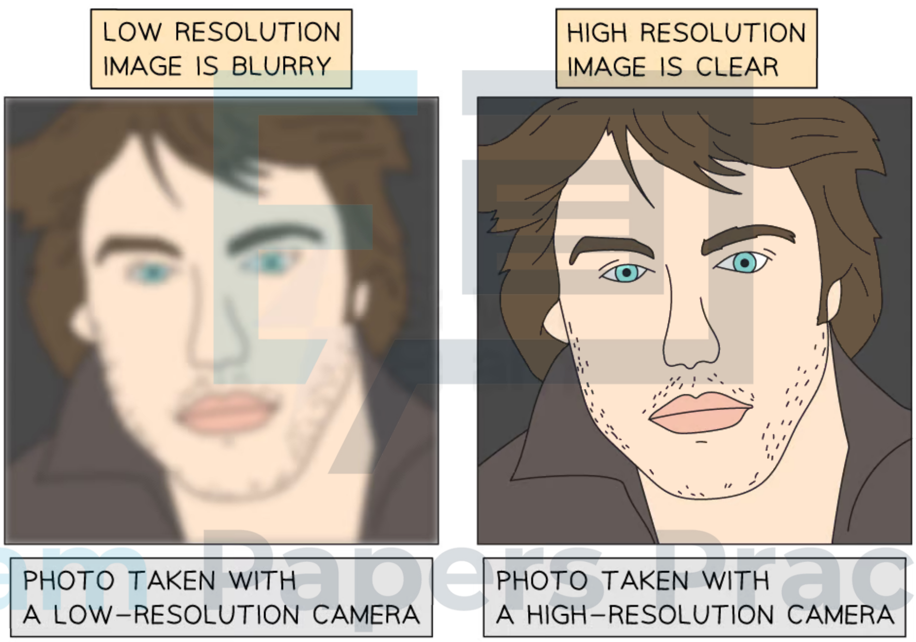
You will not be asked to draw any images of parts of the eye, such as the retina and rods or cones. You may be asked to sketch one of the graphs shown on this page.

10.1.5 Spatial Resolution of the Eye

Spatial Resolution of the Eye

- **Resolution** is related to the amount of detail that can be seen in an image
  - The greater the resolution, then the greater the detail
- A digital camera with a higher resolution can take more detailed photos
- A person with "better" eyesight can see things with more resolution

Low and High-Resolution Images taken with a Digital Camera

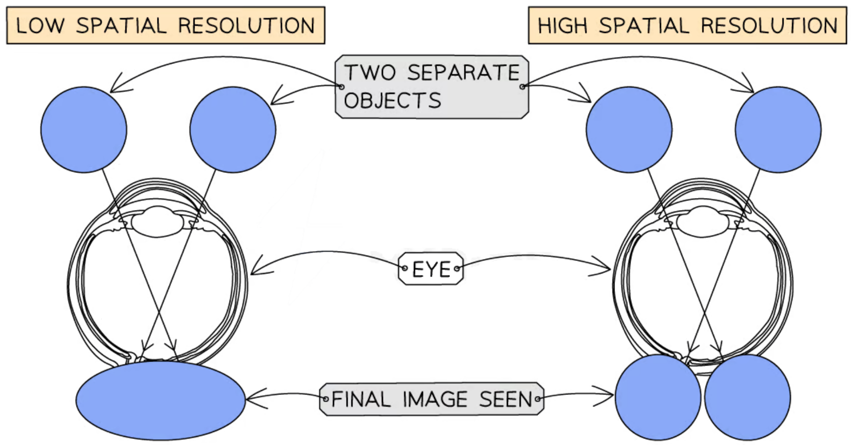


A low-resolution image will appear blurry whereas a high-resolution image will be clear and contain lots of details

Spatial Resolution

- **Spatial Resolution** is needed for the eye to be able to see something in detail
- It is a measure of the eye's ability to form **separate images** of objects that are close together
  - Through an eye that has poor spatial resolution, two objects close together can look like one big object

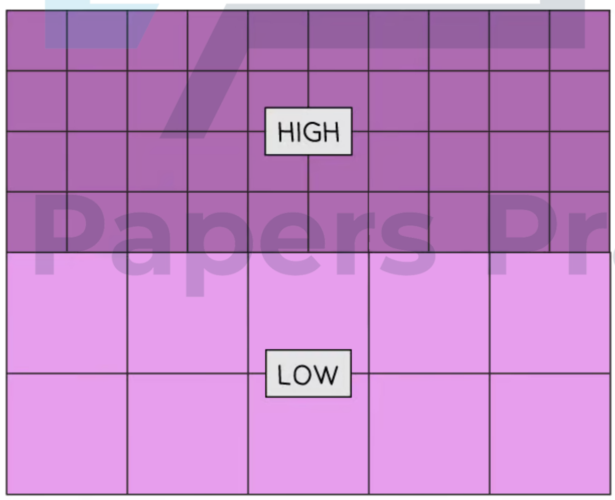
Two Objects Viewed By an Eye with High and an Eye with Low Spatial Resolution



Two objects viewed with a low spatial resolution are seen as one big object but when viewed with a high spatial resolution they are seen as two separate objects

- The better the **spatial resolution** the more detail that is seen in an image
  - An image of a wall viewed with a **higher spatial resolution** has more bricks visible than one viewed with a **lower spatial resolution**

A Brick Wall Viewed with a High and Low Spatial Resolution



High spatial resolution means more detail can be seen in an image as the eye can form separate images of each object making up the image

The Role of Rods and Cones in Spatial Resolution

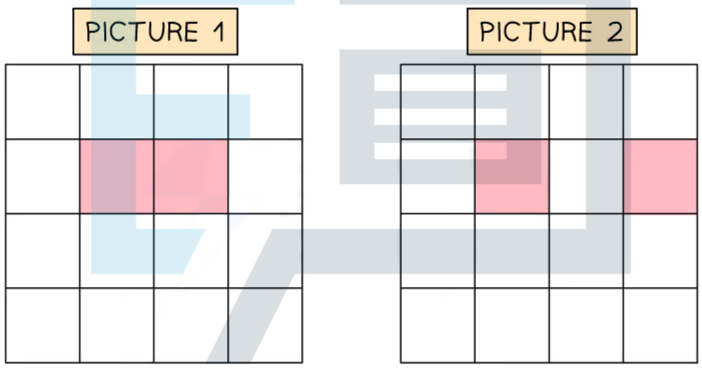
- Small details in an image are best seen:
  - By the **rods** and **cones** on the **fovea** in the centre of vision (and not on the **periphery**) in high-intensity light levels
  - By the **rods** and **cones** in the **peripherals** of vision in low-intensity light levels
- For two details in an image or two objects to be distinguished then:
  - The **two sources** of light must fall on the **retina**

  - So that there is at least **one unbleached rod** and **one unbleached cone** between them
- In addition, the rod or cone between the light rays must **not share** an **optic nerve** with any of the rods or cones detecting the light
- If this is not the case then the brain cannot resolve the two rays of light and sees the objects / details as one

Worked example

A person looks at two objects placed at different distances apart. A grid of squares represents the image of the objects on the retina. Each white square represents a cone, and each red square represents a stimulated cone detecting light.

The cone's representation of the objects in different orientations is shown in pictures 1 and 2 below.



Describe the arrangement of the objects that would be seen in each picture.

Answer:

Picture 1:

- The two red squares are too close together / not separated by a cone
- The two objects must be interpreted as one big object by the brain
- So, the objects are placed close together

Picture 2:

- The two red squares are further apart / separated by a cone
- The two objects are interpreted as two separate objects by the brain
- So, the objects are placed far enough apart

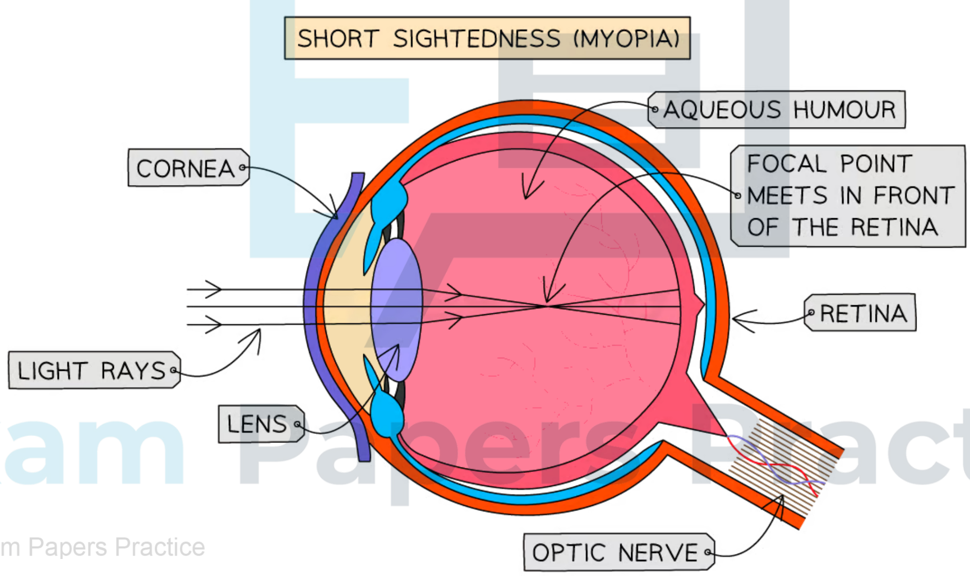
10.1.6 Defects of Vision

Defects of Vision

Short-sightedness

- Short-sightedness is also called **myopia**
- It happens when the lens is more curved than normal
  - So the **cornea** and **lens** are too powerful
  - Myopia can also occur if the eyeball is too long
- This means light rays are refracted too much so the focal point of the image falls in front of the retina (rather than on it)
  - So distant **objects appear blurry** as people with short-sightedness cannot focus on distant objects

Ray Diagram of Short-Sightedness

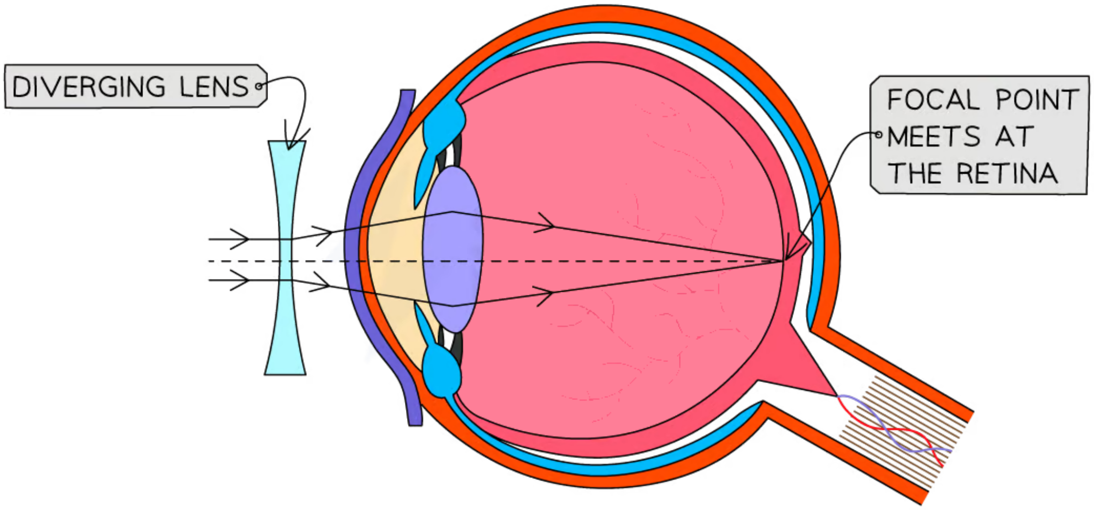


An eye that is short-sighted has a wider lens with a larger focussing power so the light rays meet and form an image in front of the retina and not on it

Treatment of Short-sightedness

- Short-sightedness can be corrected using contact lenses or glasses with a **diverging** (concave) **lens**
  - The lens causes the light rays to **diverge** before reaching the eye
  - So when they are focussed by the eye the image now forms on the **retina**
- Remember from 10.1.1 Converging & Diverging Lenses that
  - Diverging lenses have a negative focal length and a negative power
- A short-sighted person can remove their glasses if they wish to read or view something close-up because it is easy for them to focus on objects close to the eye

The Effect of a Diverging Lens on a Short-sighted Eye

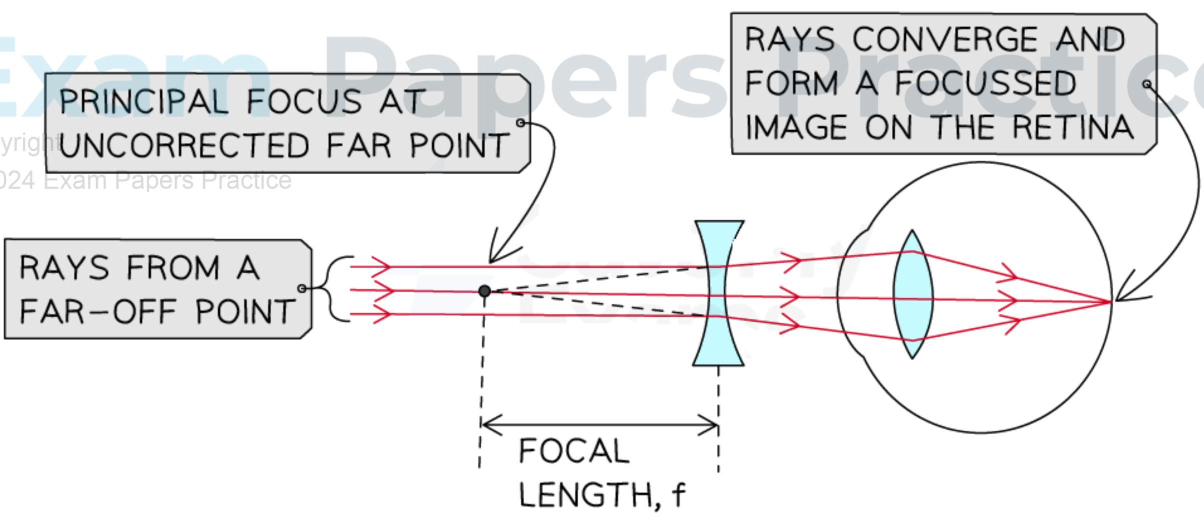


The diverging lens causes the rays to diverge before they reach the eye, so the image is formed on the retina and not in front of it

The Far Point and Short-sightedness

- Remember that a "normal-sighted" person has a **far point** at **infinity**
  - A **short-sighted** person, however, has a **far point** that is **less** than infinity
- So choosing the correct **diverging lens** depends on the position of the **far point** for that person
  - The lens must have its **principal focus** in the same position as the eye's **faulty far point**

A Ray Diagram Showing the Far Point of the Eye and the Focal Length of the Lens



The focal length of the correcting lens is the same as the principal focus at the uncorrected far point of the eye

Worked example

A short-sighted person has a far point of 8 m.

Calculate the power of the lens needed to correct their vision.

Answer:

Step 1: List the known quantities

- Remember that the focal length of a diverging lens is negative
- So, focal length, f = far point = –8 m

Step 2: Recall the equation for power and focal length

- $P = \frac{1}{f}$

Step 3: Substitute the known quantities

- $P = \frac{1}{-8}$

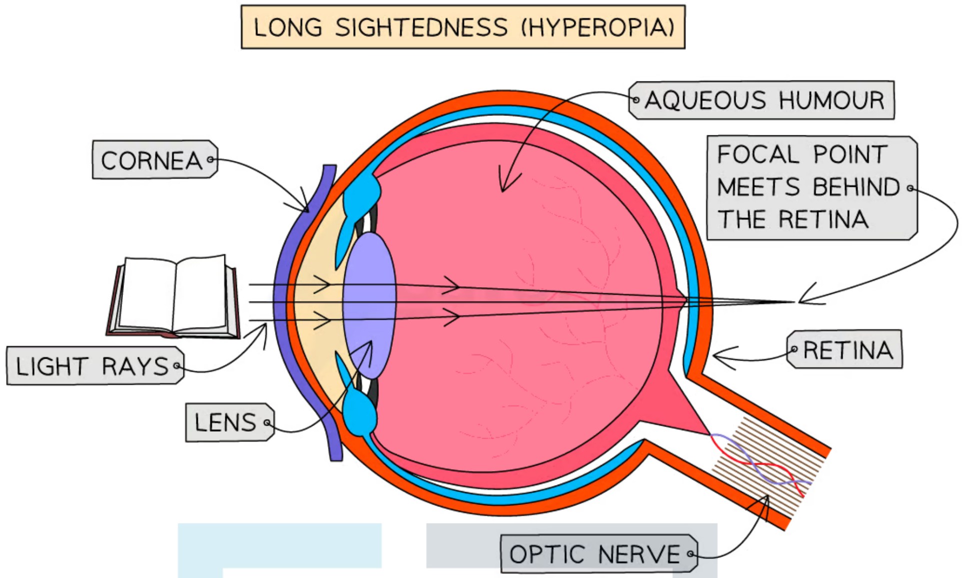
Step 4: Calculate the power

- P = –0.125 D (Dioptres)

Long-sightedness

- Long-sightedness is also called **hyperopia**
- It happens when the lens is **less curved** than normal or the eyeball is too short
  - So the **cornea** and **lens** are too weak
  - Hyperopia can also occur if the eyeball is too short
- This means light rays are not refracted enough and so the focal point of the image falls behind the retina (rather than on it)
  - So **close objects appear blurry** because people with long-sightedness are unable to focus on near objects

Ray Diagram of Long-Sightedness

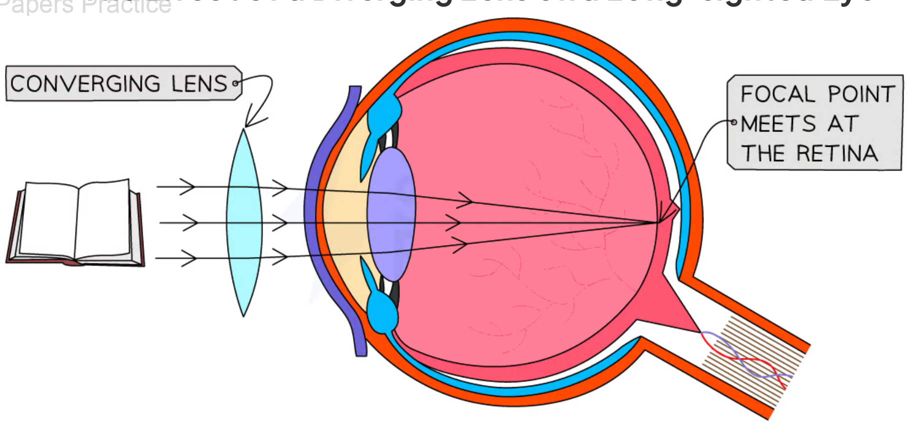


An eye that is long-sighted has a narrower lens with a smaller focussing power so the light rays meet and form an image behind the retina and not on it

Treatment of Long-sightedness

- Long-sightedness can be corrected using contact lenses or glasses with a **converging** (convex) **lens**
  - The lens causes the light rays to **converge** before reaching the eye
  - So when they are focussed by the eye the image now forms on the **retina**
- Remember from 10.1.1 Converging & Diverging Lenses that
  - Virtual images have a **negative distance** to the lens, *v*
  - But the lens has a positive power
- A long-sighted person may need to wear glasses for reading but might remove them when driving because they can easily focus on objects far away from the eye

The Effect of a Diverging Lens on a Long-sighted Eye

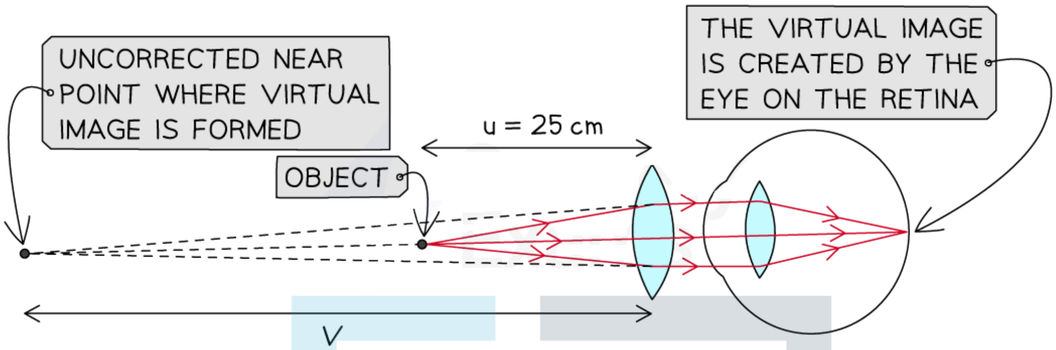


The converging lens causes the rays to converge before they reach the eye, so the image is formed on the retina and not behind it

The Near Point and Long-Sightedness

- Remember that a "normal-sighted" person has a **near point** at around **25 cm**
  - A **long-sighted** person, however, has a **near point** which is further than this
- So choosing the correct **converging lens** depends upon the position of the **near point** for that person
  - The lens must produce a **virtual image** of objects that are 25 cm away at the eyes **uncorrected near point**

A Ray Diagram Showing the Uncorrected Near Point of an Objected at 25 cm



A virtual image of the object is formed at the uncorrected near point of the eye

Worked example

A long-sighted person has a near point of 6 m.

What power of the lens is needed to correct this?

Answer:

Step 1: List the known quantities

- Image is a virtual image, so image distance, v = –6 m
- Object distance = "normal-sighted" focal point, u = 25 cm = 0.25 m

Step 2: Recall the lens equation

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Step 3: Substitute the known quantities to obtain a value for $\frac{1}{f}$

$$\frac{1}{f} = \frac{1}{0.25} - \frac{1}{6}$$

$$\frac{1}{f} = \frac{23}{6} = 3.83$$

Step 4: Recall the equation for power and focal length

$$P = \frac{1}{f}$$

Step 5: State the power of the lens

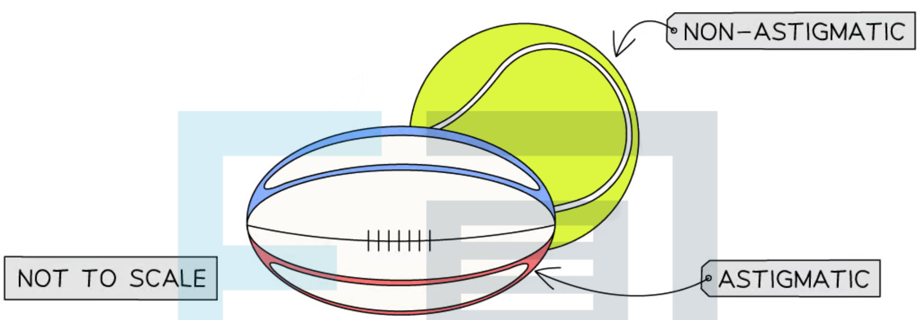
P = 3.8 D

> **Exam Tip**
>
> Remember the lens equations you studied before also apply in situations with correcting lenses for the eye. It is worth noting that the space between the eye lens and the correcting lens does affect the overall power of the optical system but only by a small fraction of a dioptre.

Astigmatism

- The shape of the **cornea** is often assumed to be a **perfect sphere**, like a tennis ball
- People with **astigmatism** have eyes with **irregularly shaped corneas**, like an egg or a rugby ball

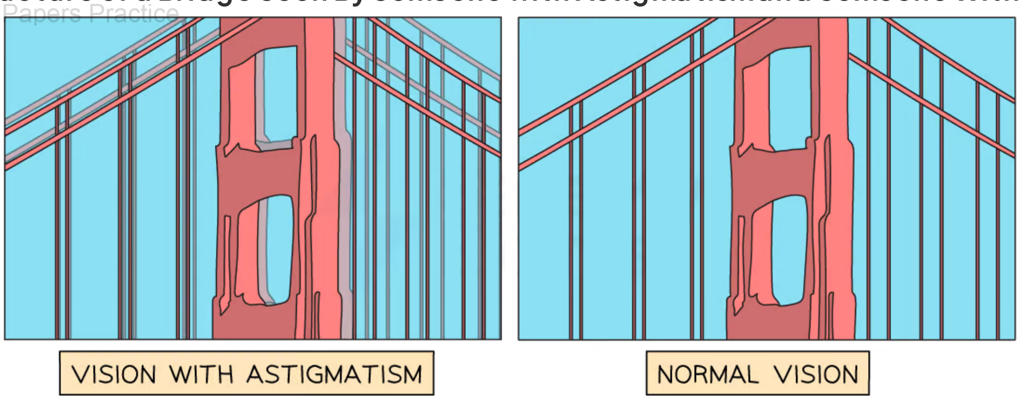
The Difference Between Perfect Spheres and Irregularly Shaped Corneas



The tennis ball represents a cornea that is a perfect sphere and non-astigmatic whereas the rugby ball represents a cornea that is irregular and astigmatic

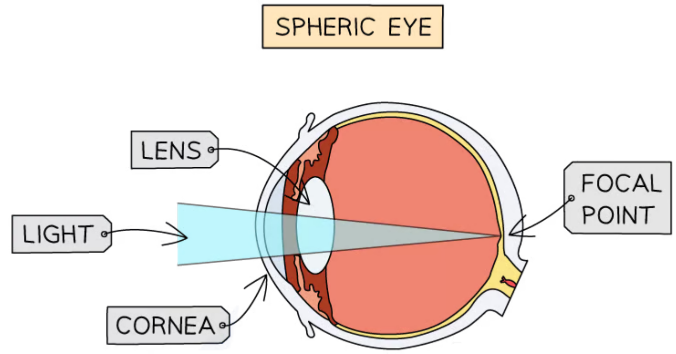
- People with an **irregularly shaped cornea** have **different focal lengths** for **different planes** of vision
  - For example, when vertical lines are in focus then horizontal lines might not be
  - This is because light rays from each plane will come together at a different point
  - These planes of vision can occur at any angle
    - It depends on the angle of the curvature of the cornea

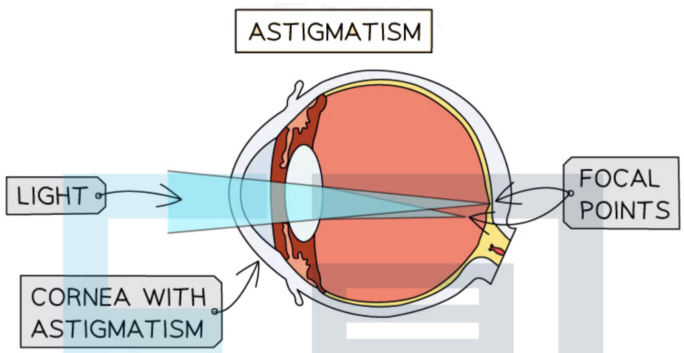
The Structure of a Bridge Seen By Someone with Astigmatism and Someone Without



Someone with astigmatism struggles to focus horizontal and vertical lines at the same time

Comparison of Light Rays Brought Together for Astigmatic and Non-Astigmatic Eyes





In an eye with a spherically shaped cornea, the light rays come to the same point of focus at the retina. In an astigmatic eye, the light rays come together at different points of focus.

Worked example

An eye test shows that a person suffers from astigmatism.

(a) State the main cause of astigmatism.

(b) State the effect of astigmatism on the image seen.

Answer:

(a) The main cause of astigmatism is:

- An irregularly shaped / non-spherical cornea

(b) The effect of an astigmatism on the image seen:

- One plane of vision is in focus but the plane perpendicular / at 90° to it is out of focus

Exam Tip

These questions are common easy mark exam questions on the basics of astigmatism. Read them carefully though!

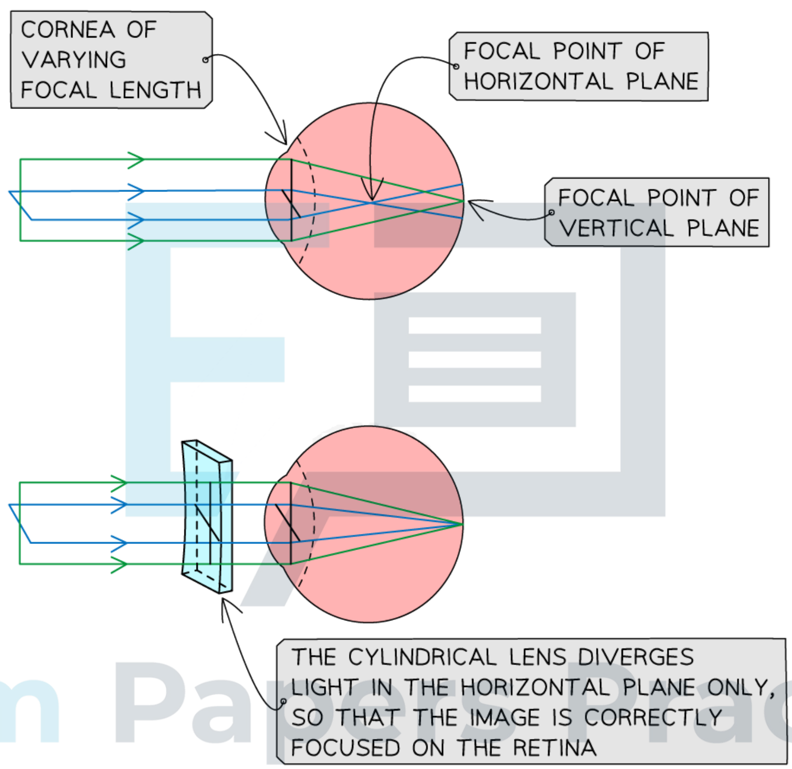
- "Cause" means why someone might have an astigmatism, it is not asking what an astigmatism is.
- Be **specific** about the effect on the image seen, again the question is not asking what astigmatism is.

Astigmatism & Prescriptions

Correcting for an Astigmatism

- **Astigmatism** can be corrected with a **cylindrical lens** that adds power to rays of light coming from one plane but not the plane perpendicular to it

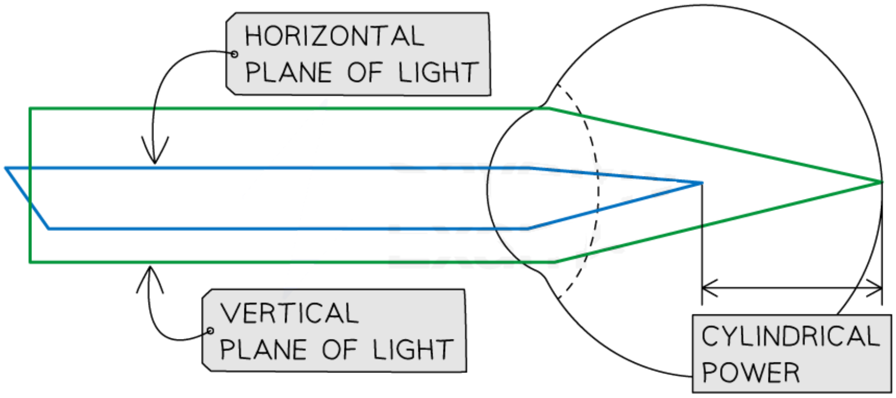
An Example of a Cylindrical Lens Adding Power to One Plane of Light



The cylindrical lens brings light rays in the horizontal plane to a focus but does not affect the light rays in the perpendicular vertical plane

- There are many different combinations of **astigmatism**
- A few examples are:
  - One plane is short-sighted and the other long-sighted
  - One plane has correct vision and the is other long-sighted
  - Both planes are short-sighted by different amounts
- The **cylindrical power** (CYL) of the **astigmatism** is related to the difference in power between the two points of focus of the two planes of light
  - The greater the difference then the greater the **astigmatism**
  - The smaller the difference then the smaller the **astigmatism**
  - It is measured in **Dioptres** (D)

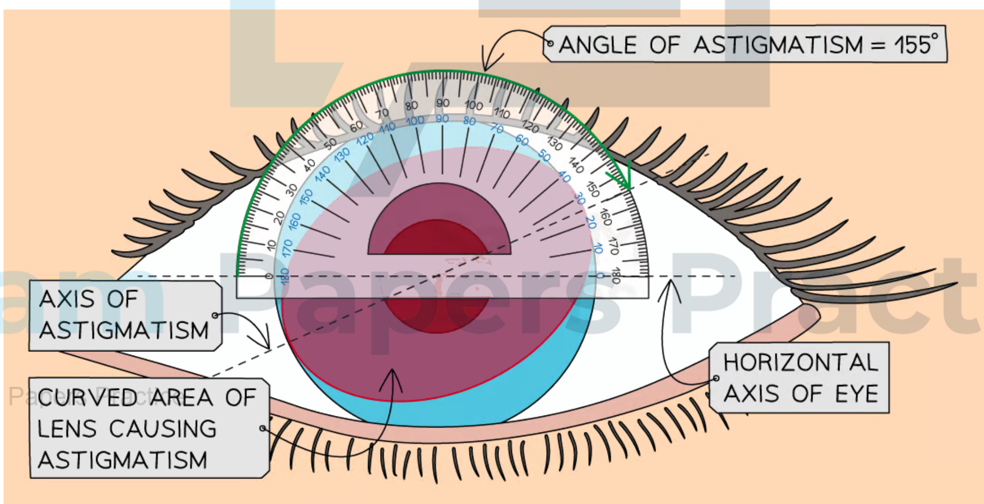
The Cylindrical Power of the Astigmatism



The difference between the points of focus for the two planes of light is related to the cylindrical power of the astigmatism

- The **astigmatism** can be present at any angle on the curvature of the eye known as the **angle of astigmatism**
  - This is measured in the same way as if a **protractor** is placed against the front of the eye
  - It is an angle measured from the left-hand side of the protractor between 0° and 180°

Angle of Astigmatism

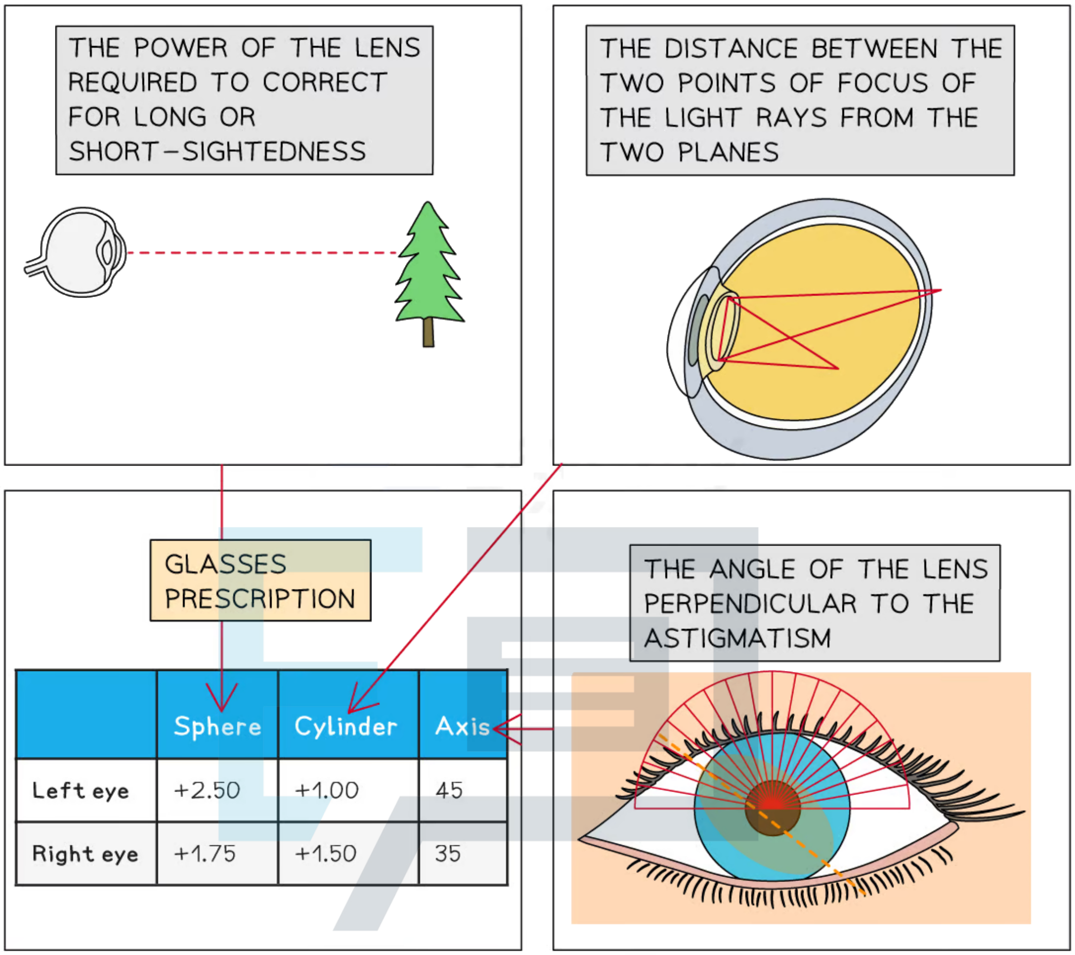


The axis of astigmatism in the eye is found using the angle of the plane of the curved area of the eye. It is the curved area of the cornea that causes astigmatism. In this example, it is 155°.

Prescription for Astigmatism

- The **prescription** for the **cylindrical lens** to correct **astigmatism** will state the following three pieces of information for each eye:
  1. The **sphere** (SPH) - The **focal power** needed to correct for either **long** or **short-sightedness**
  2. The **cylinder** (CYL) - The **cylindrical power** needed to correct for the **astigmatism**
  3. The **axis angle** - This is the angle needed by the lens to correct for **astigmatism**

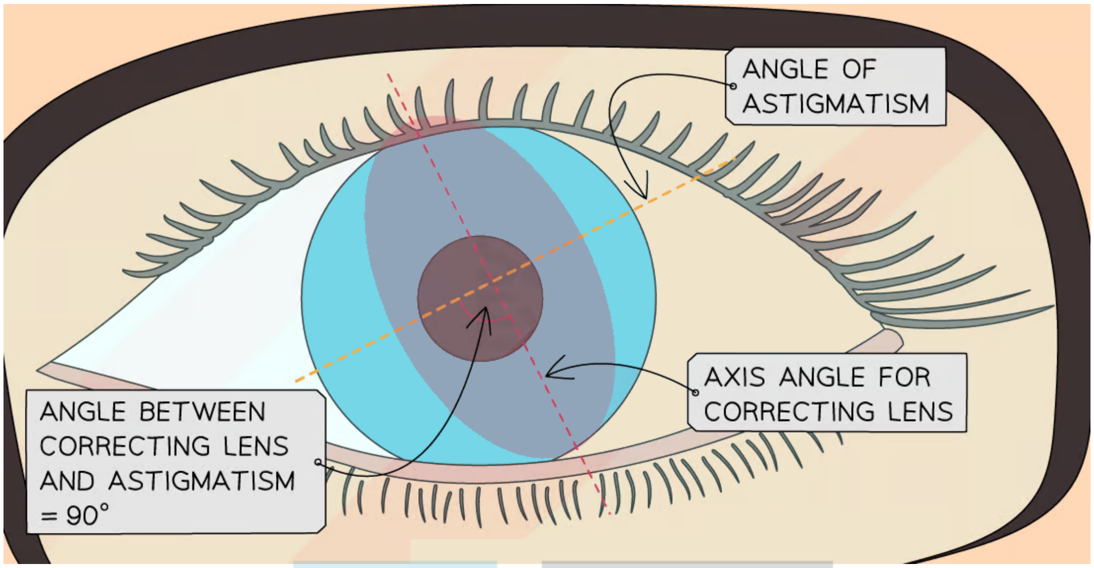
An Example Astigmatism Prescription



The astigmatism prescription shows the sphere focal power, cylindrical power and axis angle

- In your exam, you may be asked to **calculate** the power of the lens needed in a prescription
- This is calculated for each eye by subtracting CYL from SPH
  - For example, in the image for the left eye this is +2.50 – 1.00 = 1.50 D
  - In the right eye this is +1.75 – 1.50 = 0.25 D
- Remember that one or both of the SPH and CYL values can be negative depending on the vision defect
  - So, you may need to subtract a negative power
  - e.g. +1.50 – – 0.50 = 1.50 + 0.50 = 2.00 D
- It is important to note that the **angle** of **astigmatism** and the **axis angle** for the **prescription** are perpendicular to each other
  - A curved area on the **cornea** at a specific angle causes **astigmatism**
  - This is corrected by an equally curved area in the **correcting lens** placed **perpendicular** to it

Angle of Astigmatism vs Axis Angle for Prescription



The diagram shows that the axis angle for the correcting lens must be perpendicular to the angle of astigmatism. The angle of astigmatism in this example is 155°, so the axis angle is 155 – 90 = 65°

Worked example

A patient has the prescription shown below.

	Sphere	Cylinder	Axis
Right	+1.00	−0.50	15°
Left	+1.5	−1.00	150°

Explain the following information:

- The type of vision the prescription is correcting
- The power and angle of the lens required to correct the vision

Answer:

Step 1: Identify the type of vision the prescription is correcting

- The patient is long-sighted because the powers of the correcting lenses for both eyes are positive

Step 2: Determine whether the patient has an astigmatism

- The patient has astigmatism because there is information in the "cylinder" and "axis" columns of the prescription

Step 3: Explain the type of correcting lens needed for the astigmatism

- In the right eye, the patient has astigmatism of 1.00 –– 0.50 = 1.50 at an angle of 15° to the left side horizontal
- In the left eye, the patient has astigmatism of 1.50 –– 1.00 = 2.50 at an angle of 150° to the left side horizontal

Exam Tip

You will not be required to draw any ray diagrams showing or correcting for an astigmatism but you do need to understand the complexities of focussing and not focussing light from different planes of vision and be able to interpret different types of prescription.