Edexcel GCSE Physics

Your notes

Optics

Contents

Reflection & Refraction

Your notes

Reflection

- Reflection occurs when:

  A wave hits a boundary between two media and does not pass through, but instead stays in the original medium

- Light, sound and water waves can all be reflected
  - The reflection of light waves is seen in a mirror
- Angles are measured between the wave (ray) direction and a line at 90 degrees to the boundary (the normal)
  - The angle of the wave approaching the boundary is called the **angle of incidence (i)**
  - The angle of the wave leaving the boundary is called the **angle of reflection (r)**
- The **law of reflection** states that these angles are the same:

  Angle of incidence (i) = Angle of reflection (r)

- When drawing a ray diagram, an arrow is used to show the direction the wave is travelling
  - An **incident** ray has an arrow pointing **towards** the boundary
  - A **reflected** ray has an arrow pointing **away** from the boundary
- The **angles** of **incidence** and **reflection** are usually labelled **i** and **r** respectively

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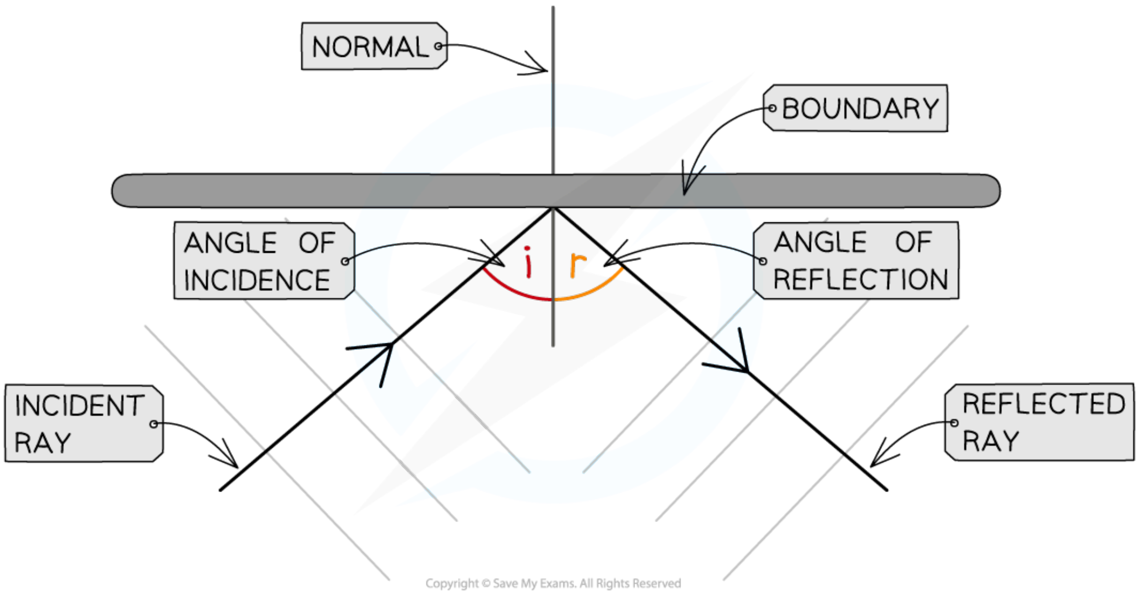


Reflection of a wave at a boundary

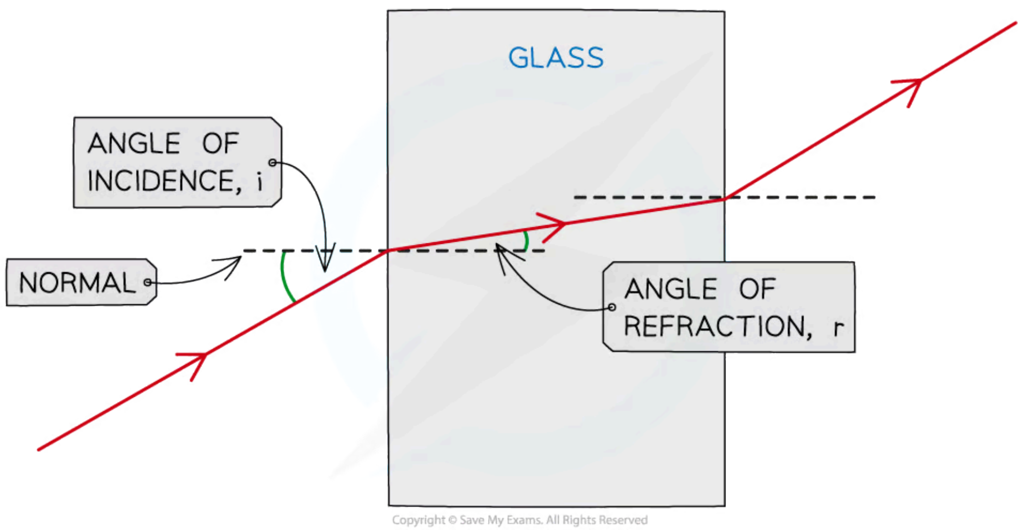
Examiner Tips and Tricks

When drawing ray diagrams, a simple line with an arrow is enough to represent the wave. Make sure these are drawn with a ruler or a straight edge to be as neat as possible, and don't forgot to label the direction of the arrow!

Refraction Ray Diagrams

- Refraction occurs when light passes a boundary between two **different** transparent media
- At the boundary, the rays of light undergo a **change in direction** because the light **changes speed**
- The direction is taken as the angle from a hypothetical line called the normal
  - This line is **perpendicular** to the surface of the boundaries and is usually represented by a straight dashed or dotted line
- The change in direction depends on which media the light rays pass between:
  - From **less** dense to **more** dense (e.g air to glass), light bends **towards** the normal
  - From **more** dense to **less** dense (e.g. glass to air), light bends **away** from the normal

- When passing along the normal (perpendicular) the light **does not bend** at all



How to construct a ray diagram showing the refraction of light as it passes through a rectangular block

- The change in direction occurs due to the change in **speed** when travelling in different substances
  - When light passes into a **denser** substance the rays will **slow down**, hence they bend towards the normal
- The only properties that change during refraction are speed and wavelength – the frequency of waves **does not change**
  - Different frequencies account for different **colours** of light (red has a low frequency, whilst blue has a high frequency)
  - When light refracts, **it does not change colour** (think of a pencil in a glass of water), therefore, the frequency does not change

Worked Example

The diagram below shows two parallel rays of light entering and passing through prism **A** and prism **C**.

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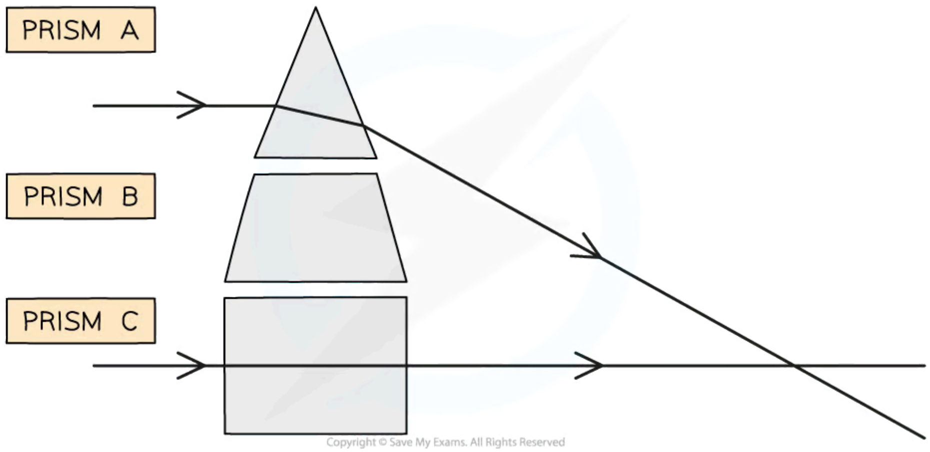
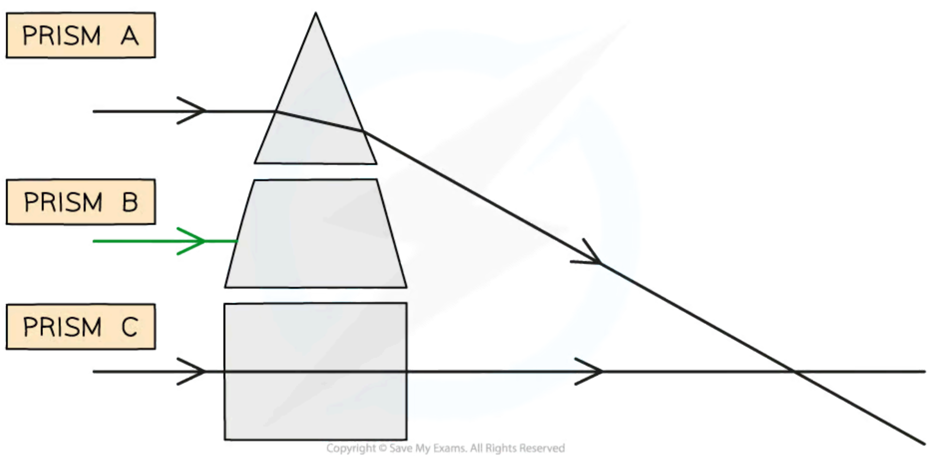


Draw a third parallel ray entering and passing through prism **B**.

Answer:

Step 1: Draw a parallel ray on the left



Step 2: Draw the refracted ray at the first surface

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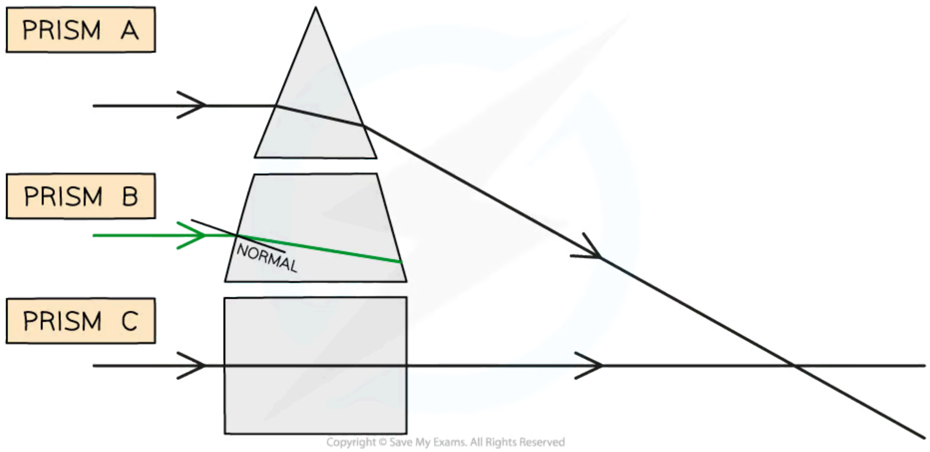
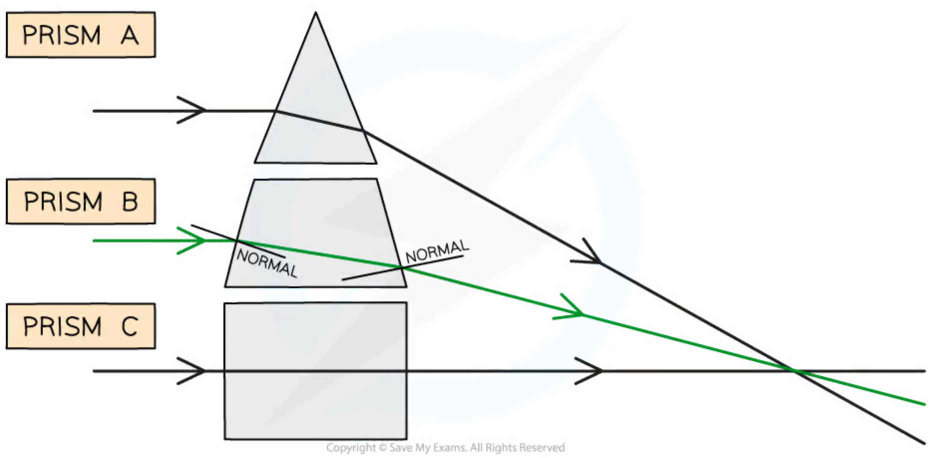


- As the ray **enters** the block it bends **towards** the normal since it is going into a denser material
- In this case, the angle of refraction is **smaller** than the angle of incidence

Step 3: Draw the refracted ray at the second surface



- As the ray **leaves** the block it bends **away** from the normal
- In this case, the angle of refraction is **larger** than the angle of incidence

Examiner Tips and Tricks

Practice drawing refraction diagrams as much as you can! It's very important to remember which way the light bends when it crosses a boundary:As the light **enters** the block it bends **towards** the

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normal line

Remember: Enters Towards

When it **leaves** the block it bends **away** from the normal line

Remember: Leaves Away

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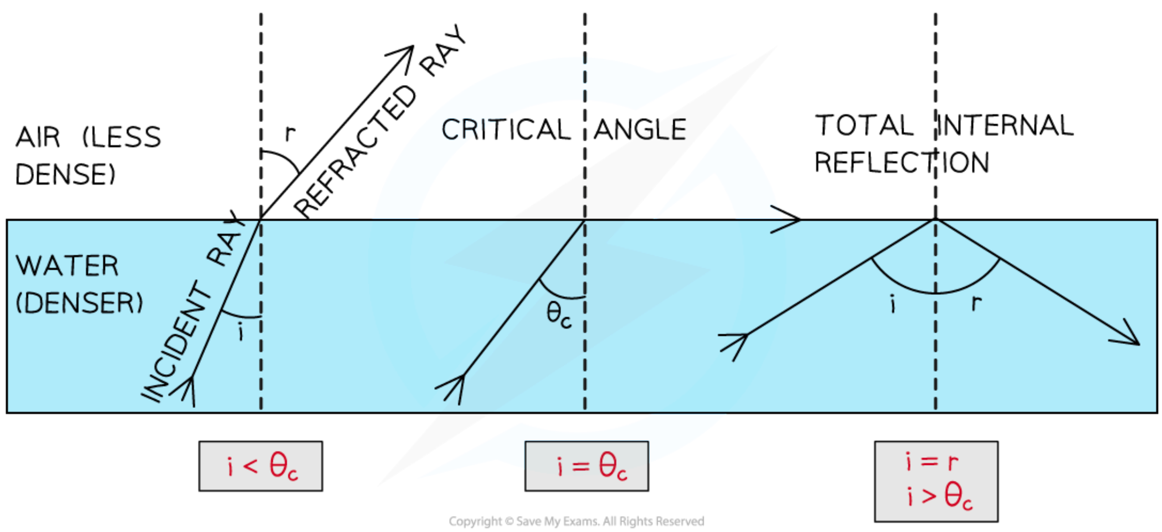
Total Internal Reflection

Total Internal Reflection

- As the angle of incidence is increased, the angle of refraction also increases until it gets closer to 90°
- When the angle of refraction is exactly 90° the light is refracted along the boundary
  - At this point, the angle of incidence is known as the **critical angle** θ_c
- Total internal reflection (TIR) occurs when:

  The angle of incidence is greater than the critical angle and the incident material is denser than the second material
- Therefore, the **two** conditions for total internal reflection are:
  - The angle of incidence > the critical angle ($i > \theta_c$)
  - The incident material is **denser** than the second material

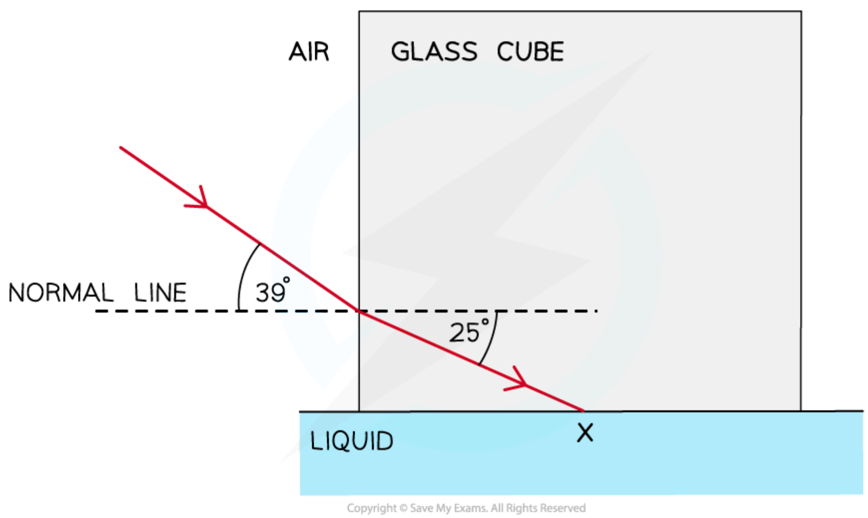


Critical angle and total internal reflection

Worked Example

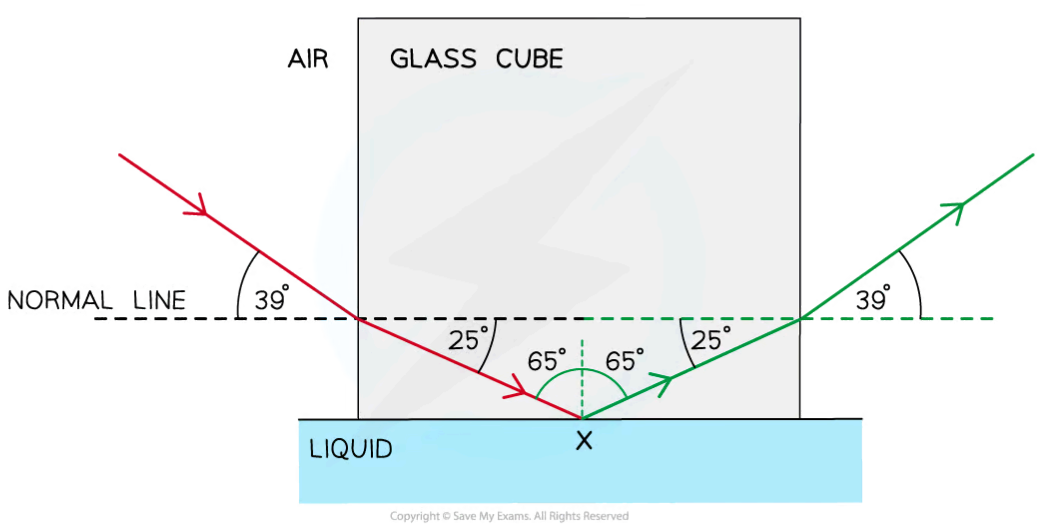
Your notes

A glass cube is held in contact with a liquid and a light ray is directed at a vertical face of the cube. The angle of incidence at the vertical face is 39° and the angle of refraction is 25° as shown in the diagram. The light ray is totally internally reflected for the first time at **X**.



Complete the diagram to show the path of the ray beyond **X** to the air and calculate the critical angle for the glass-liquid boundary.

Answer:



Step 1: Draw the reflected angle at the glass-liquid boundary

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- When a light ray is reflected, the angle of incidence = angle of reflection (i = r)
- Therefore, the angle of incidence (or reflection) is 90° – 25° = 65°

Step 2: Draw the refracted angle at the glass-air boundary

- At the glass-air boundary, the light ray refracts **away** from the normal
- Due to the reflection, the light rays are symmetrical to the other side

Step 3: Calculate the critical angle

- The question states the ray is "totally internally reflected for the first time" meaning that this is the lowest angle at which TIR occurs
- Therefore, 65° is the critical angle

Your notes

Light & Surfaces

Your notes

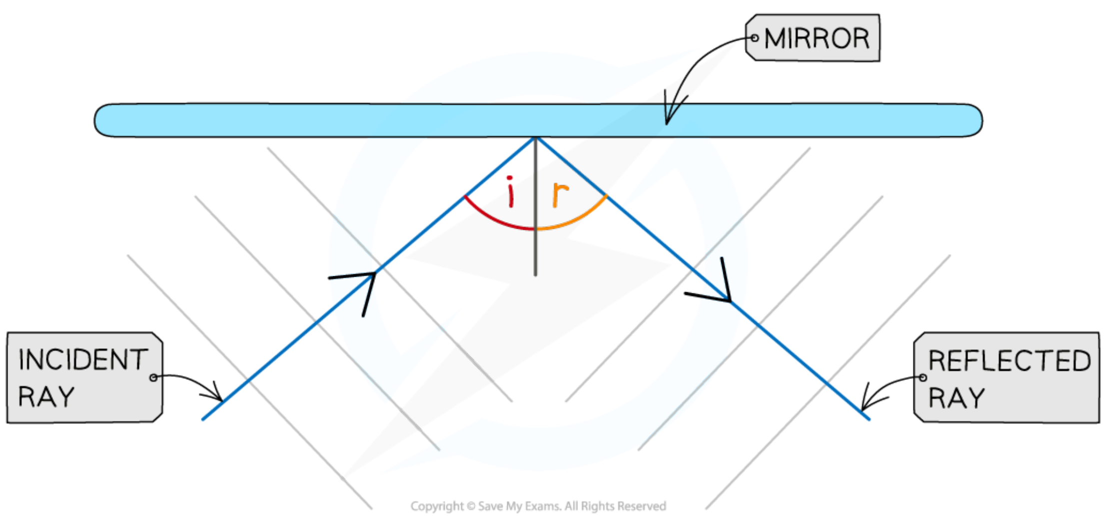
Specular & Diffuse Reflection

Specular Reflection

- Specular reflection is defined as:

  Reflection from a smooth surface in a single direction

- When light reflects off a **smooth** surface, such as a mirror, specular reflection occurs
  - This is what gives a mirror its shiny appearance
- This is why a reflection can be seen clearly in a mirror
- In this case, the angle of reflection ***r*** is **equal** to the angle of incidence ***i***



When reflecting off a mirror, the specular reflection occurs. The angle of incidence is equal to the angle of reflection

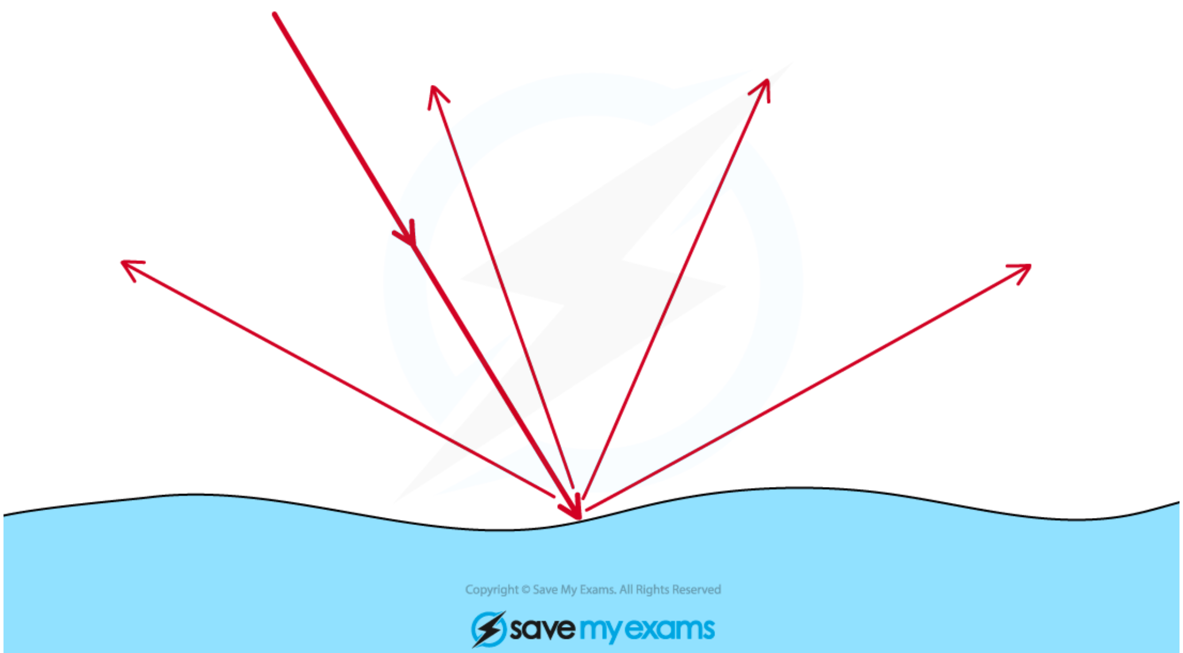
Diffuse Reflection

- Diffuse reflection is defined as:

  Reflection from a rough surface causes scattering

- When light reflects off a **rough** surface, which applies to the majority of surfaces, diffuse reflection occurs

- This is what gives objects a dull or matt appearance
- This is why a reflection **cannot** be seen clearly from a table surface, for example
  - Even though a table's surface may look smooth from afar, it is actually made up of many tiny ridges which the light rays are scattered off
- When light scatters, it leaves the surface in all directions



When light is reflected from the majority of surfaces it is scattered – a process known as diffuse reflection

Colour

Differential Absorption of Colour

- Absorption occurs when:

  Energy is transferred from the wave into the particles of a substance

- Waves can be partially or completely absorbed
  - Sound waves are absorbed by brick or concrete in houses
- Light will be absorbed if the frequency of light matches the energy levels of the electrons

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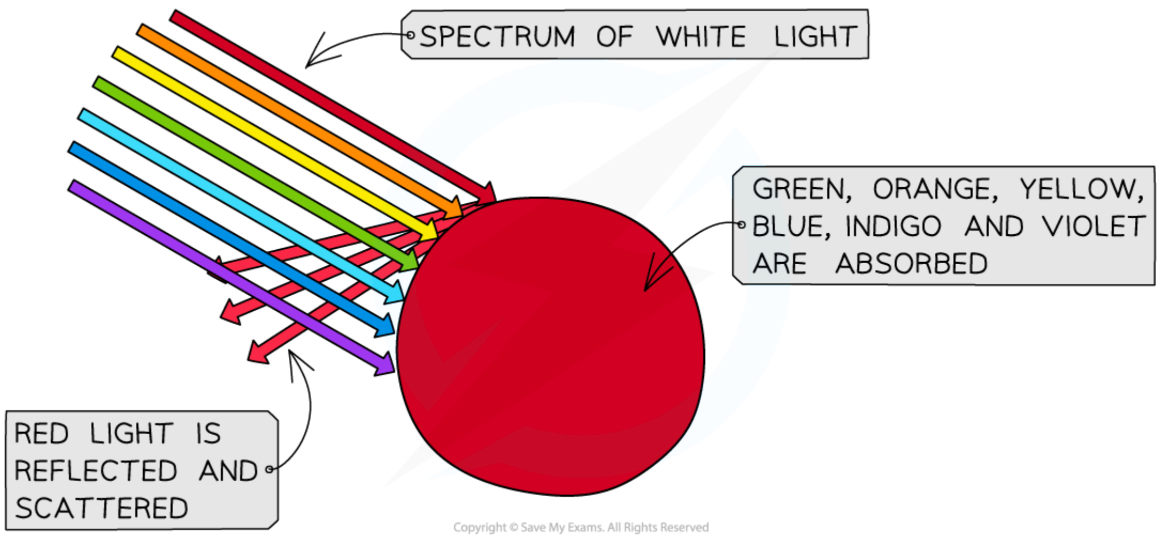
- The light will be absorbed, and then reemitted over time as heat
- If an object appears red, this means:
  - Only red light has been **reflected**
  - All the other frequencies of visible light have been **absorbed**



The object is seen as red since the red light is reflected whilst the other colours are absorbed

Colour Filters

- Colour filters work by **absorbing** certain wavelengths and **transmitting** other wavelengths
  - These certain wavelengths correspond to certain **colours**
- When white light passes through a coloured filter, some colours are absorbed whilst others are able to pass straight through
- For example, when white light passes through a **red** filter:
  - Red light is **transmitted**
  - All the other colours are **absorbed**
- The colour that is transmitted is the same colour as the filter

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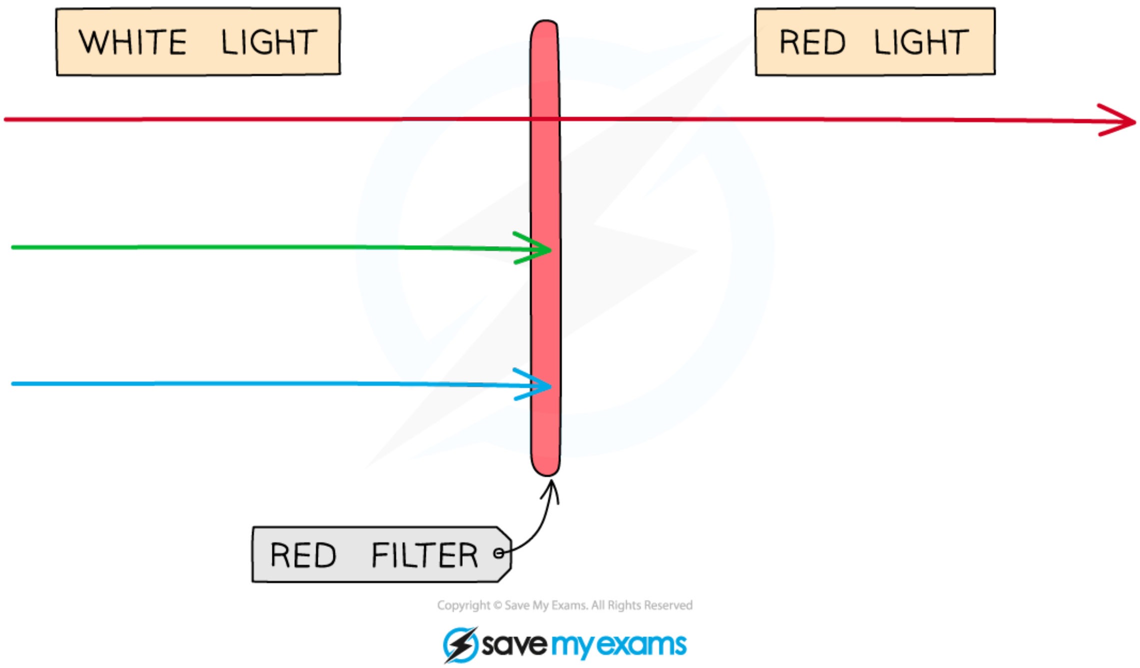


A red filter transmits only red light and absorbs all other colours of light

Examiner Tips and Tricks

Remember that the **smaller** the wavelength, the **greater** the refraction

Lenses

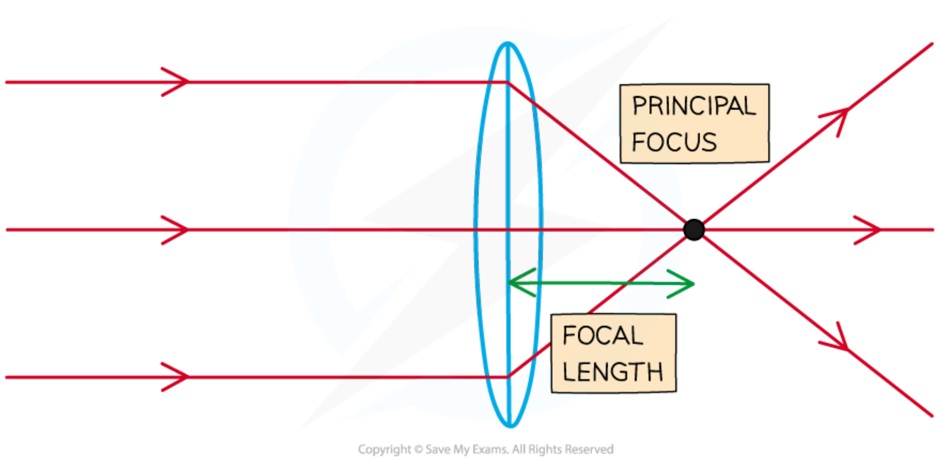
Your notes

Converging & Diverging Lenses

- A lens is a piece of equipment that forms an image by **refracting** light
- There are two types of lens:
  - Converging
  - Diverging

Converging Lenses

- In a converging lens, parallel rays of light are brought to a focus
  - This point is called the **principal focus**
- This lens is sometimes referred to as a **convex** lens
- The distance from the lens to the principal focus is called the **focal length**
  - This depends on how **curved** the lens is
  - The **more** curved the lens, the **shorter** the focal length



The focal length is the distance from the lens to the principal focus

Diverging Lenses

- In a diverging lens, parallel rays of light are made to diverge (spread out) from a point

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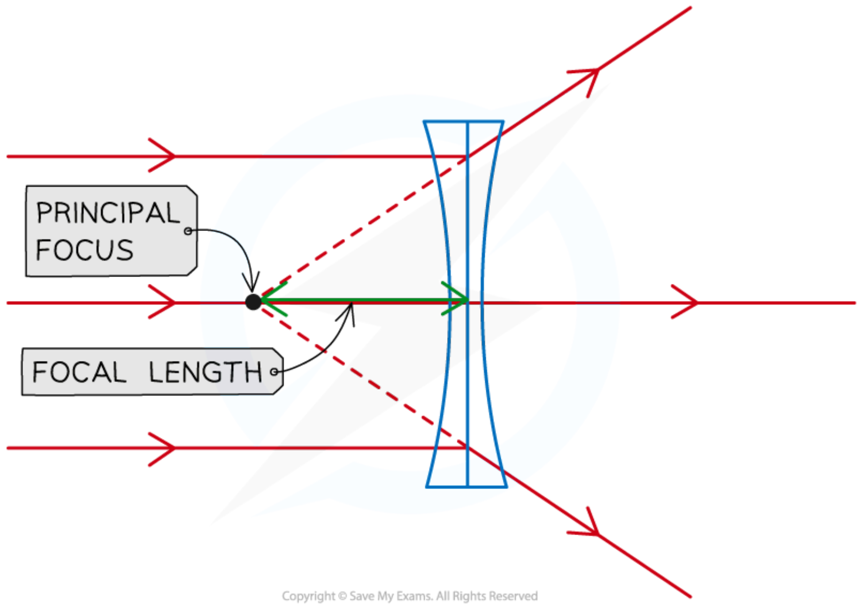
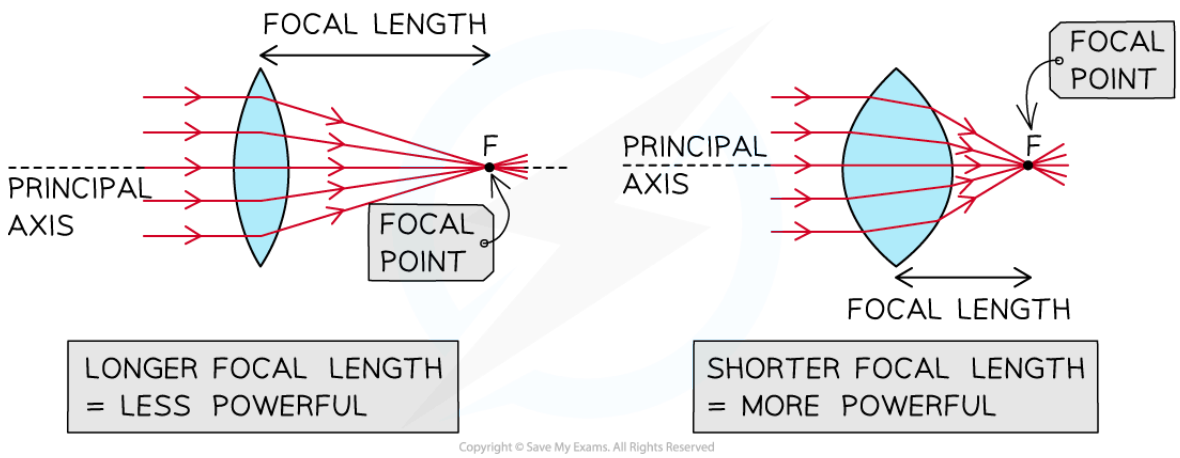
- This lens is sometimes referred to as a **concave** lens
- The principal focus is now the point from which the rays appear to diverge from



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

Lens Power

- The **power** of a lens is related to:
  - The **focal length** of the lens
  - The **shape** of the lens
- The **power** of a lens is a measure of how strongly it focuses the light
  - The **more** curved the lens, the **shorter** the focal length
  - The **shorter** the focal length, the **greater** the power of the lens



The power of a lens depends on its focal length

- Power is defined by the equation:

$$power = \frac{1}{focal\ length}$$

- Power is measured in **dioptres**
- Sometimes the focal length is negative
  - A negative focal length is often used for a **diverging** lens

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Real & Virtual Images

Real & Virtual Images

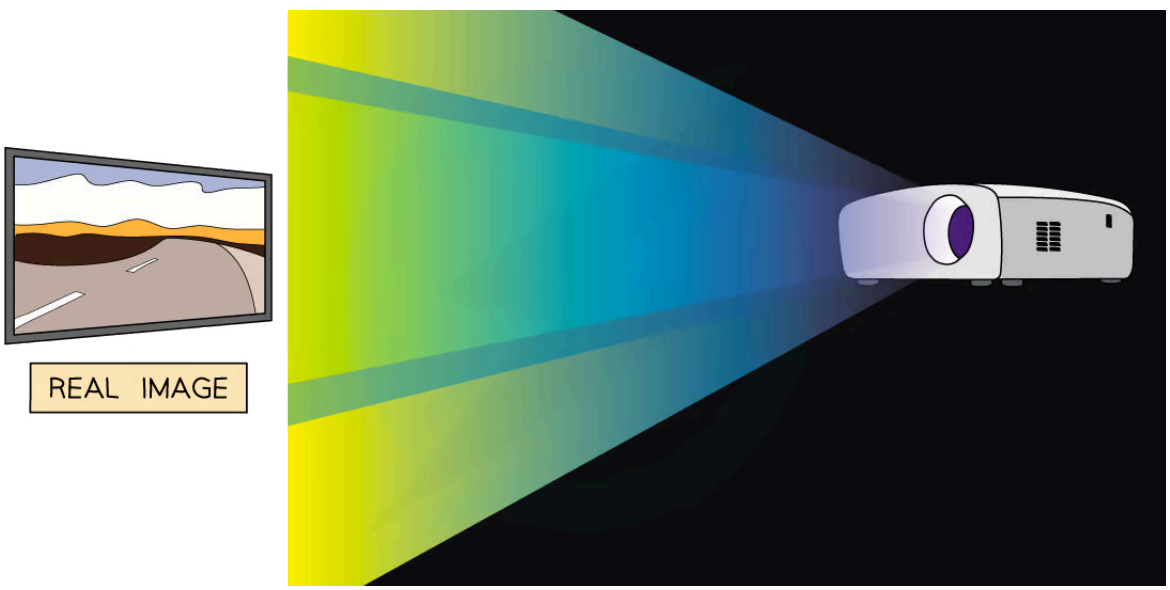
- Images produced by lenses can be one of two types:
  - A real image
  - A virtual image

Real Images

- A real image is defined as:

  An image that is formed when the light rays from an object converge and meet each other and can be projected onto a screen

- A real image is one produced by the **convergence** of light towards a focus
- Real images are always **inverted**
- Real images can be projected onto pieces of paper or screens
  - An example of a real image is the image formed on a cinema screen



A real image can be projected onto a screen

- Real images are where two **solid lines** cross in ray diagrams

Virtual Images

Your notes

- A virtual image is defined as:

  An image that is formed when the light rays from an object do not meet but appear to meet behind the lens and cannot be projected onto a screen

- A virtual image is formed by the **divergence** of light away from a point
- Virtual images are always **upright**
- Virtual images **cannot** be projected onto a piece of paper or a screen
  - An example of a virtual image is a person's reflection in a mirror

A reflection in a mirror is an example of a virtual image

- Virtual images are where two **dashed lines,** or **one dashed and one solid line** crosses in ray diagrams

Drawing Ray Diagrams

- Lenses can be used to form images of objects placed in front of them
- The location (and nature) of the image can be found by drawing a ray diagram
- When describing an image, consider if it is:
  - **Real** or **virtual**

Your notes

- **Magnified** (larger) or **diminished** (smaller)
- **Upright** or **inverted**

Converging Lens Ray Diagrams – Real Images

- If an object is placed **further** from the lens than the focal length *f* then a **real** image will be formed, and the converging lens ray diagram will be drawn in the following way:

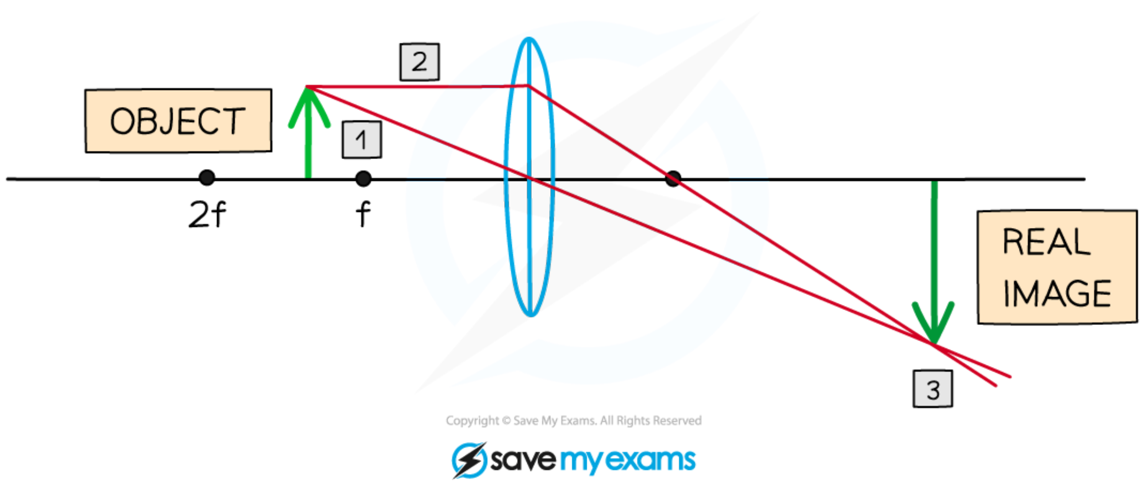


Diagram showing the formation of a real image by a lens

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 travel directly through the **principal focus** *f*
3. The image is the line drawn from the axis to the point where the above two rays **meet**

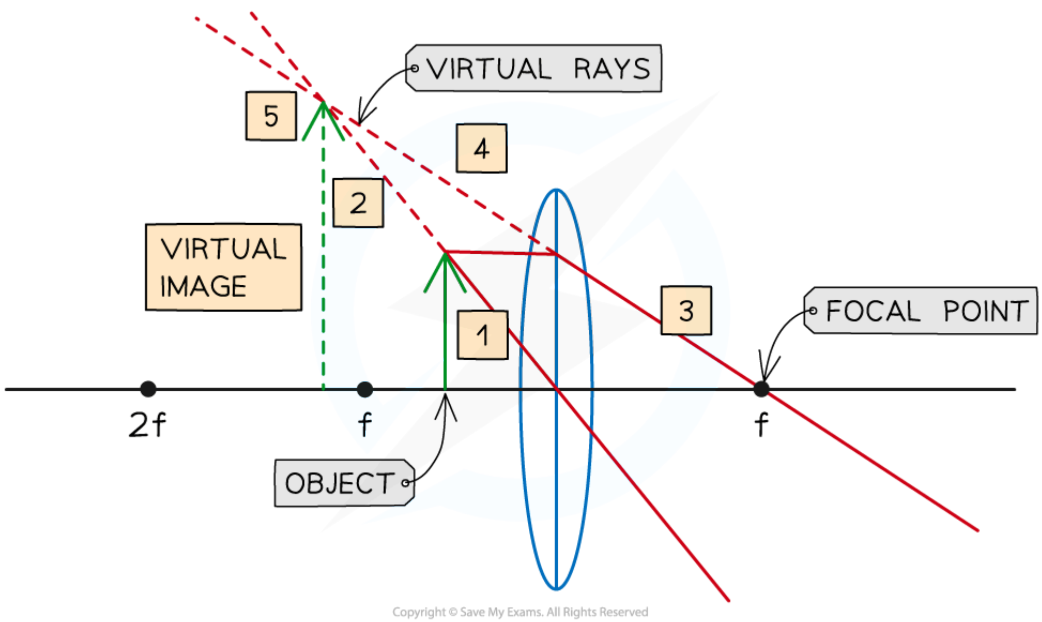
- In the above diagram, the image is:
  - **Real**: the light rays meet each other after refraction
  - **Magnified**: the image is larger than the object
  - **Inverted**: the image is formed on the opposite side of the principal axis

Converging Lens Ray Diagrams – Virtual Images

- A converging lens will produce a **real** image of an object which is placed at a distance **greater** than the focal length from the lens

Your notes

- If the object is placed **closer** to the lens than the focal length *f* then a **virtual** image will be formed and the converging lens ray diagram will be drawn in the following way:



A virtual image formed when the object is placed closer than the focal length

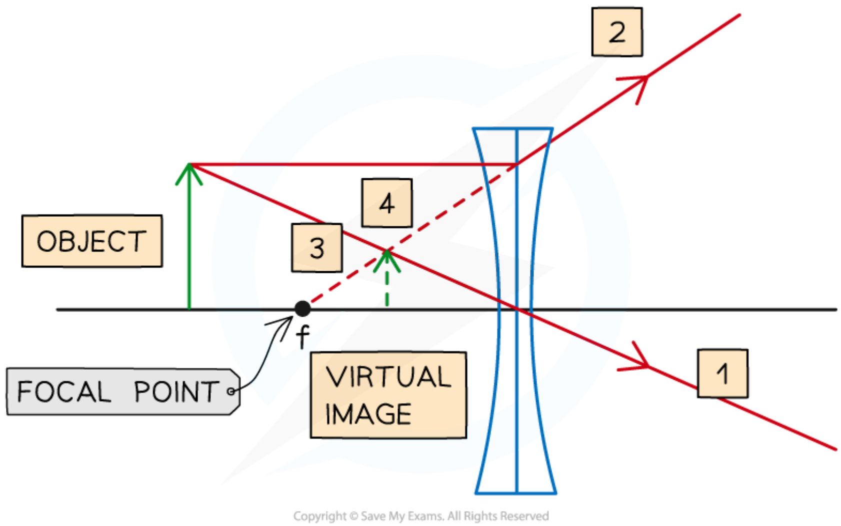
1. Start by drawing a ray going from the top of the object through the **centre** of the lens. This ray will continue to travel in a straight line
2. Draw a dashed line continuing this ray upwards
3. Next draw a ray going from the top of the object, travelling parallel to the axis to the lens. When this ray emerges from the lens it will travel directly through the **principal focus** *f*
4. Also, draw a dashed line continuing this ray upwards
5. The image is the line drawn from the axis to the point where the two dashed lines **meet**

- In this case, the image is:
  - **Virtual**: the light rays appear to meet when produced backwards
  - **Magnified**: the image is larger than the object
  - **Upright**: the image is formed on the same side of the principal axis

Diverging Lens Ray Diagrams

- Diverging (concave) lenses can also be used to form images, although the images are always **virtual** in this case

- If an object is placed **further** from the lens than the focal length *f* then a diverging lens ray diagram will be drawn in the following way:



Diverging lenses only produce virtual images

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 travel directly upwards away from the axis
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**

- In this case, the image is:
  - **Virtual**: the light rays appear to meet when produced backwards
  - **Diminished**: the image is smaller than the object
  - **Upright**: the image is formed on the same side of the principal axis

Comparing Converging & Diverging Lenses

- The image produced by a **converging** lens can be either **real** or **virtual**
  - This means the image can be inverted (real) or upright (virtual)
- The image produced by a **diverging** lens is always **virtual**
  - This means the image will always be upright

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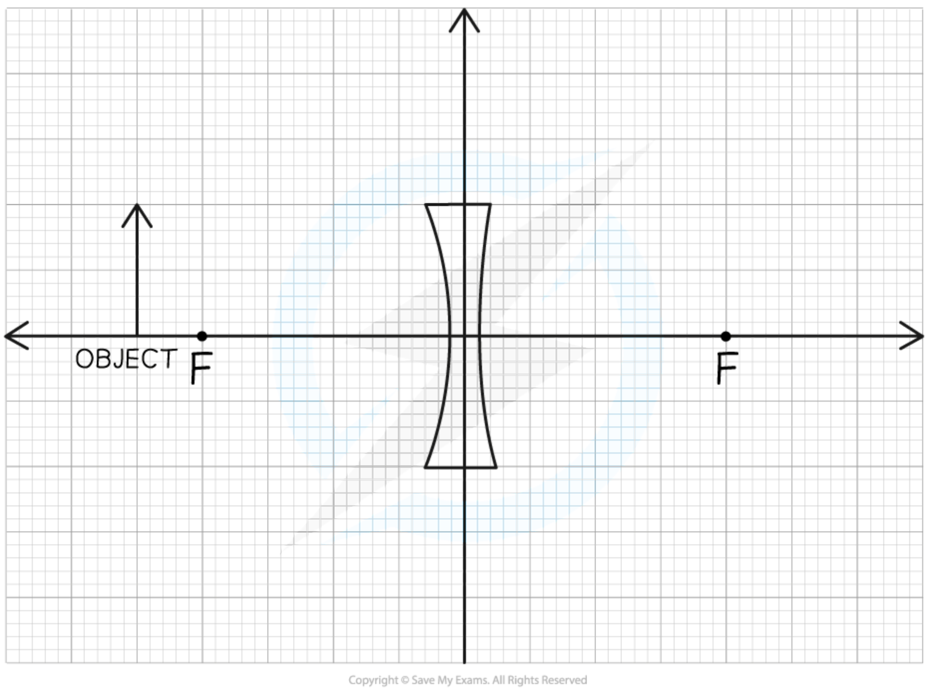
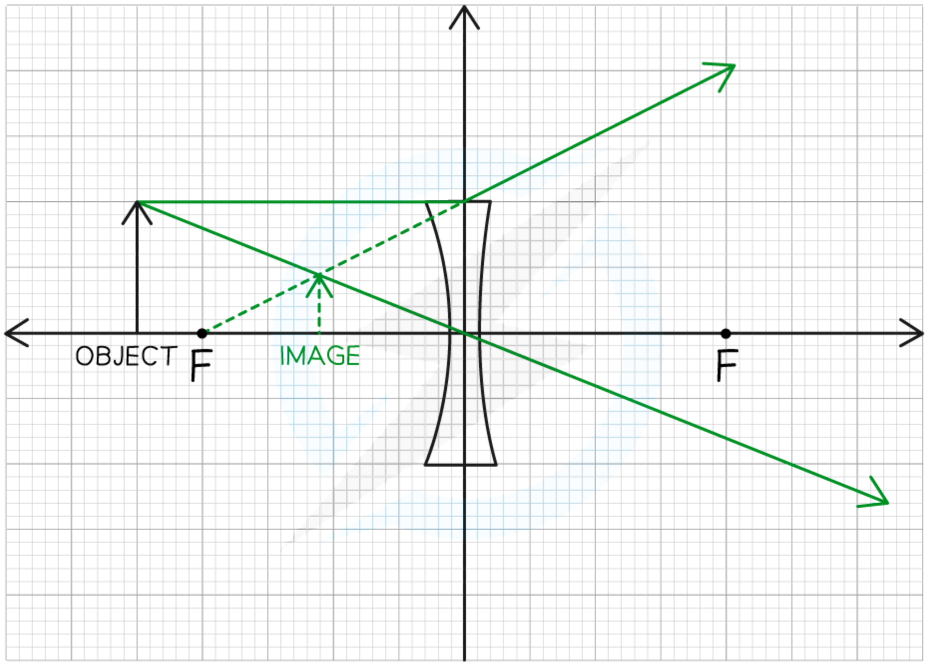
Worked Example

An object is placed outside the focal point of a concave lens.



Complete the ray diagram by drawing where the image of this object will be seen.

Answer:



Step 1: Draw a line from the top of the object through the middle of the lens

- The top of the image lies somewhere along this line

Step 2: Draw a line from the focal point through the top of the lens

- The dashed line shows the continuation of the upwards arrow
- The top of the image is where the two lines cross

Examiner Tips and Tricks

The best way to remember these ray diagrams is to draw them and see the results for yourself. Remember to always use a ruler or a straight edge in the exam when drawing the rays to gain full marks and produce the most accurate drawings

Your notes