AS Level Physics

Chapter 5 – Waves and Particle Nature of Light

5.5.1 Optics (Edexcel Only)

Notes

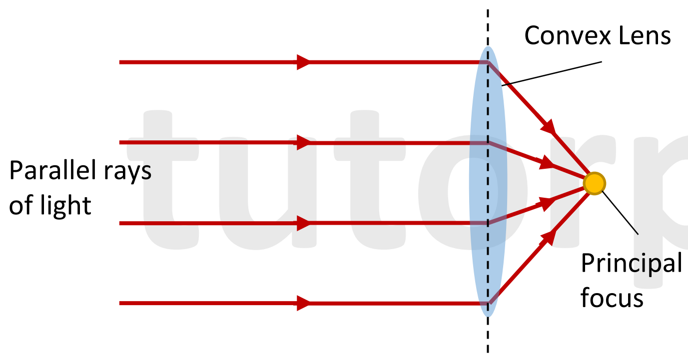
Converging and Diverging Lenses

Lenses bend light by refracting it as it passes through the curved surface of a transparent glass or plastic piece. They are used in everyday products such as cameras, telescopes, binoculars, microscopes, and corrective glasses.

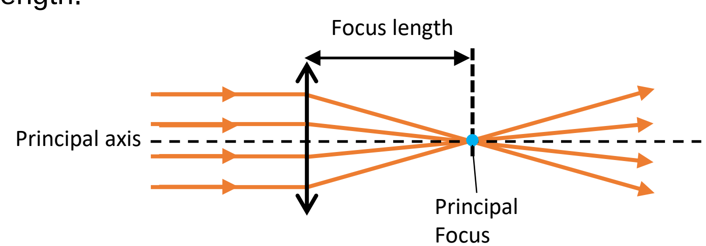
A lens can be convex or concave.

Convex Lenses

A convex lens has a greater thickness at its center compared to its edges, causing incoming parallel light rays to converge at a specific point known as the principal focus.



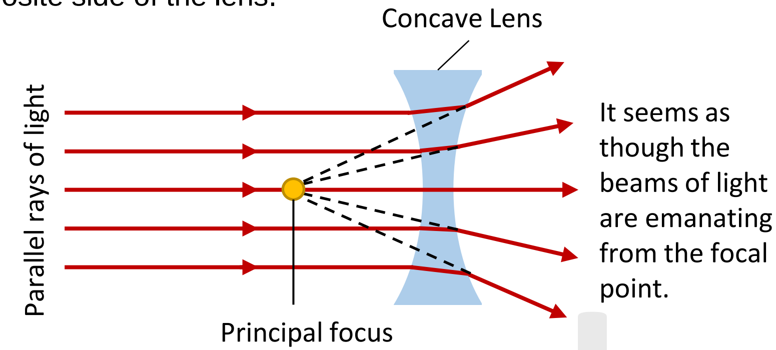
In a ray diagram, a convex lens is represented as a vertical line with outward-facing arrows to indicate its shape. The distance between the centre of the lens and the principal focus is referred to as the focal length.



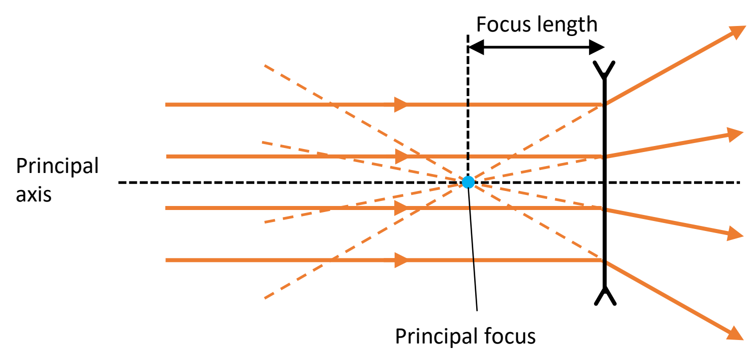
Converging and Diverging Lenses

Concave Lenses

A concave lens has a thinner centre than the edges. This causes parallel light rays to diverge instead of converging. These light rays are dispersed, but they seem to originate from a principal focus on the opposite side of the lens.



In a ray diagram, a concave lens is illustrated as a vertical line with inward-pointing arrows to represent its shape. As the lens diverges light rays, they do not converge at a particular point, but rather spread apart. By tracing the path of the light rays backward from where they emerge, which is indicated by green dashed lines, we can identify their source. This reveals that the light rays seem to have originated from a focal point.



Power of a Lens

The strength of a lens can be determined by its focal length, which is the distance between the lens and its focal point. A shorter focal length denotes a more powerful lens, as it can bring light rays closer together in a shorter distance. If the focal length is known, we can calculate the lens's power using the following equation:

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

Where:

P = power in dioptres, D

f = focal length in metres, m

A dioptre is the reciprocal of the focal length measured in metres and is used to measure the optical power of a lens or curved mirror.

$$1\ dioptre\ =\ 1\ m^{-1}$$

A diverging lens' power will be recorded as a negative value because it has a negative focal length.

Example:

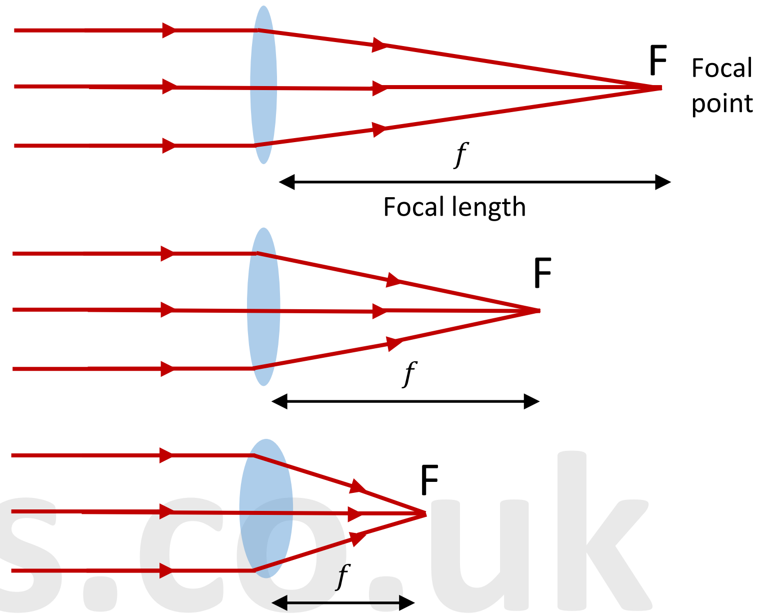
The focal length of a telescope lens has a 42 cm. What is its power?

$$P = \frac{1}{f} = \frac{1}{0.42\ m} = 2.38\ D$$

The virtual focus of a concave lens for a pair of glasses is 33.2cm from the centre of the lens. What is its power?

$$P = \frac{1}{f} = \frac{1}{-0.332\ m} = -3.01\ D$$

Power of a Lens



Convex lenses with a greater thickness at the centre typically have a shorter focal length, which indicates they are more powerful.

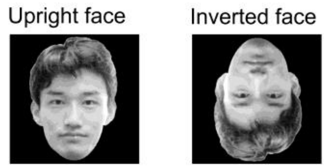
When two lenses are placed on top of each other, in a combination, the total power of the arrangement is equivalent to the sum of each lens's individual power.

$$P = P_1 + P_2 + P_3 + \ ......$$

Real and Virtual Images

Lens produce images that can be:

- Upright or inverted (upside down compared to the object)



- Magnified or diminished (smaller than the object) or the same size

- Real or virtual

An image that can be projected onto a screen is referred to as a real image. A 'virtual image' is an image that cannot be projected onto a screen.

Ray diagrams are useful to determine the location, size, orientation, and type of image that is formed by a lens. They are also a useful representation of the possible paths light can take to get from one place to another.

To draw a ray diagram:

1) First, draw a ray parallel to the principal axis from the object to the lens. Once through the lens, the ray should pass through the principal focus.

2) Then, draw a ray which passes from the object through the centre of the lens.

3) Where the two lines cross is where you will find the position of the image.

4) A third ray can be seen in some ray diagrams, however, to find the position of an image, just two rays are necessary. The third ray can be used for verification.

Real and Virtual Images

When light rays, from one spot on an object, are focused to meet at the same point, an image of that spot of the object appears.

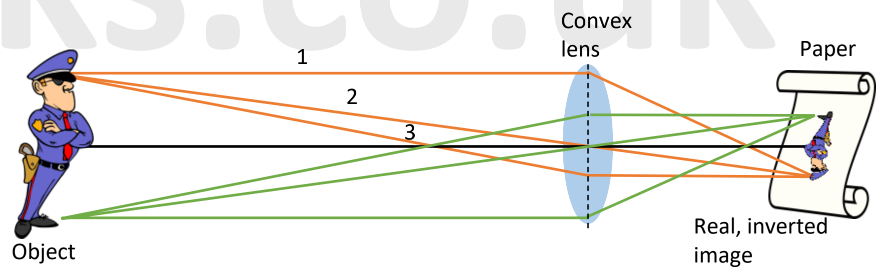
The below diagram shows how the light rays originating from the boy's feet are refracted by the lens and converge to a point on the screen, where an image of his feet will appear.

This process is repeated for all parts of the object, resulting in the complete image being formed.. The rays displayed below follow the rules mentioned earlier:

- The first ray is parallel to the principal axis and will go through the lens, passing through the focal point on the other side.

- The second ray passes through the centre of the lens continuing in a straight line.

- The third ray passes through the focal length on its way to the lens and will emerge parallel to the principal axis (see next page).

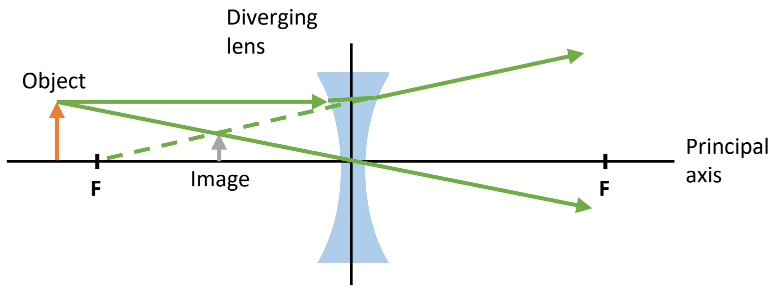


The above process occurs for every individual point of an object producing an image on the screen. This image produced is known as the 'real image' and is common with convex lenses.

One characteristic of the image formed is its orientation, which is upside-down compared to the original object, as shown in the above diagram. We refer to this as an "inverted" image.

Real and Virtual Images

Due to their diverging nature, concave lenses always disperse light rays, making it challenging to create a real image on a screen since the rays do not converge at a point. Instead, a virtual image is formed. The given diagram below illustrates the formation of a virtual image by a concave lens.



A 'virtual image' is an image that cannot be projected onto a screen.

The orientation of the image in the above diagram is upright.

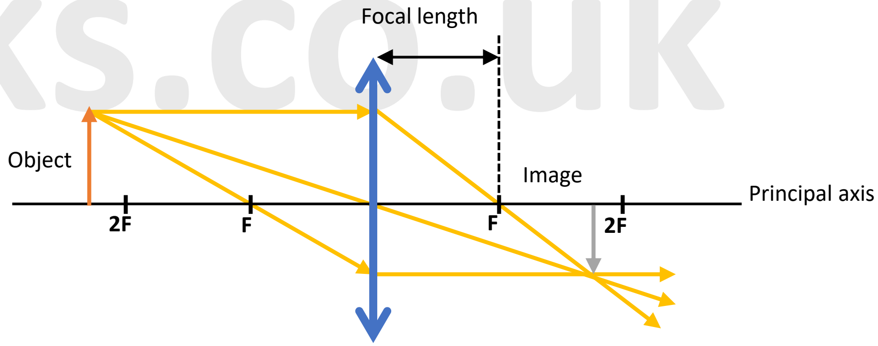
Ray Diagrams (Convex Lenses)

The type of image created by a convex lens is influenced by both the lens itself and the distance between the lens and the object.

A camera or human eye

Convex lenses are used in cameras and eyes, among other applications. When an object is located at a distance of more than twice the focal length from the lens, the resulting image is:

- Inverted
- Diminished (made smaller or less)
- Real



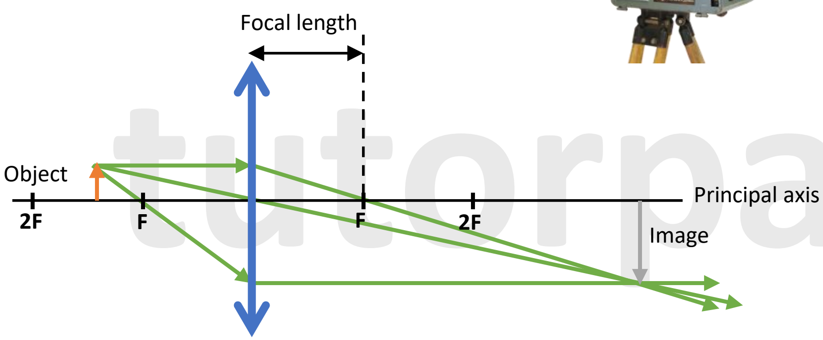
Ray diagram for an object placed at a distance greater than two focal lengths from a convex lens.

Ray Diagrams (Convex Lenses)

Projectors

Projectors also use convex lenses. When an object is positioned between one and two focal lengths from the lens, the resulting image is:

- Inverted
- Magnified
- Real



The ray diagram above shows an object located between 2F and F from a convex lens.

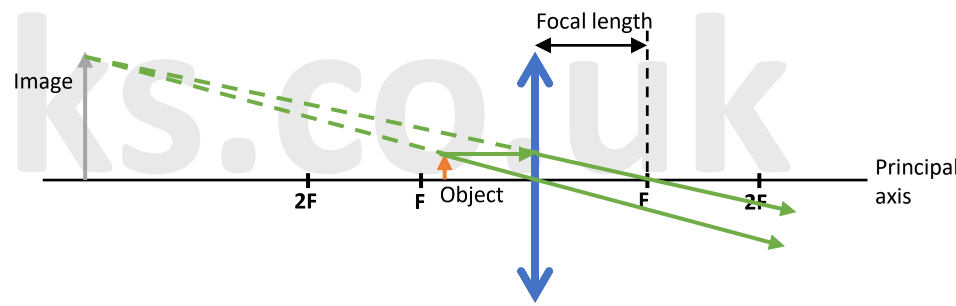
In a film or data projector, this image is formed on a screen. The image will be inverted, so to ensure that the projected image is the right way up, the film must be fed into the projector upside down.

Ray Diagrams (Convex Lenses)

Magnifying Glasses

A magnifying glass is a convex lens that magnifies an object to make it seem much larger than it is. This effect is achieved when the object is placed at a distance closer than the focal length. The resulting image is:

- Upright
- Magnified
- Virtual



The ray diagram above shows an object located at a distance less than one focal length from a convex lens.

The image produced by a magnifying glass can only be viewed by the person using it.

Since the image formed by a magnifying glass is virtual, it cannot be projected onto a screen.

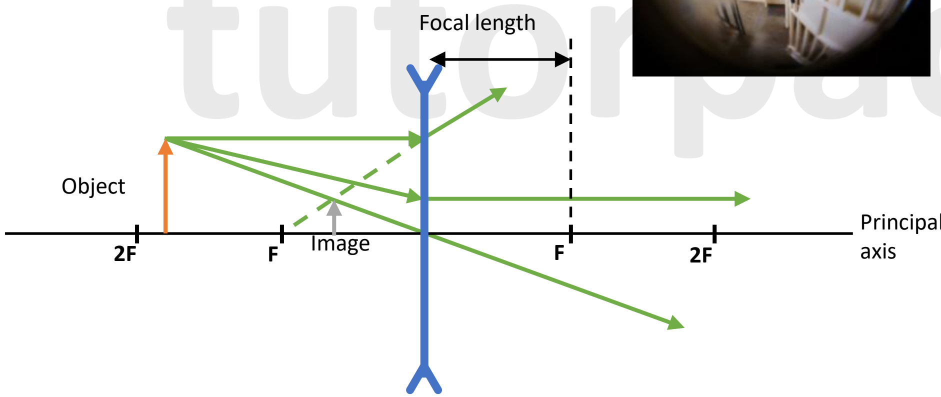
Ray Diagrams (Concave Lenses)

Images created by concave lenses are always:

- Upright
- Diminished
- Virtual

Peep hole lenses

Doors are fitted with peep holes so that the occupant may identify a visitor before opening the door.



The Ray diagram above shows an object viewed through a concave lens.

Ray Diagrams (Concave Lenses)

When an object is viewed through a concave lens, the light rays originating from the top of the object will bend and diverge upon passing through the lens. As a result, the rays will emerge from the same side of the principal axis, leading to the creation of an upright image.

A concave lens produces a virtual image that is always smaller than the object.

Image Calculations

There is an equation that links the focal length of a thin lens with the positions of the object and the image it forms. The lens formula is as follows:

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

Where:

u = object distance in m

v = image distance in m

f = focal length in m

As shown in the diagram below all the measurements made would be positive.

If a diverging lens is used, the focal length value will be negative.

If an image was formed on the same side of the lens as the real object, we say a virtual image is created and the value of v would be negative. Below is the typical lens formula measurement.

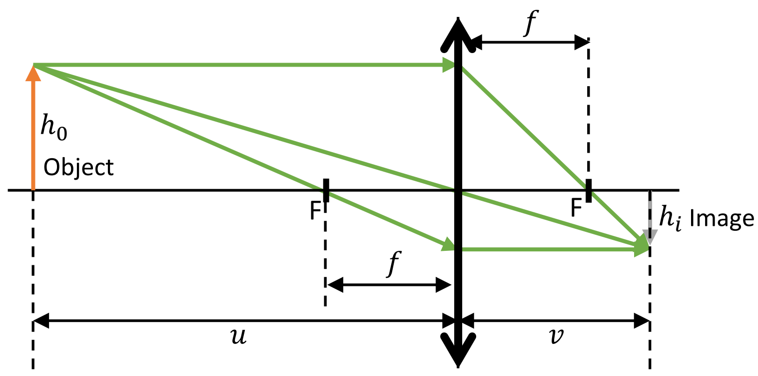


Image Calculations

This formula can also be used to calculate the power of a lens. We know that:

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

Therefore:

$$Power, P=\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$$

Magnification

Magnification is a measurement of how big an image is in comparison to the true size of the object. Magnified pictures can be created using lenses and curved mirrors.

The equation for calculating the magnification produced by a lens is:

$$magnification = \frac{image\ height}{object\ height}$$

Magnification has no units because it is a ratio between two lengths. However, the image height and object height should both be measured in the same units, such as centimetres (cm) or millimetres (mm), and not a combination of the two.

Example 1:

A 4cm tall object creates a 600cm tall image. Calculate the magnification.

$$magnification = \frac{image\ height}{object\ height} = \frac{600}{4}$$
$$\therefore magnification = 150\ (magnified)$$

Example 2:

A 1.65 m tall object creates a 1.65 cm tall image. Calculate the magnification.

First convert metres to centimetres: $1.65 \times 100 = 165\ cm$

$$magnification = \frac{image\ height}{object\ height} = \frac{1.65}{165}$$

$$\therefore magnification = 0.01\ (diminished)$$

Magnification

Magnification can also be calculated using the following formula:

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

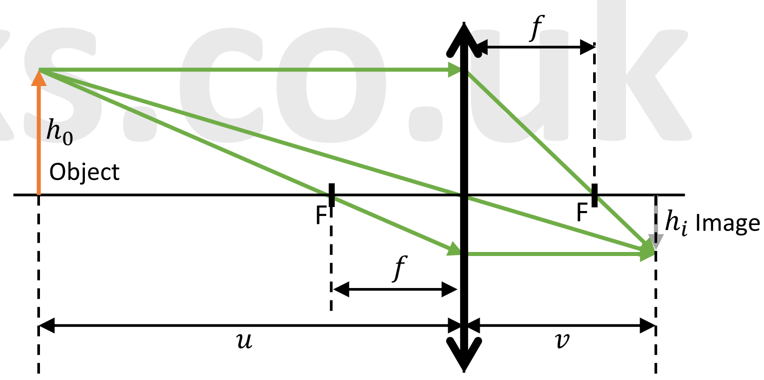
Where:

m = magnification

v = image distance in m

u = object distance in m

The formula above works because if we examine the diagram below we can see similar triangles (a GCSE maths concept):



Also using the diagram above we can get:

$$magnification = \frac{image\ height}{object\ height} = \frac{h_i}{h_o}$$

Please see ‘5.5.2 Optics worked examples’ pack for exam style questions.

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