Lenses

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Lenses

Types of Lenses

A **converging (convex) lens**

is thicker in the middle than at the edges. It brings parallel rays of light to a real focus (the **principal focus** F) on the other side of the lens.

A **diverging (concave) lens** is thinner in the middle than at the edges. It spreads parallel rays apart so that they appear to come from a virtual focus on the same side as the incoming light.

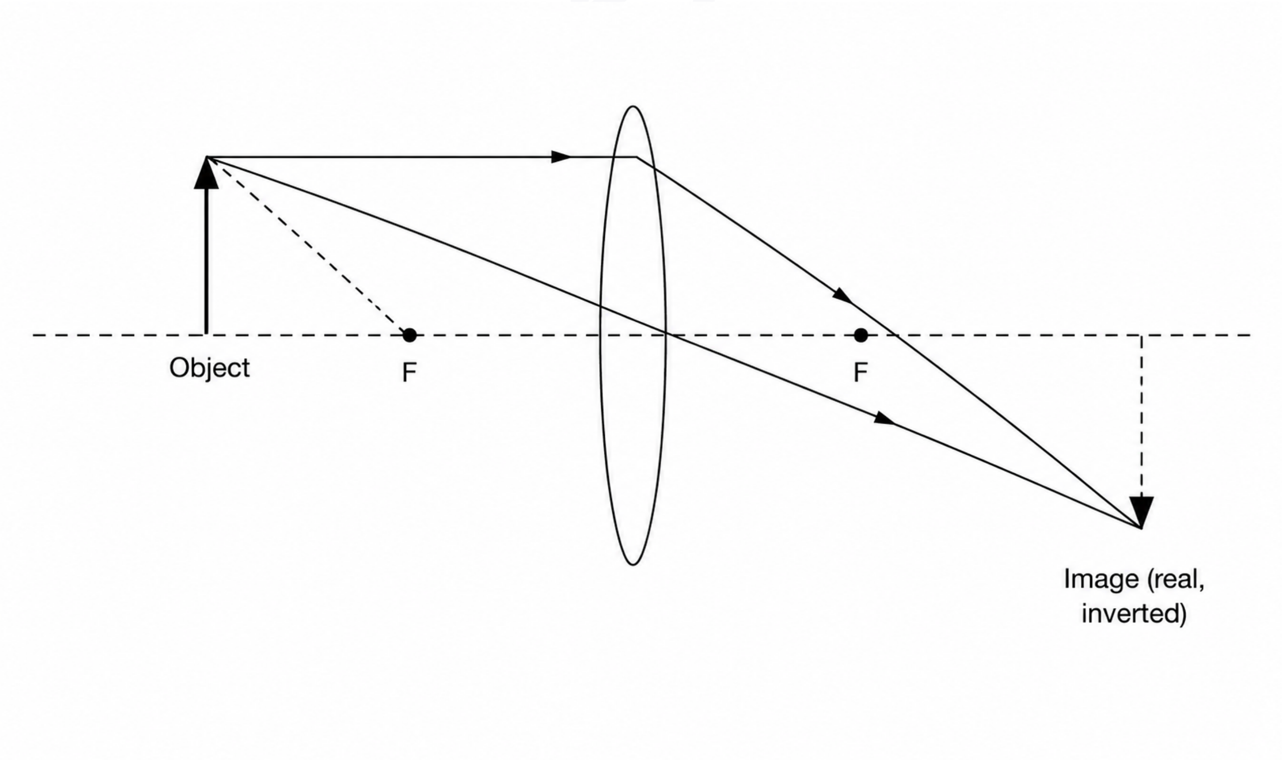

Diagram of a converging (convex) lens showing parallel rays entering from the left, refracting through the lens, and converging to the principal focus F on the right; the optical centre and principal axis are labelled, and the focal length f is marked as the distance from the optical centre to F

The **focal length** f is the distance from the optical centre of the lens to the principal focus.

Ray Diagrams

Three standard rays are used to locate an image:

- 1. A ray **parallel to the principal axis** , refracts through the principal focus F (converging) or appears to come from F (diverging).
- 2. A ray **through the optical centre**, passes straight through without bending.
- 3. A ray **through the near focal point** F (converging) or directed toward the far F (diverging), emerges parallel to the principal axis.

The image is where any two of these rays intersect (or appear to intersect, for virtual images).

Image Types

Object position	Image type	Image location	Characteristics
Beyond [Math: 2F]	Real	Between [Math: F] and [Math: 2F] (other side)	Inverted, diminished
At [Math: 2F]	Real	At [Math: 2F] (other side)	Inverted, same size
Between [Math: F] and [Math: 2F]	Real	Beyond [Math: 2F] (other side)	Inverted, magnified
At [Math: F]	No image	At infinity	(rays emerge parallel)
Inside [Math: F]	Virtual	Same side as object	Upright, magnified

A **real image** is formed where refracted rays actually converge, it can be projected onto a screen. A **virtual image** cannot be projected, the eye traces rays backward to an apparent intersection.

Summary of converging lens ray diagrams for all object positions: beyond 2F (inverted, diminished), at 2F (inverted, same size), between F and 2F (inverted, magnified), at F (parallel rays), and inside F (virtual, upright, magnified). Each row shows the ray diagram, image type, image distance, and a real-world application.

Magnification

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

where v is the image distance and u $m > 1$

is the object distance (both measured from the optical centre). For a real image, means magnified; $m < 1$ means diminished. A virtual image from a converging lens has $m > 1$ (magnifying glass).

The Lens Formula

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

Sign convention:

distances measured from the optical centre are positive on the side to which light is refracted (the other side from the object for a real image). A virtual image gives a negative v.

Converging lens image distance and magnification (2022 Paper 02, Q3)

An object is placed 15 cm in front of a converging lens of focal length 10 cm.

Image distance:

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

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

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{15}$$

$$\frac{1}{v} = \frac{3}{30} - \frac{2}{30}$$

$$\frac{1}{v} = \frac{1}{30}$$

$$v = 30\,\text{cm}$$

The image is 30 cm from the lens on the other side.

Magnification:

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

$$m = \frac{30}{15}$$

$$m = 2$$

Nature: real, inverted, and magnified (twice the object height). The image is on the opposite side of the lens from the object.

Converging lens with object inside F (magnifying glass) (2015 Paper 02, Q6)

An object AB is placed 20 cm from a converging lens of focal length 10 cm.

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{20}$$

$$\frac{1}{v} = \frac{2}{20} - \frac{1}{20}$$

$$\frac{1}{v} = \frac{1}{20}$$

$$v = 20\,\text{cm}$$

The image is real, at the same distance as the object.

$$m = \frac{20}{20}$$

$$m = 1$$

The image is real, inverted, and the same size as the object (object at $2F$).

Applications of Lenses

Application	Lens type	Use
Magnifying glass	Converging	Object inside [Math: F], produces upright, magnified virtual image
Camera	Converging	Object beyond [Math: 2F], produces real, inverted, diminished image on sensor
Projector	Converging	Object between [Math: F] and [Math: 2F], produces real, inverted, magnified image on screen
Spectacles (long-sight)	Converging	Converges light before it enters the eye to focus on the retina
Spectacles (short-sight)	Diverging	Diverges light before the eye so the eye can focus it
Microscope	Two converging lenses	Objective lens forms a magnified real image; eyepiece magnifies it further

📝 **Exam Tip**

Use $1/f = 1/u + 1/v$ consistently. A common error is adding $1/u + 1/v$ when you should subtract: rearrange carefully.

When describing the nature of an image, always state four things: real or virtual, upright or inverted, magnified or diminished (or same size), and on which side of the lens it lies.