

LENSES

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Types of Lenses

(The word lens is derived from the Latin word *lenticula*, which means lentil. A lens is in the shape of a lentil.)

Most lenses are made of transparent glass or very hard plastic.

A lens is a curved transparent material that is smooth and regularly shaped so that when light strikes it, the light refracts in a controlled path.

There are many possible shapes for lenses.

However, we will be considered with only two basic shapes of lenses.

The first is a **converging lens**, (sometimes called **convex lens**), a lens that is thickest in the middle than at the centre; and that causes incident parallel light rays to converge through a single point, (the **focus**), after refraction.

(Converging : refers to when parallel light rays exiting a lens travel towards each other.)

A converging lens brings parallel light rays together through a focus after refraction.

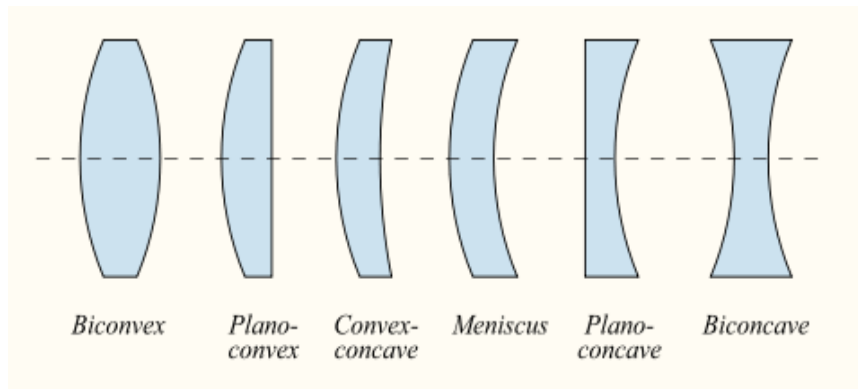
The second kind of lens causes incident parallel light rays to spread away from a common point, (virtual focus), or to diverge, thus called a **diverging lens**, sometimes called a **concave lens**.

A diverging lens is thinnest in the middle and thickest at the edge.

A diverging lens spreads parallel light rays apart after refraction so that it looks as if they have come from a virtual focus.

(Diverging refers to when parallel light rays exiting a lens travel away from each other.)

Diagram: Lenses can be grouped into two types , converging and diverging, depending on how they refract the light that enters them.



LENS TERMINOLOGY

In a lens, light is refracted at the first air to glass surface. Light then travels through the glass of the lens and is refracted again at the glass to air surface on the other side.

This means that there are always two refractions in a lens.

However, we will be concerned with the simpler version of the incident ray entering the lens, refraction occurring at the centre of the lens and the refracted ray leaving the lens.

The following terminology applies to both converging and diverging lenses.

Optical centre, O:	the geometric centre of the lens.
Axis of symmetry:	is an imaginary vertical line drawn through the optical centre of a lens.
principal axis, PA:	a line drawn through the optical centre of the lens, perpendicular to both surfaces.
Principal focus, F, F':	the point on the principal axis where rays parallel to the principal axis converge (refract). Light can strike the lens from either side, hence both sides of the lens can focus parallel rays. The focal point where the light either comes to a focus or appears to diverge from a focus is given the symbol F , while that on the opposite side is represented by F' . The principal focus of a <i>converging lens</i> is on the <i>opposite side</i> of the lens as the incident rays. The principal focus of a <i>diverging lens</i> is on the <i>same side</i> of the lens as the incident rays.
Focal length, f:	is the distance from the axis of symmetry to the principal focus measured along the principal axis. Since light behaves the same way travelling in either direction through a lens, both types of thin lenses have two equal focal lengths.
Focal plane:	the plane perpendicular to the principal axis on which the focal points lie.

CHARACTERISTICS OF IMAGES IN CONVERGING AND DIVERGING LENSES, (SALT)

There are four *characteristics* of an image, i.e. the kind of image, where it will be and what the image will look like. (Recall: Plane Mirrors)

An image can be described by four characteristics:

size, (i.e. magnification), attitude, (i.e. upright or inverted), location (i.e. position), type (i.e. kind).

Size (or Magnification):	of the image compared to the object may be the same size, enlarged or diminished. The height of the object, h_0 , in relation to the height of the image, h_i ($M = h_i / h_0$)
Attitude (or upright or inverted):	of image may be erect, (upright) or inverted compared to the object.

Location (or Position): of an image created by a plane mirror is measured with reference to the reflecting surface (i.e. closer than, further than, or the same distance as the object to the plane mirror).
Distance between the object and the lens, d_o , and the distance between the image and the lens, d_i .

Type of Image (or Kind): describes whether the image is real or virtual. A real image is one that can be seen on a screen : light rays converge to a point..
A *virtual image*, (i.e. the image is imaginary because you only imagine that an image forms at this location), can not be caught on a screen, but can be seen by the eye, and can be photographed, (consider your image in a mirror).
[A *virtual image* is any image formed by rays that do not come from the location of the image.]

[use the acronym **SALT**: to remember the four characteristics of an image.
Size, Attitude, Location, Type]

DRAWING RAY DIAGRAMS FOR CONVERGING AND DIVERGING LENSES

Using ray diagrams, the size, attitude, location, and the type of image that appears through a lens may be determined.

As with mirrors, once the principal focus, (a.k.a.: focal point), has been located, three key rays passing through the lens, close to the principal axis are chosen, to locate the image:

Ray 1: starts at the top of the object, (usually a solid, erect arrow), travels parallel to the principal axis and on emerging from the lens after refraction , either passes through the principal focus F of the converging lens, or appears to come from the principal focus F of a diverging lens.

Ray 2: starts at the top of the object and passes through the optical centre, O, of the lens. Because the sides are essentially parallel, the emerging ray is parallel to the incident ray.

The centre of the lens acts like a flat piece of glass, so rays leave in the same direction that they entered.

(In reality the emerging ray is slightly laterally displaced, i.e. the ray would shift to the right, not really noticeable for a thin lens.)

Ray 3: goes from the top of the object, through the principal focus F' , on the near side of the converging lens, or aims towards F' on the far side of the diverging lens. Any ray that enters the lens from the principal focus leaves the lens after refraction, parallel to the principal axis.

The place where the rays intersect, or appear to do so after refraction, gives the location of the image; the top of the image is at the point where the three rays meet. The bottom of the image is on the principal axis.

Usually, any two of these rays are drawn from the tip of the object; the third ray serves as a check. Real rays are drawn as solid lines and virtual rays as dotted lines.

See diagram below how this is done for a converging and a diverging lens.

A real ray can be caught on a screen since it is formed where real rays intersect. A real image is drawn as a solid arrow.

A virtual image can not be caught on a screen since it is formed by the intersection of one or more virtual rays. However, a virtual image can be seen by looking into the lens. A virtual image is always shown as a dotted arrow.

Diagram: Passage of key rays through a Converging Lens

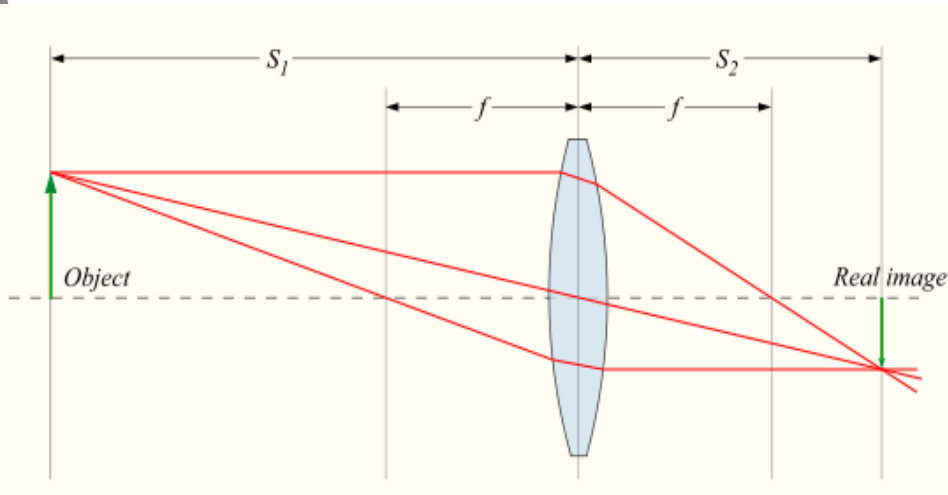
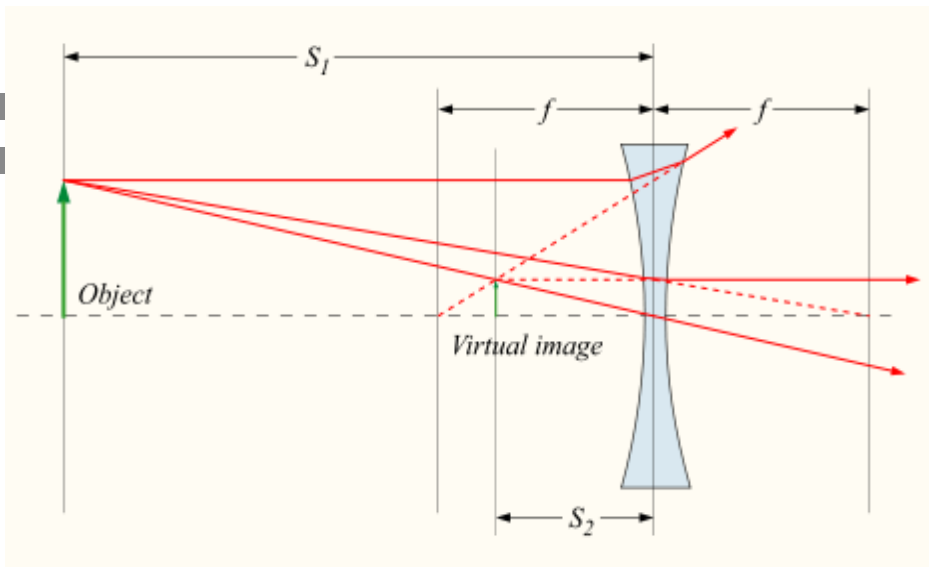


Diagram: Passage of key rays through a Diverging Lens



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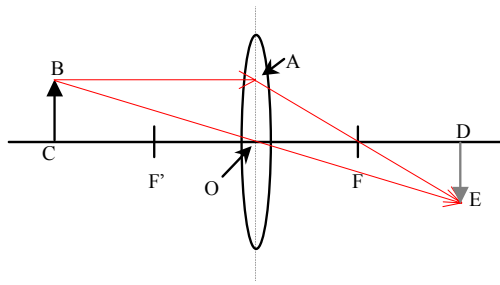
IMAGES FROM A CONVERGING LENS

Draw the following 5 Cases ray diagrams with the object in different positions relative to the lens and the focal point in order to determine the characteristics of the image formed the converging lens.

Case1: The object is a distant object: further than the principal focus: $2F'$

Case 2: The object is at $2F'$

(note: $2F$ relates to C in mirrors)



Case 3: The object is between $2F'$ and F'

Case 4: The object is at F'

Case 5: The object is between F' and Lens

Conclusions of Image Characteristics for a Converging Lens

OBJECT Location	Size of image	Attitude of Image	Location of Image	Type of Image
beyond $2F$	diminished, smaller	inverted	somewhere between F and $2F$	real
at $2F$	unchanged, same size	inverted	at $2F$	real
between $2F$ and F	enlarged, larger	inverted	outside $2F$	real
at F	no image, undefined			
between F and Lens	enlarged	erect	same side as object, behind the object	virtual

As the object distance decreases, and the object moves closer to the principal focus F , the real inverted image increases in size and moves outward from the principal focus F . Light is actually arriving at the image location, and the image may be viewed on a paper screen.

A camera uses a converging lens in this way to create diminished images of an object.

When the object distance is $2F$ from the lens, the image distance is also $2F$ on the other side of the lens. The inverted, real image of the object when it is at $2F$ is the same size as the object. Photocopiers that make identical copies place the object at this position.

When the object is between F and $2F$ from the lens, the inverted image is real and enlarged. A photocopier that makes enlargements uses this placement, as well as photograph enlargers, slide projectors, and movie projectors. (A slide must be inverted in the projector to obtain an erect image on the screen.)

When the object is at the principal focus, F , no image is formed because the refracted rays leaving the lens are parallel and never intersect, i.e. the image is undefined.

An intense light source at the principal focus of a searchlight produces the parallel beam we sometimes see sweeping the sky at an airport.

When the object is closer to the lens than F , the image is erect, larger than the object and virtual. The image appears to be behind the lens because the refracted rays leaving the lens appear to diverge from a point.

A magnifying glass and a reading glass uses this property of a converging lens.

Drawing a Diverging Lens Ray diagram

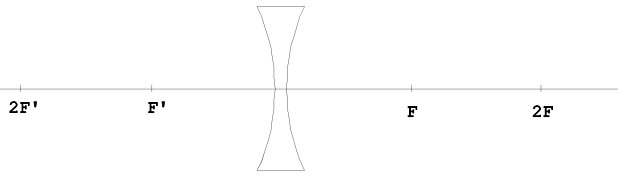
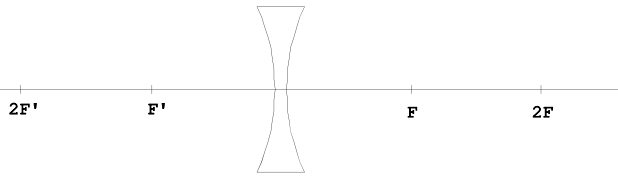
See Above: two rays are used to predict image location:

1. The first ray of a diverging lens ray diagram travels from the tip of the object parallel to the principal axis. When the refracted ray emerges from the lens, it appears to come from the principal focus.
2. The second ray travels from the tip of the object through the optical centre of the lens, and is not refracted.

The virtual image is drawn where the rays appear to intersect.

Complete the following ray diagrams for a Diverging Lens

Image formed by a Diverging Lens



IMAGES FORMED BY A DIVERGING LENS

A diverging lens always produces the same image characteristics no matter where the object is located.

As parallel light rays pass through a diverging lens, they are refracted away from the axis of symmetry of the lens, hence the light rays diverge and they will never meet on the other side of the lens.

Thus, the image formed is always smaller than the object, upright, virtual and on the same side of the lens as the object. (Note: similar to diverging, (convex) mirrors.)

As the object moves farther from the lens, the image becomes smaller.

A tiny diverging lens, fitted into a door is used as a security viewer to allow a person inside to observe who is outside.