Convex and Concave Lenses

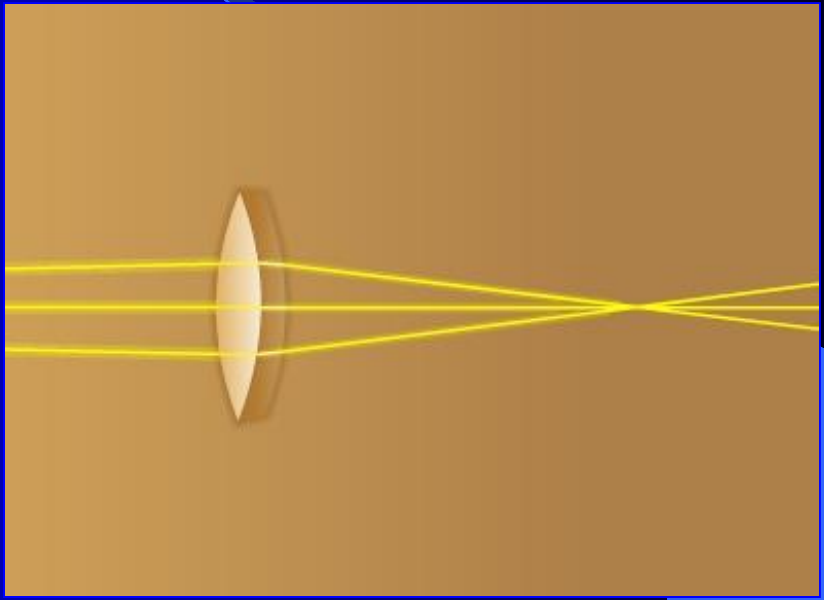
Types of Lenses

- A **lens** is a piece of transparent material, such as glass or plastic, that is used to focus light and form an image.
- Each of a lens's two faces might be either curved or flat.

Convex and Concave Lenses

Types of Lenses

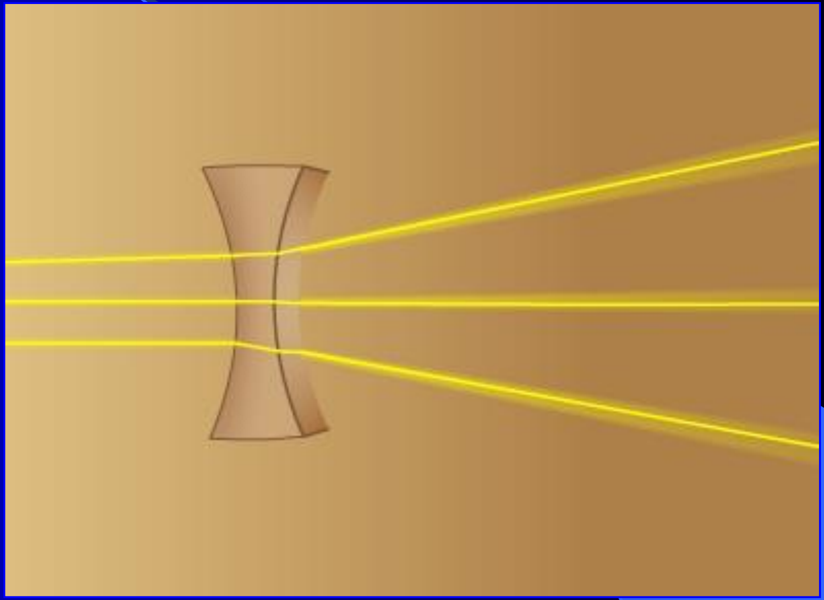
- The lens shown in the figure is called a **convex lens** because it is thicker at the center than at the edges.
- A convex lens often is called a converging lens because when surrounded by material with a lower index of refraction, it refracts parallel light rays so that the rays meet at a point.



Convex and Concave Lenses

Types of Lenses

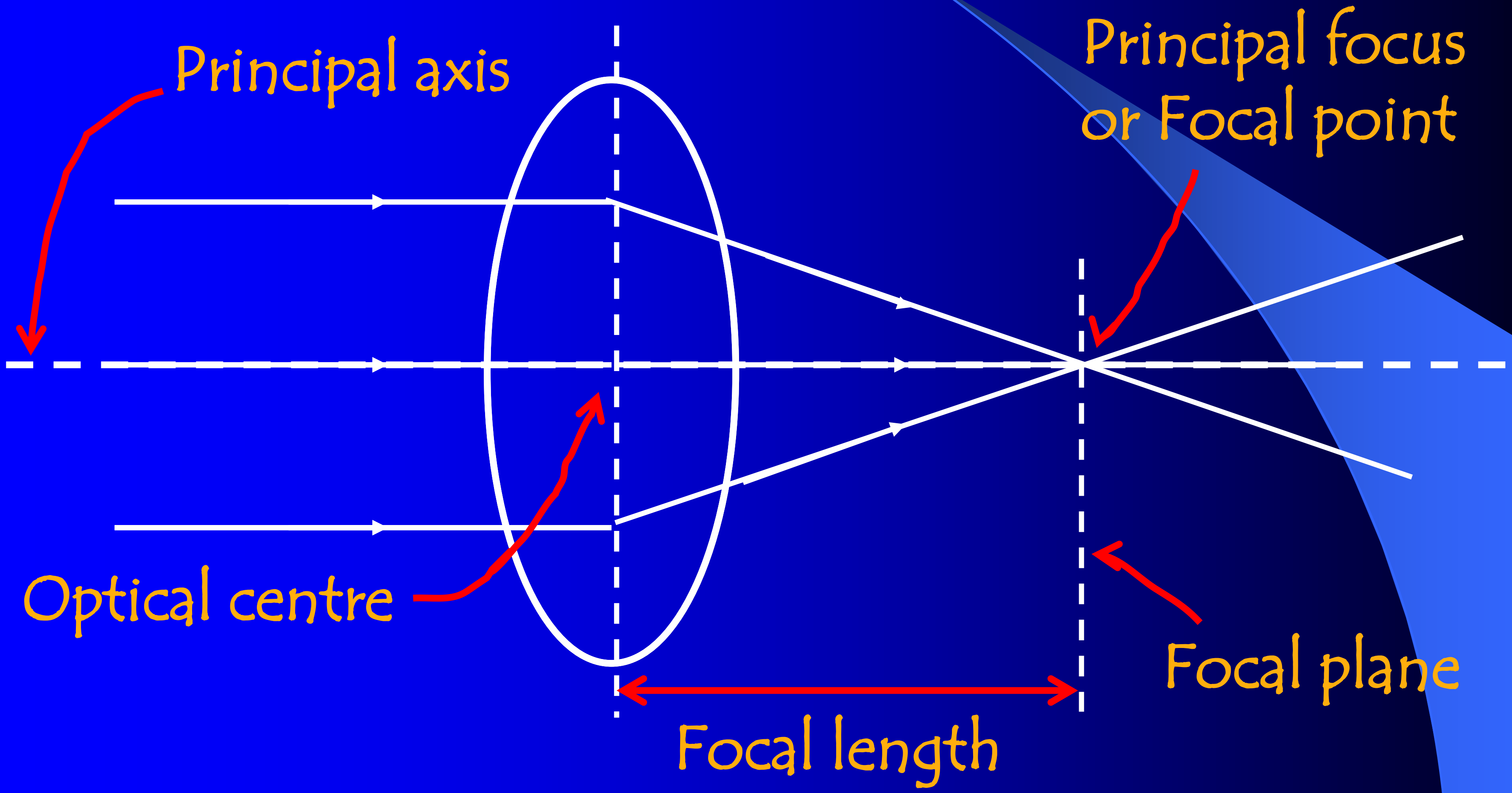
- The lens shown in the figure is called a **concave lens** because it is thinner in the middle than at the edges.
- A concave lens often is called a diverging lens because when surrounded by material with a lower index of refraction, rays passing through it spread out.



Ray diagrams for lenses

- Ray diagrams are drawings of the different situations for lenses.
- For the ray diagrams, assume that the lenses are thin.

Converging Lenses



Principal axis

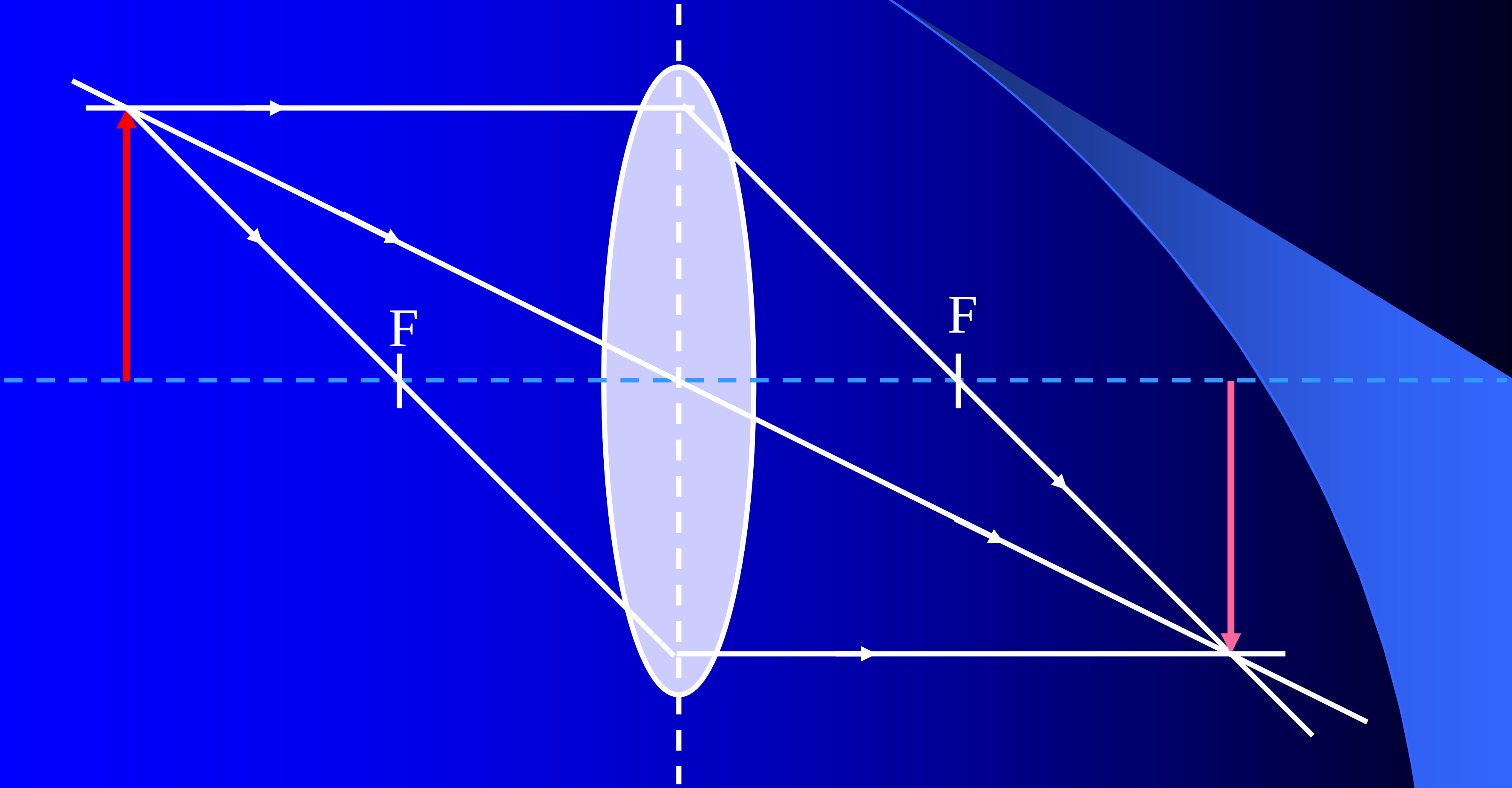
Principal focus or Focal point

Optical centre

Focal plane

Focal length

Ray Diagrams



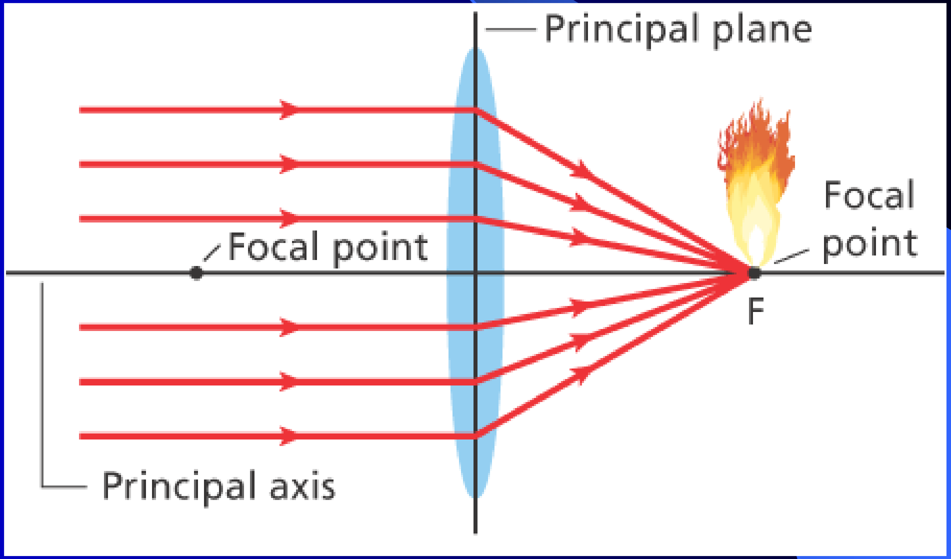
Convex and Concave Lenses

Convex Lenses and Real Images

- Paper can be ignited by producing a real image of the Sun on the paper.
- The rays of the Sun are almost exactly parallel when they reach Earth.

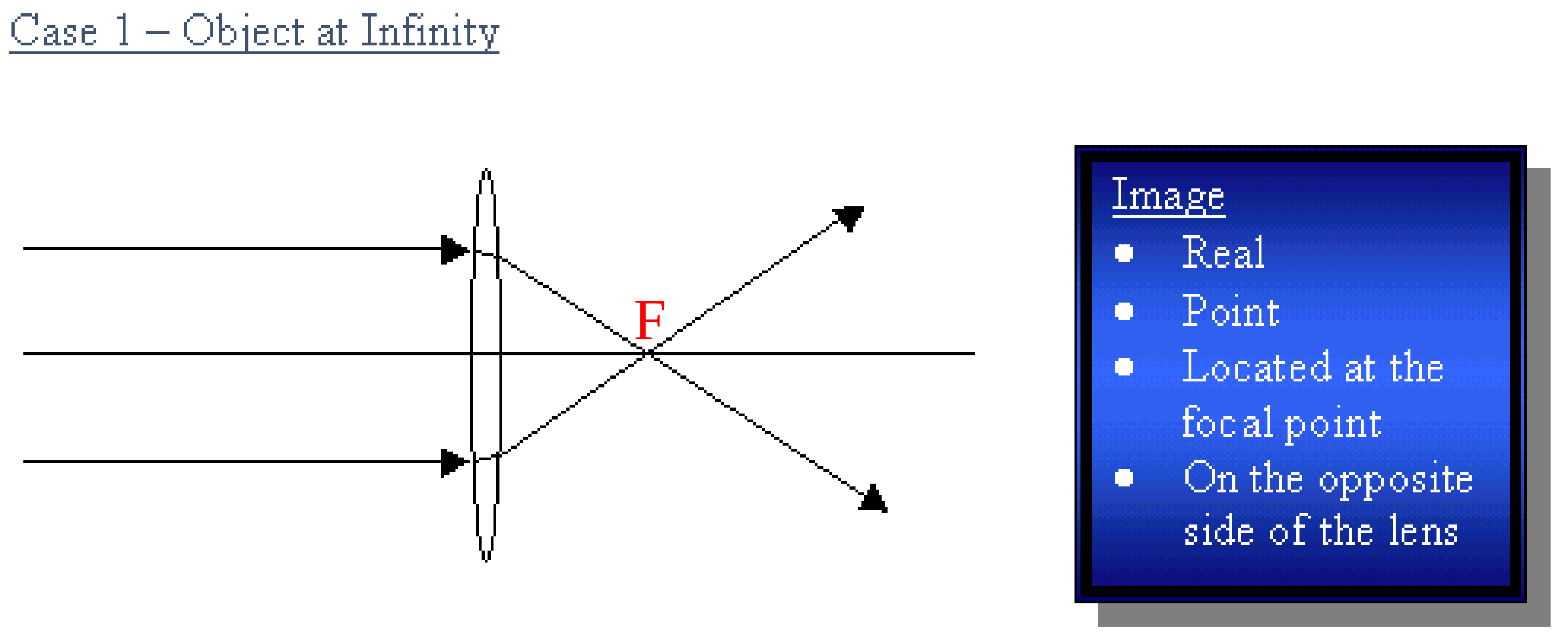
Convex Lenses and Real Images

- After being refracted by the lens, the rays converge at the focal point, *F*, of the lens.
- The figure shows two focal points, one on each side of the lens.
- You could turn the lens around, and it will work the same.



Ray diagrams for a double convex lens

- Object is at infinity

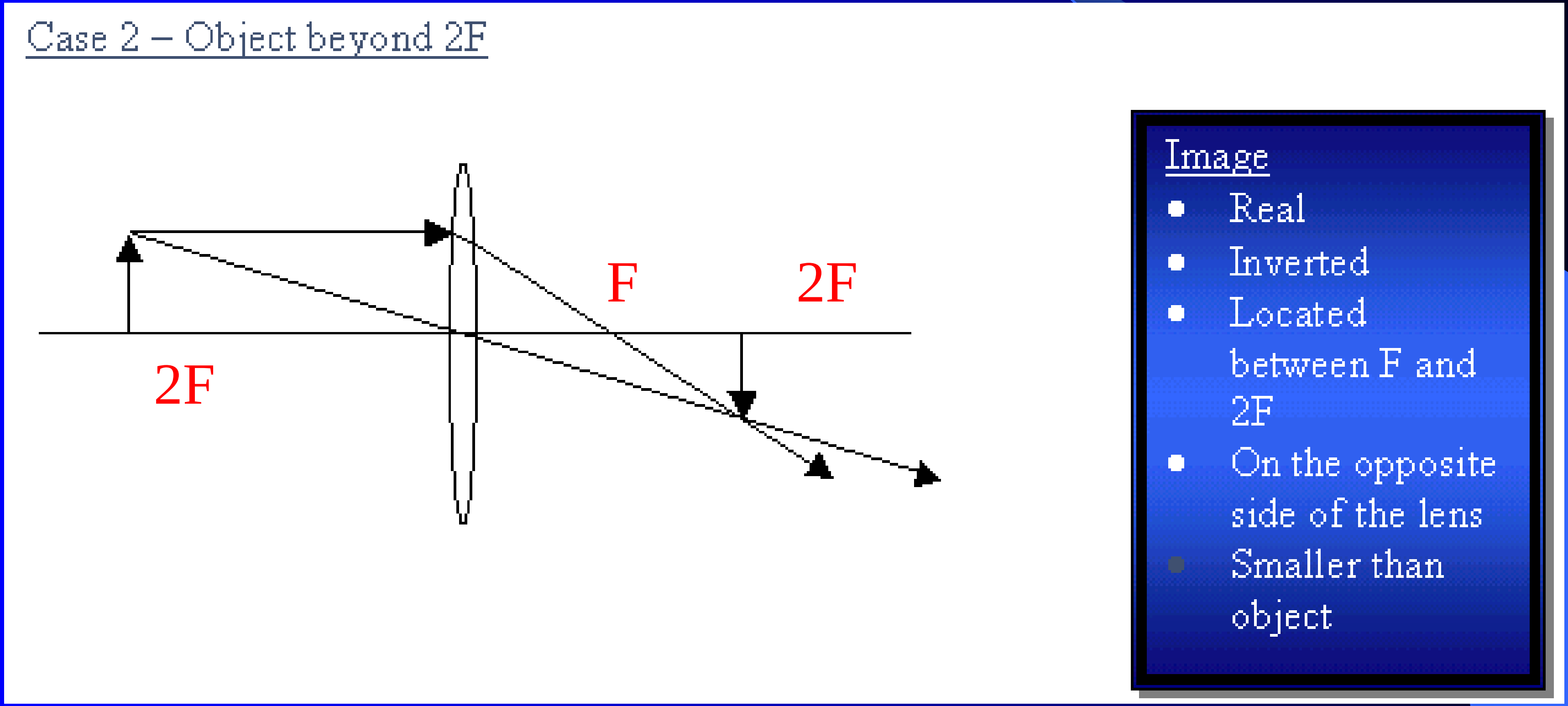


Case 1 – Object at Infinity

Image

- Real
- Point
- Located at the focal point
- On the opposite side of the lens

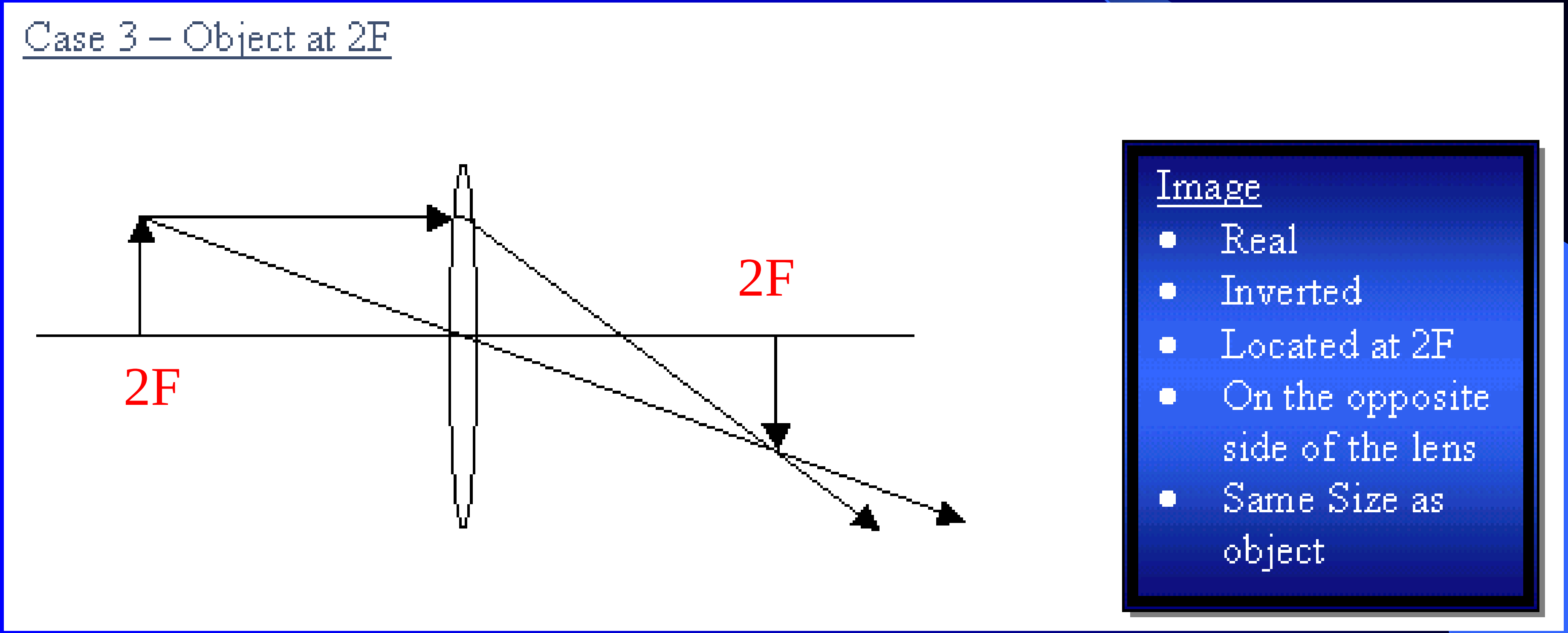
Object beyond 2F



Case 2 – Object beyond 2F

Image
- Real
- Inverted
- Located between F and 2F
- On the opposite side of the lens
- Smaller than object

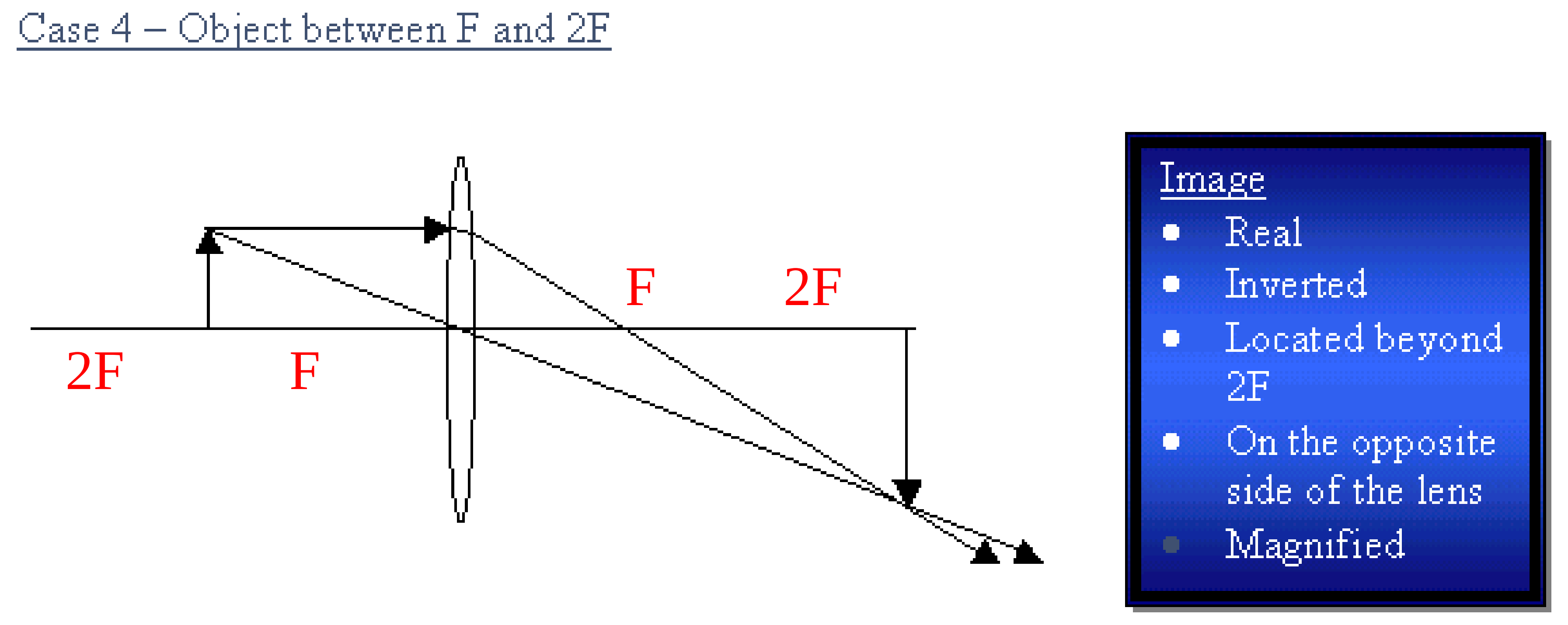
Object at 2F



Case 3 – Object at 2F

Image
- Real
- Inverted
- Located at 2F
- On the opposite side of the lens
- Same Size as object

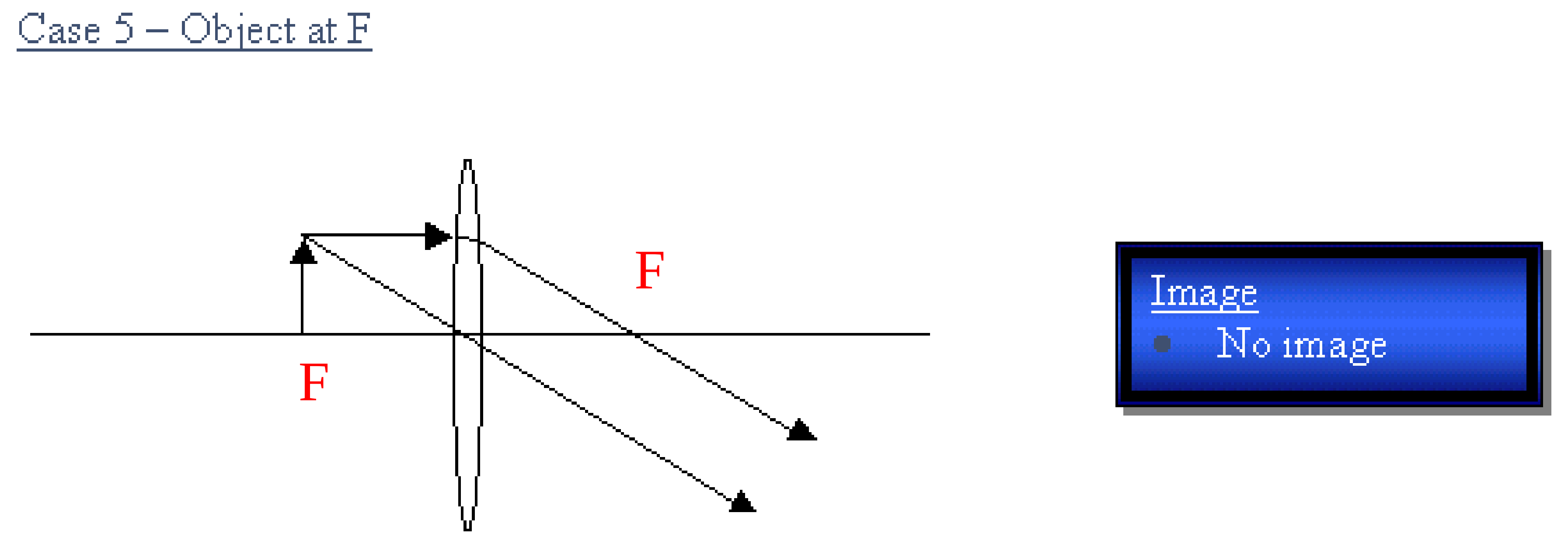
Object between F and 2F



Case 4 – Object between F and 2F

Image
- Real
- Inverted
- Located beyond 2F
- On the opposite side of the lens
- Magnified

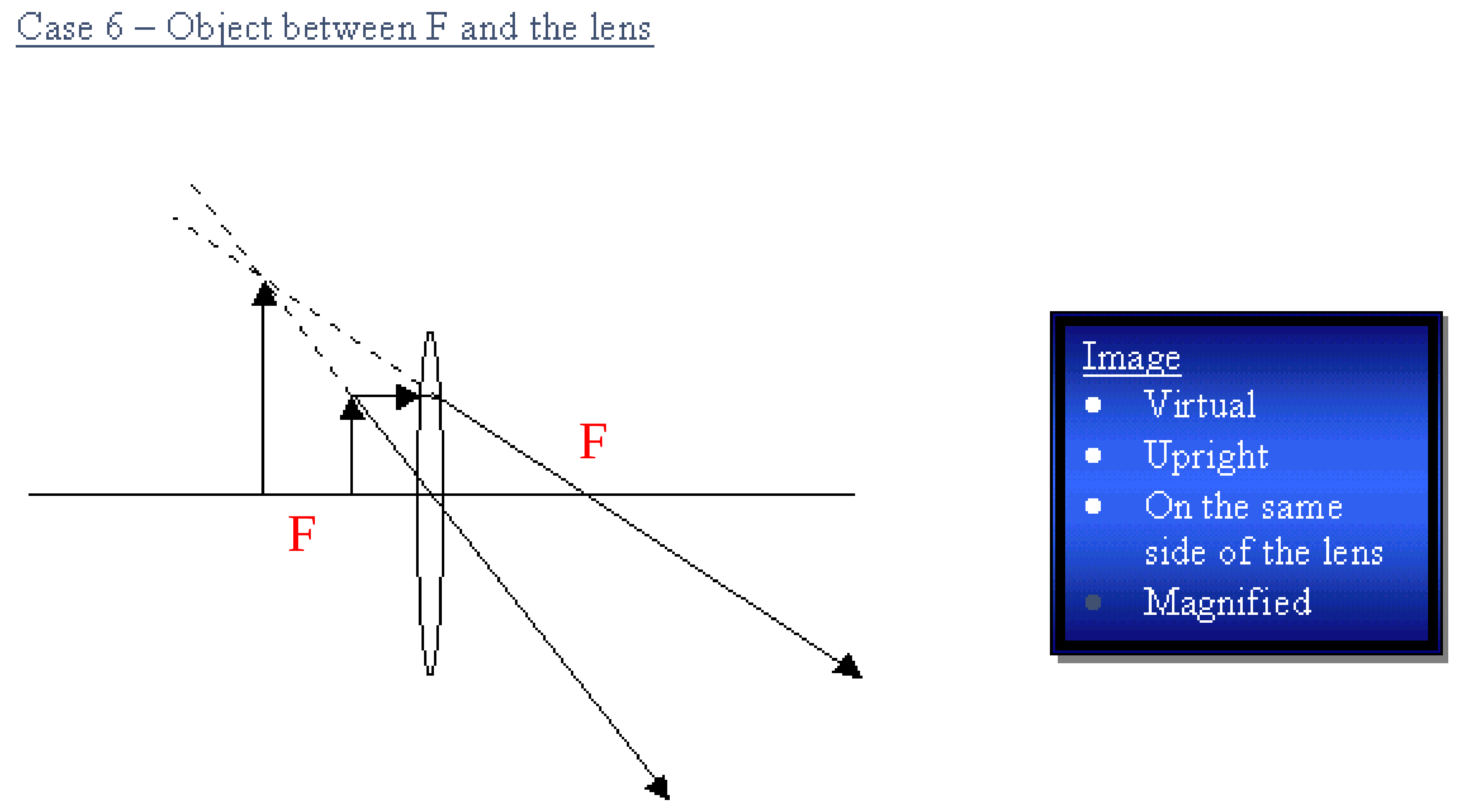
Object at F


Case 5 – Object at F

Image

- No image

Object between F and the lens



Case 6 – Object between F and the lens

Image
- Virtual
- Upright
- On the same side of the lens
- Magnified

Images Formed by Lens

Object distance	Type of image	Uses
$u = \infty$	Inverted, smaller, real	Telescope
$u > 2f$	Inverted, smaller, real	Camera, eye
$u = 2f$	Inverted, same size, real	Photocopier
$f < u < 2f$	Inverted, magnified, real	Projector
$u = f$	upright, magnified, real	Spotlight
$u < f$	upright, magnified, virtual	Magnifying glass

Lens Equations

- The **thin lens equation** relates the focal length of a spherical thin lens to the object position and the image position.

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

- The inverse of the focal length of a spherical lens is equal to the sum of the inverses of the image position and the object position.

Thin Lens Equation

The thin lens equation is stated as follows:

where

d_o is the distance (measured along the axis) from the object to the center of the lens

d_i is the distance (measured along the axis) from the image to the center of the lens

f is the focal length of the lens

The expression 1/f is called the power of a lens. It is measured in Diopters, where 1 D = 1 m^{-1}.

Lens Equations

- The magnification equation for spherical mirrors also can be used for spherical thin lenses.

- It is used to determine the height and orientation of the image formed by a spherical thin lens.

$$m \equiv \frac{h_\mathrm{i}}{h_\mathrm{o}} = \frac{-d_\mathrm{i}}{d_\mathrm{o}}$$

- The magnification of an object by a spherical lens, defined as the image height divided by the object height, is equal to the negative of the image position divided by the object position.

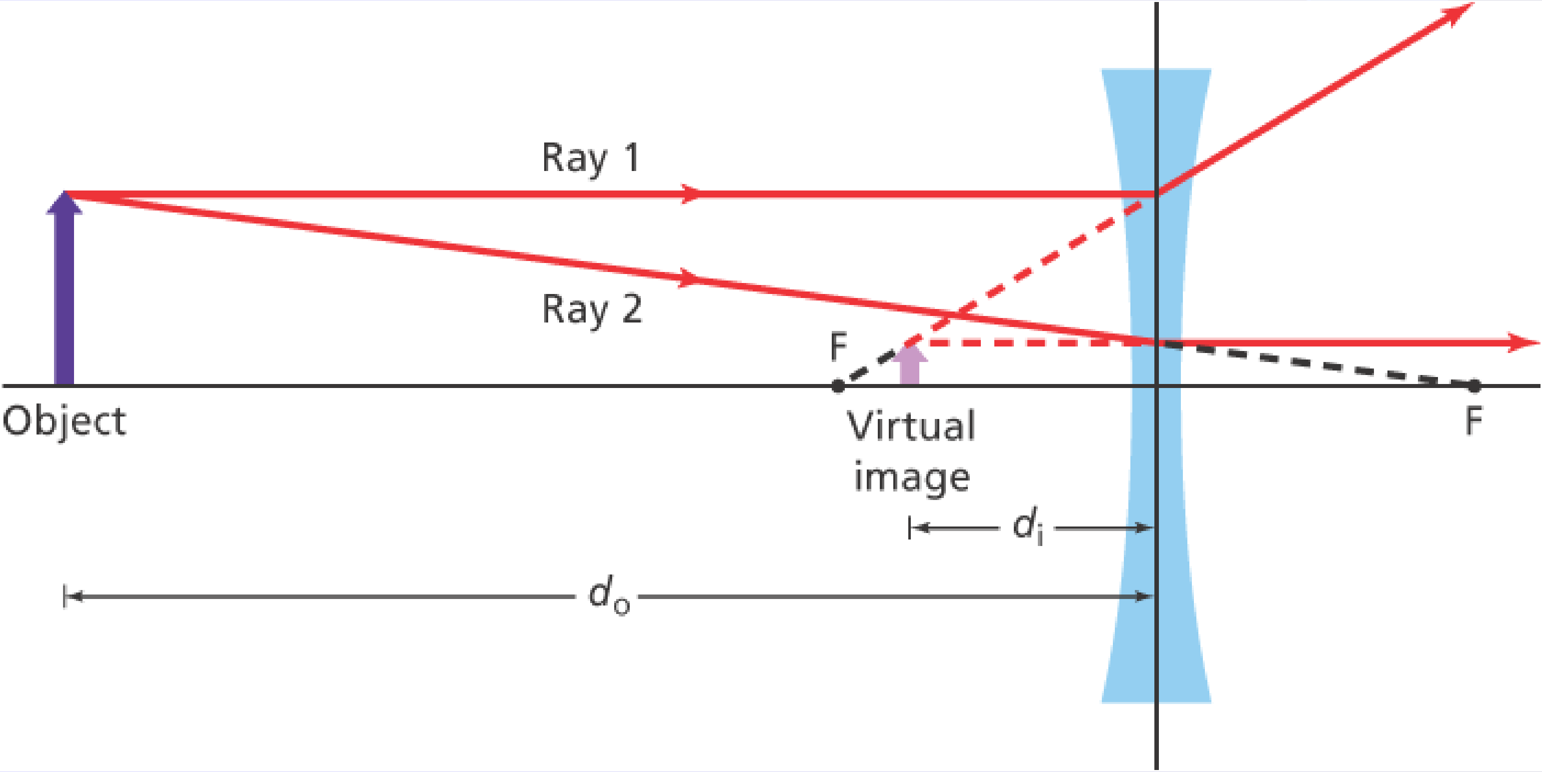
- **d_o** is always positive with a single lens
  d_i is positive for real images, negative for virtual images
  f is positive for converging lenses, negative for diverging lenses

When using this equation, signs are very important: Remember that d_o, d_i, and f must be measured in the same unit - usually meters is preferred.

d_o	positive	when the object is placed "in front of the lens"
d_i	positive	when real images are formed (inverted, "behind the lens")
d_i	negative	when virtual images are formed (upright, "in front of the lens")
f	positive	when the lens is converging
f	negative	when the lens is diverging

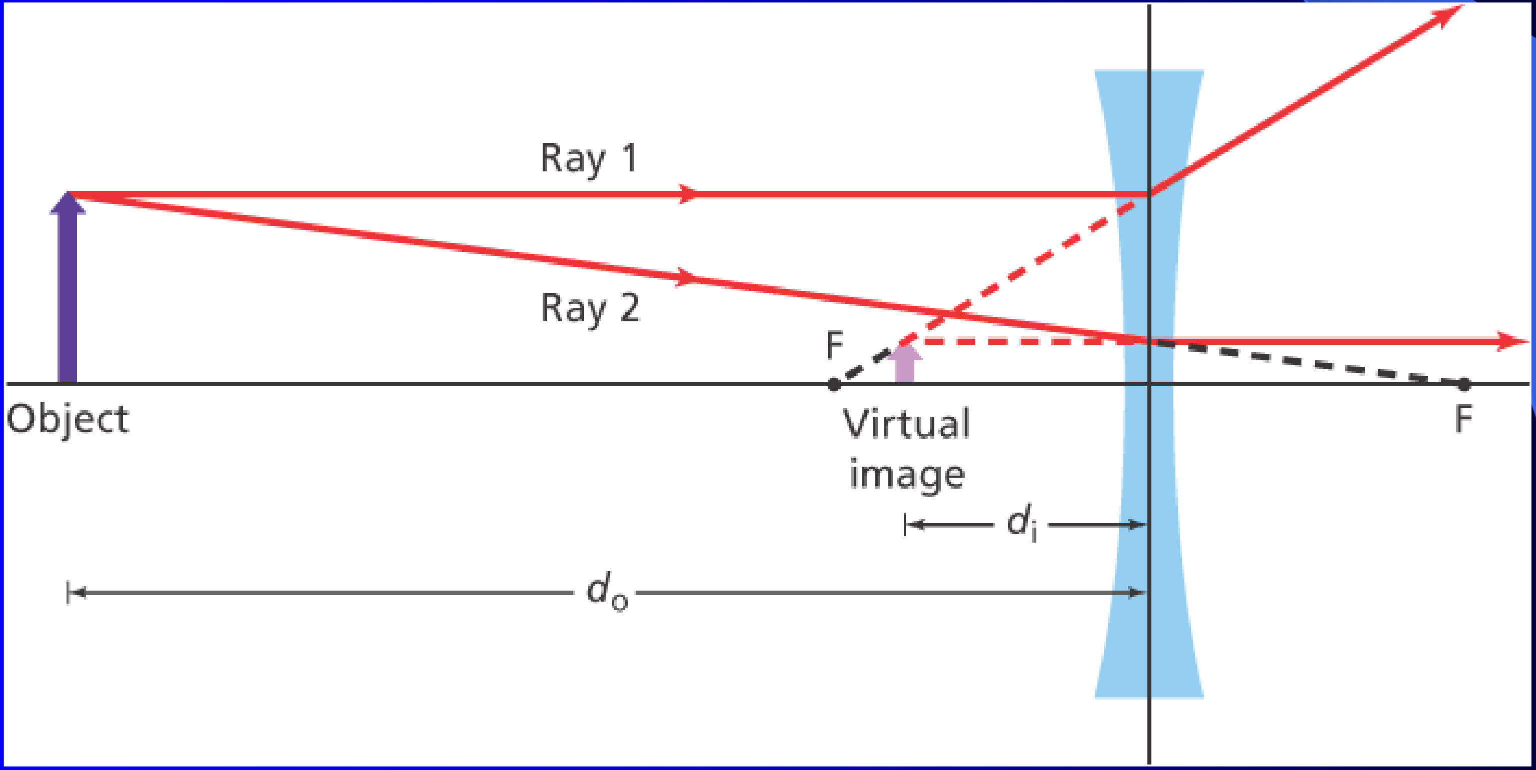
Concave Lenses

- A concave lens causes all rays to diverge.
- The figure shows how such a lens forms a virtual image.



Concave Lenses

- The image is located at the point from where the two rays apparently diverge.
- The image also is upright and smaller compared to the object.

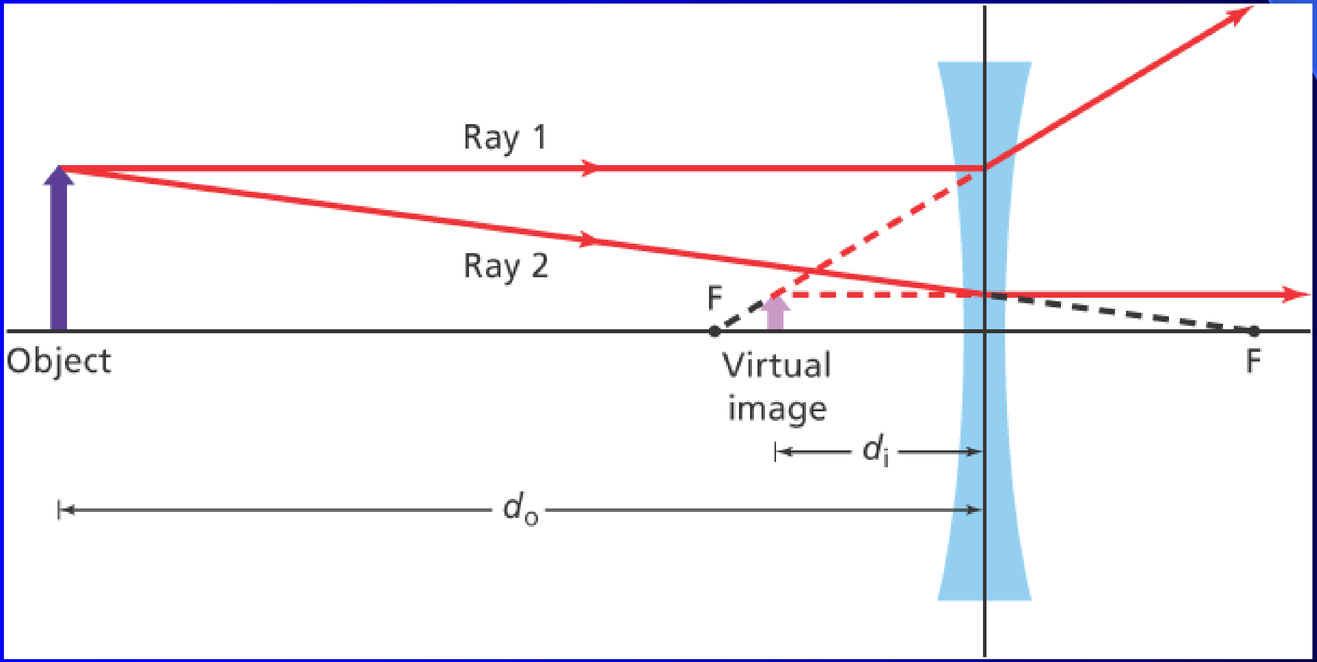


Convex and Concave Lenses

Concave Lenses

- Ray 1 approaches the lens parallel to the principal axis, and leaves the lens along a line that extends back through the focal point.

- Ray 2 approaches the lens as if it is going to pass through the focal point on the opposite side, and leaves the lens parallel to the principal axis.



Concave Lenses

- The sight lines of rays 1 and 2 intersect on the same side of the lens as the object.
- Because the rays diverge, they produce a virtual image.