

Warm-Up | Lenses

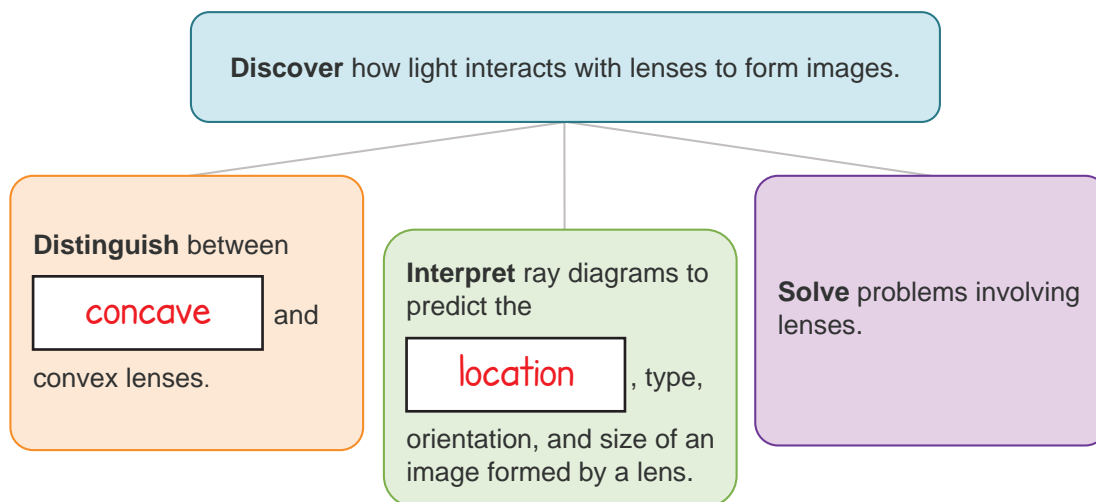


Lesson Question

How does light interact with lenses to form images?



Lesson Goals



Words to Know

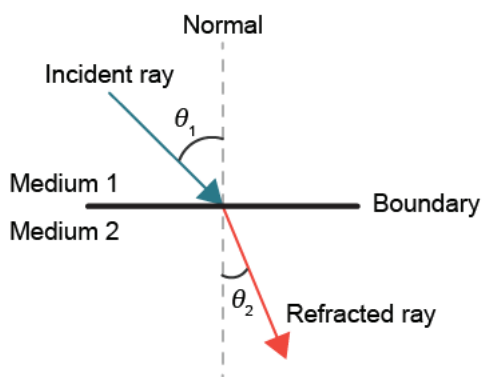
Fill in this table as you work through the lesson. You may also use the glossary to help you.

diverging lens	a lens that is thinnest in the middle and works by causing light rays to bend away from the principal axis
converging lens	a lens that is thickest in the middle and works by causing light rays to bend toward the principal axis
magnification equation	the equation that relates the ratio of the image distance and object distance to the ratio of the image height and object height
lens equation	the equation that states the relationship between the object distance, image distance, and focal length of a lens

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**Refraction**

- Refraction is the bending of a wave as it passes through the boundary between two **media**.
- The refracted ray passes through the **boundary** into the second medium.
- The direction of the refracted ray is determined using Snell's law.
 - $n_i \sin \theta_i = n_r \sin \theta_r$



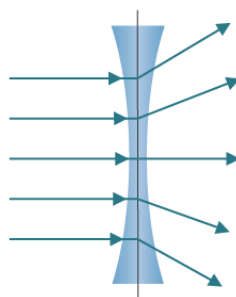
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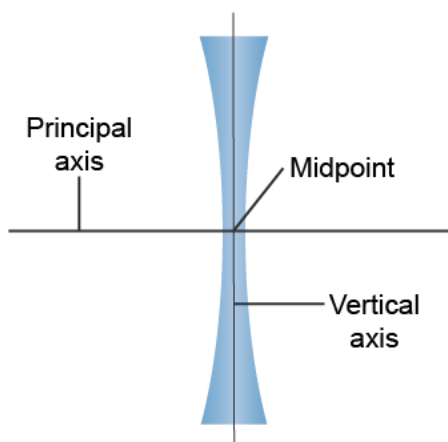
Concave Lenses

- A concave lens, or **diverging lens**, is thinnest in the middle and causes light rays to bend **away** from the principal axis.



Features of a Concave Lens

- The principal axis is the horizontal line that runs through the center of curvature, dividing the lens **symmetrically**.
- The vertical axis is the vertical line that divides the lens symmetrically.
- The midpoint of lens is the point where the **principal** and vertical axes meet.



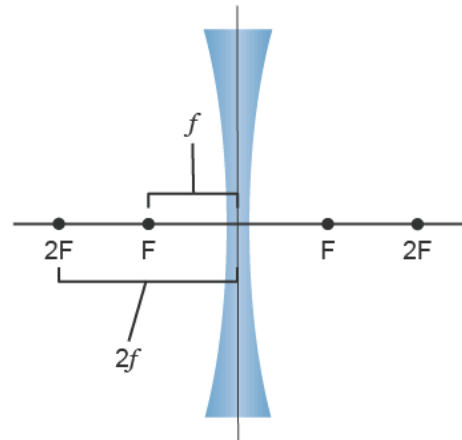
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Features of a Concave Lens

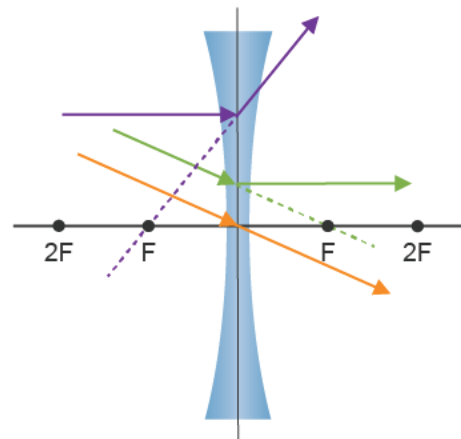
- F (focal point) is the point on the principal axis where **refracted** light converges or appears to diverge.
- f (focal length) is the distance between the focal point and the midpoint of the lens.
- $2F$ is the point on the principal axis that is the **center of curvature** and equal to two times the focal length.



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Rule of Thumb for Concave Lenses

- Incident rays that travel parallel to the principal axis refract and then travel as though they have passed through the **focal point** in front of the lens.
- Incident rays that travel as though they are moving toward the focal point behind the lens refract and then travel **parallel** to the principal axis.
- Incident rays that travel through the center of the lens continue to move in a straight line without **bending** after striking the principal axis.



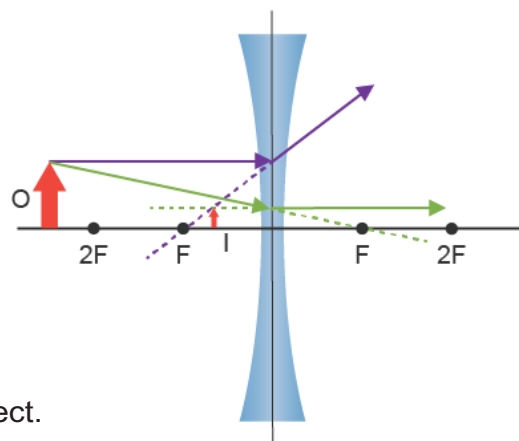
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Predicting the Characteristics of Images Formed by Concave Lenses

- For an object in front of the lens beyond $2F$, the image will be:
 - in front of the lens, between the focal point and the **lens**.
 - virtual
 - upright.
 - **smaller** than the actual object.



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Lens Equation

- The **lens equation** states the relationship between the **object** distance, the image distance, and the focal length.
 - f = focal length
 - d_o = distance of object from lens
 - d_i = distance of image from lens
 - Negative value = **virtual image**
 - Positive value = real image

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

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Determining the Distance of an Image from a Lens

EXAMPLE

A 12.5 cm object is 28 cm from a concave lens, which has a focal length of -13 cm.

What is the distance of the image from the lens?

- Given:

- $d_0 = 28$ cm

- $f = -13$ cm

- Unknown: d_i

- Formula to be used: $\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_0}$$

$$= \frac{1}{\boxed{-13 \text{ cm}}} - \frac{1}{28 \text{ cm}}$$

$$= -0.11 \text{ cm}$$

$$d_i = \frac{1}{-0.11 \text{ cm}} = \boxed{-9.1 \text{ cm}}$$

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Magnification Equation

- The **magnification equation** states the relationship between the ratio of the image distance to the object distance, and the ratio of the image height to the object height.

- $M =$ magnification

- Less than one = smaller image

- Greater than one = larger image

- $h_i =$ height of image

- $h_o =$ height of object

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

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Determining the Distance of an Image from a Lens

EXAMPLE

A 12.5 cm object is 28 cm from a concave lens, which has a focal length of -13 cm. Its image is -8.9 cm from the concave lens.

What is the height of the image?

• Given:

• $d_0 = 28$ cm

• $d_i = -8.9$ cm

• $h_0 = 12.5$ cm

• Unknown: h_i

• Formula to be used: $\frac{h_i}{h_0} = -\frac{d_i}{d_0}$

$$h_i = -h_0 \left(\frac{d_i}{d_0} \right)$$

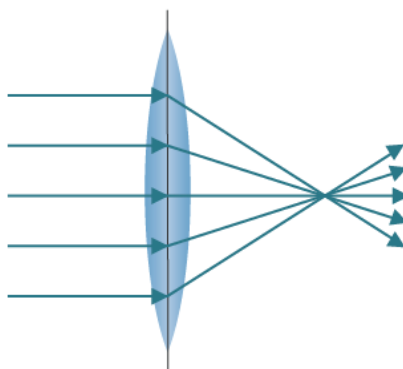
$$= (12.5 \text{ cm}) \left(\frac{-8.9 \text{ cm}}{28 \text{ cm}} \right)$$

$$= 4.0 \text{ cm}$$

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Convex Lens

- A convex lens, or **converging lens**, is **thickest** in the middle and works by causing light rays to bend **toward** the principal axis.



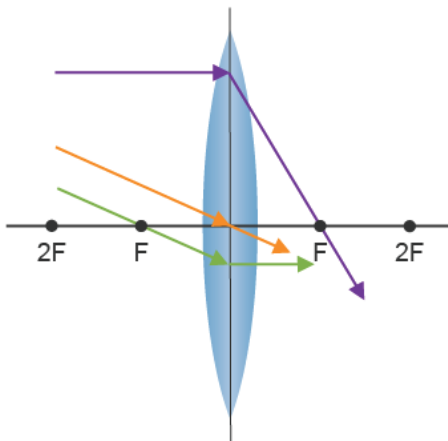
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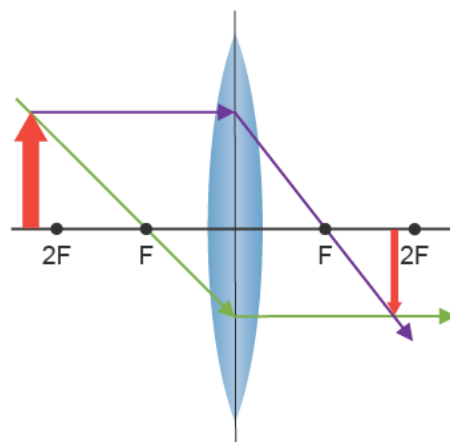
Rule of Thumb for Convex Lenses

- Incident rays that travel parallel to the principal axis refract and then pass through the **focal point** on the other side of the lens.
- Incident rays that travel through the focal point in front of lens **refract** and then travel parallel to the principal axis.
- Incident rays that travel through the center of the mirror continue to move in the same direction after striking the principal axis.



Predicting the Characteristics of Images Formed by Convex Lenses

- For an object in front of the lens beyond $2F$, the image will be:
 - behind the lens, between F and $2F$.
 - real.
 - **inverted**.
 - smaller than the actual object.



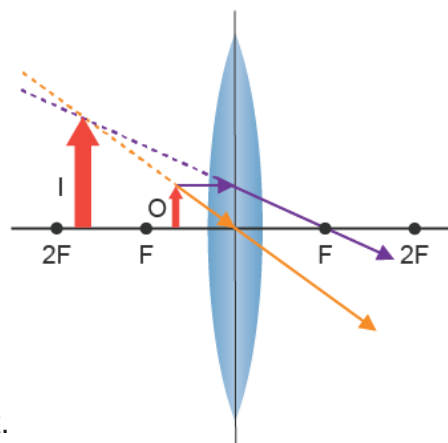
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Predicting the Characteristics of Images Formed by Convex Lenses

- For an object between the lens and F, the image will be:
 - in front of the lens, between 2F and F.
 - **virtual**.
 - upright.
 - **bigger** than the actual object.



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Determining the Distance of an Image from a Lens

A 4 cm object is 10 cm from a convex lens, which has a focal length of 4 cm. What is the distance of the image from the lens?

- Given:

- $d_o = 10$ cm
- $f = 4$ cm

- Unknown: d_i

- Formula to be used:

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

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

$$\frac{1}{d_i} = \frac{1}{4 \text{ cm}} - \frac{1}{10 \text{ cm}} = 0.15 \text{ cm}$$

$$d_i = \frac{1}{0.15 \text{ cm}} = 7 \text{ cm}$$

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Determining Image Height

A 3 cm object is 10 cm from a convex lens, which has a focal length of 4 cm. The image is 7 cm from the lens.

What is the height of the image?

• Given:

- $d_o = 10 \text{ cm}$

- $d_i = 7 \text{ cm}$

- $h_o = 3 \text{ cm}$

• Unknown: h_i

• Formula to be used: $\frac{h_i}{h_o} = \boxed{-\frac{d_i}{d_o}}$

$$\begin{aligned} h_i &= -h_o \left(\frac{d_i}{d_o} \right) \\ &= -3 \text{ cm} \left(\frac{7 \text{ cm}}{\boxed{10 \text{ cm}}} \right) \\ &= -2 \text{ cm} \end{aligned}$$

Summary | Lenses



Lesson Question

How does light interact with lenses to form images?



Answer

(Sample answer) Light always interacts with lenses following Snell's law. The interaction of light with a lens results in images with specific locations, orientations, and sizes depending on the type of lens used.

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Review: Key concepts

- Concave, or diverging, lenses have surfaces that curve **inward**.
- The images formed by concave lenses are:
 - in front of the lens.
 - virtual.
 - **upright**.
 - smaller than the actual object.

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- Convex, or converging, lenses have surfaces that curve outward.
- The characteristics of images formed by convex lenses depend on where the object is **located**.

Location of Object	Image Characteristics
In front of lens, beyond 2F	Behind the lens, real, inverted, and smaller than the actual object
Between 2F and F	Behind the lens, real, inverted, and bigger than the actual object
Between F and the lens	In front of the lens, virtual , upright, and bigger than the actual object

- Lens equation: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$
- Magnification equation: $M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$
- Positive and negative values of variables indicate direction and **orientation**.
- Magnifications larger than one indicate that the image is **larger** than the object.
- Magnifications less than one indicate that the image is smaller than the object.

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Variable Description	Image Characteristic
Positive distance	Behind the lens
Negative distance	In front of the lens
Positive height	Upright
Negative height	Inverted
Magnification greater than one	Bigger than actual object
Magnification less than one	Smaller than actual object

Use this space to write any questions or thoughts about this lesson.