New Jersey Center for Teaching and Learning

Progressive Science Initiative

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Geometric Opitics

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Reflection

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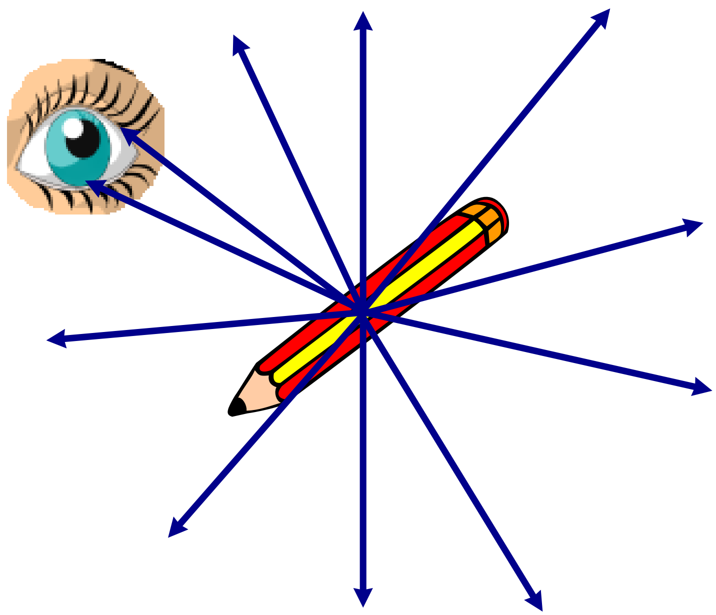
The Ray Model of Light

Light can travel in straight lines. We represent this usingrays, which are straight lines emanating from a light source or object. This is really an idealization but it is very useful.

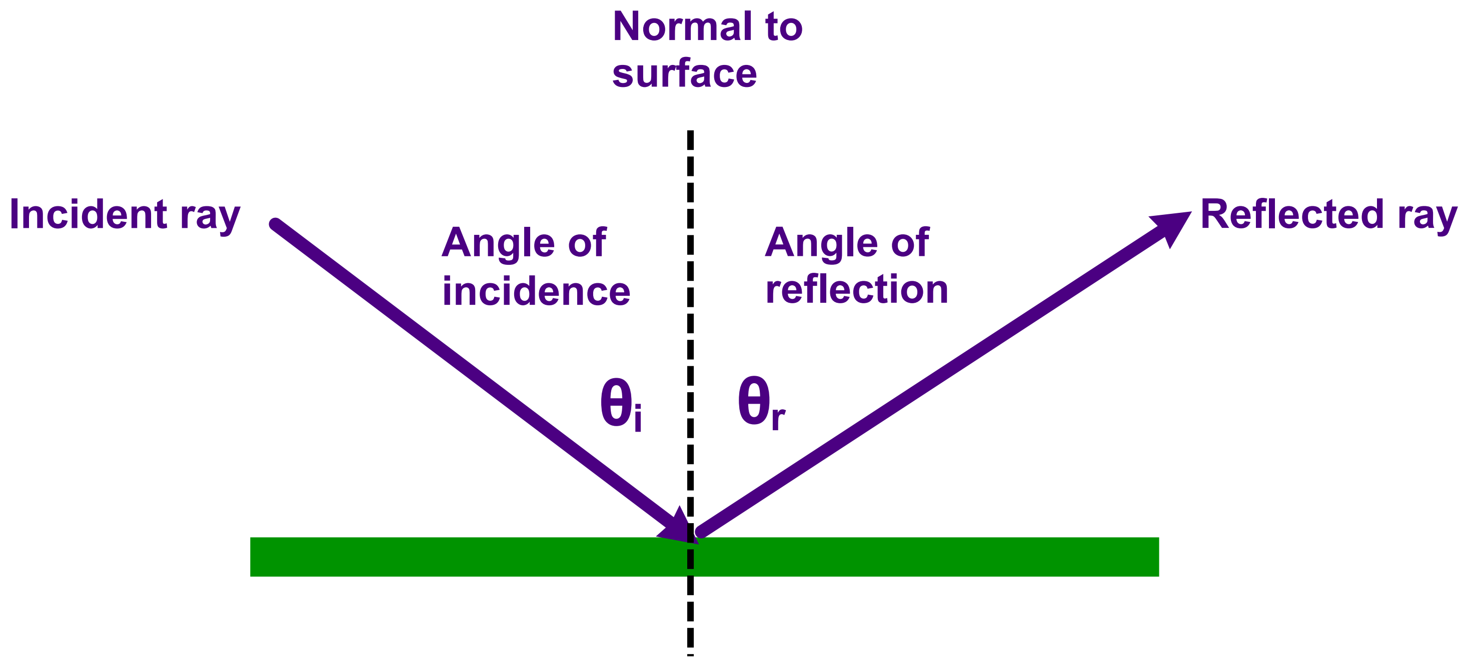
For instance, you can see a pencil on a desk from any angle as long as there is nothing in your way. Light reflects off the pencil in all directions, which is represented by rays. You see the rays that hit your eye.



Reflection

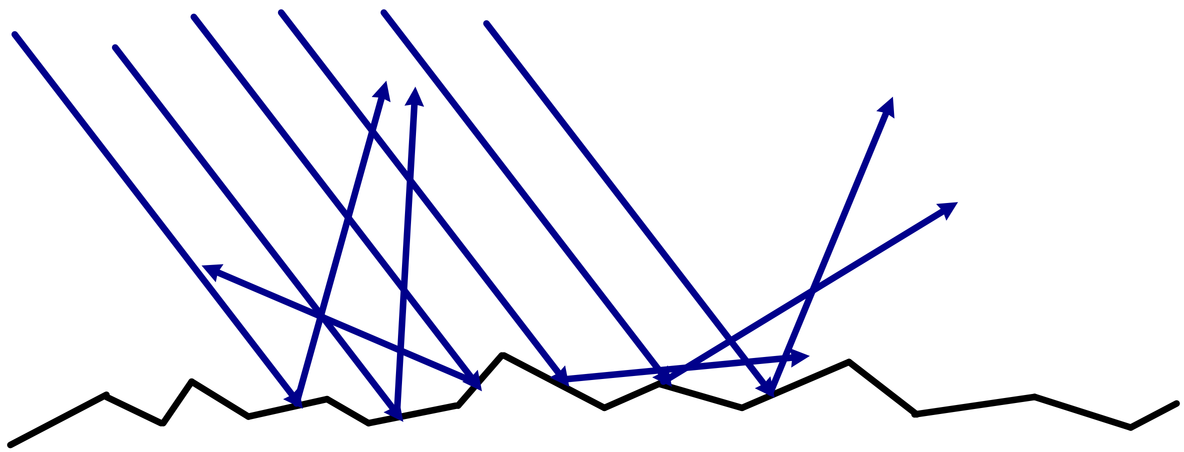
Law of reflection:

The angle of incidence is equal to the angle of reflection. Both angles are measured from the line normal to the surface. (Remember: Normal means perpendicular.)



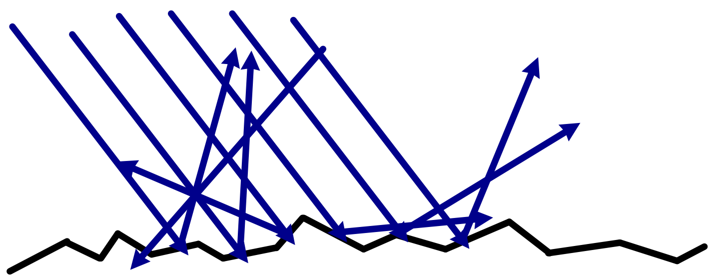
Reflection

When the light hits a rough surface and reflects, the law of reflection still holds but the angle of incidence varies so the light is diffused.

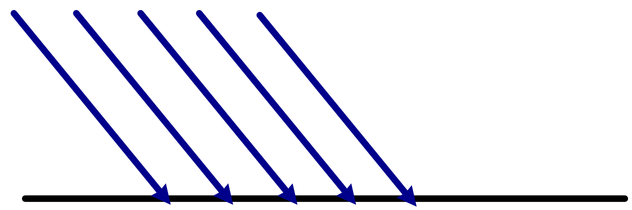


Reflection

With diffuse reflection, your eye sees reflected light at allangles but no image is really formed. With specular reflection (from a mirror) , your eye must be in the correct position.



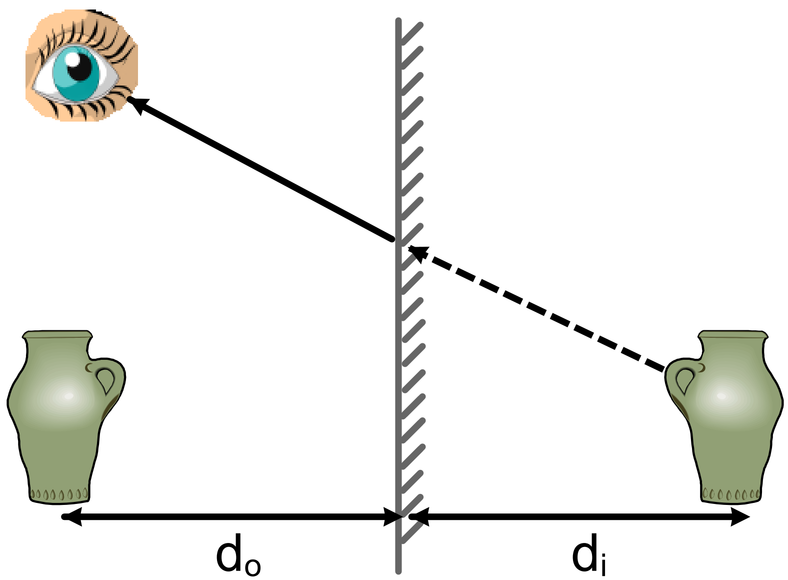
Both eyes see some reflected light.



One eye sees reflected light the other does not.

Reflection

When you look into a plane (or flat) mirror, you see an image which appears to be behind the mirror. This is called a virtual image since the light does not go through it. The distance from the object to the mirror is the same as the distance from the mirror to the image.



1 The angle of reflection is ________ the angle of incidence.

- A less than
- B equal to
- C greater than

Answer

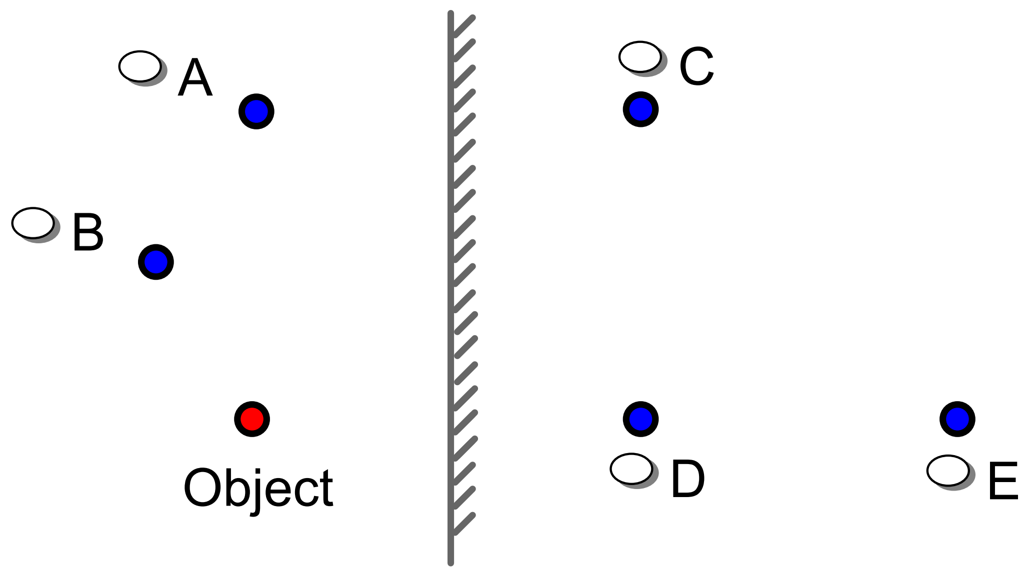
1 The angle of reflection is _________ the angle of incidence.

- A less than
- B equal to
- C greater than

Answer

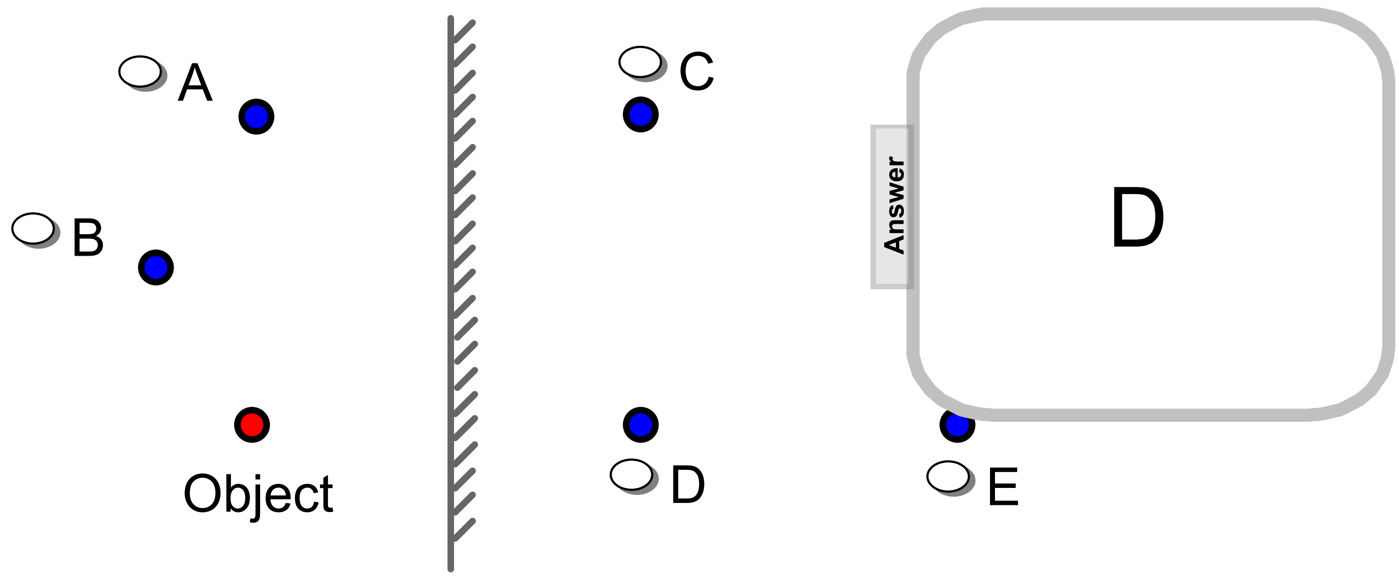
B

2 An object is placed in front of a plane mirror. Where is the image located?



Answer

2 An object is placed in front of a plane mirror. Where is the image located?



Spherical Mirror

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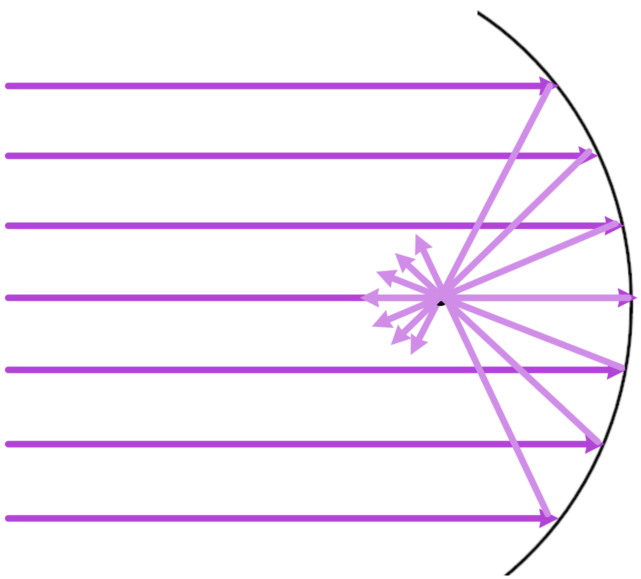
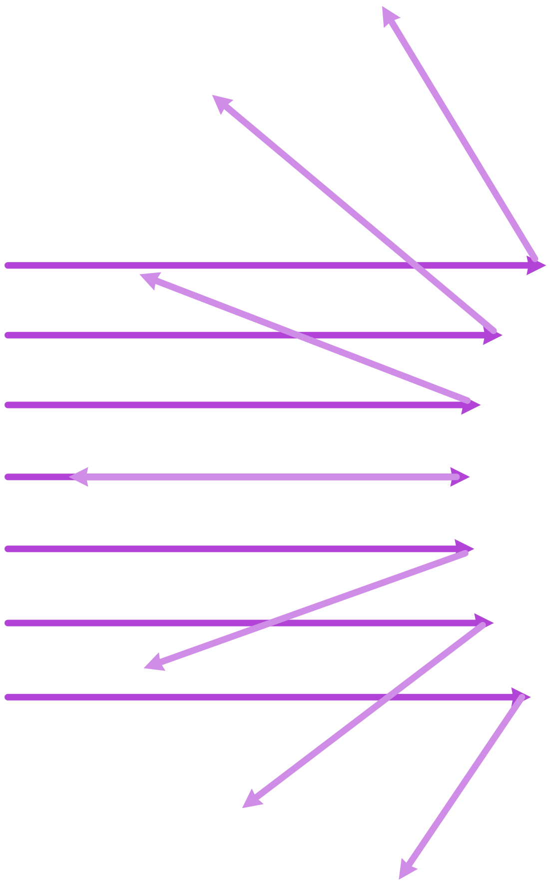
Spherical Mirror

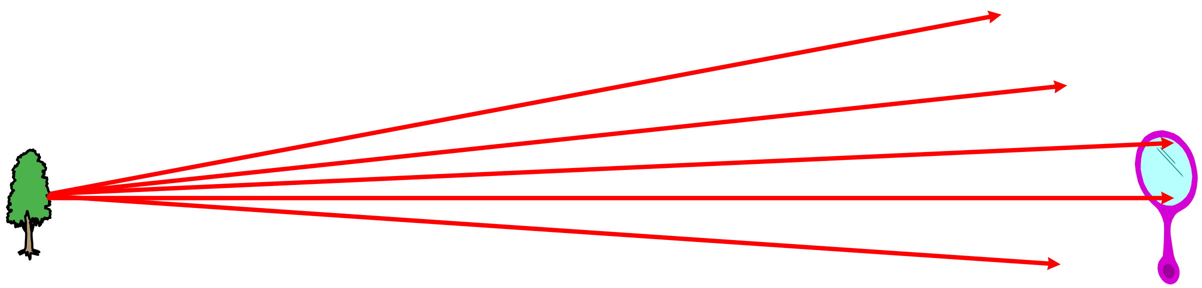
Spherical Mirrors are shaped like sections of a sphere and may be reflective on either the inside called concave (where parallel rays reflect and converge) or outside called convex (where parallel rays reflect and diverge).





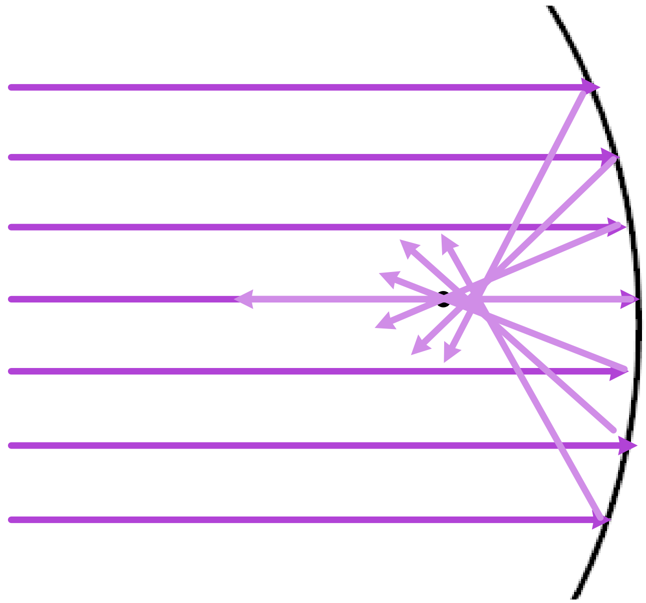
Spherical Mirror

Rays coming in from a far away object are effectively parallel.



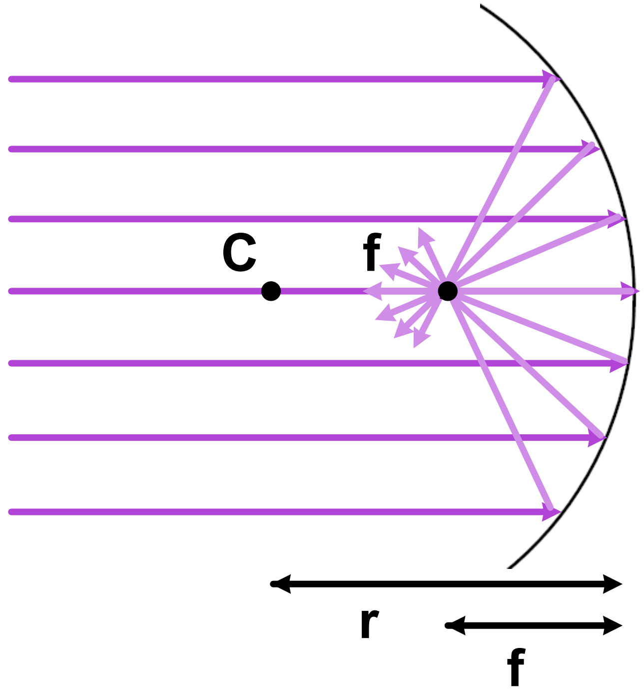
Spherical Mirror

For mirrors with large curvatures, parallel rays do not all converge at exactly the same point. This is called sphericalaberration.



Spherical Mirror

If the curvature is small, the focus is much more precise. The focal point is where the rays converge.



The focal length of a spherical mirror is half the radius ofcurvature.

$$f = \frac{r}{2}$$

Spherical Mirror

We can use ray diagrams to determine where the image will be when using a spherical mirror. We draw three principle rays:

1. A ray that is first parallel to the axis and then, after reflection, passes through the focal point.

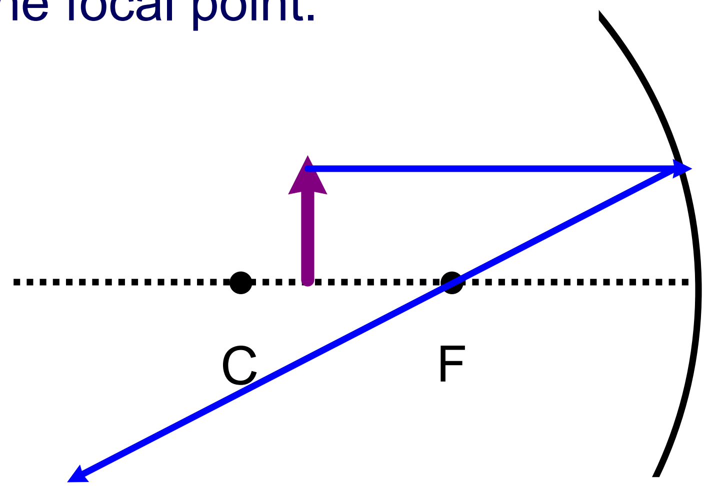
2. A ray that first passes through the focal point and then, after reflection, is parallel to the axis.

3. A ray perpendicular to the mirror and then reflects back on itself.

4. A ray that strikes the mirror at the principal axis (and a certain angle) and reflects back (at the same angle).

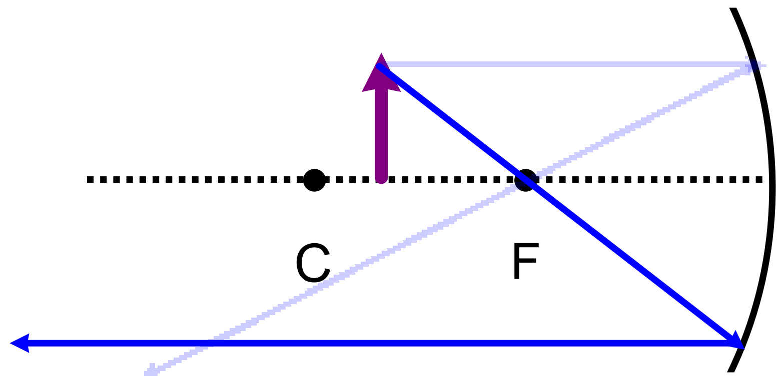
Spherical Mirror

1. A ray that is first parallel to the axis and then, after reflection, passes through the focal point.



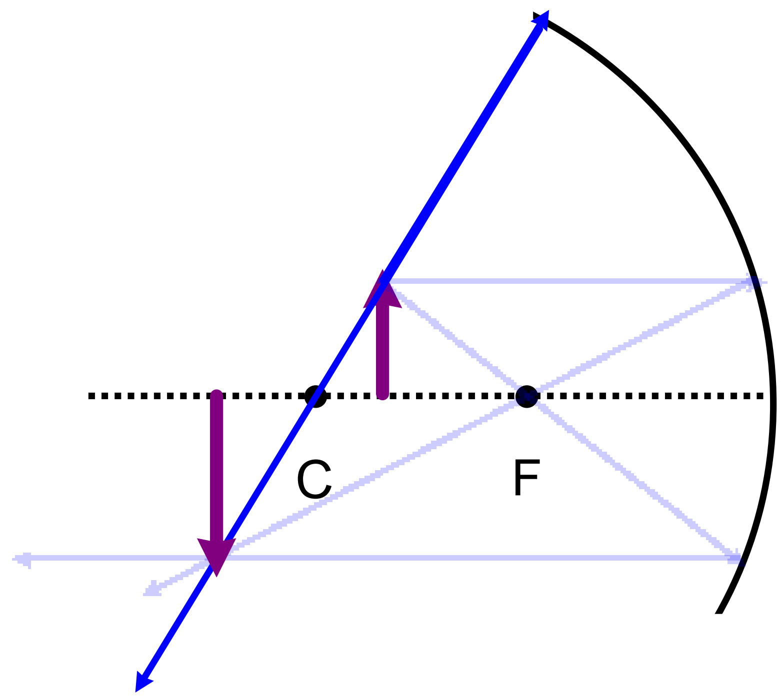
Spherical Mirror

2. A ray that first passes through the focal point and then, after reflection, is parallel to the axis.



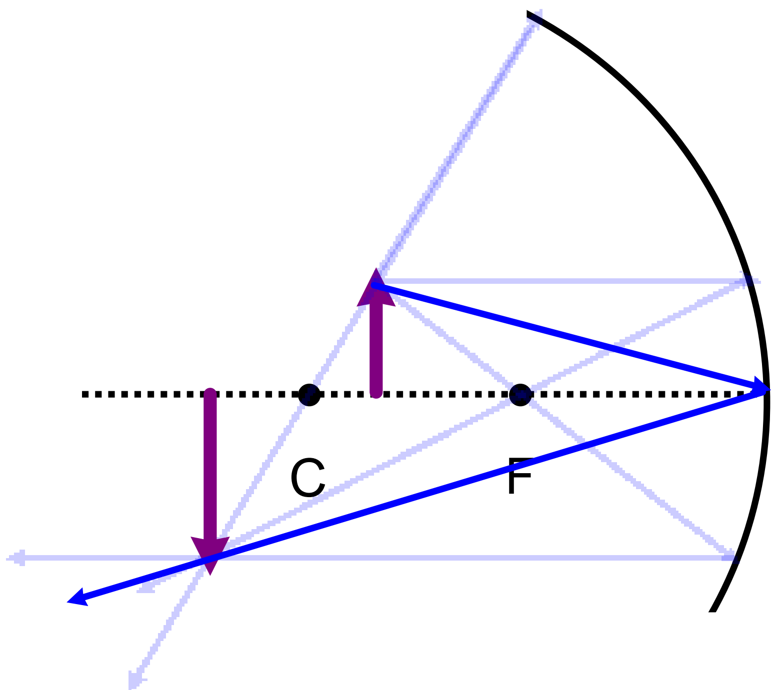
Spherical Mirror

3. A ray perpendicular to the mirror and then reflects back on itself. (Note: this ray always goes through the center of curvature.)



Spherical Mirror

4. A ray that strikes the mirror at the principal axis (and a certain angle) and reflects back (at the same angle).

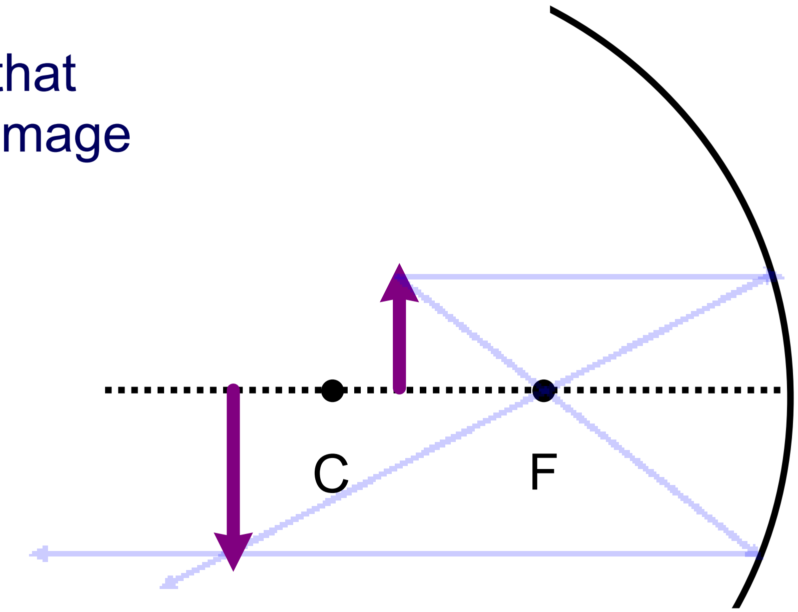


Really, only two rays are needed to see where the image is located, but it is sometimes good to draw more.

Spherical Mirror

We can derive an equation that relates the object distance, image distance, and focal length.

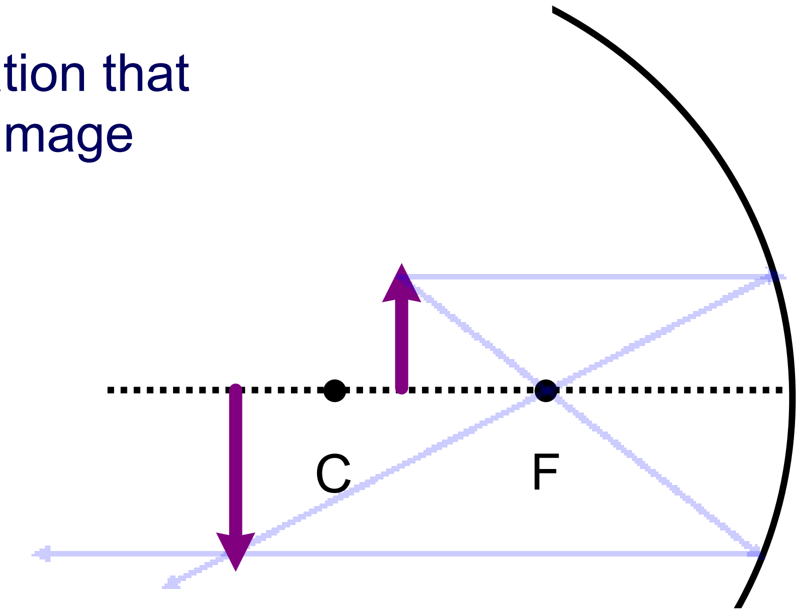
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$



Spherical Mirror

We can also derive an equation that relates the object distance, image distance, and magnification.

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

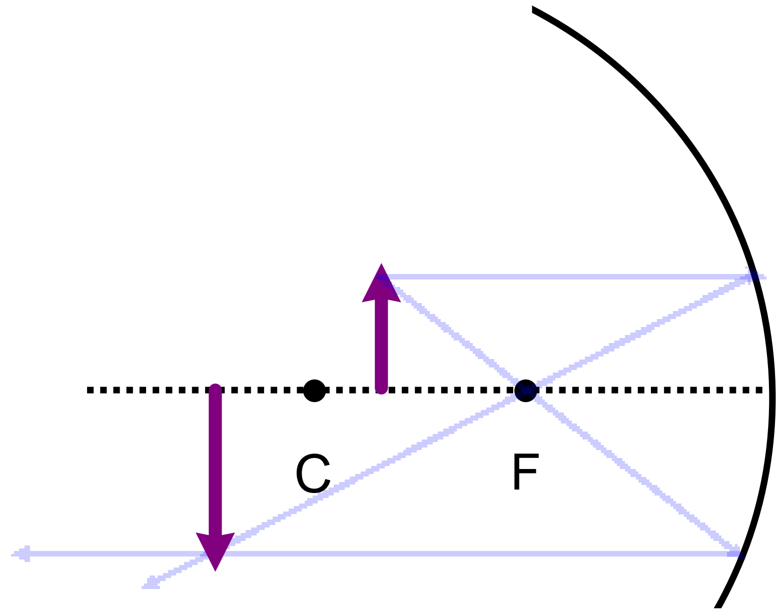


The negative sign indicates that the image is inverted. (We do not need to use the negative sign because we can always draw a ray diagram and see if the image is inverted or upright.)

Spherical Mirror

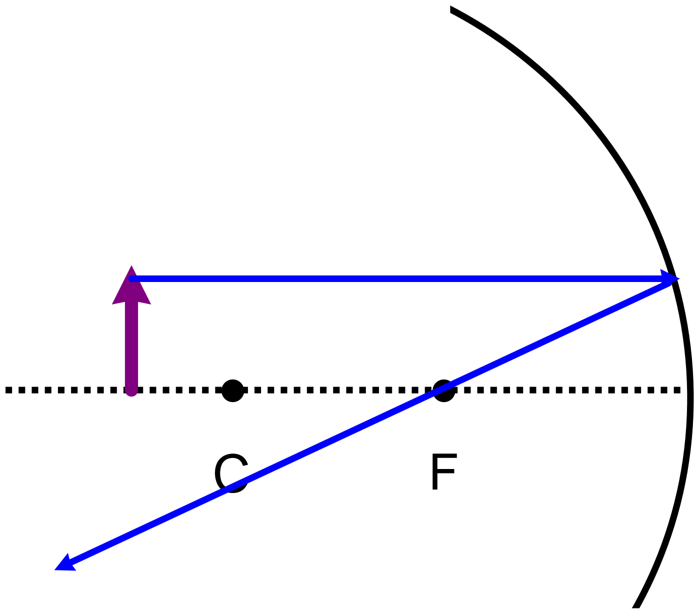
This object is between the center of curvature and the focal point.

Its image is magnified, real, and inverted.



Spherical Mirror

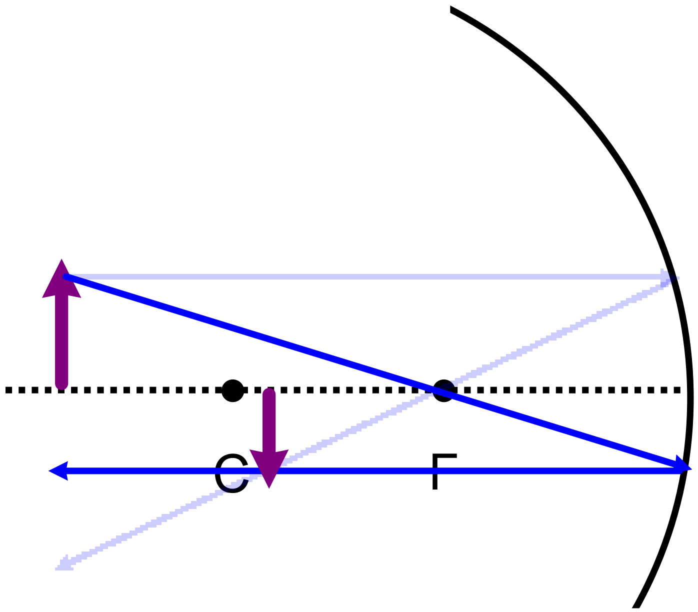
If the object is past the center of curvature...



Spherical Mirror

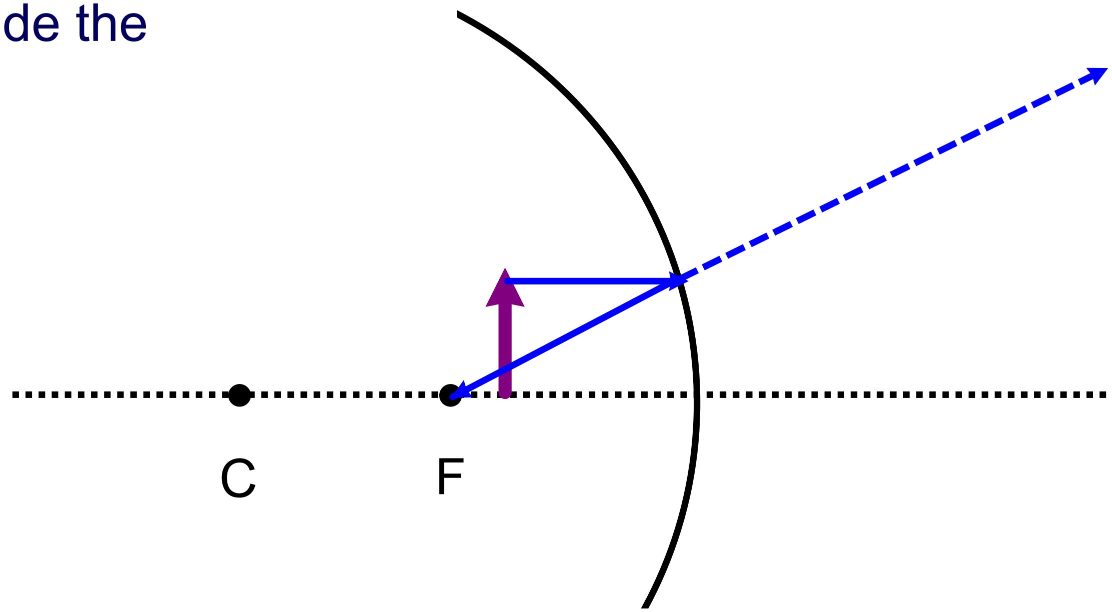
If the object is past the center of curvature...

the image is de-magnified, real, and inverted.



Spherical Mirror

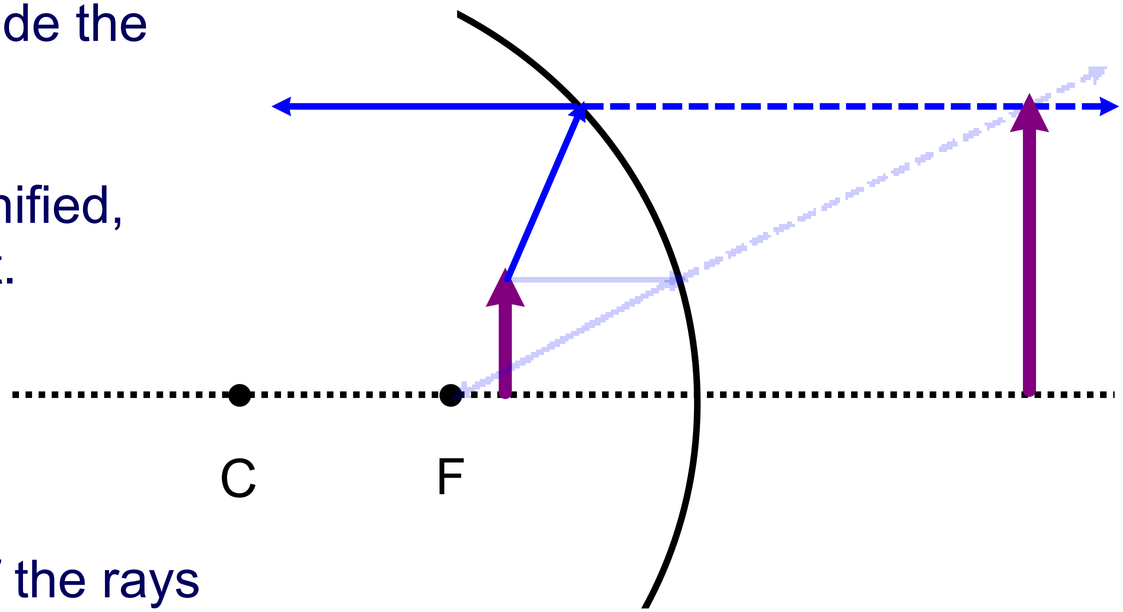
If the object is inside the focal point...



Spherical Mirror

If the object is inside the focal point...

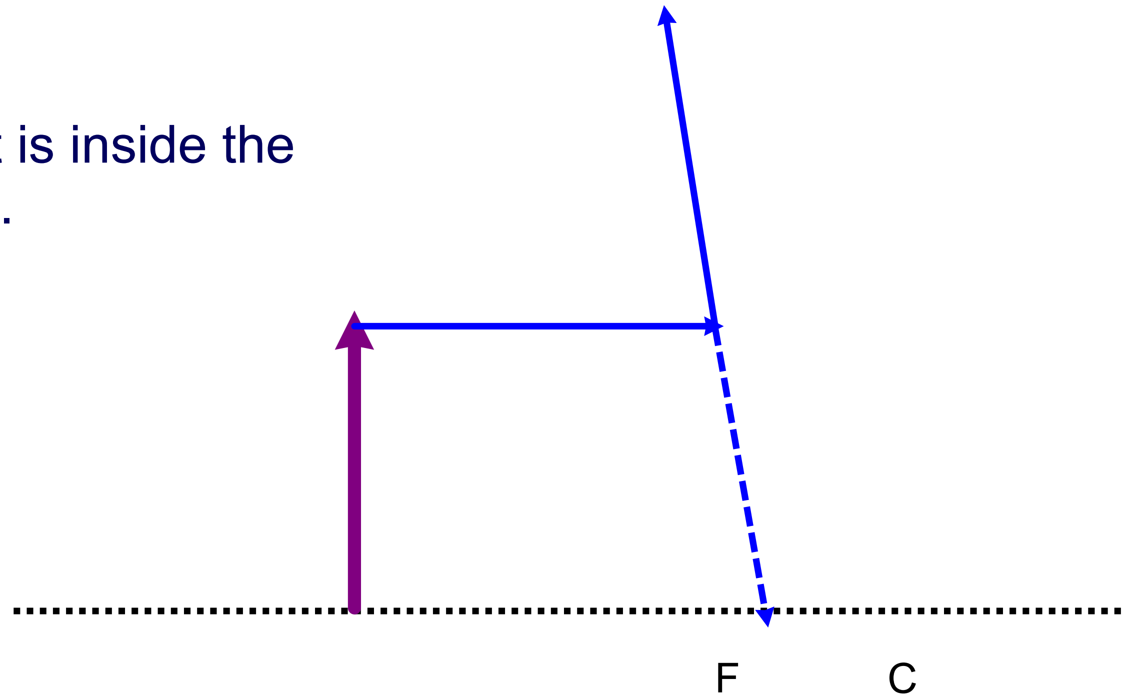
the image is magnified, virtual and upright.



As you can see, if the rays do not intersect in real space, we must extended dotted lines backwards to form a virtual image

Spherical Mirror

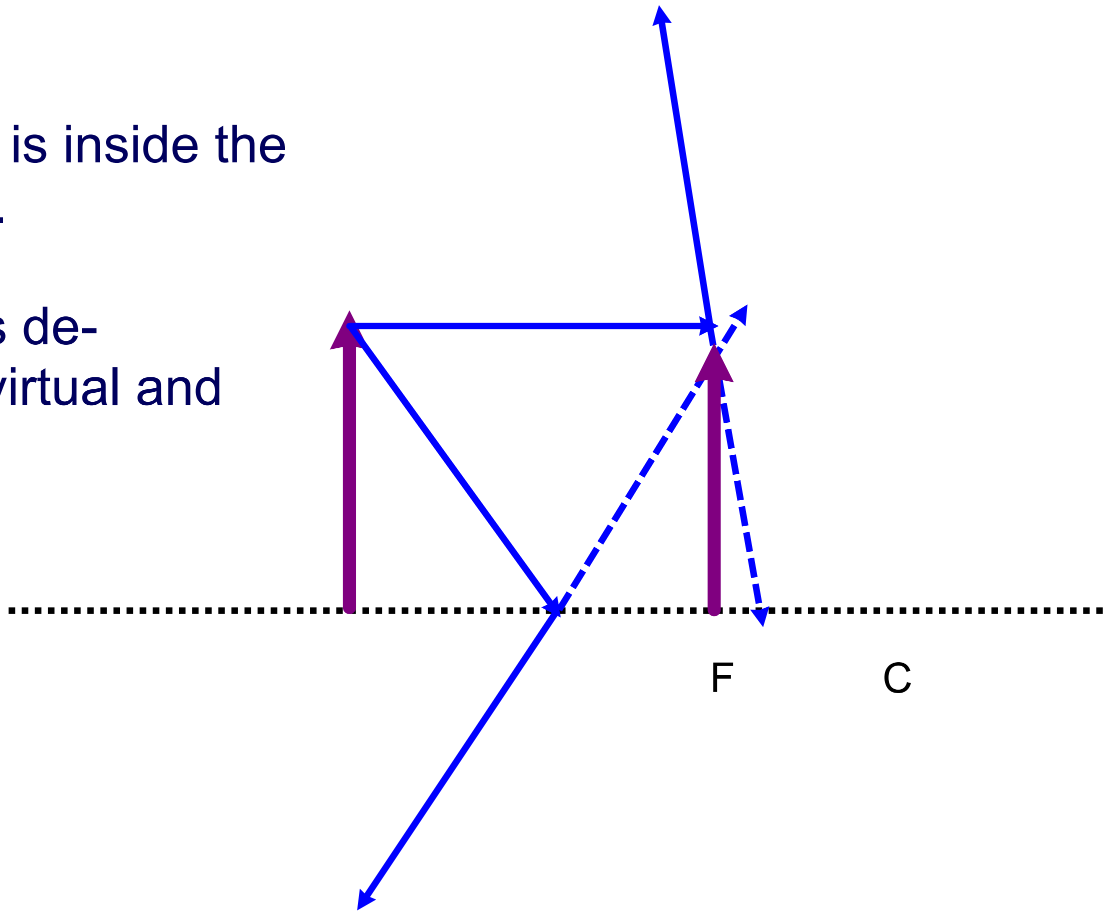
If the object is inside the focal point...



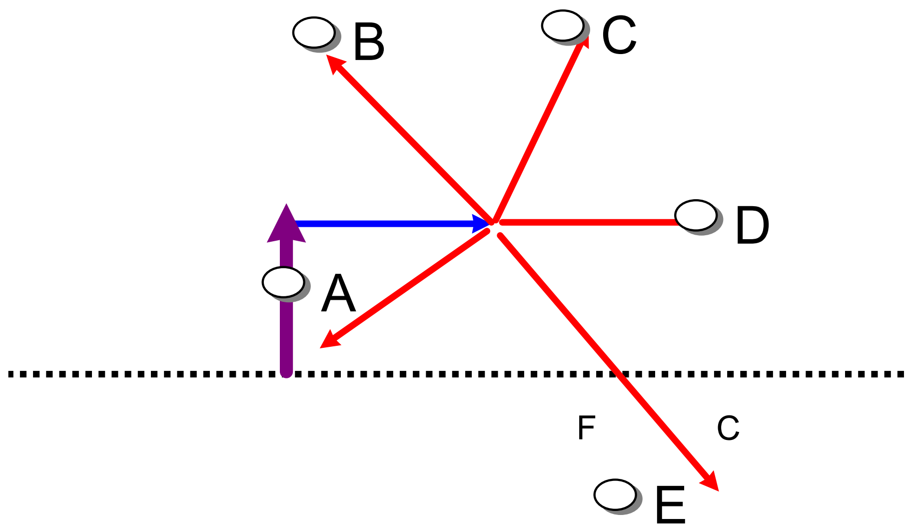
Spherical Mirror

If the object is inside the focal point...

the image is de-magnified, virtual and upright.

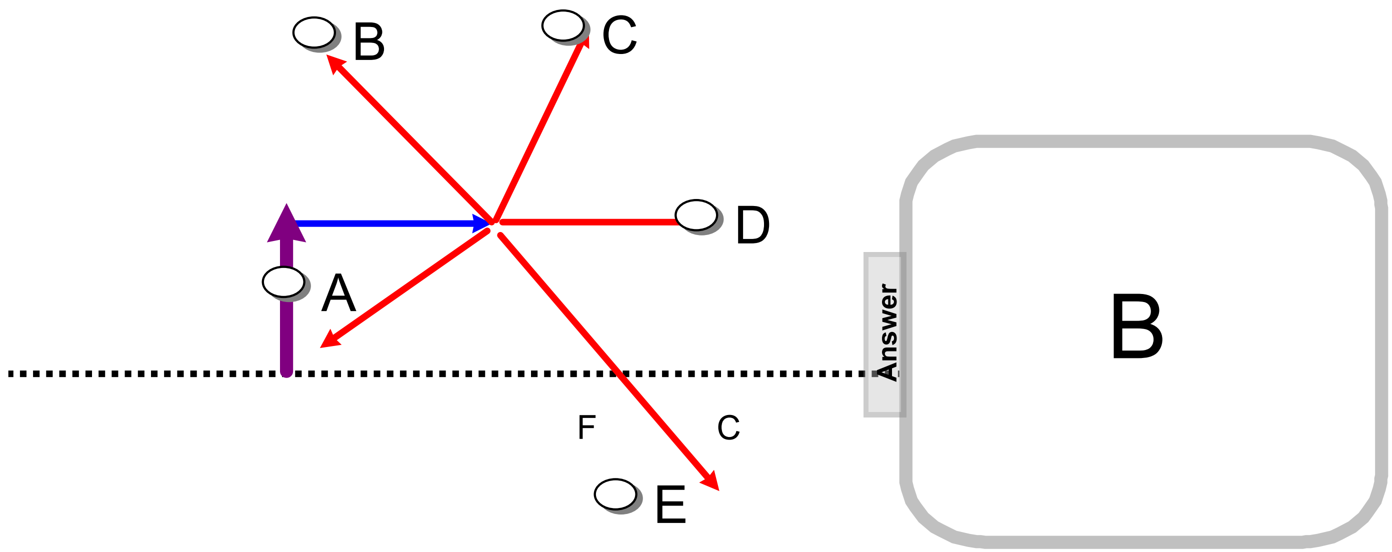


3 A ray of light strikes a convex mirror parallel to the central axis. Which of the following represents the reflected ray?



Answer

3 A ray of light strikes a convex mirror parallel to the central axis. Which of the following represents the reflected ray?



4 A candle is placed in front of a concave mirror between the center of curvature and the focal point. The image is:

- A real, inverted, and magnified.
- B real, inverted, and demagnified.
- C virtual, upright, and magnified.
- D virtual, upright, and demagnified.
- E real, upright, and magnified.

Answer

4 A candle is placed in front of a concave mirror between the center of curvature and the focal point. The image is:

- A real, inverted, and magnified.
- B real, inverted, and demagnified.
- C virtual, upright, and magnified.
- D virtual, upright, and demagnified.
- E real, upright, and magnified.

Answer

C

5 A candle with a height of 21 cm is place in front of a concave mirror with a focal length of 7 cm. How far is the image from the mirror?

Answer

5 A candle with a height of 21 cm is place in front of a concave mirror with a focal length of 7 cm. How far is the image from the mirror?

Answer

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

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

$$\frac{1}{d_i} = \frac{1}{7} - \frac{1}{21} = \frac{2}{21}$$

$$d_i = 10.5cm$$

Refraction and Snell's Law

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Refraction and Snell's Law

As we saw in Electromagnetic Waves, light slows when traveling through a medium. The index of refraction (n) of the medium is the ratio of the speed of light in vacuum to the speed of light in the medium:

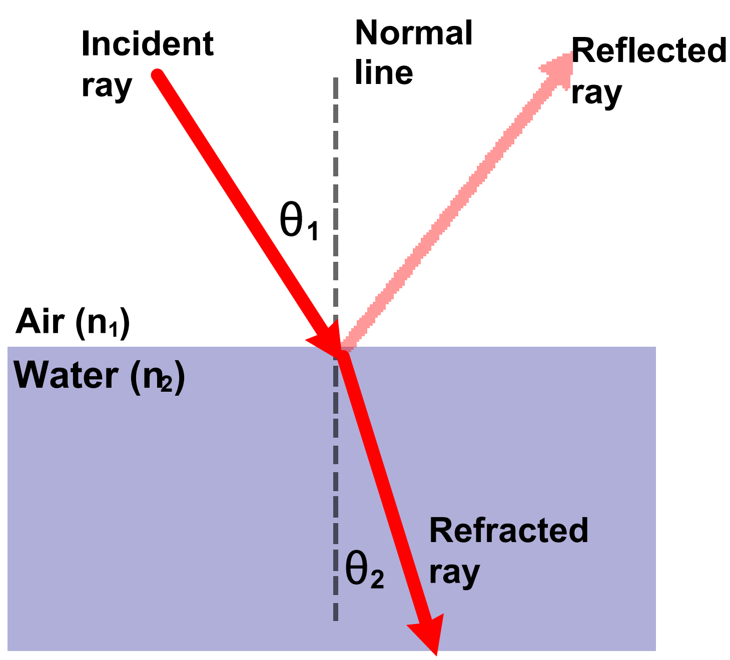
$$n = \frac{c}{v}$$

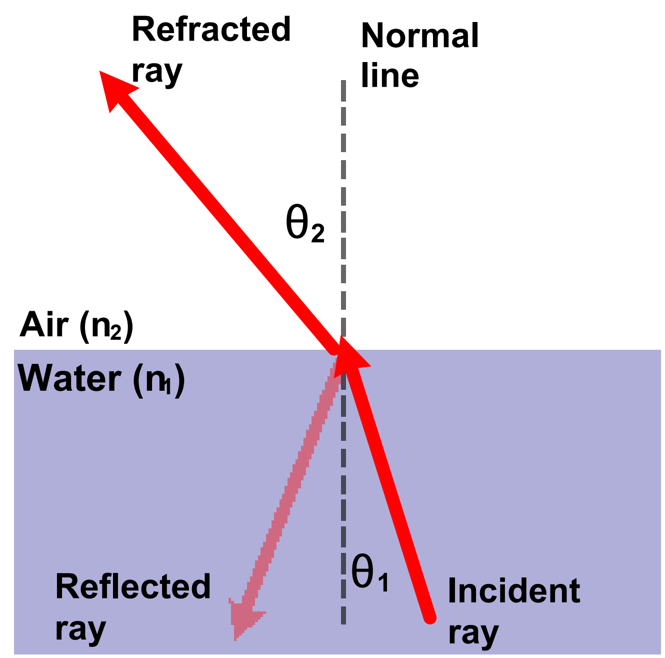
Indices of Refraction
(λ = 589 nm)

Medium	**N = c / v**
Vacuum	1.0000
Air (at STP)	1.0003
Water	1.33
Ethyl alcohol	1.36
Glass	
Fused quartz	1.46
Crown glass	1.52
Light flint	1.58
Lucite or Plexiglas	1.51
Sodium chloride	1.53
Diamond	2.42

Refraction and Snell's Law

Light also changes direction when it enters a new medium. This is called refraction. The angle of incidence is related to the angle of refraction. When the ray goes from less dense to more dense, it bends towards the normal line and the refracted angle is smaller. When the ray goes from more dense to less dense, it bends away from the normal line and the refracted angle is larger.



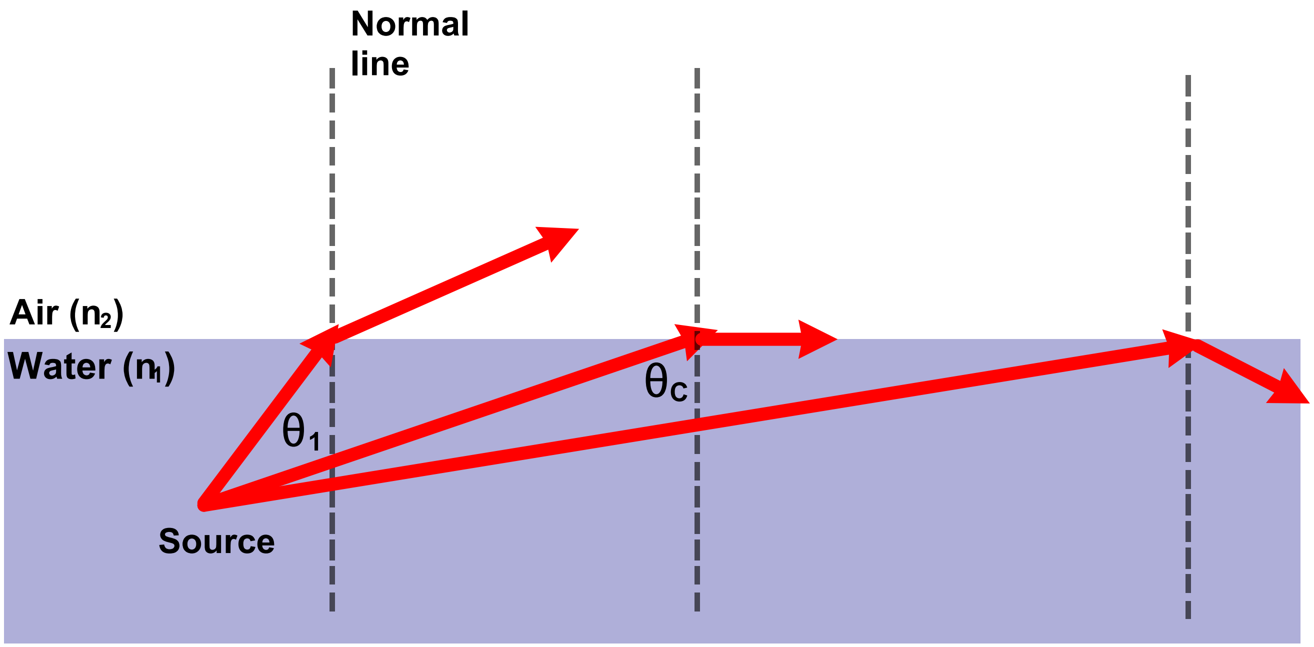


Refraction and Snell's Law

This is why objects look weird if they are partially underwater.

Refraction and Snell's Law

When the angle of incidence is larger than the criticalangle, no light escapes the medium. This is called total internal reflection.



6 A ray of light bends ________ when going from air into glass.

- A towards the normal
- B away from the normal
- C not at all

Answer

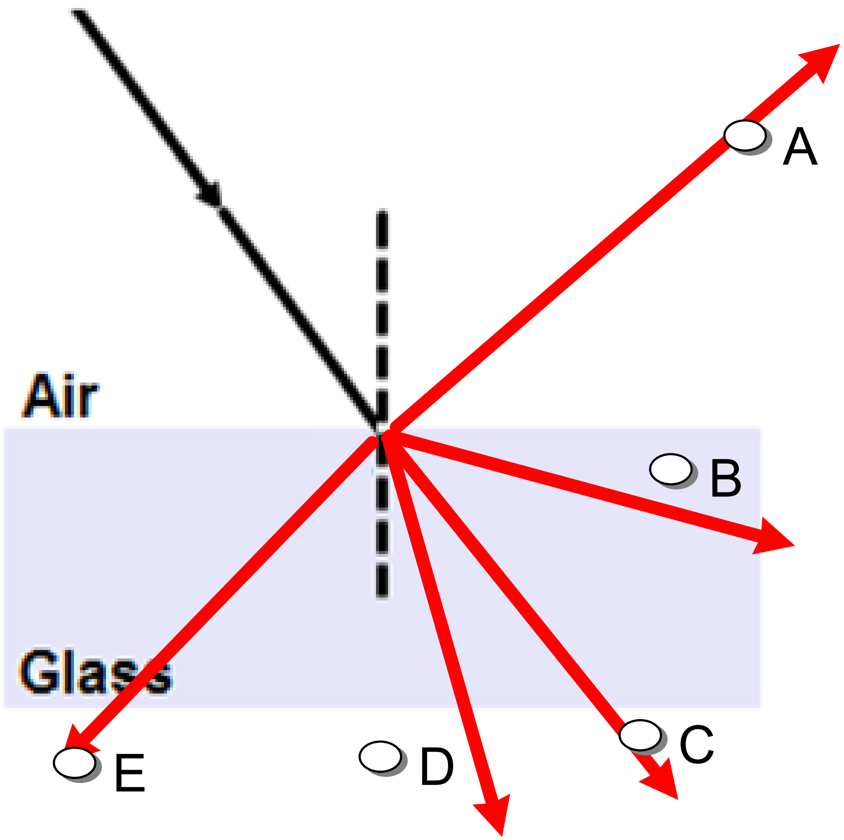
6 A ray of light bends ________ when going from air into glass.

- A towards the normal
- B away from the normal
- C not at all

Answer

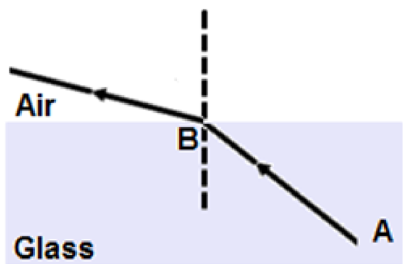
A

7 A light ray incident on the surface of glass. Which of the follow represents the refracted ray?

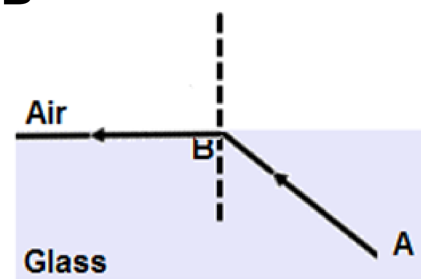


8 A ray of light passes from water to air at the critical angle. Which of the following shows the refracted ray?

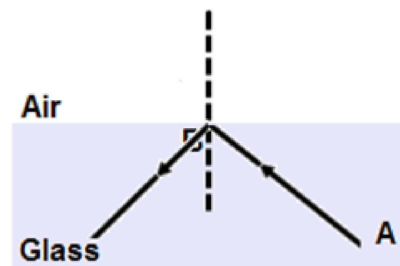
A



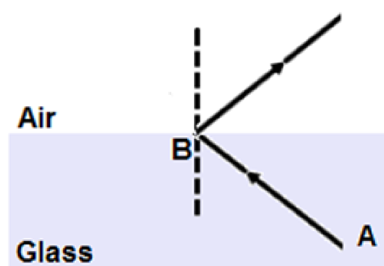
B



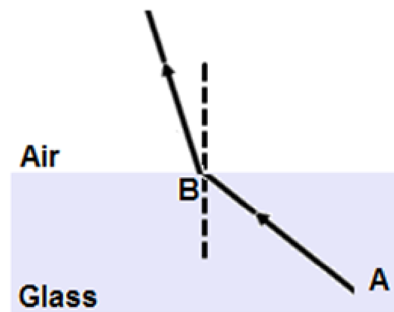
C



D



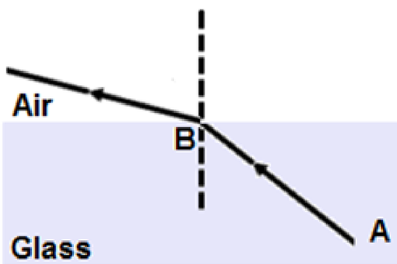
E



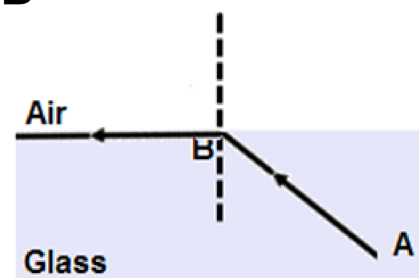
Answer

8 A ray of light passes from water to air at the critical angle. Which of the following shows the refracted ray?

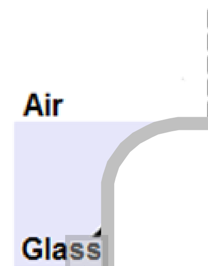
A



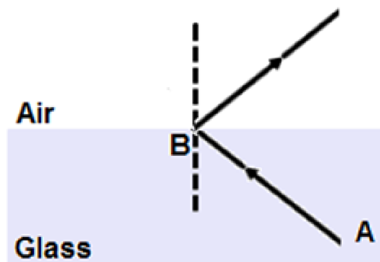
B



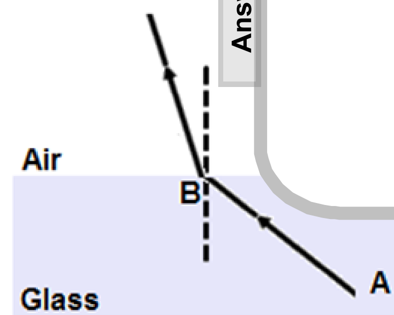
C



D



E



Answer

B

Thin Lenses

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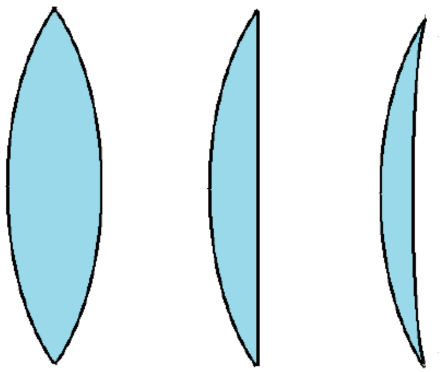
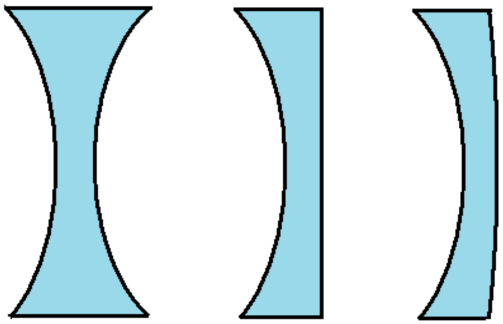
Thin Lenses

A thin lens is a lens whose thickness is small compared to its radius of curvature. Lenses can be converging or diverging.

Converging lenses are thicker in the center than at the edges.

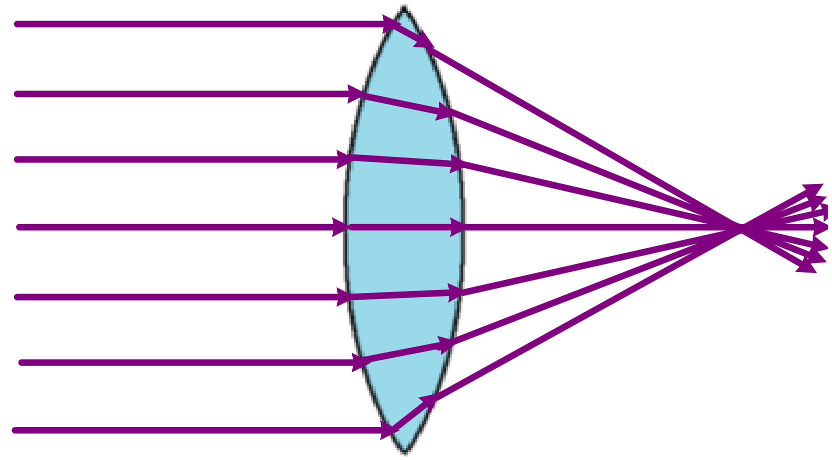


Diverging lenses are thicker at the edges than in the center.

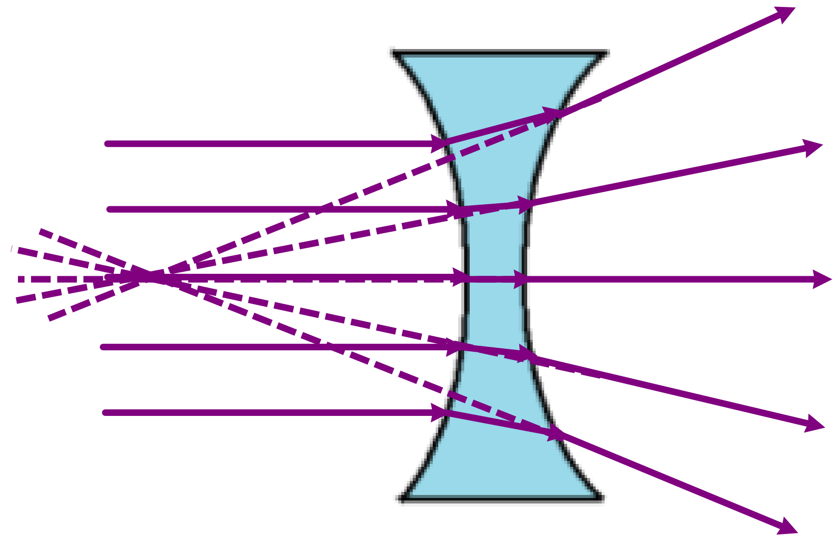


Thin Lenses

Converging lenses bring parallel rays to a focus which is the focal point.



Diverging lenses make parallel light diverge. The focal point is the point where the rays would converge if the rays were projected back.



Thin Lenses and Ray Tracing

Ray tracing can be used to find the location and size of the image created by thin lenses as well as mirrors. They have similar steps.

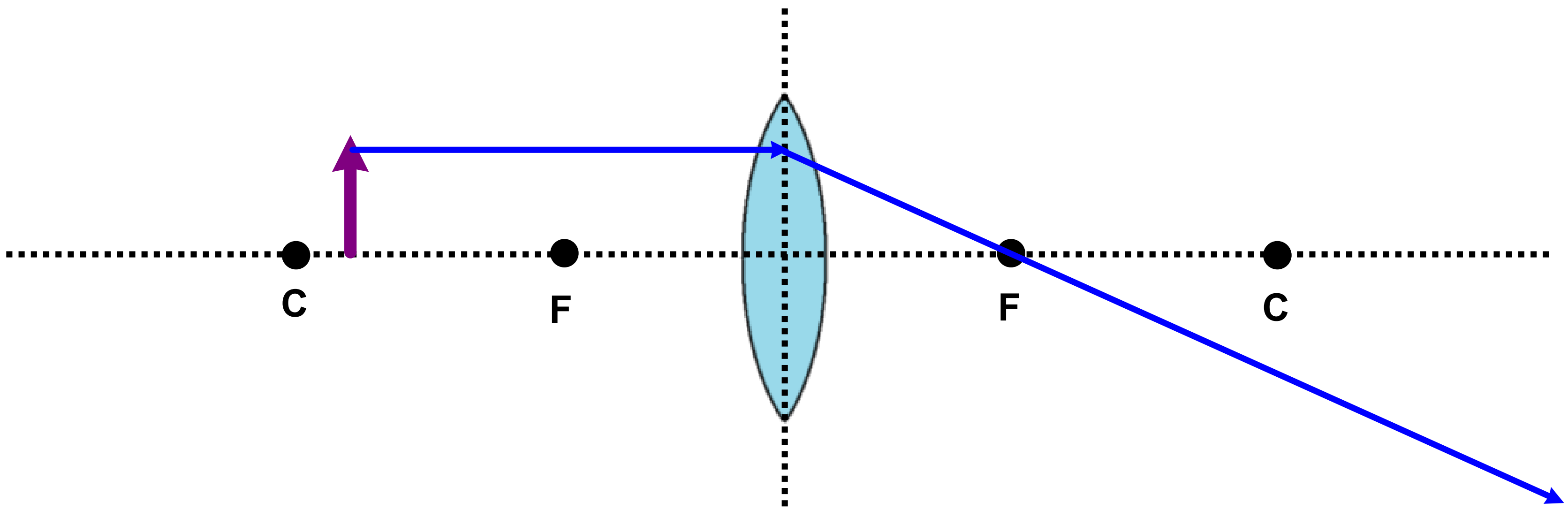
1. The first ray enters parallel to the axis and exits through the focal point.

2. The next ray enters through the focal point and then exits parallel to the axis.

3. The next ray goes through the center of the lens and is not deflected.

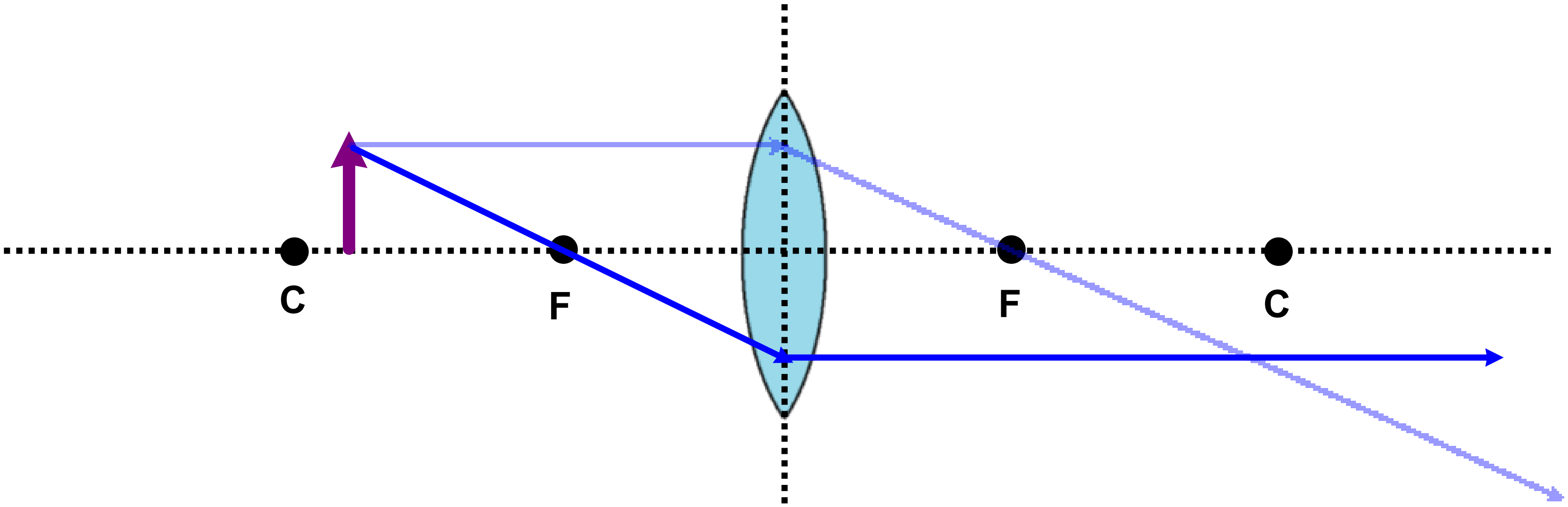
Thin Lenses and Ray Tracing

1. The first ray enters parallel to the axis and exits through the focal point.



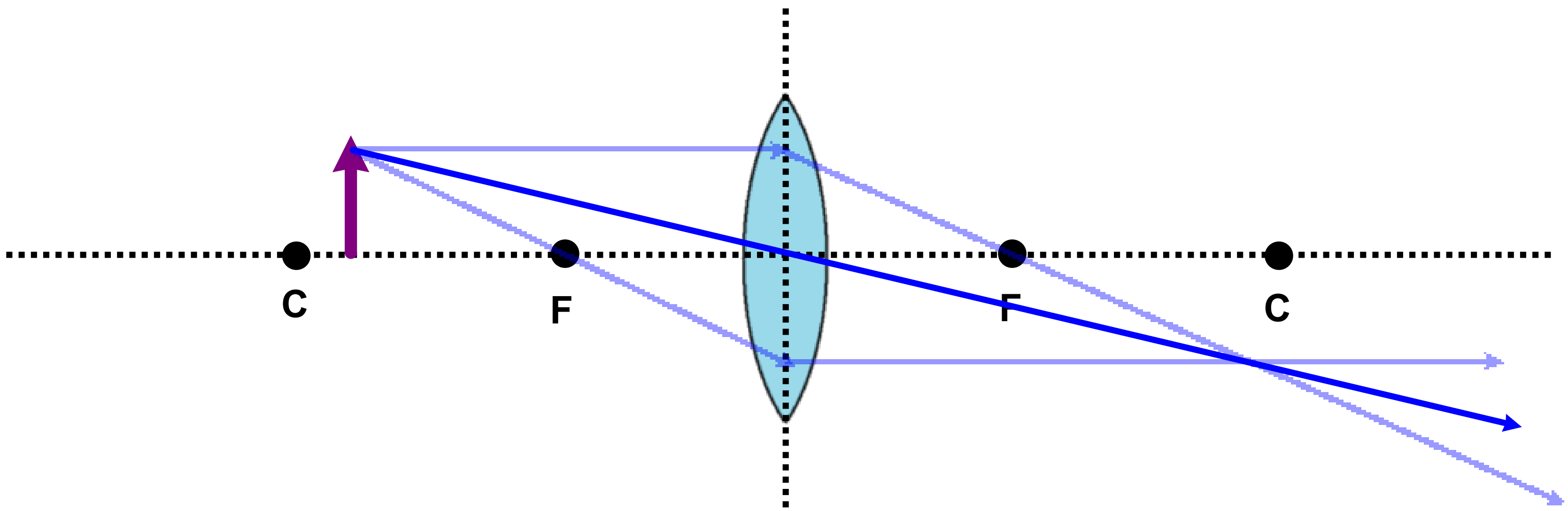
Thin Lenses and Ray Tracing

2. The next ray enters through the focal point and then exits parallel to the axis.



Thin Lenses and Ray Tracing

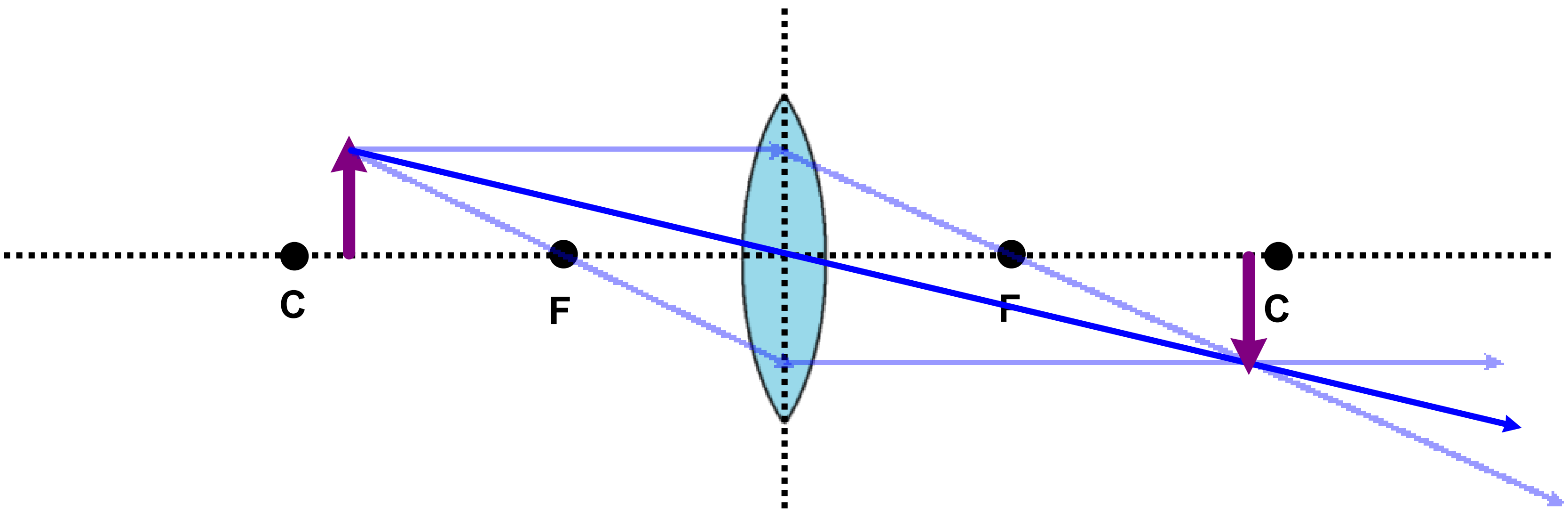
3. The next ray goes
   through the center
   of the lens and
   is not deflected.



Thin Lenses and Ray Tracing

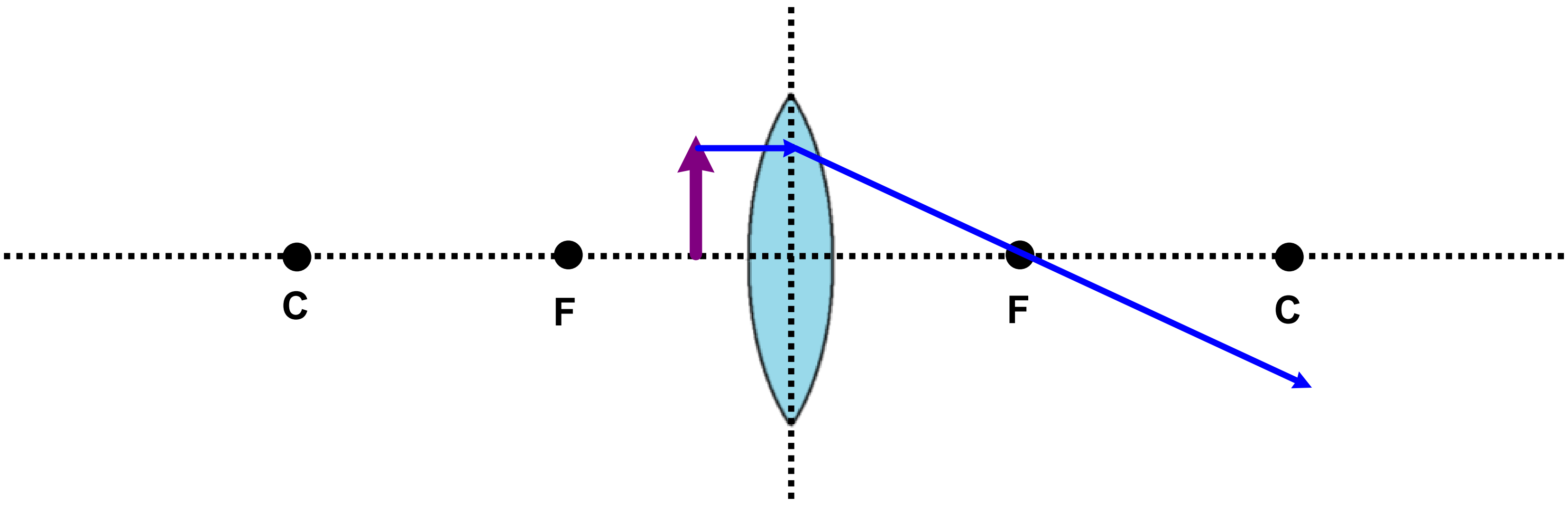
Again, we only need two rays to see where the image is.

When the object is between the focal point and center of curvature of a converging lens, the image is magnified, real, and inverted.



Thin Lenses and Ray Tracing

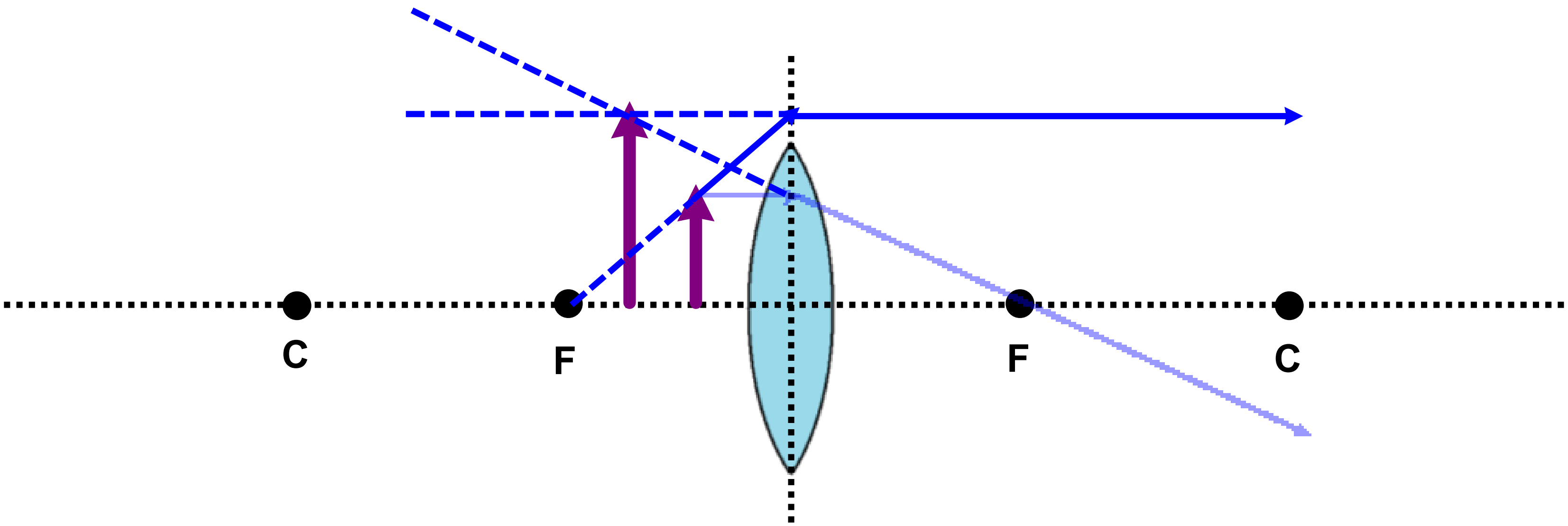
When the object is inside the focal point...



Thin Lenses and Ray Tracing

When the object is inside the focal point...

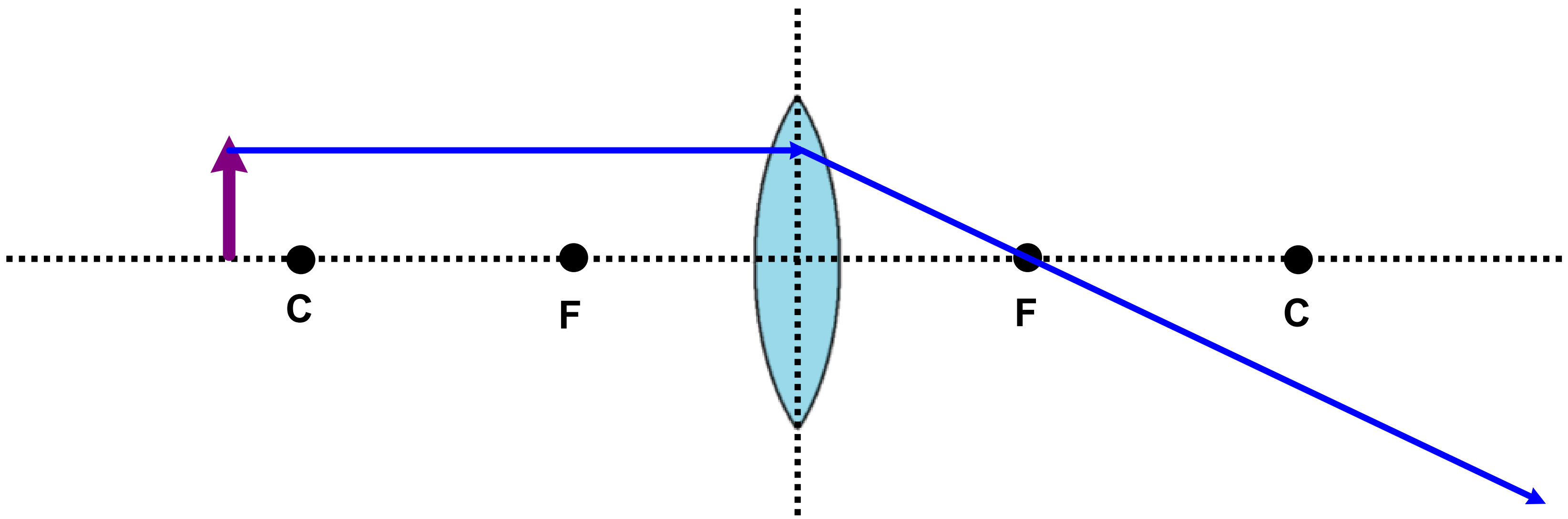
The image is magnified, virtual, and upright.



Note that when the rays do not converge on one side of the lens, they do on the other side.

Thin Lenses and Ray Tracing

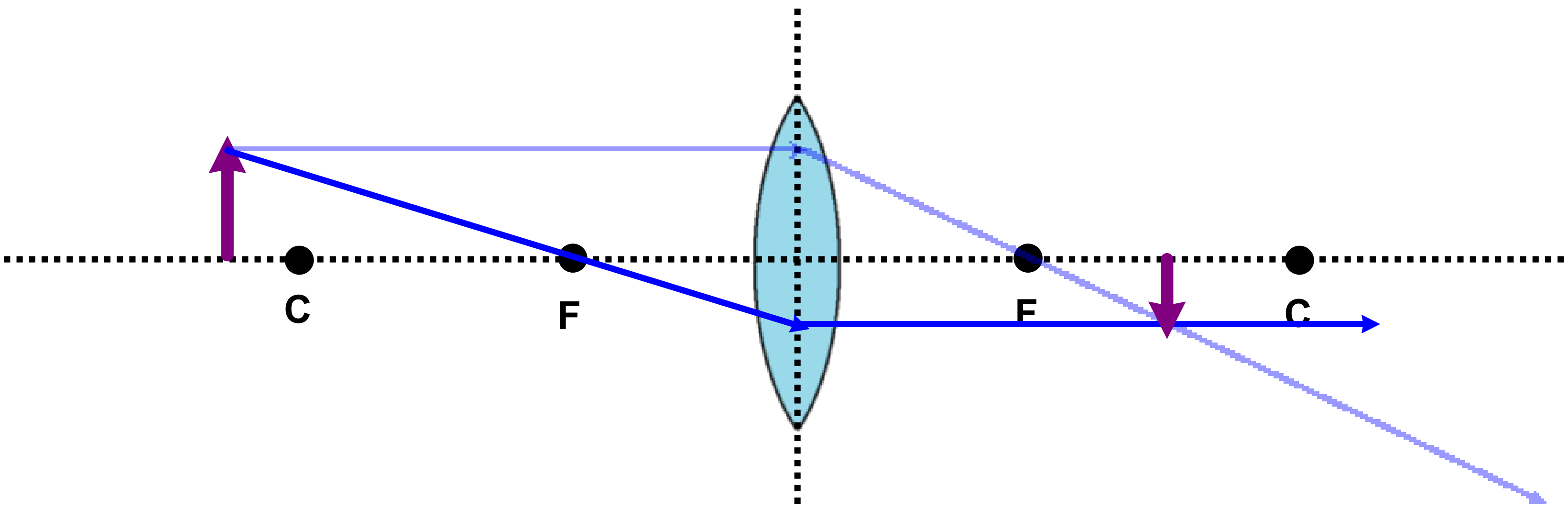
When the object is outside center of curvature...



Thin Lenses and Ray Tracing

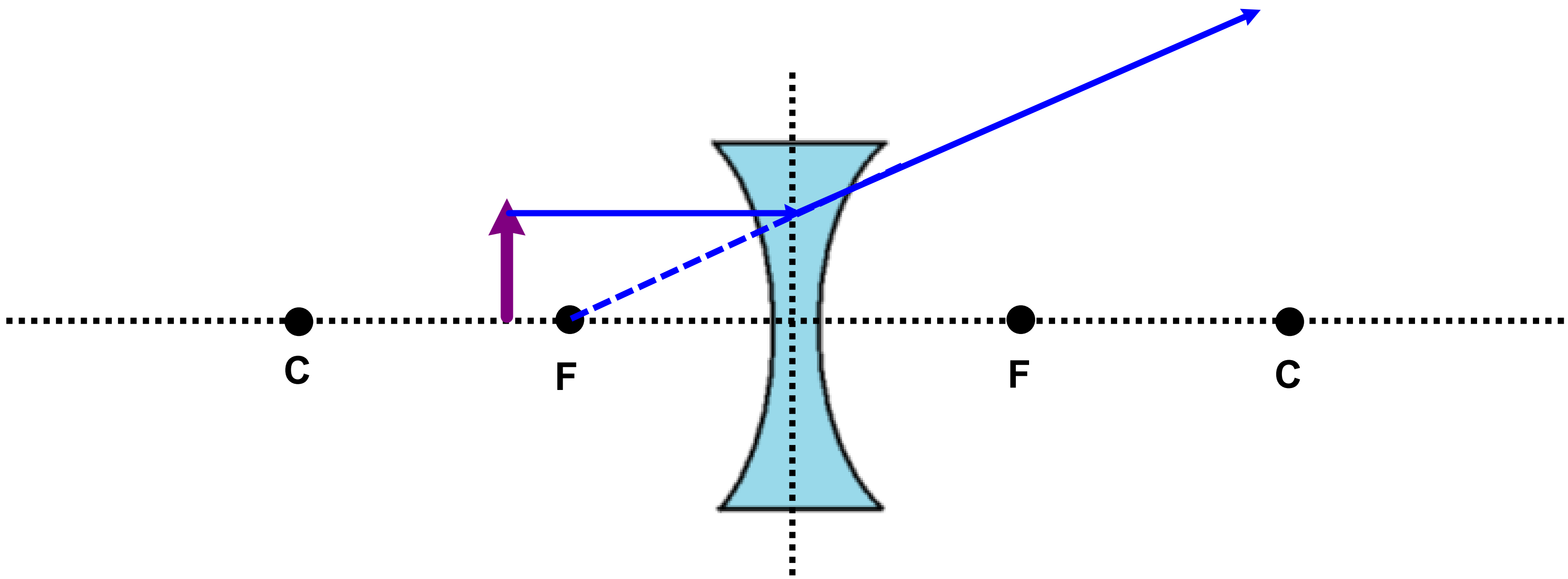
When the object is outside center of curvature...

The image is de-magnified, real, and inverted.



Thin Lenses and Ray Tracing

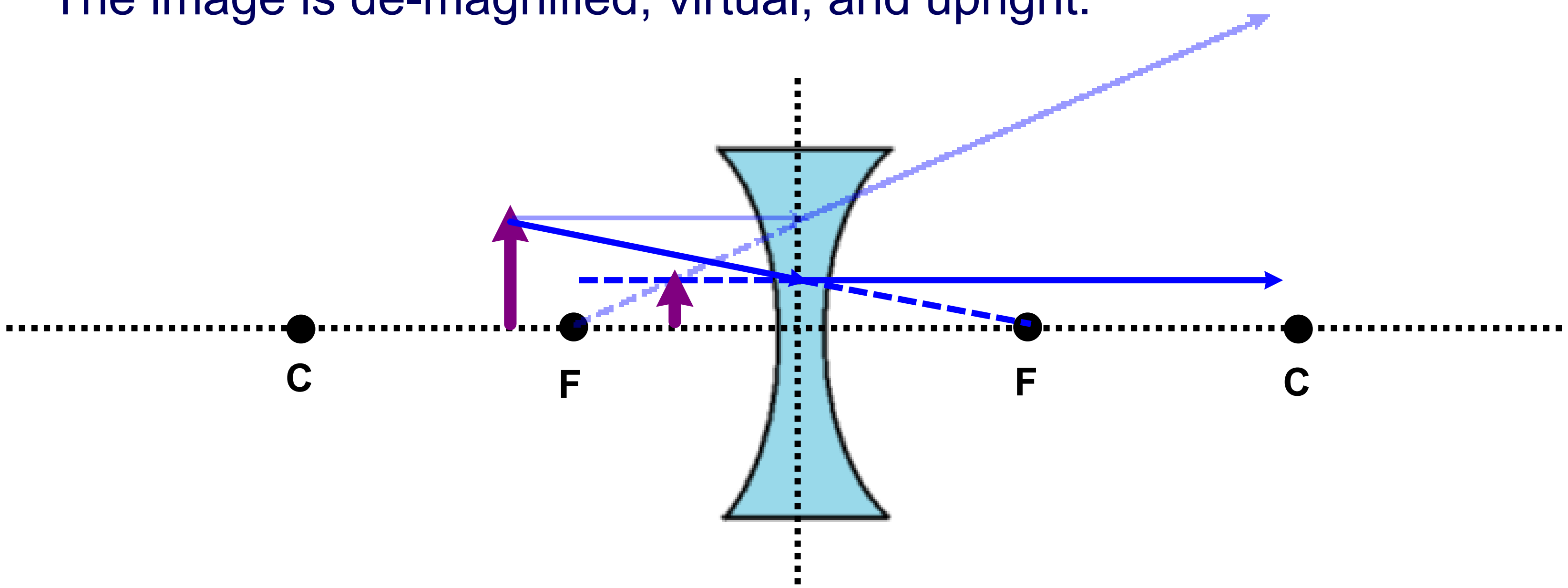
For a diverging lens, when the object is between the focal point and the center of curvature...



Thin Lenses and Ray Tracing

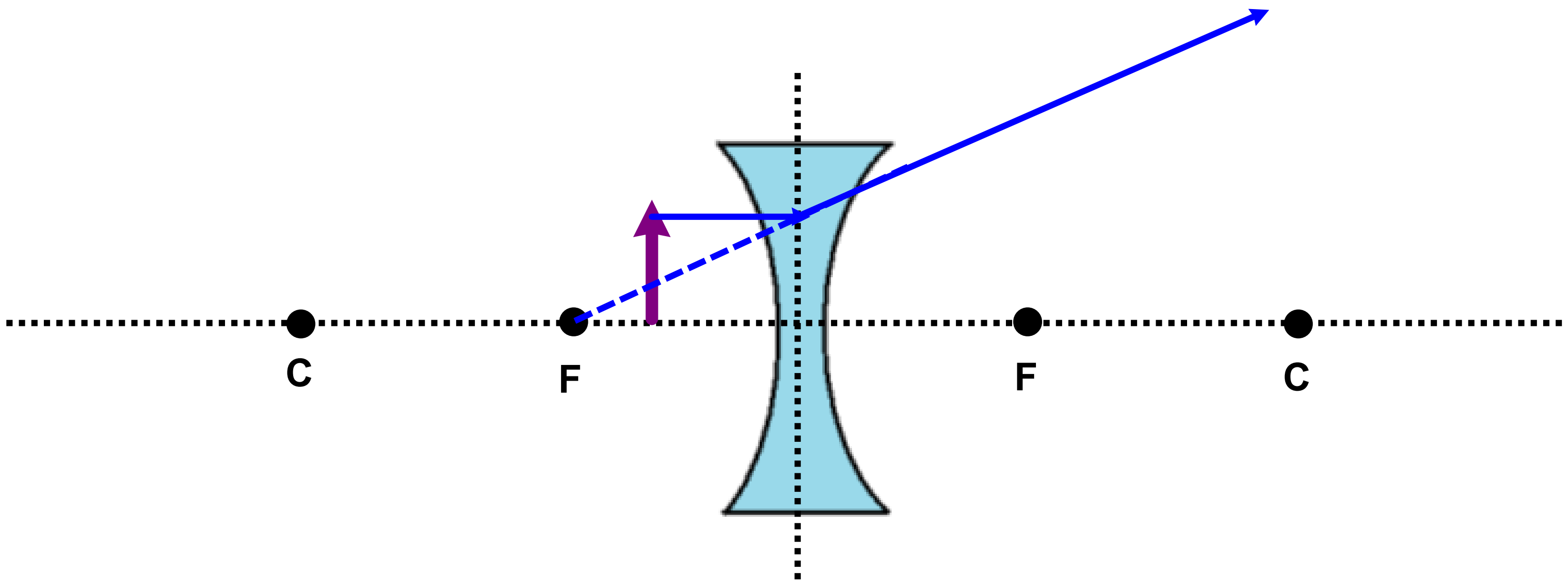
For a diverging lens, when the object is between the focal point and the center of curvature...

The image is de-magnified, virtual, and upright.



Thin Lenses and Ray Tracing

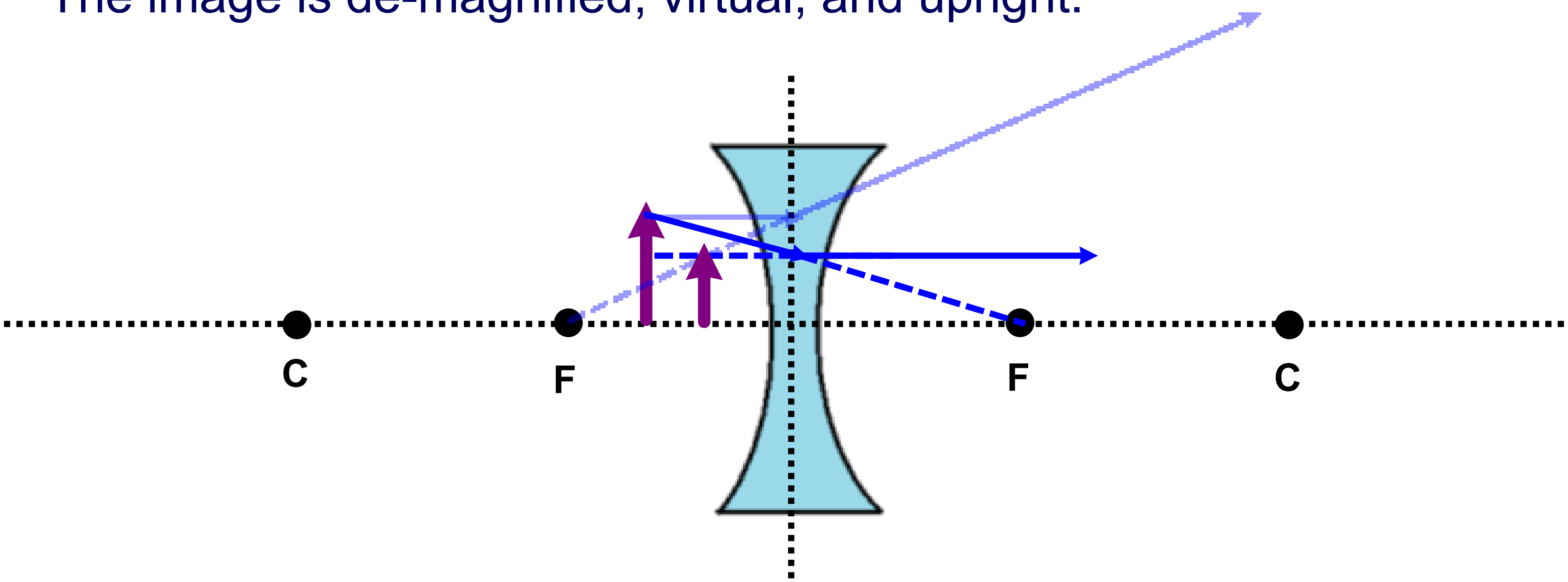
For a diverging lens, when the object is between the focal point and the center of curvature...



Thin Lenses and Ray Tracing

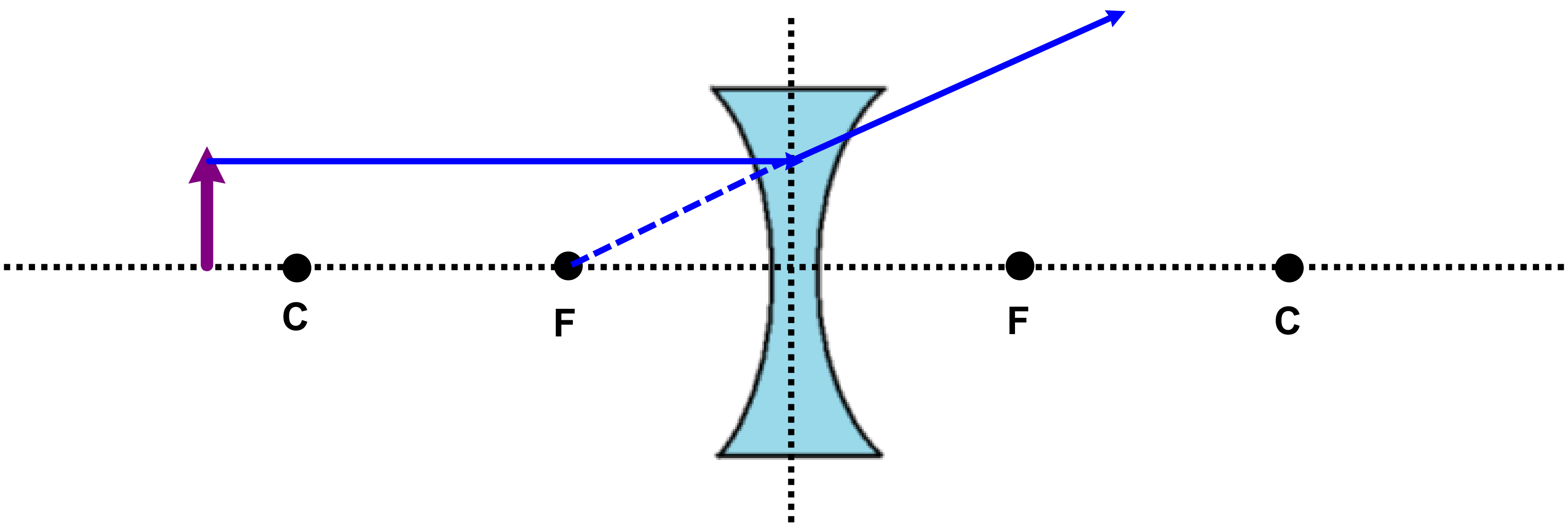
For a diverging lens, when the object is between the focal point and the center of curvature...

The image is de-magnified, virtual, and upright.



Thin Lenses and Ray Tracing

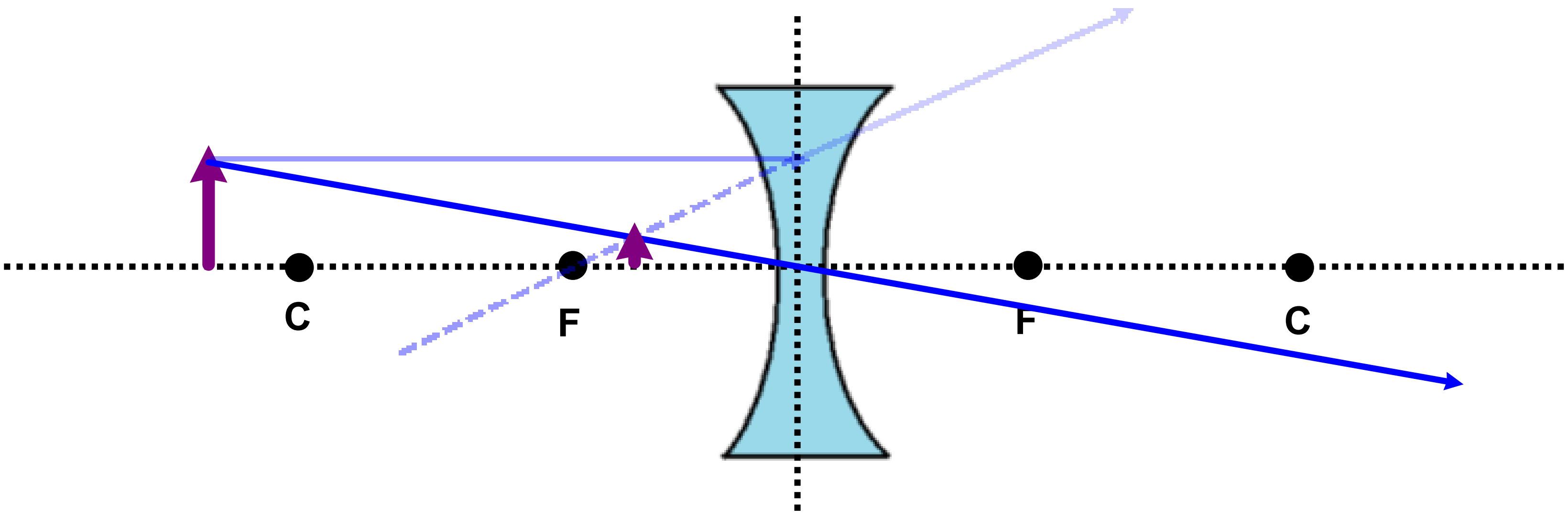
For a diverging lens, when the object is past the center of curvature...



Thin Lenses and Ray Tracing

For a diverging lens, when the object is past the center of curvature...

The image is de-magnified, virtual, and inverted.



Thin Lenses

The same equation that relates the object distance,image distance, and focal length for spherical mirrors, works for thin lenses.

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

Thin Lenses

The same equation that relates the object distance,image distance, and magnification for mirrors, works forthin lenses.

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

It works for power as well. The power is positive if the lens is converging and negative if the lens is diverging.

9 Which of these lenses are diverging lenses?

- A I and V
- B II, III, and IV
- C II and III
- D III and IV
- E IV and V

Answer

9 Which of these lenses are diverging lenses?

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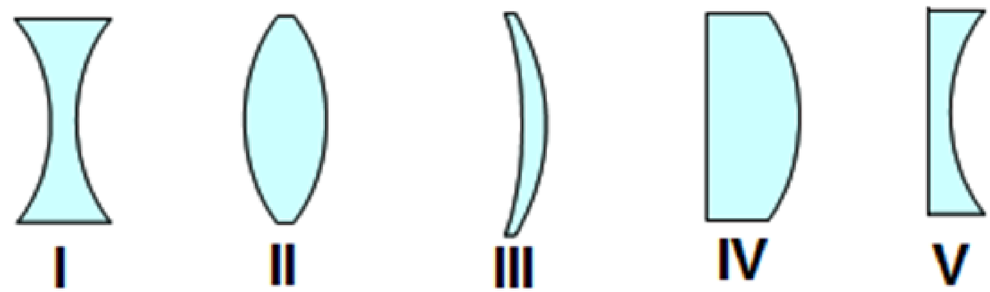

Answer

A

10 An object is placed in front of a converging lens at a distance less then the focal length. The image is:

- A real, inverted, and demagnified.
- B real, inverted, and magnified.
- C virtual, upright, and magnified.
- D virtual, upright, and demagnified.
- E virtual, inverted, and magnified.

Answer

10 An object is placed in front of a converging lens at a distance less then the focal length. The image is:

- A real, inverted, and demagnified.
- B real, inverted, and magnified.
- C virtual, upright, and magnified.
- D virtual, upright, and demagnified.
- E virtual, inverted, and magnified.

Answer

C

11 An object is placed 10 cm in front of a converging lens with a focal length of 6 cm. How far is the image from the lens?

Answer

11 An object is placed 10 cm in front of a converging lens with a focal length of 6 cm. How far is the image from the lens?

Answer

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

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

$$\frac{1}{d_i} = \frac{1}{6cm} - \frac{1}{10cm} = \frac{4}{60cm}$$

$$d_i = 15cm$$

12 An object is placed 10 cm in front of a converging lens with a focal length of 6 cm. The object has a height if 5 cm. What is the height of the image? (Use the answer to the previous question to answer this one.)

Answer

12 An object is placed 10 cm in front of a converging lens with a focal length of 6 cm. The object has a height if 5 cm. What is the height of the image? (Use the answer to the previous question to answer this one.)

Answer

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

$$h_i = \frac{d_i h_o}{d_o} = \frac{(15cm)(5cm)}{(10cm)}$$

$$h_i = 7.5cm$$

Summary

Index of refraction: $n = \frac{c}{v}$

Focal length: $f = \frac{r}{2}$

Mirror/Lens Equation: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

Magnification: $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$