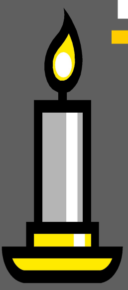
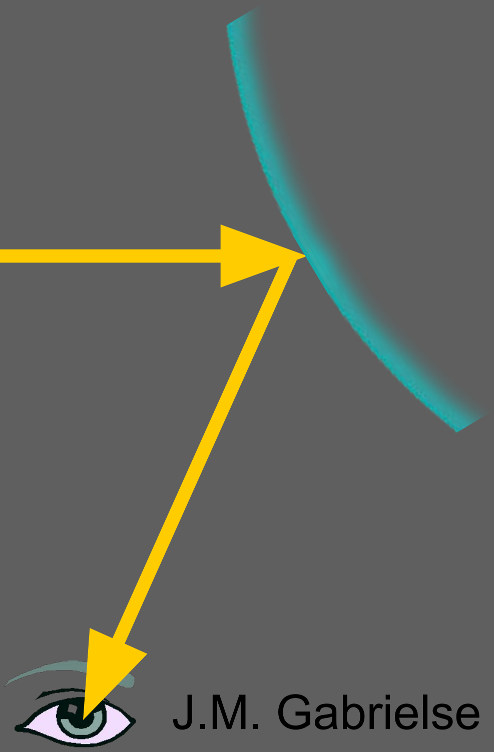
Images, Mirrors and Lenses
Adapted from J.M. Gabreilse
For Grade 11 Physics

Ray Diagrams





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Objectives:

- To draw ray diagrams
- To see how real and virtual images are formed
- To use different object distances and focal lengths to create different sized images
- To gain a working knowledge of the terms: **real image**, **virtual image**, **upright**, **inverted**, **magnified** and **diminished**.

Real or Virtual Images

- **Real Images** are formed when light ray **do come together** to form an image.
- **Virtual images** are formed when light rays **seem to come together** to form an image.
- **Sight lines** are extensions of light rays needed to show the perceived virtual image.
- Sight lines are **dashed lines in ray diagrams**.

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Symbols Used

Designation	IB	British	Russian
Focal Length	d_f	f	F
Object distance	d_o	U	d
Image distance	d_i	V	f

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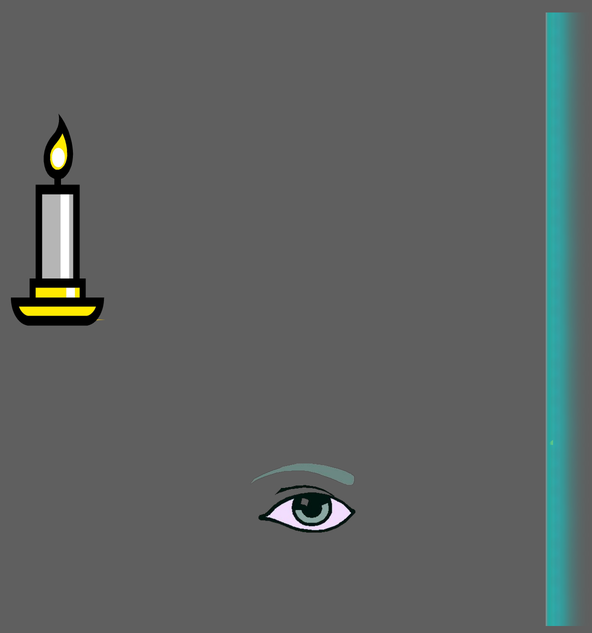
Plane Mirrors
(flat mirrors)



How do we see images in mirrors?

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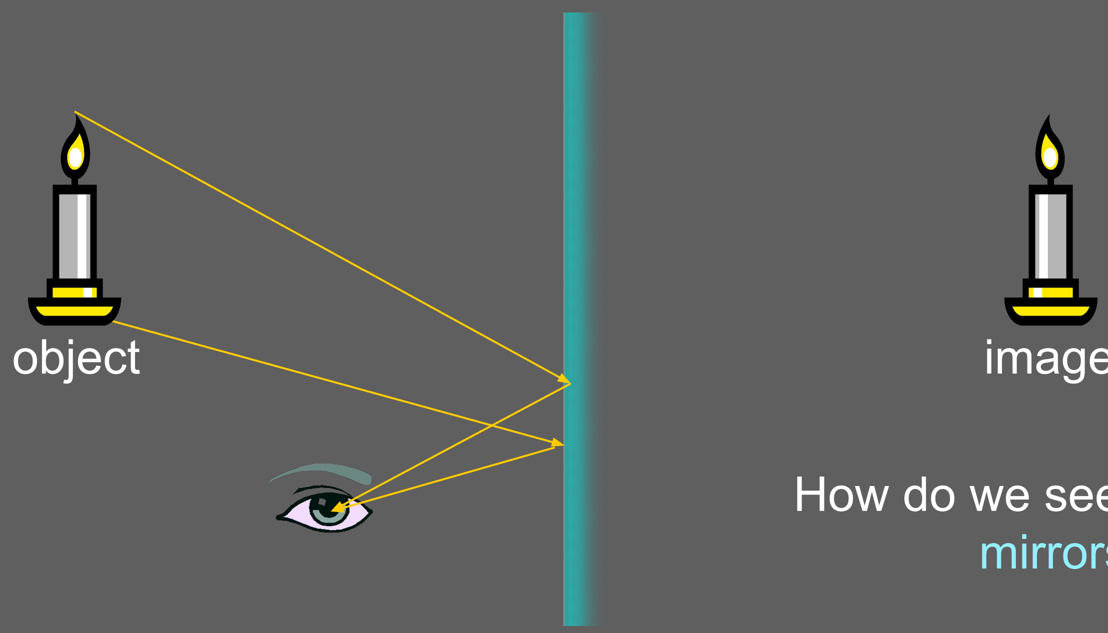
Plane Mirrors
(flat mirrors)



How do we see images in mirrors?

Light reflected off the mirror converges to form an image in the eye.

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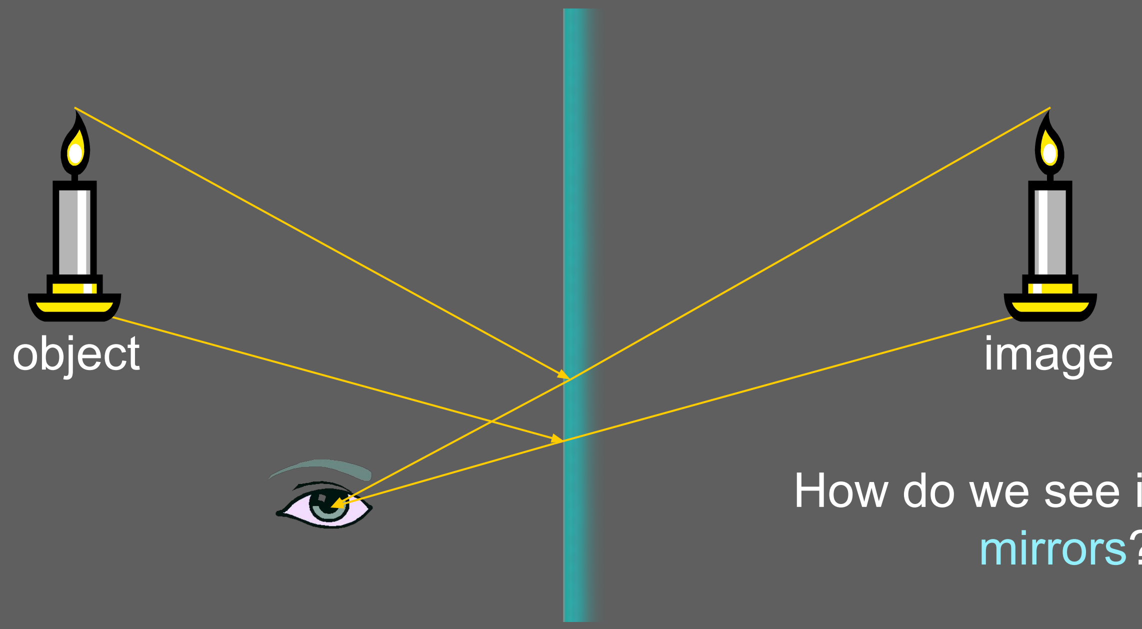
Plane Mirrors
(flat mirrors)



How do we see images in mirrors?

Light reflected off the mirror converges to form an image in the eye.

The eye perceives light rays as if they came through the mirror.

Imaginary light rays extended behind mirrors are called sight lines.

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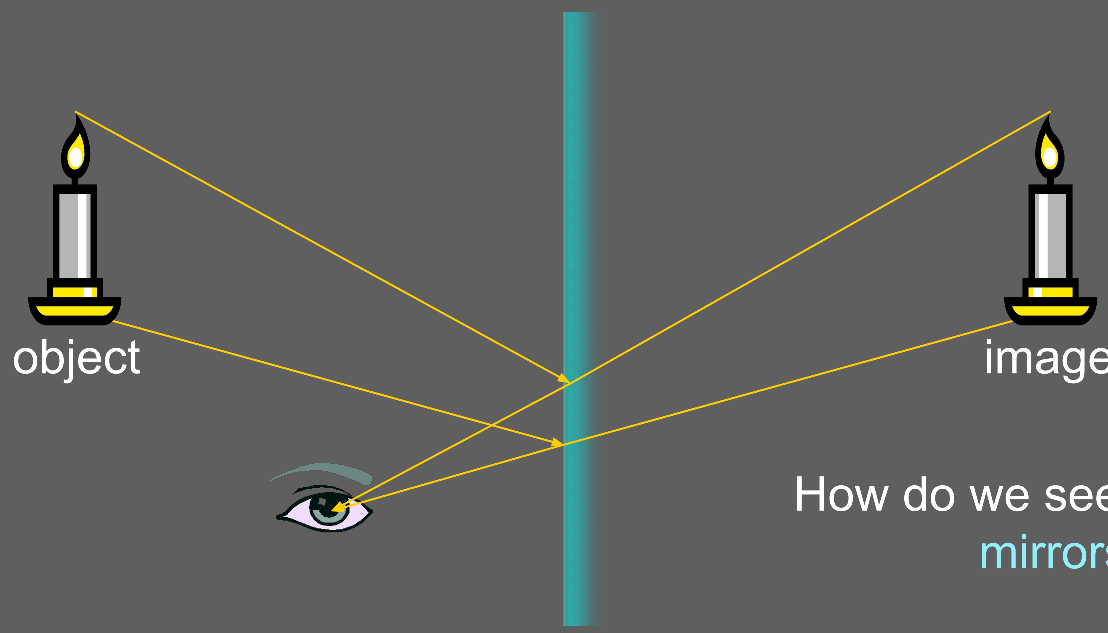
Plane Mirrors
(flat mirrors)



How do we see images in mirrors?

Light reflected off the mirror converges to form an image in the eye.

The eye perceives light rays as if they came through the mirror.

Imaginary light rays extended behind mirrors are called sight lines.

Image is virtual since it is formed by **imaginary sight lines, not real light rays**.

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Spherical Mirrors
(concave & convex)

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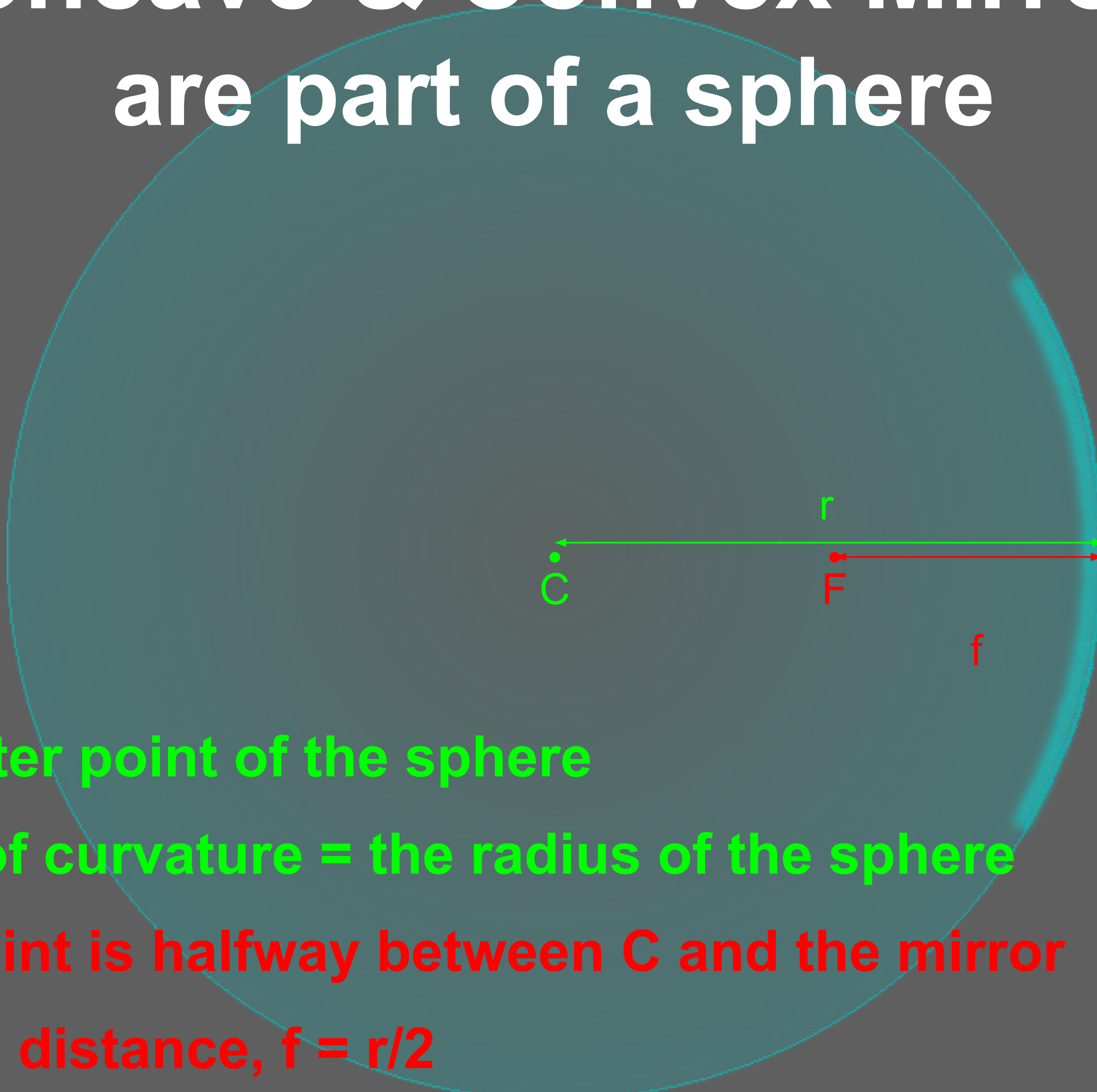
Concave & Convex Mirrors are part of a sphere



C: the center point of the sphere

r: radius of curvature = the radius of the sphere

F: focal point is halfway between C and the mirror

f: the focal distance, f = r/2

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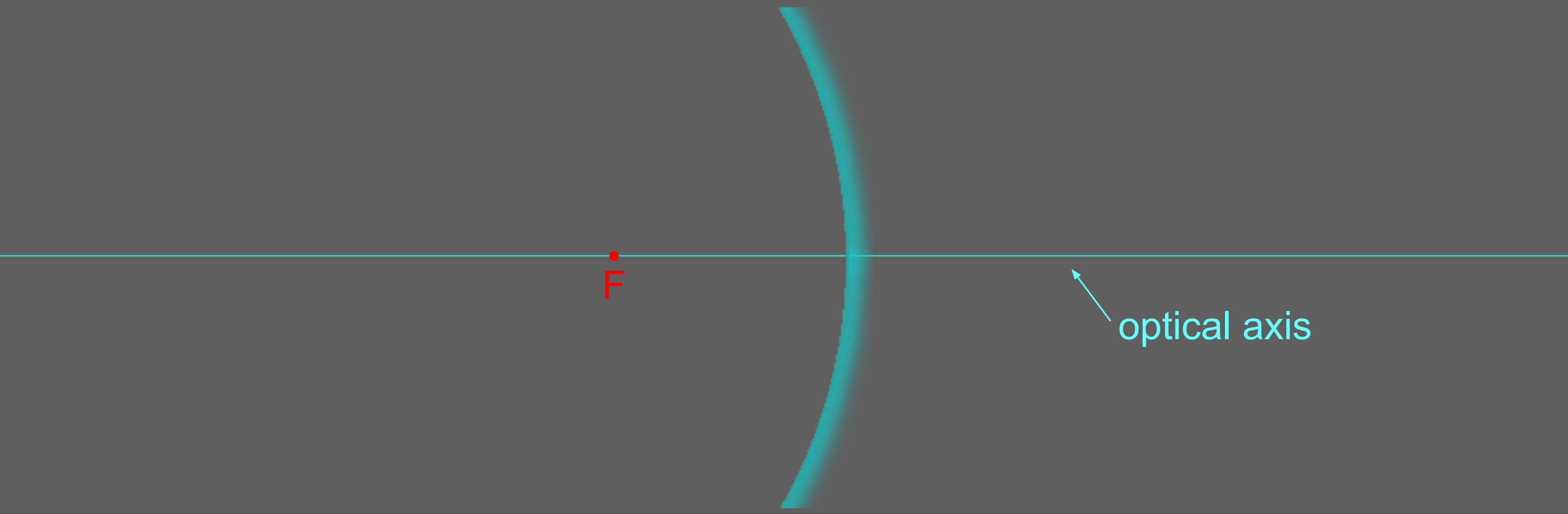
Concave Mirrors
(caved in)



Light rays that come in parallel to the optical axis reflect through the focal point.

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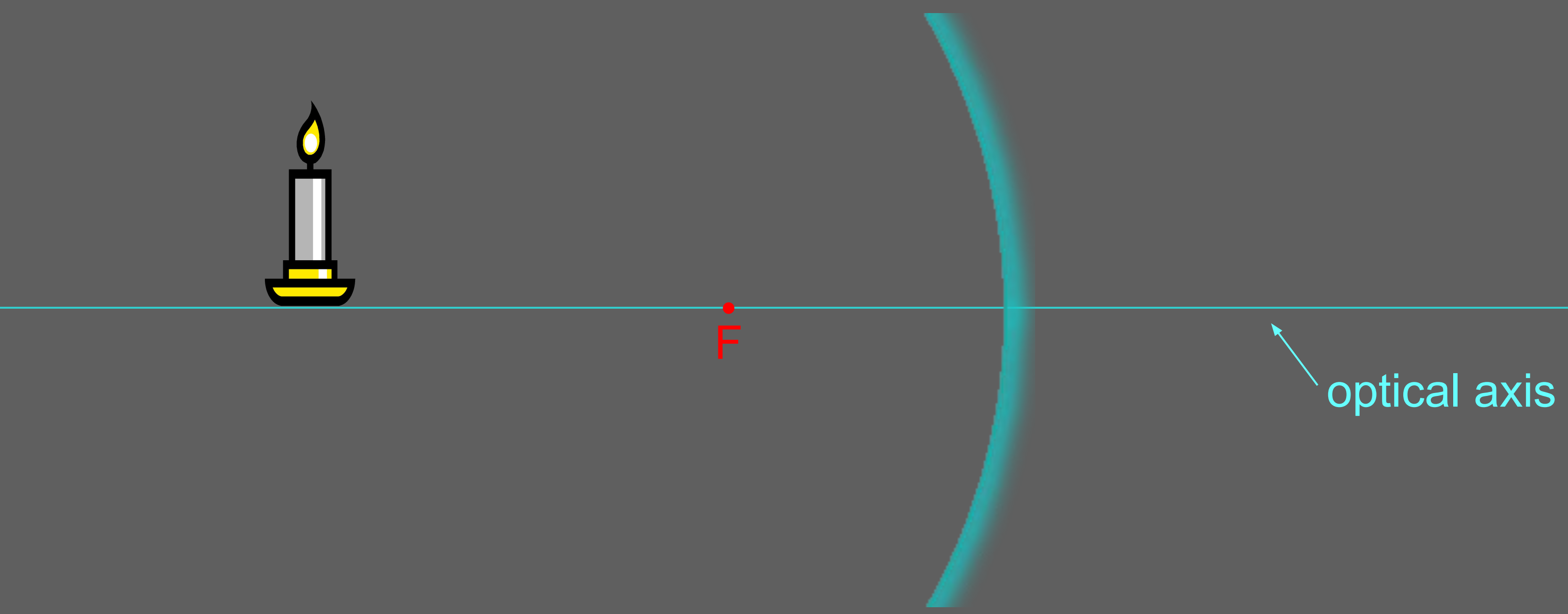
Concave Mirror

(Object distance: $d_o > d_f$)



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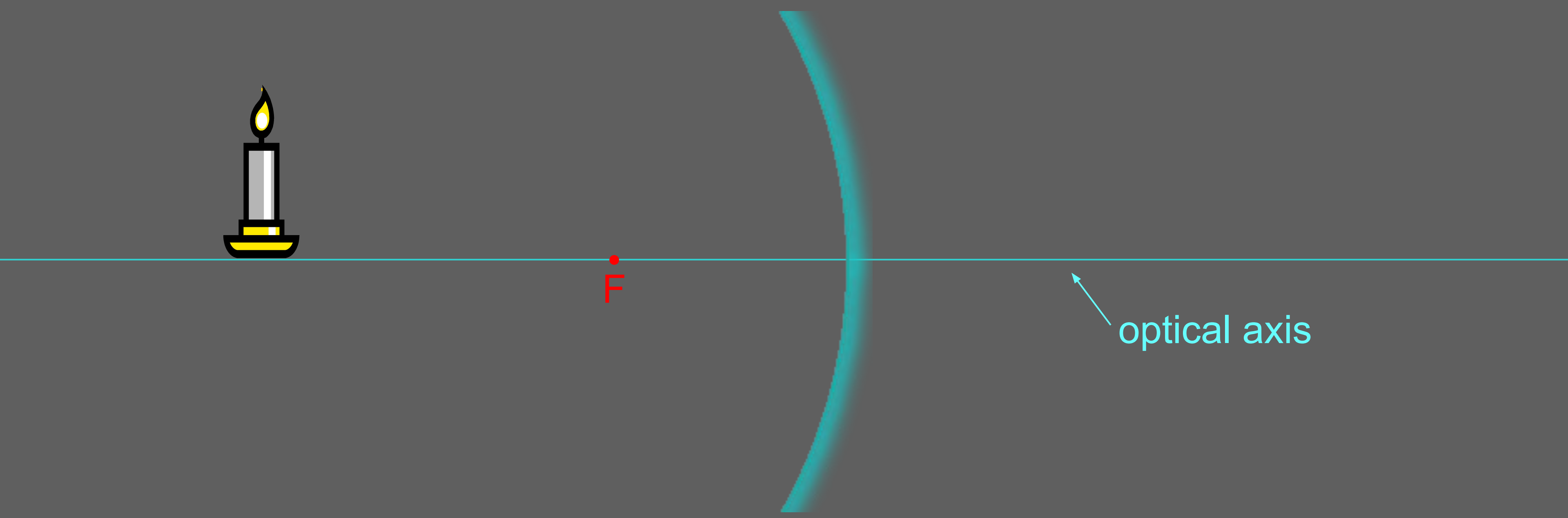
Concave Mirror

(Object distance: $d_o > d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

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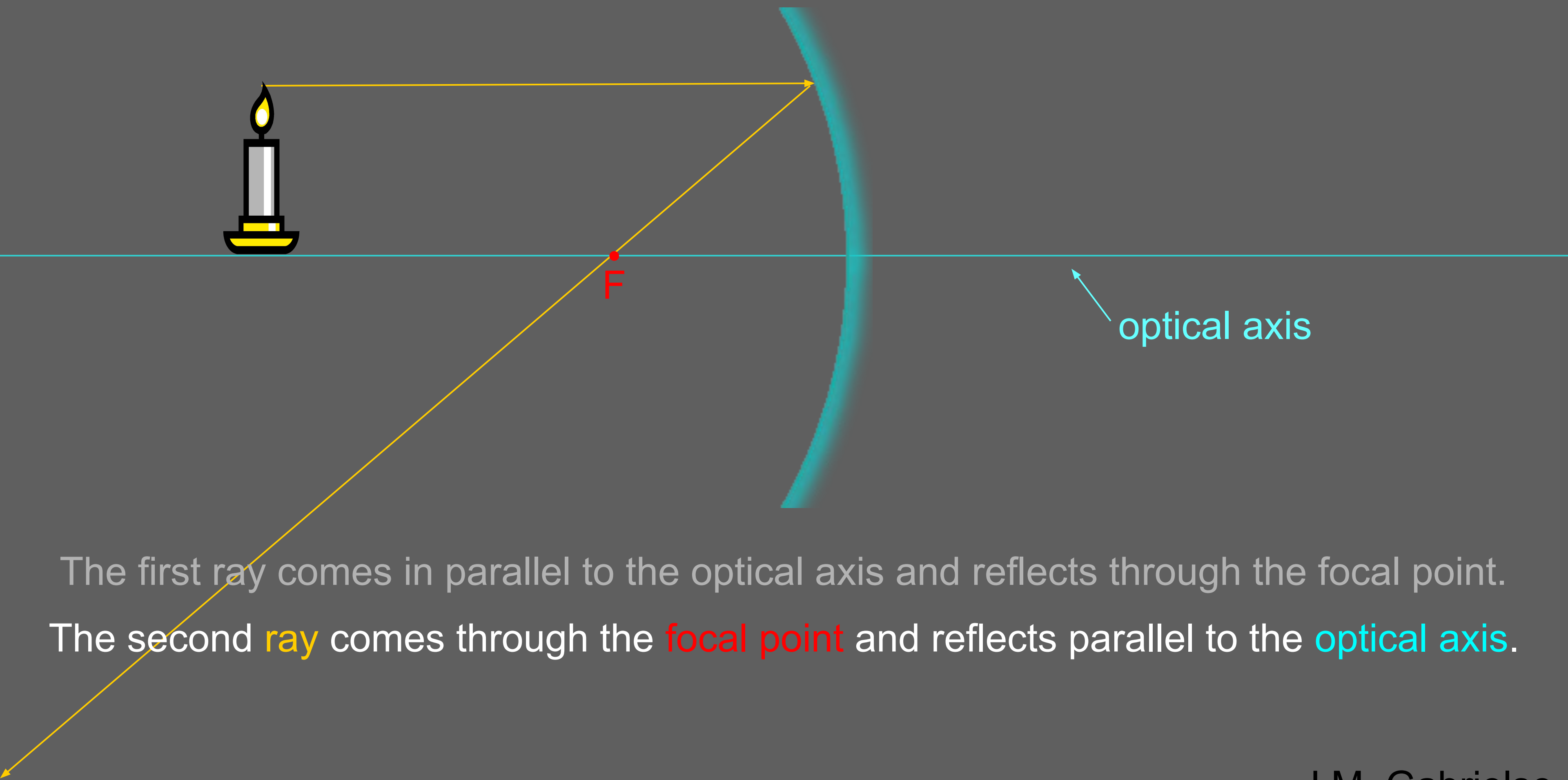
Concave Mirror

(Object distance: $d_o > d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

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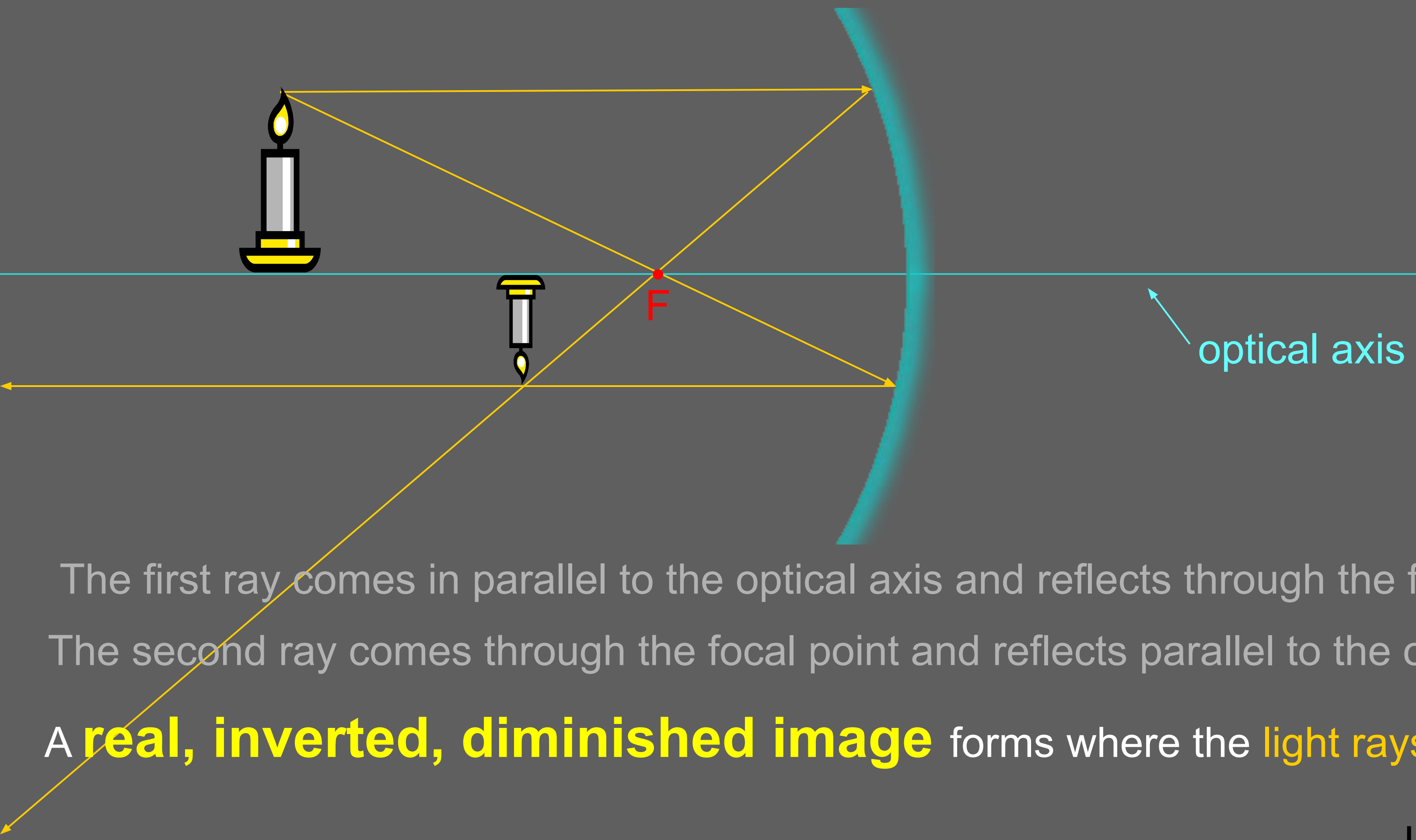
Concave Mirror
(Object distance: $d_o > d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

A **real, inverted, diminished image** forms where the light rays converge.

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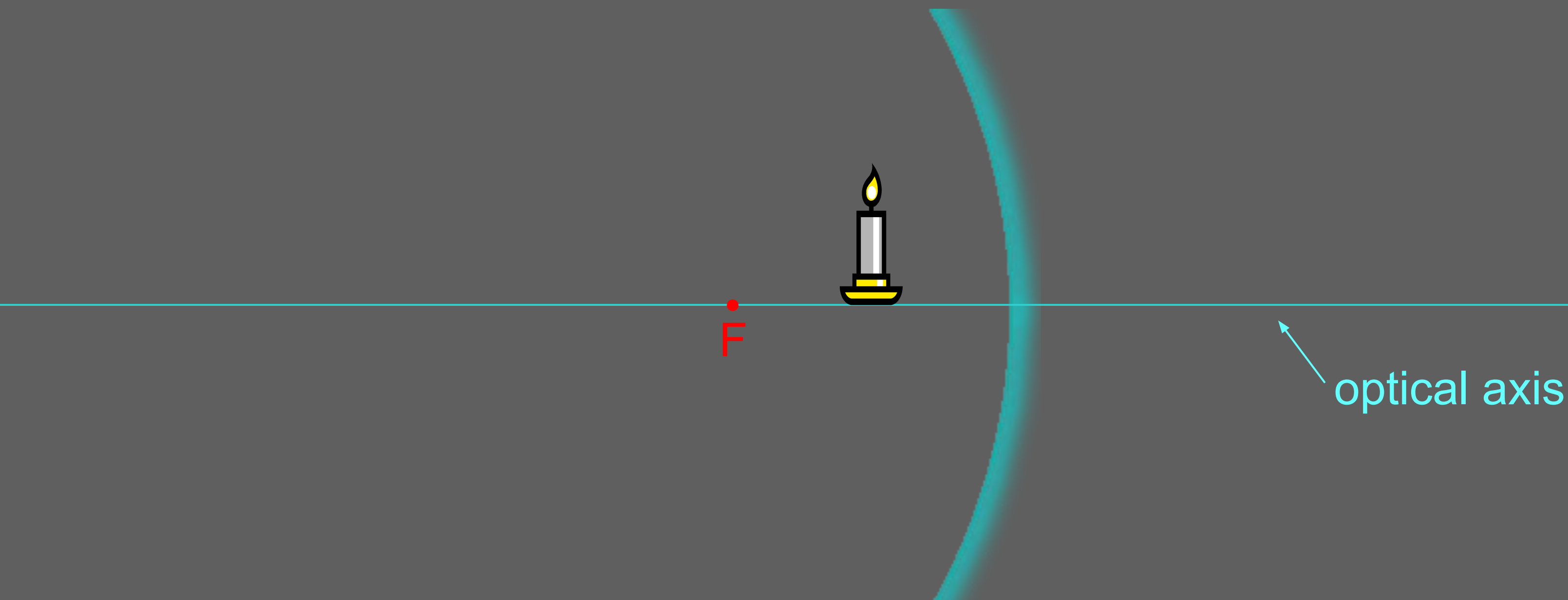
Concave Mirror
(Object distance: $d_o < d_f$)



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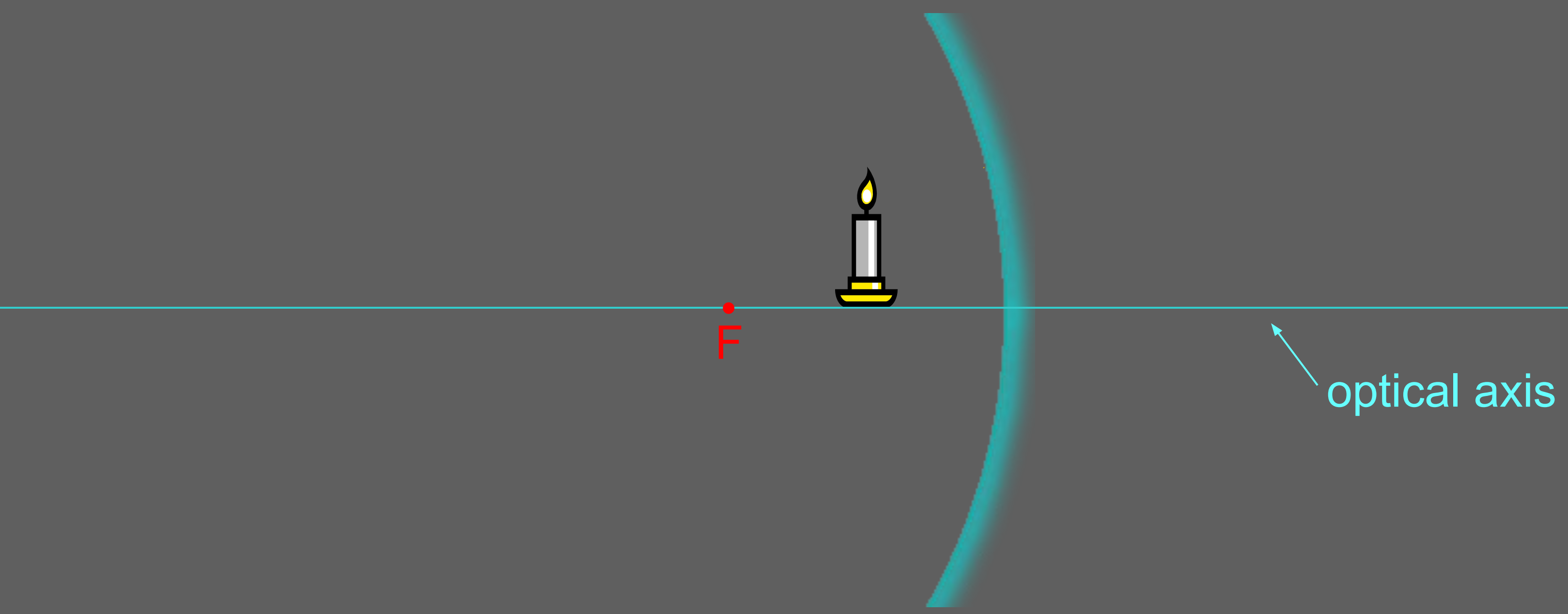
Concave Mirror

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

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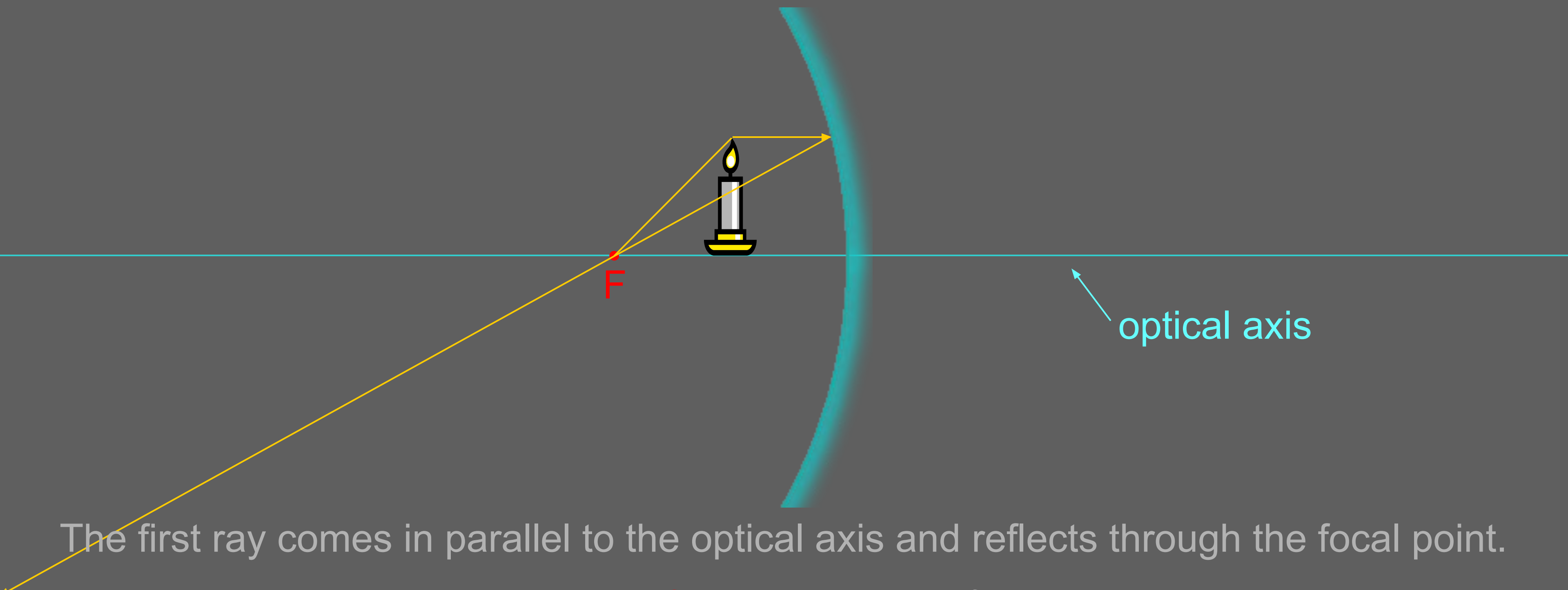
Concave Mirror

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

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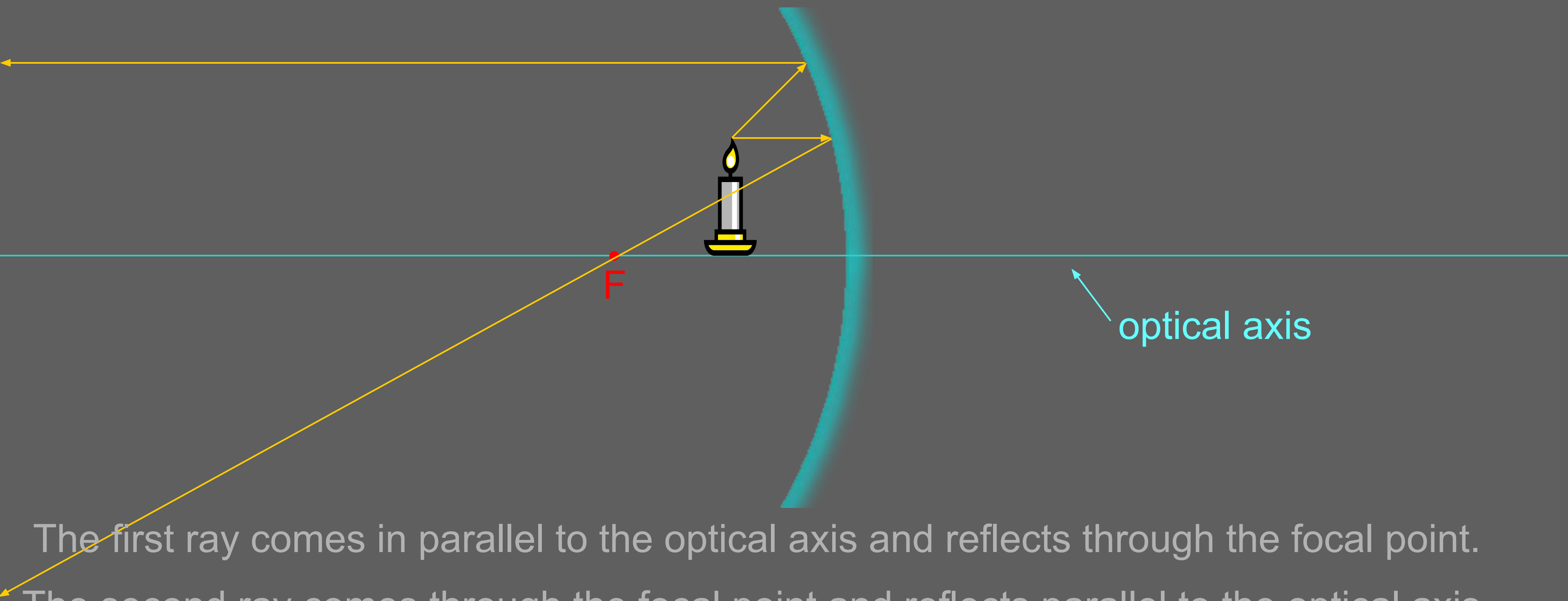
Concave Mirror

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

The image forms where the rays converge. But they don't seem to converge.

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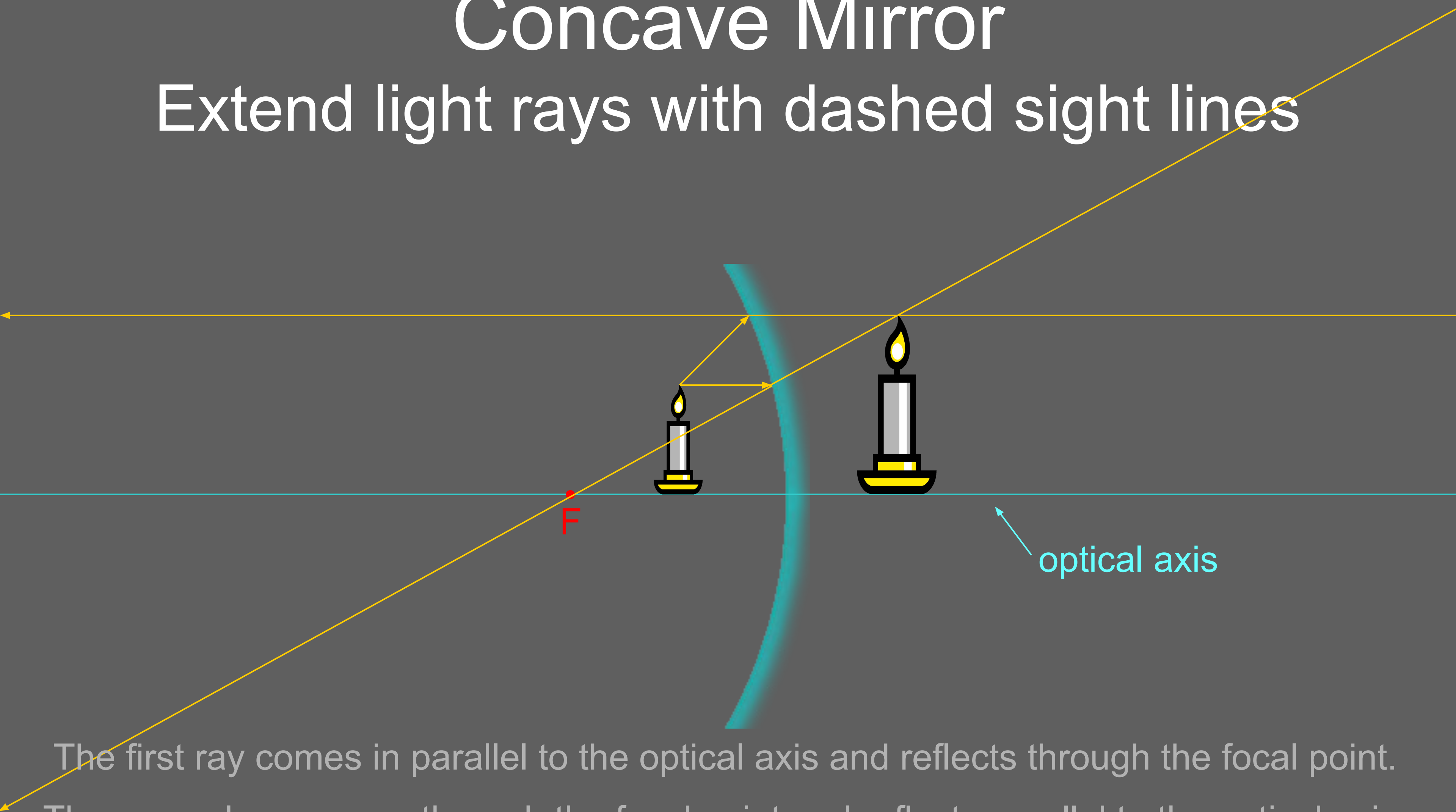
Concave Mirror

Extend light rays with dashed sight lines



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

A **virtual, upright, magnified image** forms where the sight rays converge.

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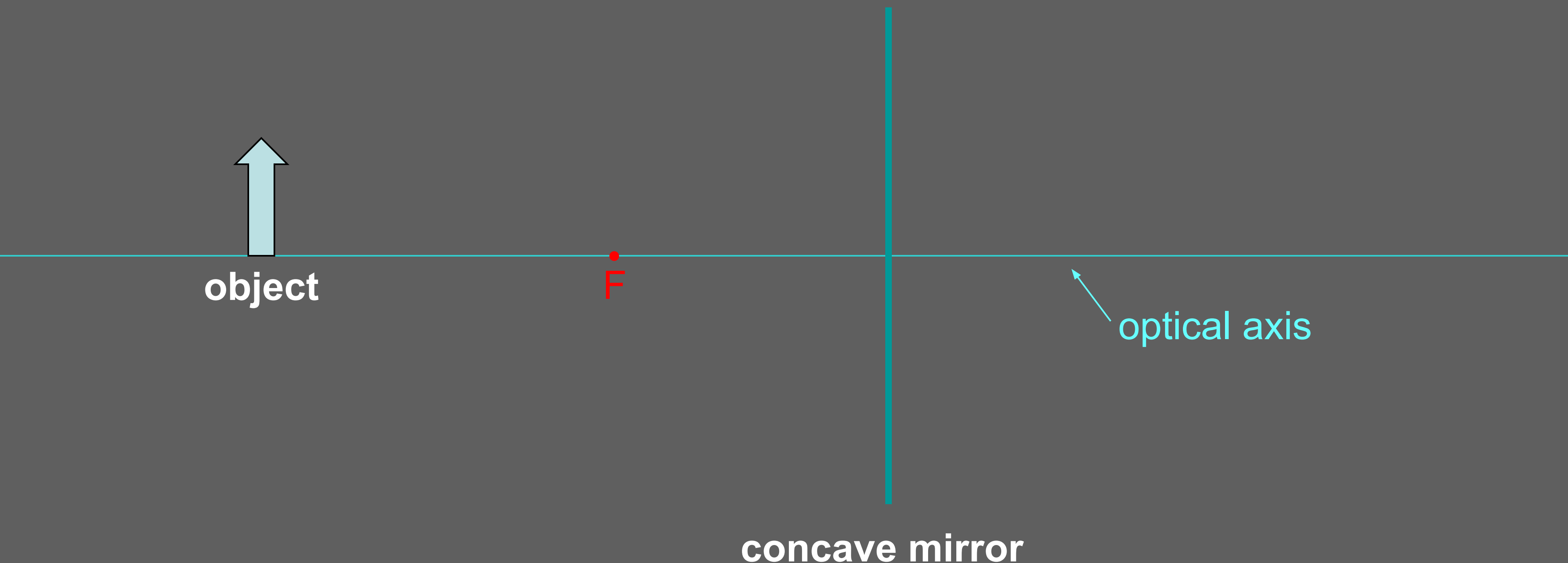
Your Turn
(Object distance $d_o > 2d_f$)



- Note: mirrors are thin enough that you just draw a line to represent the mirror
- **Locate the image of the arrow**

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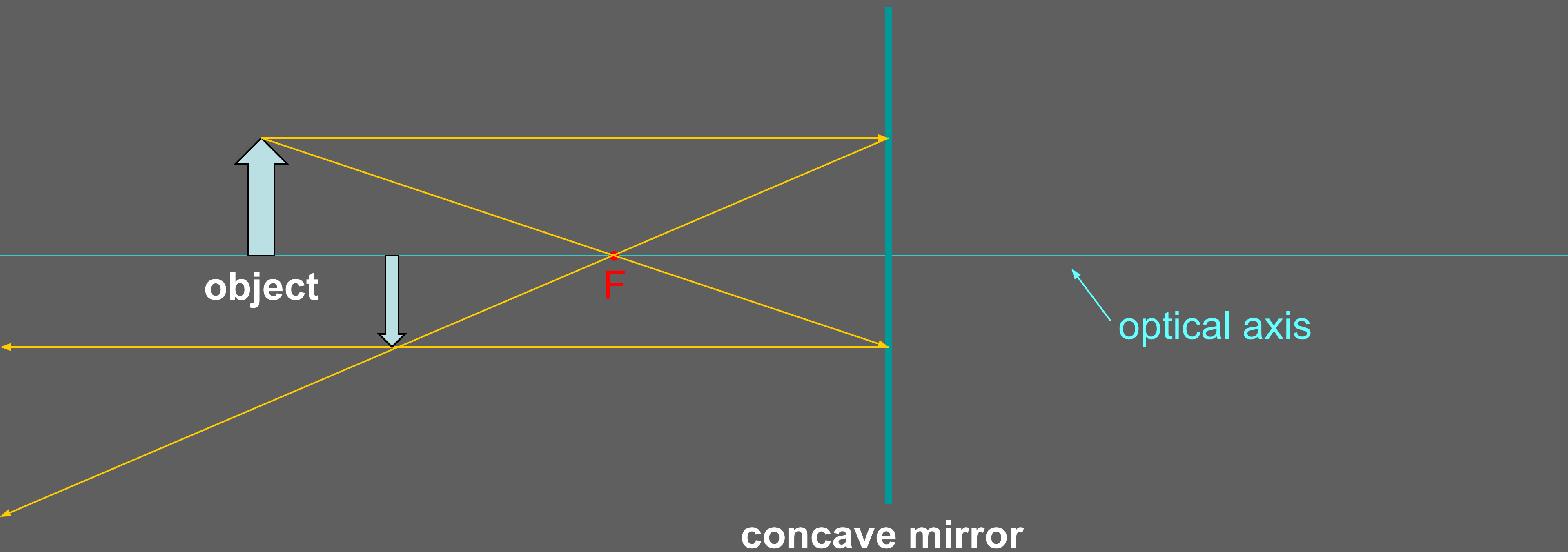
Your Turn
(Object distance: $d_o > 2d_f$)



- Note: mirrors are thin enough that you just draw a line to represent the mirror
- **Locate the image of the arrow**

A real, inverted same size image is formed.

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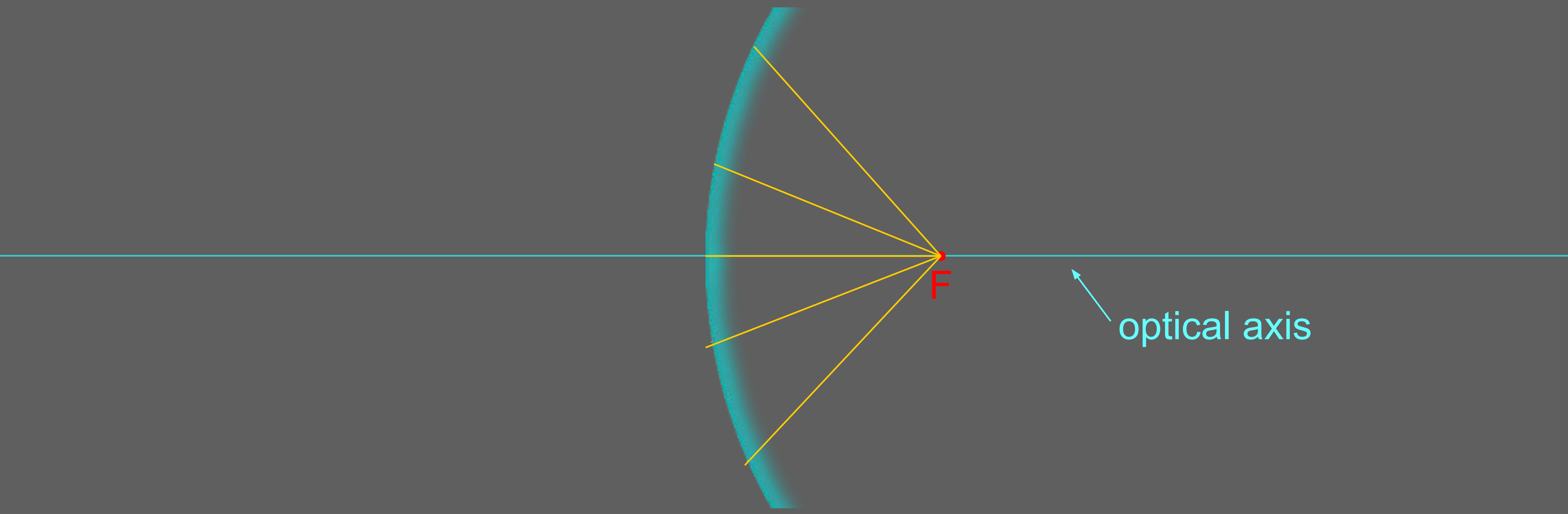
Convex Mirrors
(curved out)



Light rays that come in parallel to the optical axis reflect from the focal point.

The focal point is considered virtual since sight lines, not light rays, go through it.

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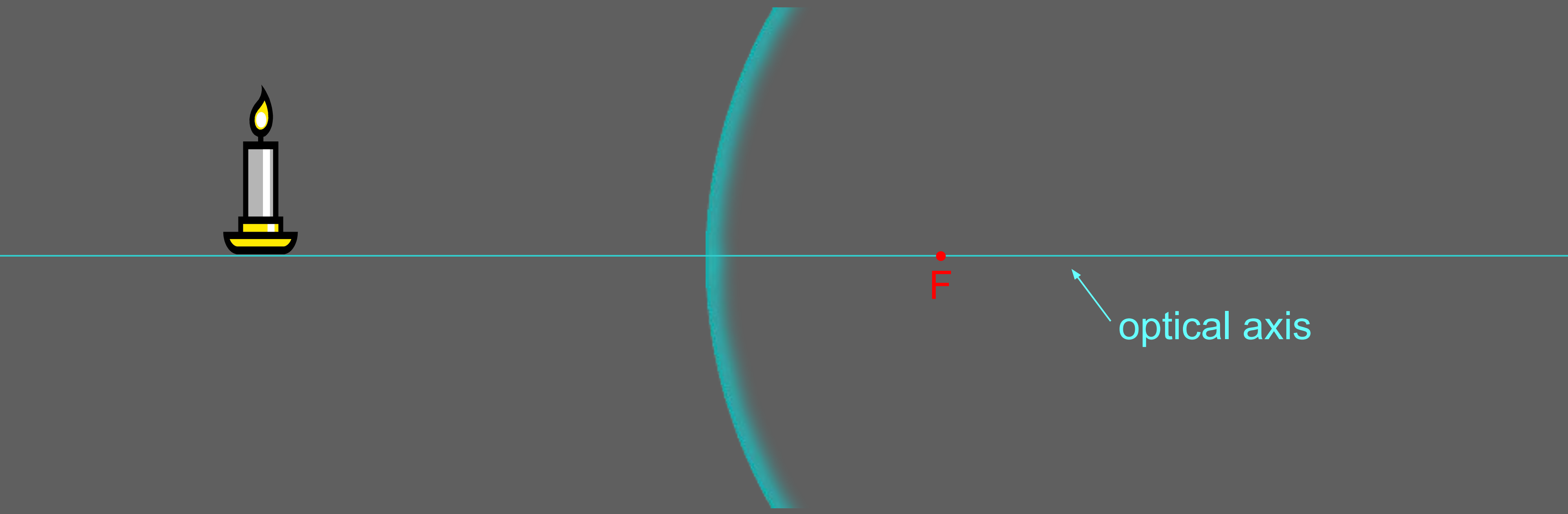
Convex Mirror
(Object distance $d_o > 2d_f$)



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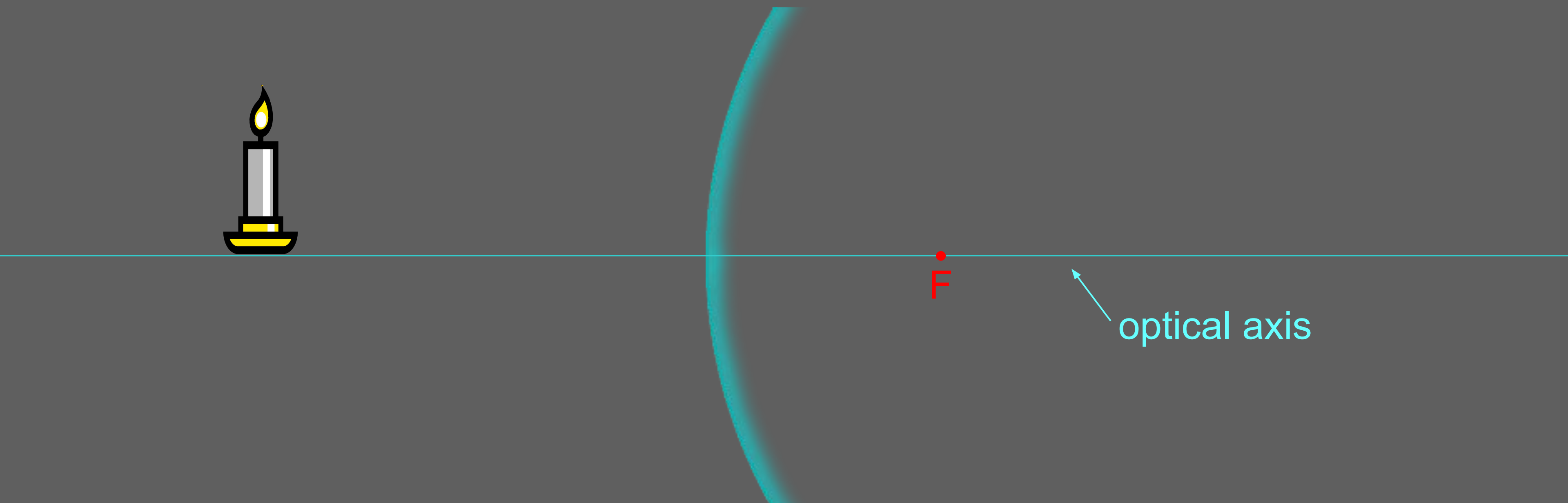
Convex Mirror

(Object distance: $d_o > 2d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

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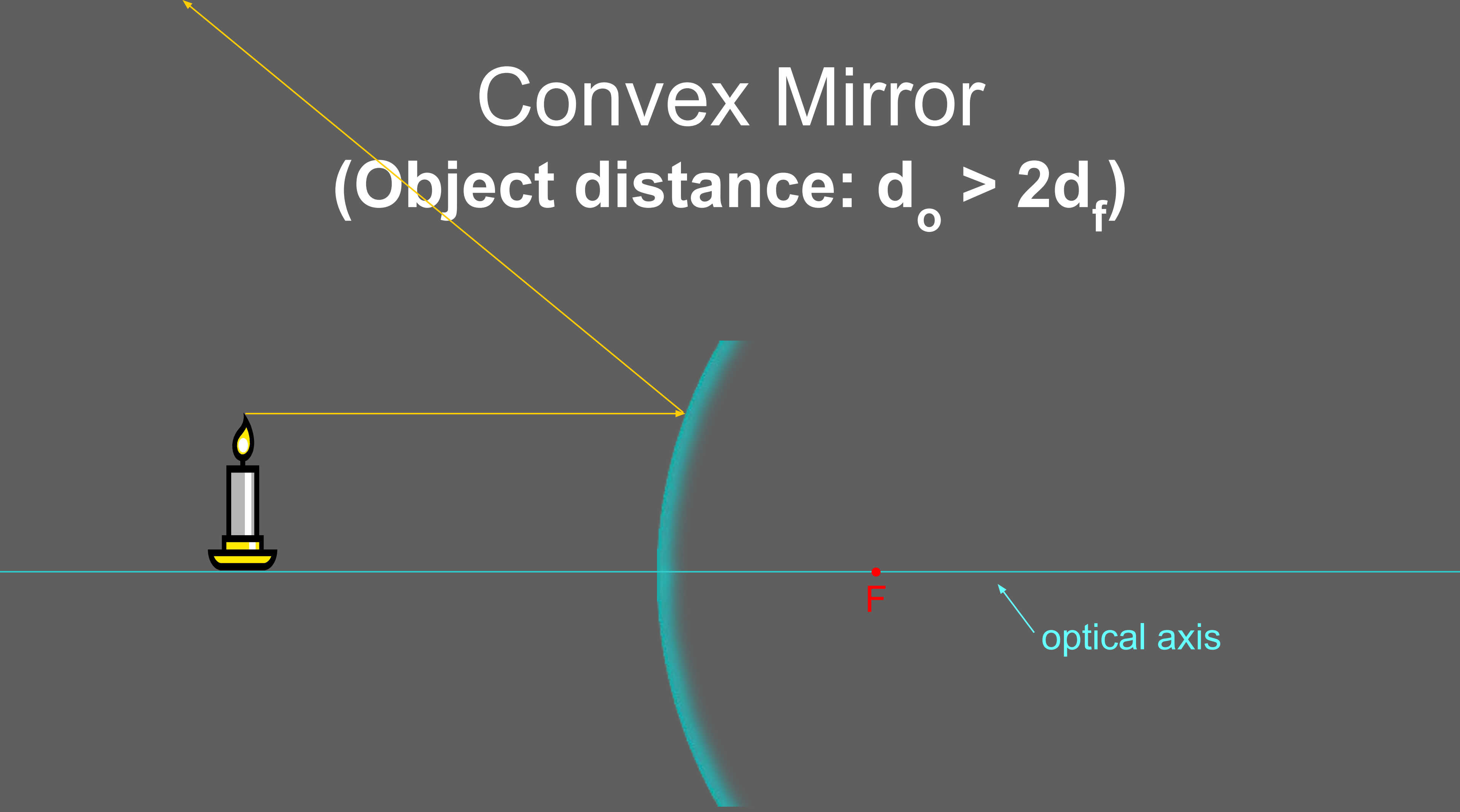
Convex Mirror

(Object distance: $d_o > 2d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

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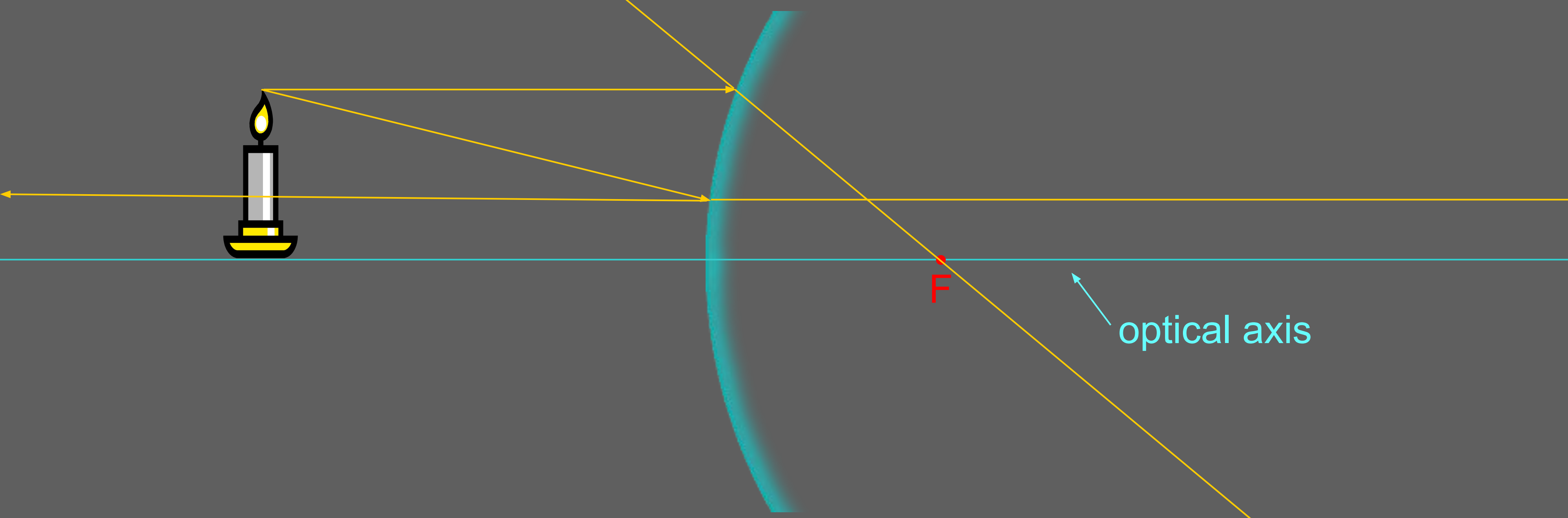
Convex Mirror

(Object distance: $d_o > 2d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

The light rays don’t converge, but the sight lines do.

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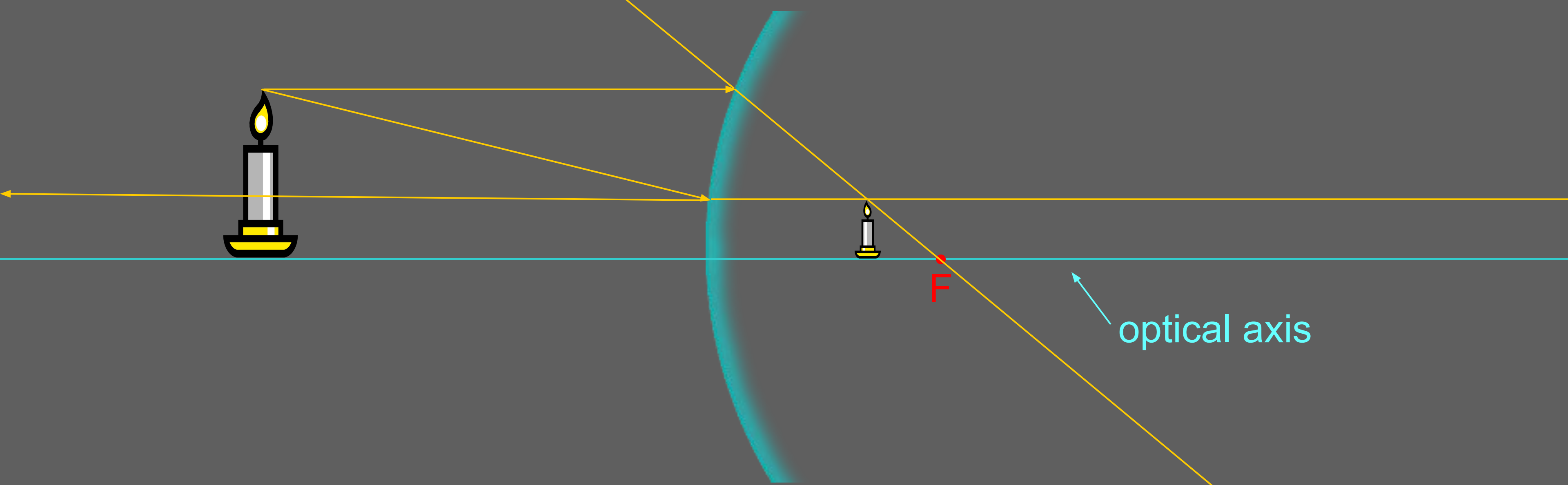
Convex Mirror

(Object distance: $d_o > 2d_f$)



The first ray comes in parallel to the optical axis and reflects through the focal point.

The second ray comes through the focal point and reflects parallel to the optical axis.

The light rays don't converge, but the sight lines do.

A **virtual, upright, diminished image** forms where the sight lines converge.

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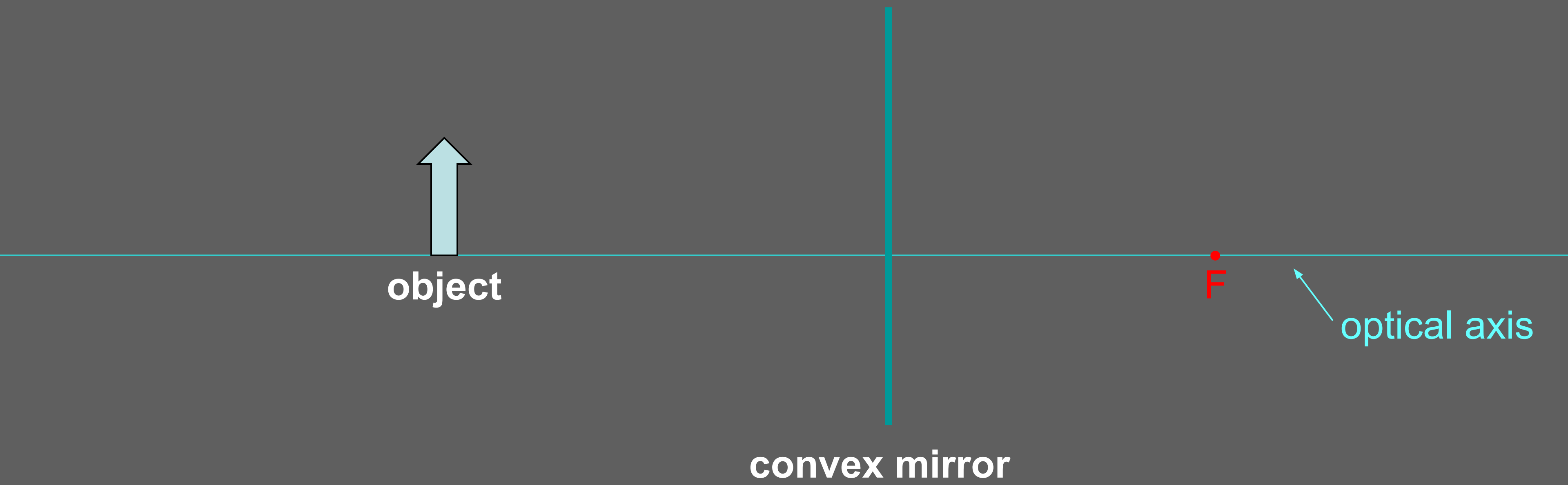
Your Turn
(Convex Mirror)



- Note: mirrors are thin enough that you just draw a line to represent the mirror
- **Locate the image of the arrow**

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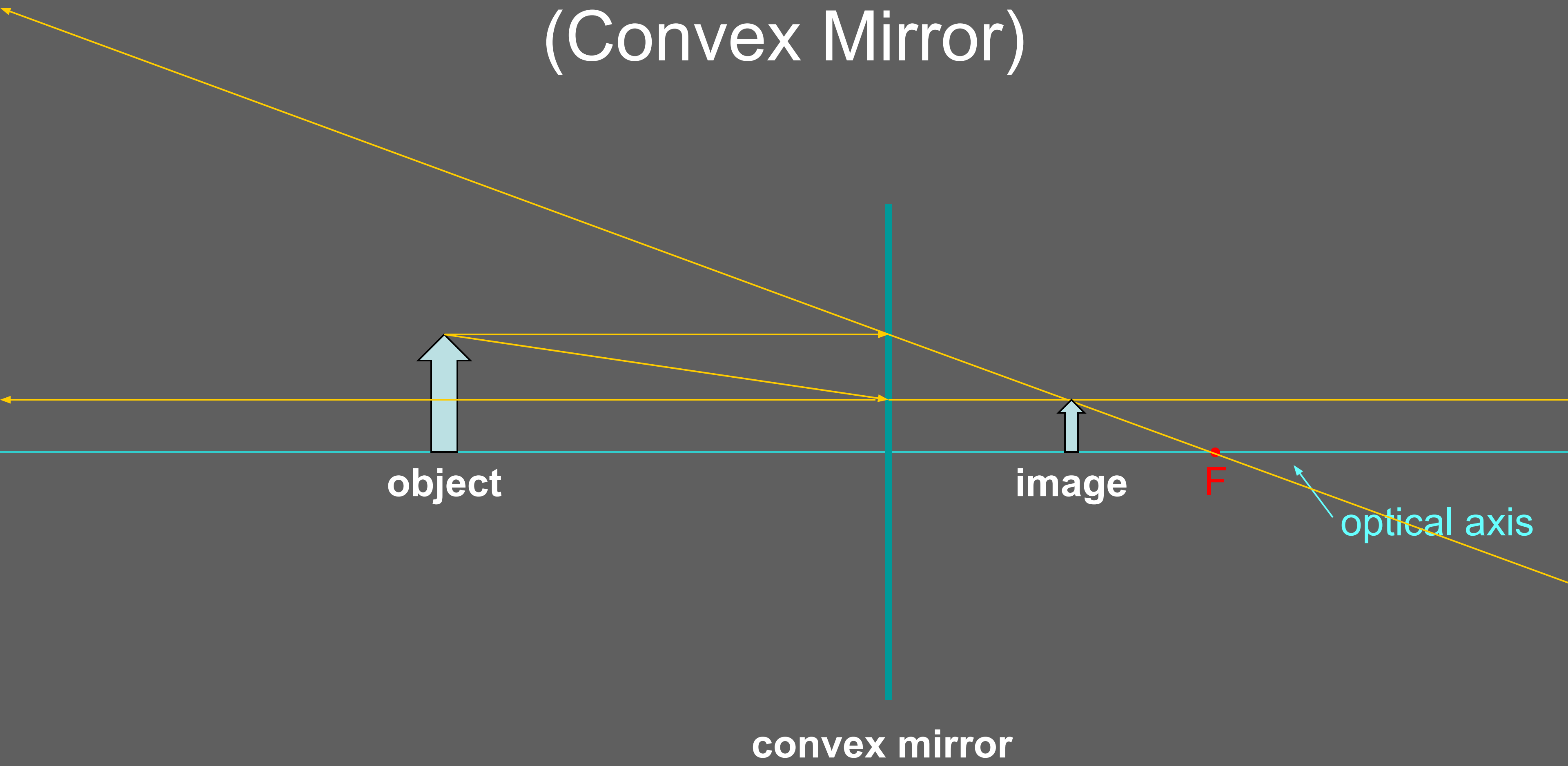
Your Turn
(Convex Mirror)



- Note: mirrors are thin enough that you just draw a line to represent the mirror
- **Locate the image of the arrow**

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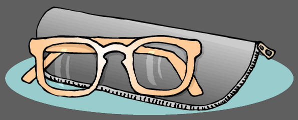

Lensmaker's Equation

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

f = focal length
d_o = object distance
d_i = image distance

if distance is negative the image is behind the mirror

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Magnification Equation

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

m = magnification
h_i = image height
h_o = object height

If height is negative the image is upside down

if the magnification is negative
the image is inverted (upside down)

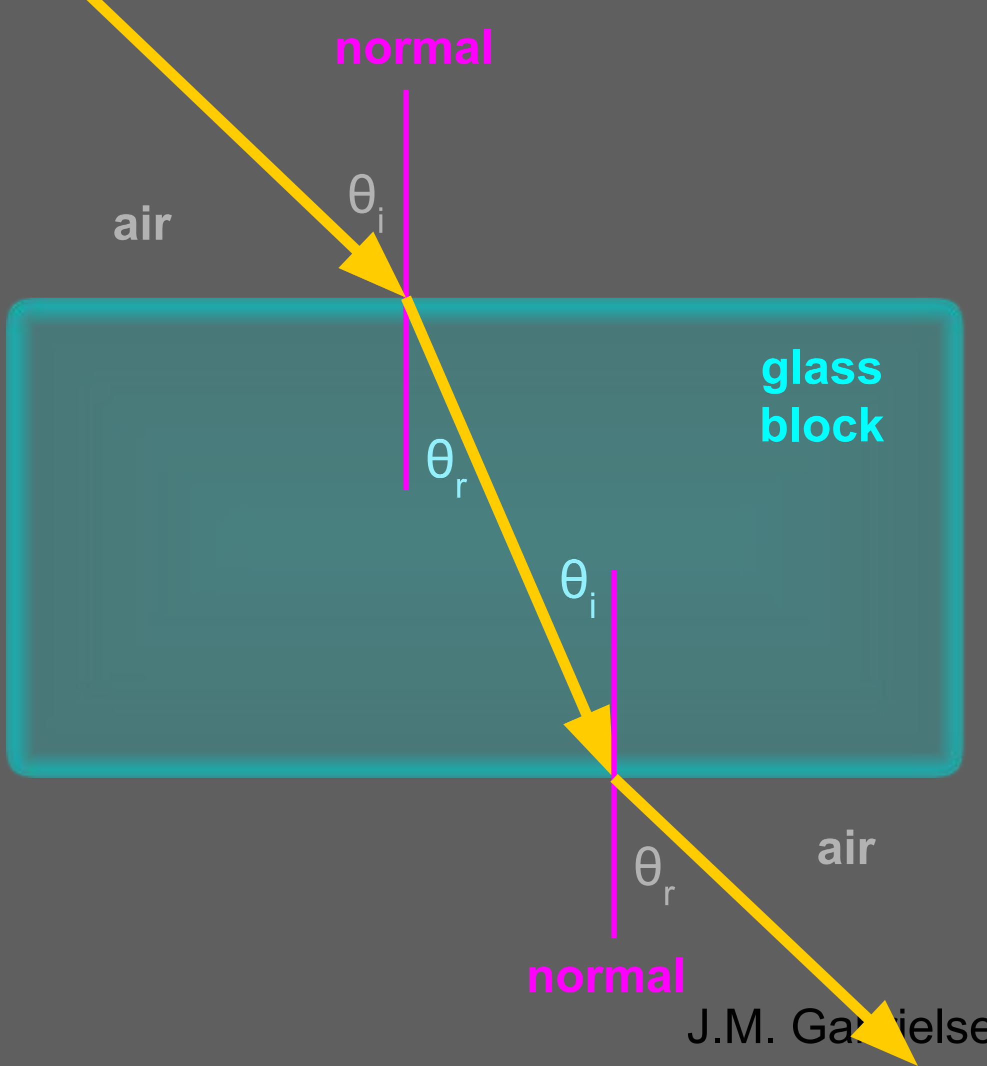
Refraction
(bending light)

Refraction is when light **bends** as it passes from one medium into another.

When light traveling through air passes into the glass block it is **refracted** towards the normal.

When light passes back out of the glass into the air, it is **refracted** away from the normal.

Since light **refracts** when it changes mediums it can be aimed. Lenses are shaped so light is aimed at a focal point.



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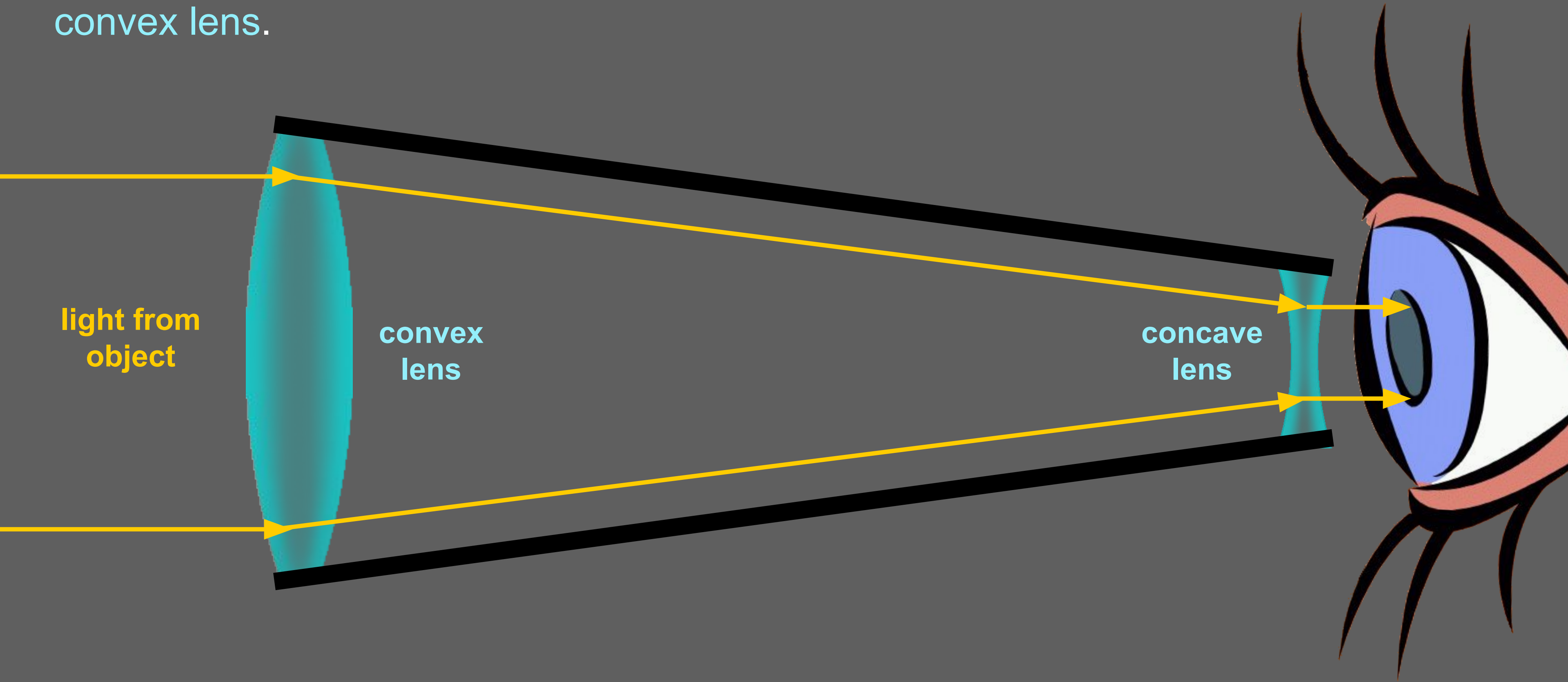
Lenses

The first telescope, designed and built by Galileo, used lenses to focus light from faraway objects, into Galileo's eye. His telescope consisted of a concave lens and a convex lens.



Light rays are always refracted (bent) towards the thickest part of the lens.

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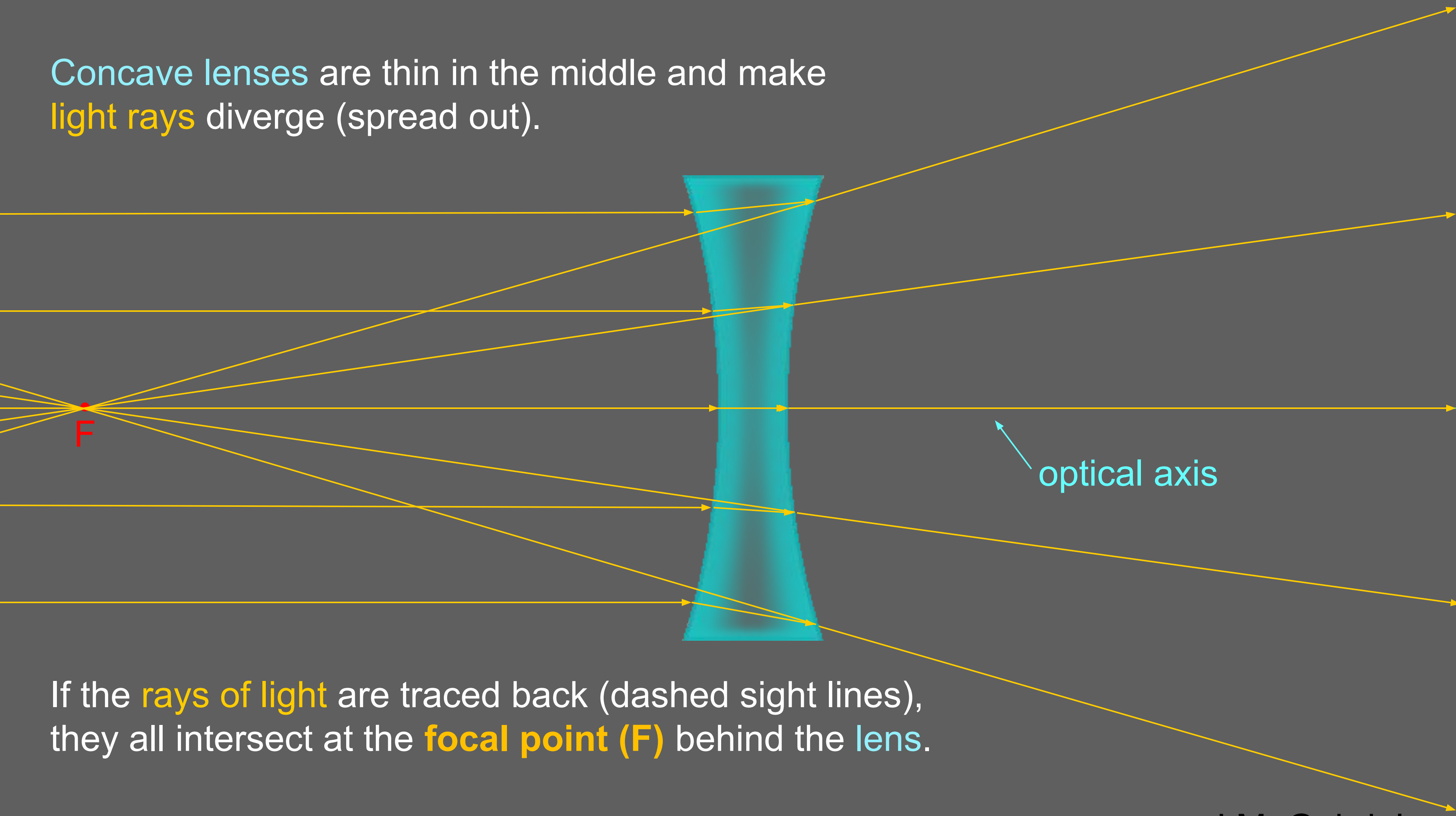
Concave Lenses

Concave lenses are thin in the middle and make light rays diverge (spread out).



If the rays of light are traced back (dashed sight lines), they all intersect at the **focal point (F)** behind the lens.

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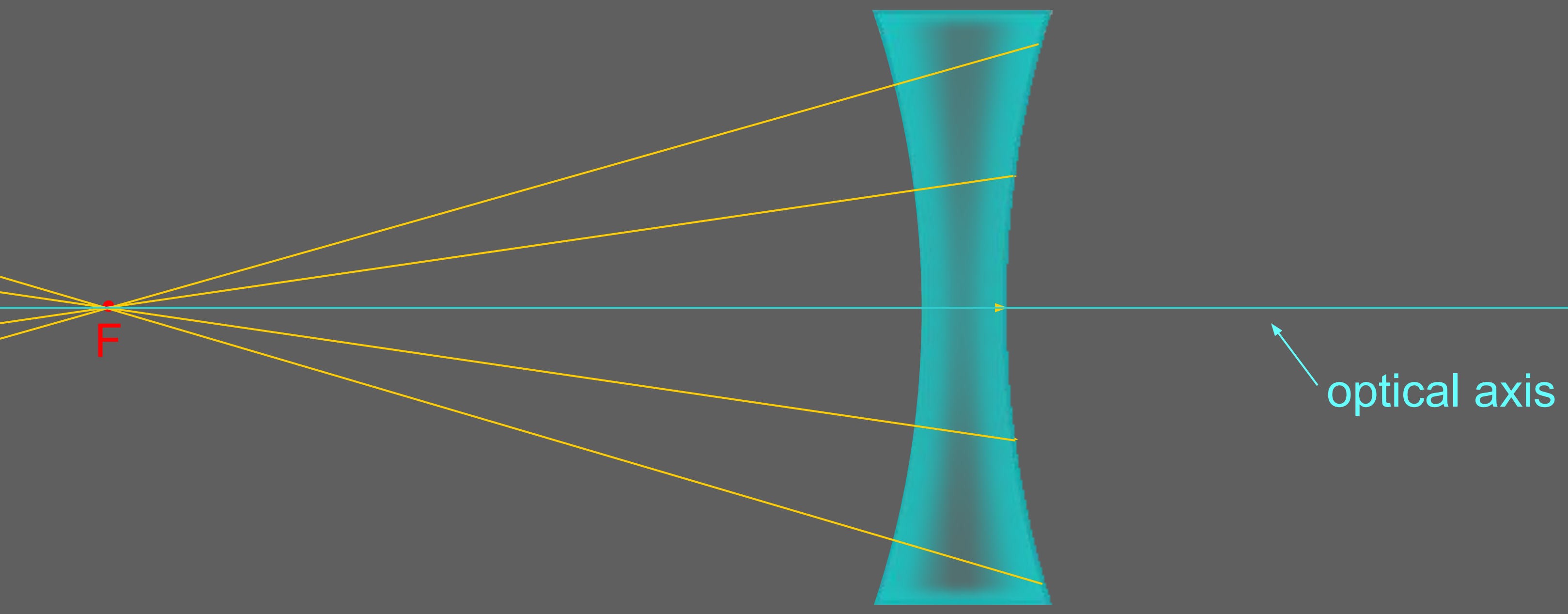
Concave Lenses



Light rays that come in parallel to the optical axis diverge from the focal point.

The light rays behave the same way if we ignore the thickness of the lens.

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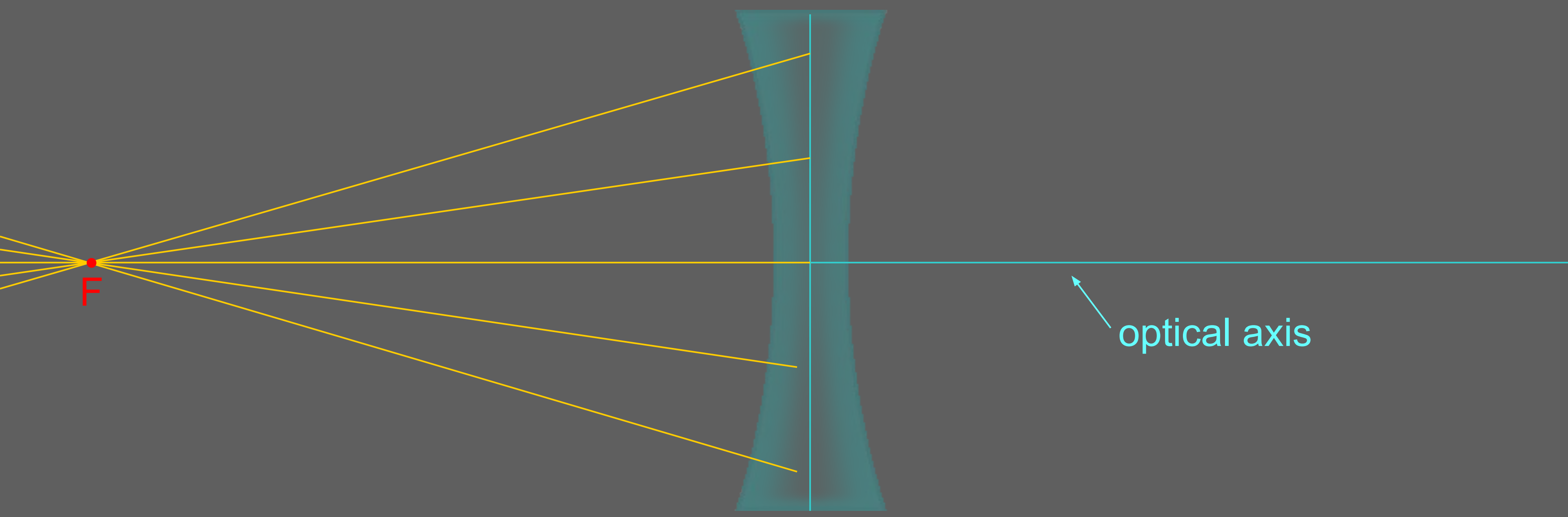
Concave Lenses



Light rays that come in parallel to the optical axis still diverge from the focal point.

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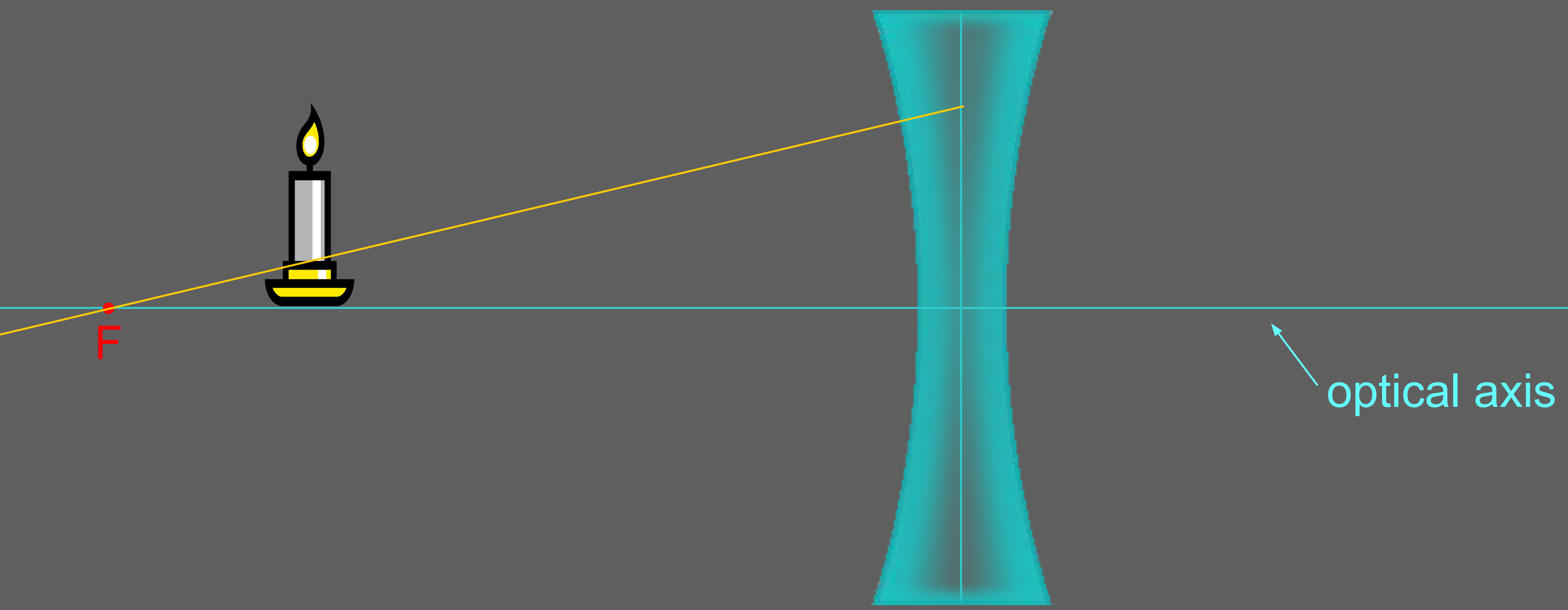
Concave Lens

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts from the focal point.

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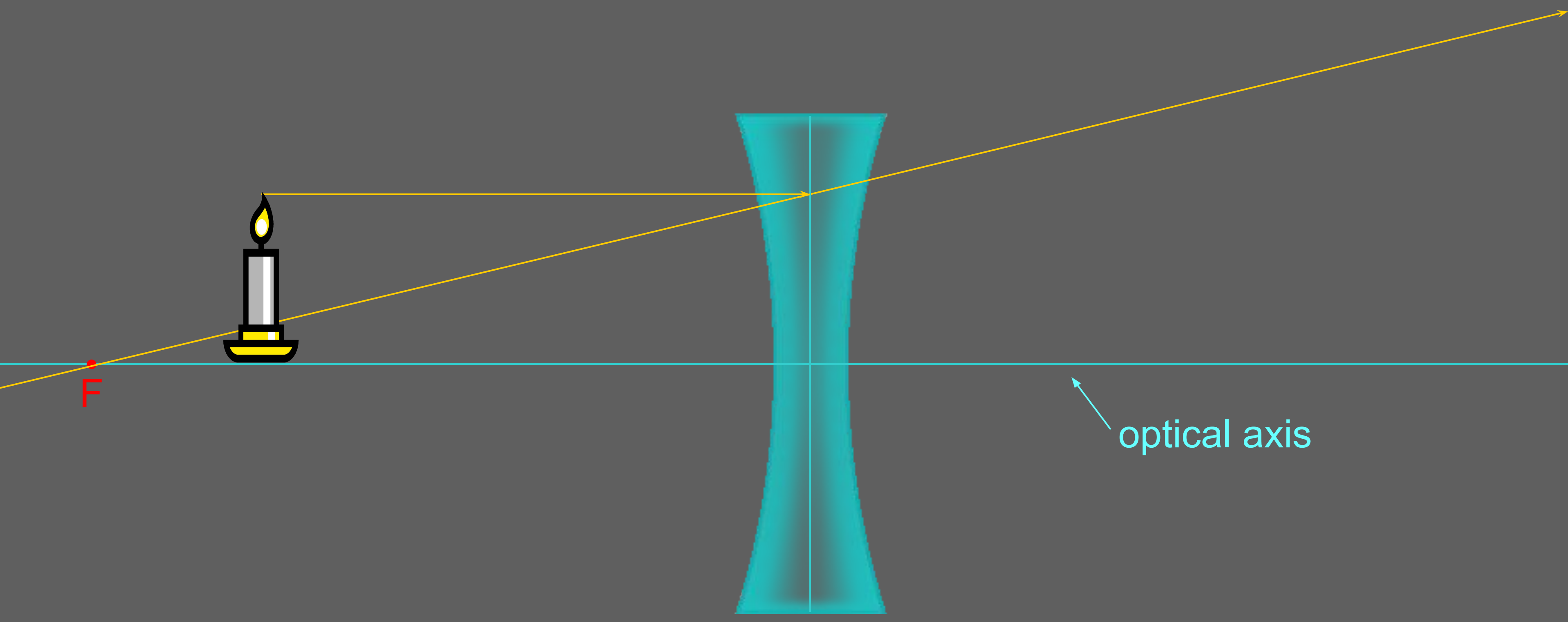
Concave Lens

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts from the focal point.

The second ray goes straight through the center of the lens.

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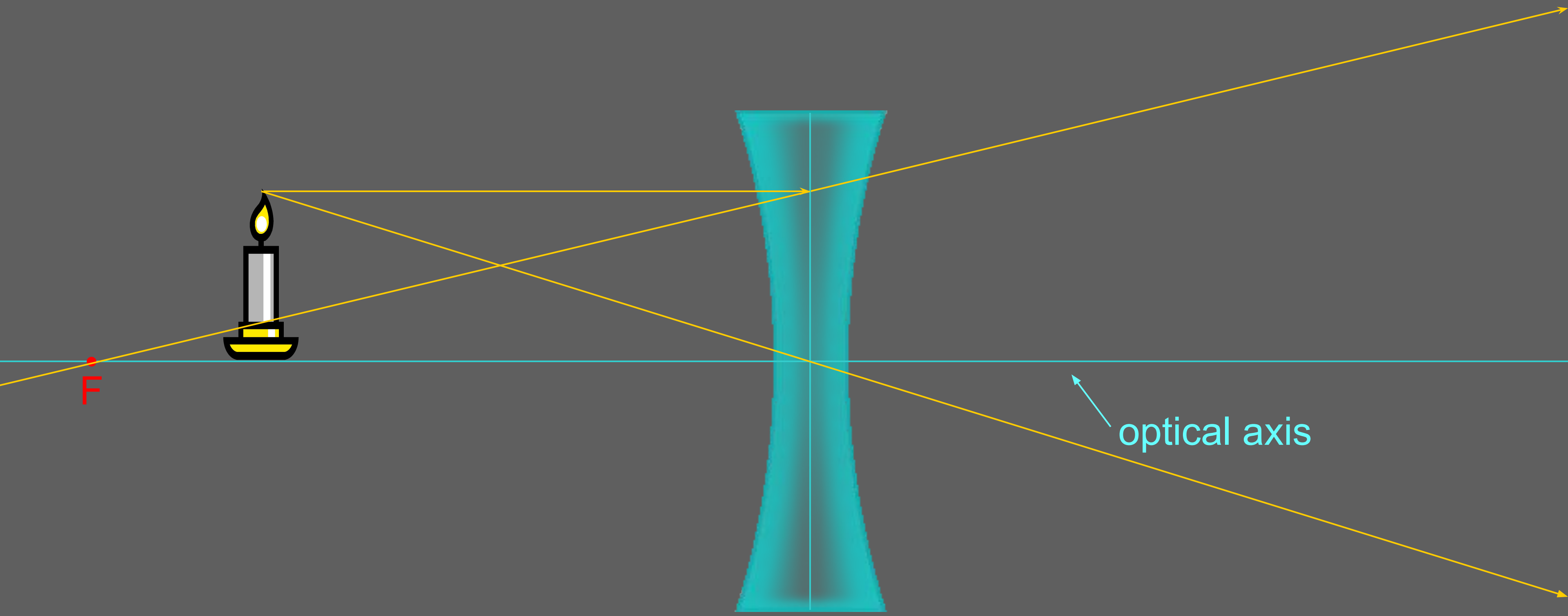
Concave Lens
(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts from the focal point.

The second ray goes straight through the center of the lens.

The light rays don't converge, but the sight lines do.

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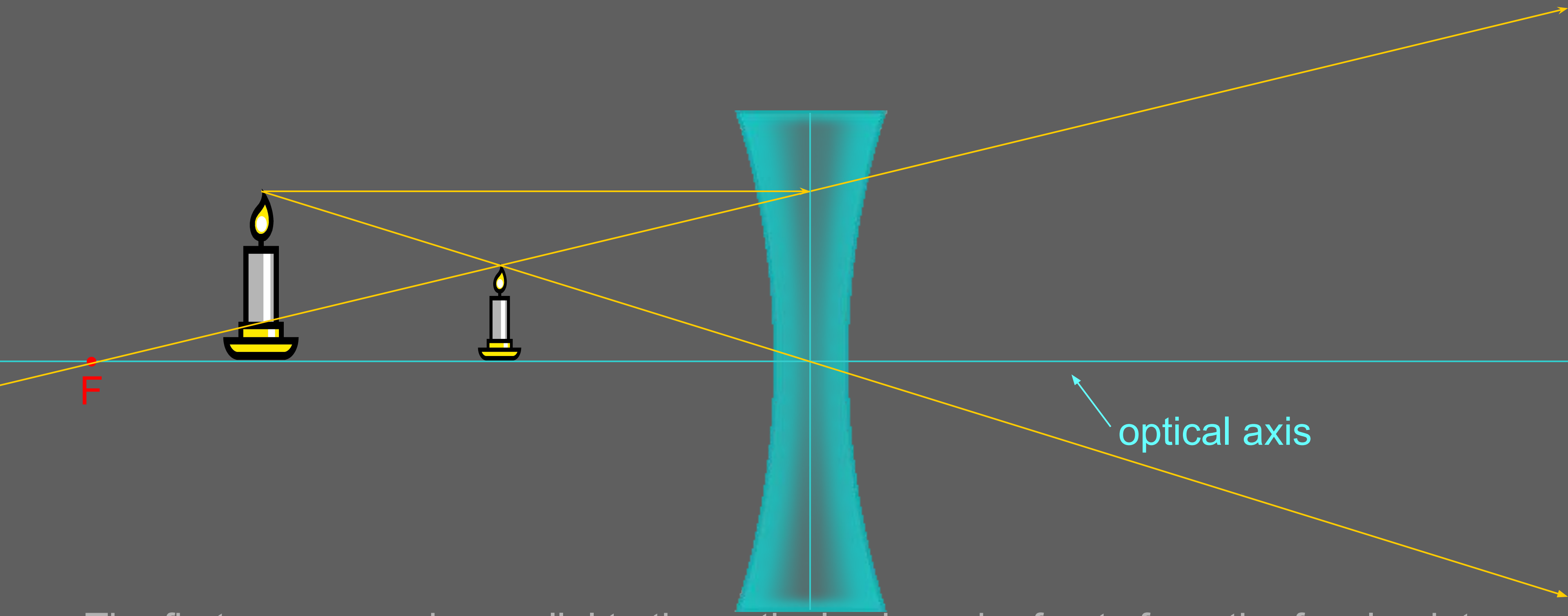
Concave Lens

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts from the focal point.

The second ray goes straight through the center of the lens.

The light rays don't converge, but the sight lines do.

A **virtual, upright, diminished image** forms where the sight lines converge.

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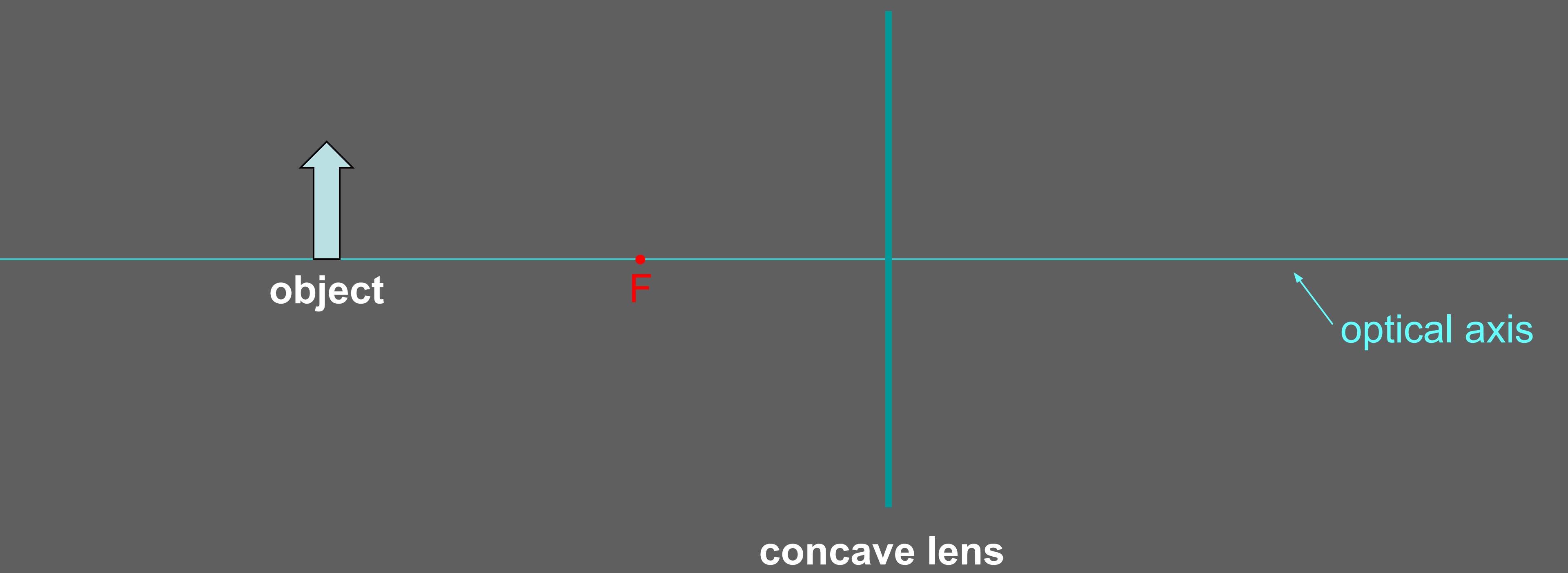
Your Turn

(Object distance: $d_o > 2d_f$)



- Note: lenses are thin enough that you just draw a line to represent the lens.
- **Locate the image of the arrow.**

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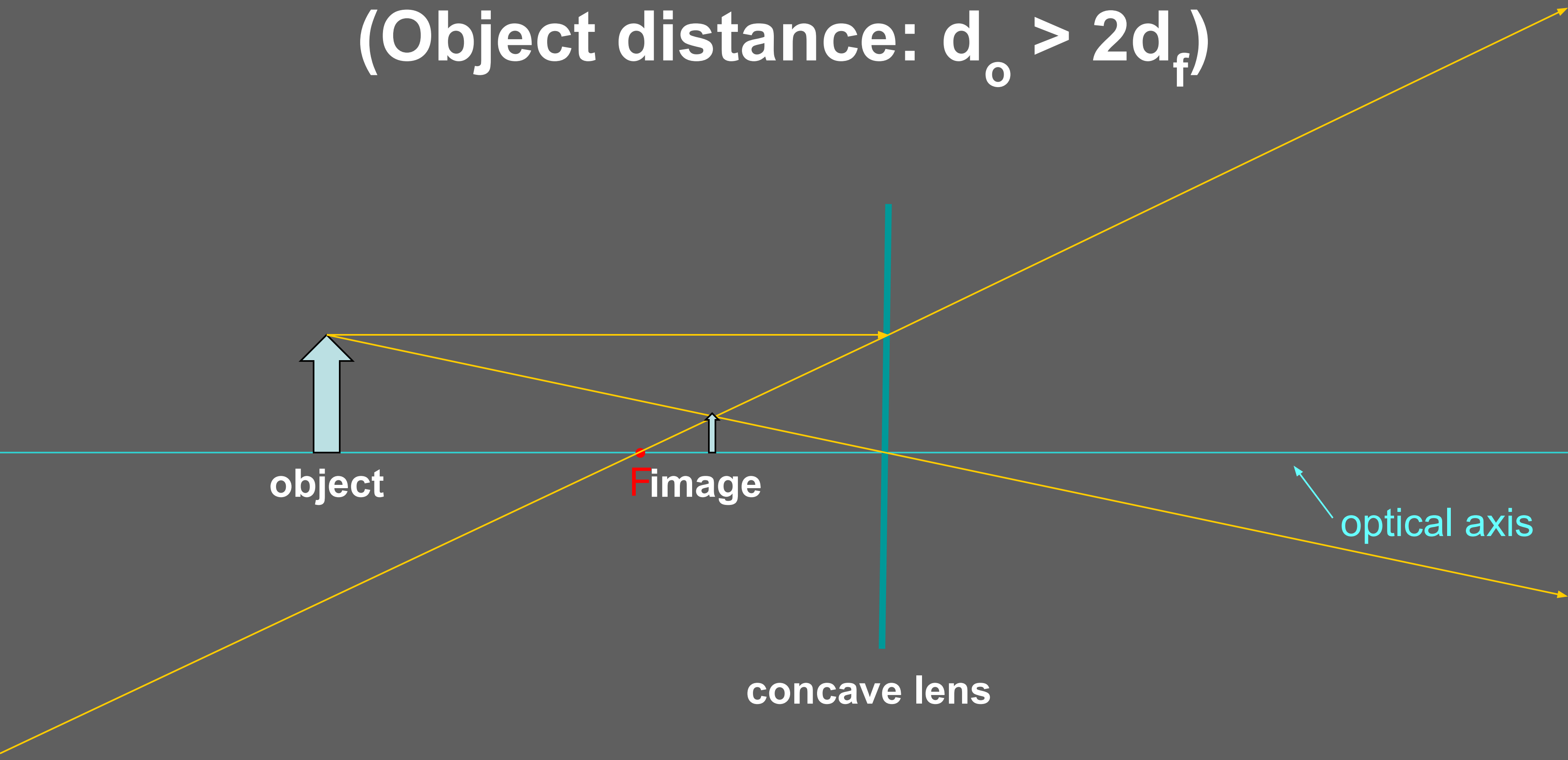
Your Turn

(Object distance: $d_o > 2d_f$)



- Note: lenses are thin enough that you just draw a line to represent the lens.
- **Locate the image of the arrow.**

A **virtual, upright, diminished image** forms where the sight lines converge.

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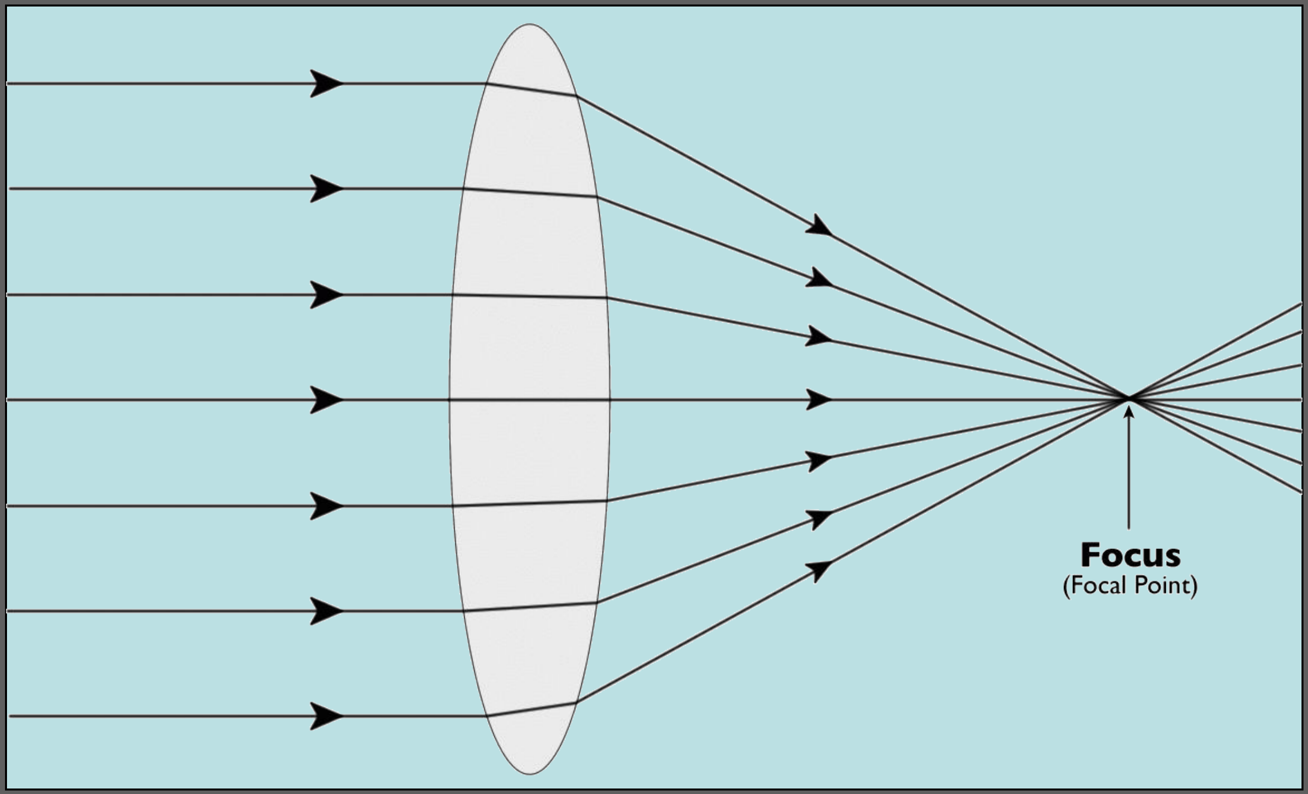
Convex Lenses

Convex lenses are thicker in the middle and focus light rays to a focal point in front of the lens.



The focal length of the lens is the distance between the center of the lens and the point where the light rays are focused.

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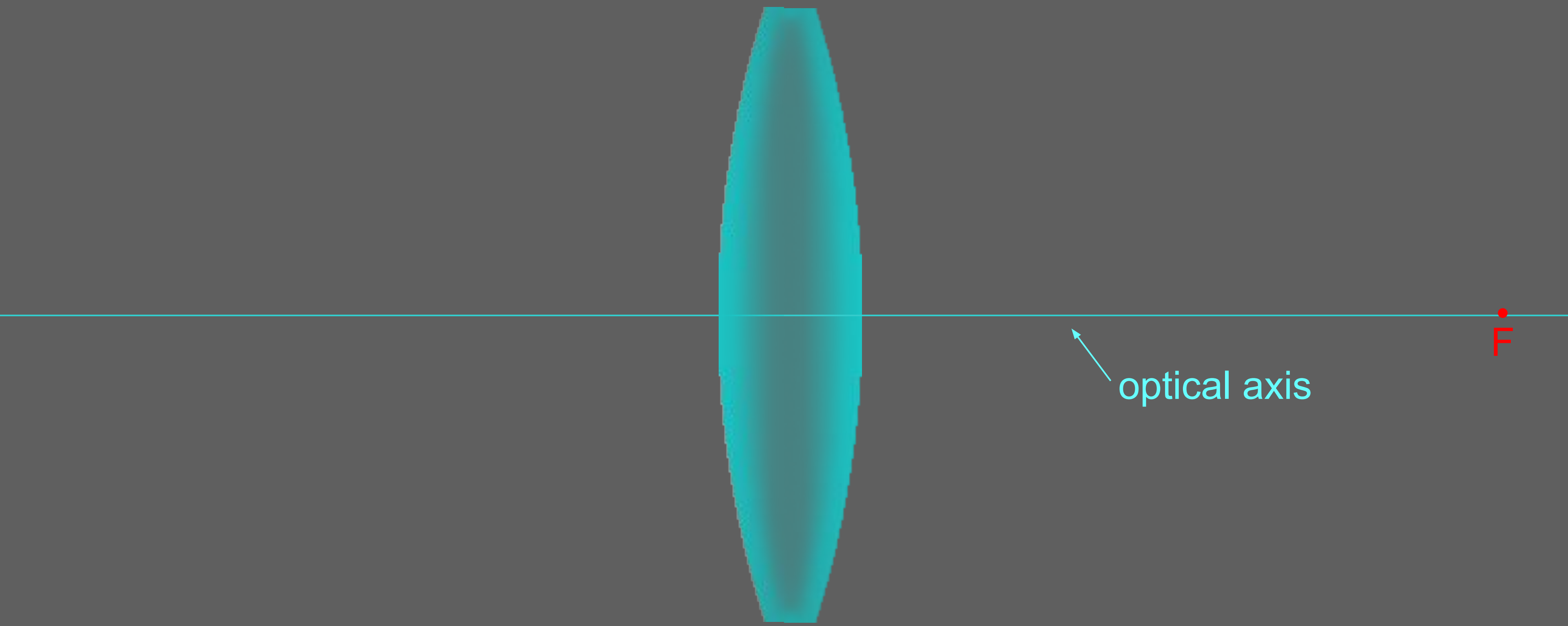
Convex Lenses



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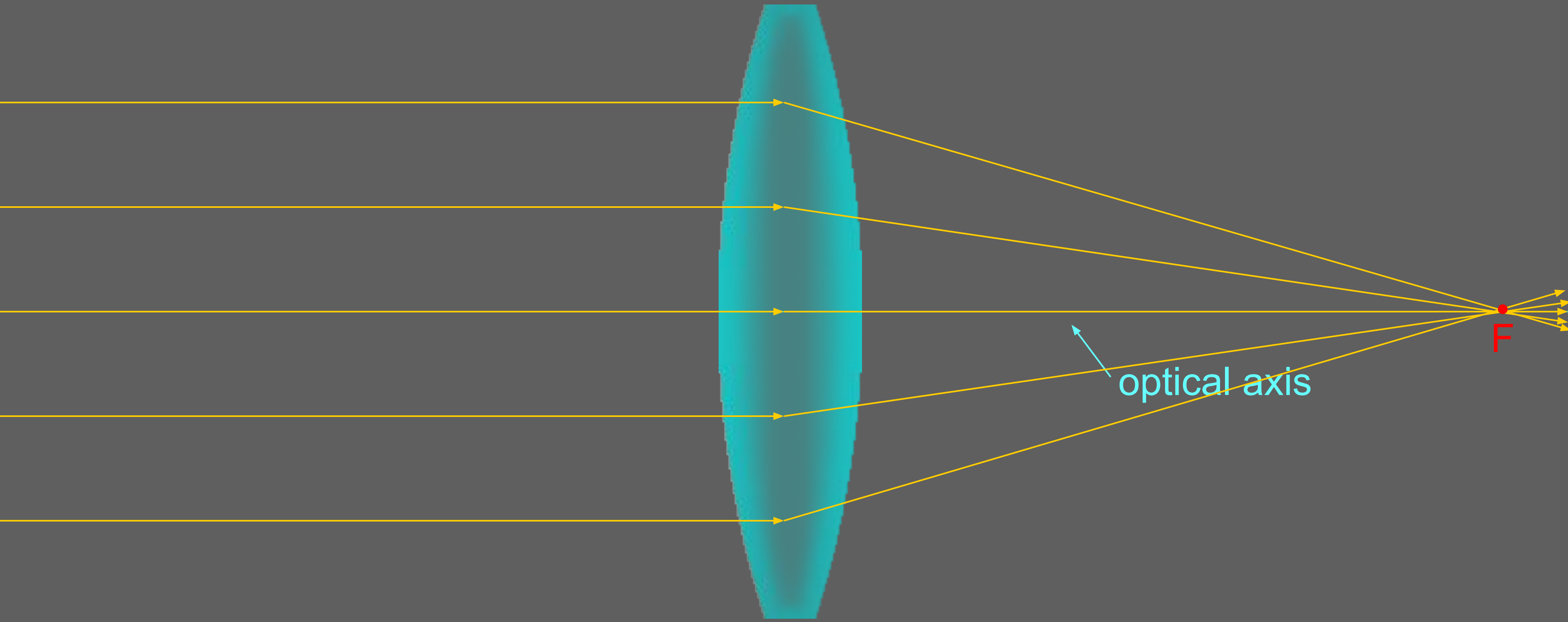
Convex Lenses



Light rays that come in parallel to the optical axis converge at the focal point.

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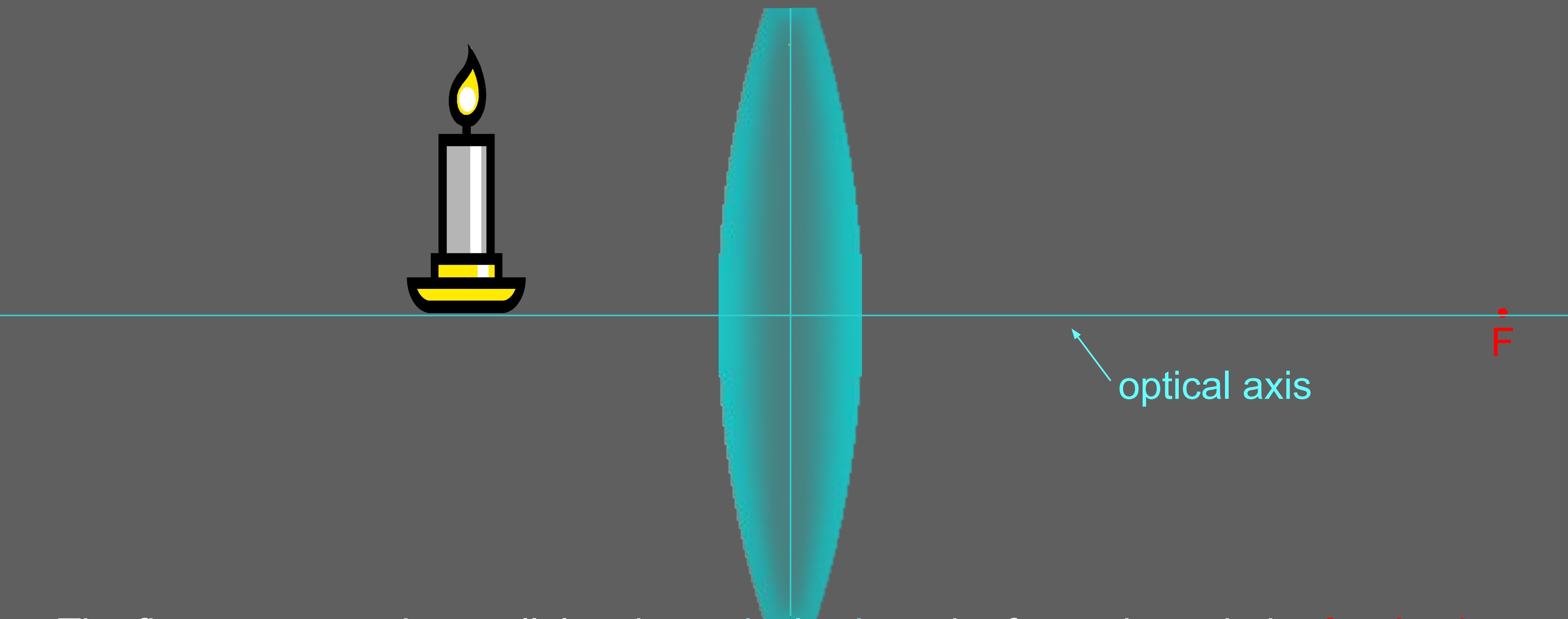
Convex Lens

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts through the focal point.

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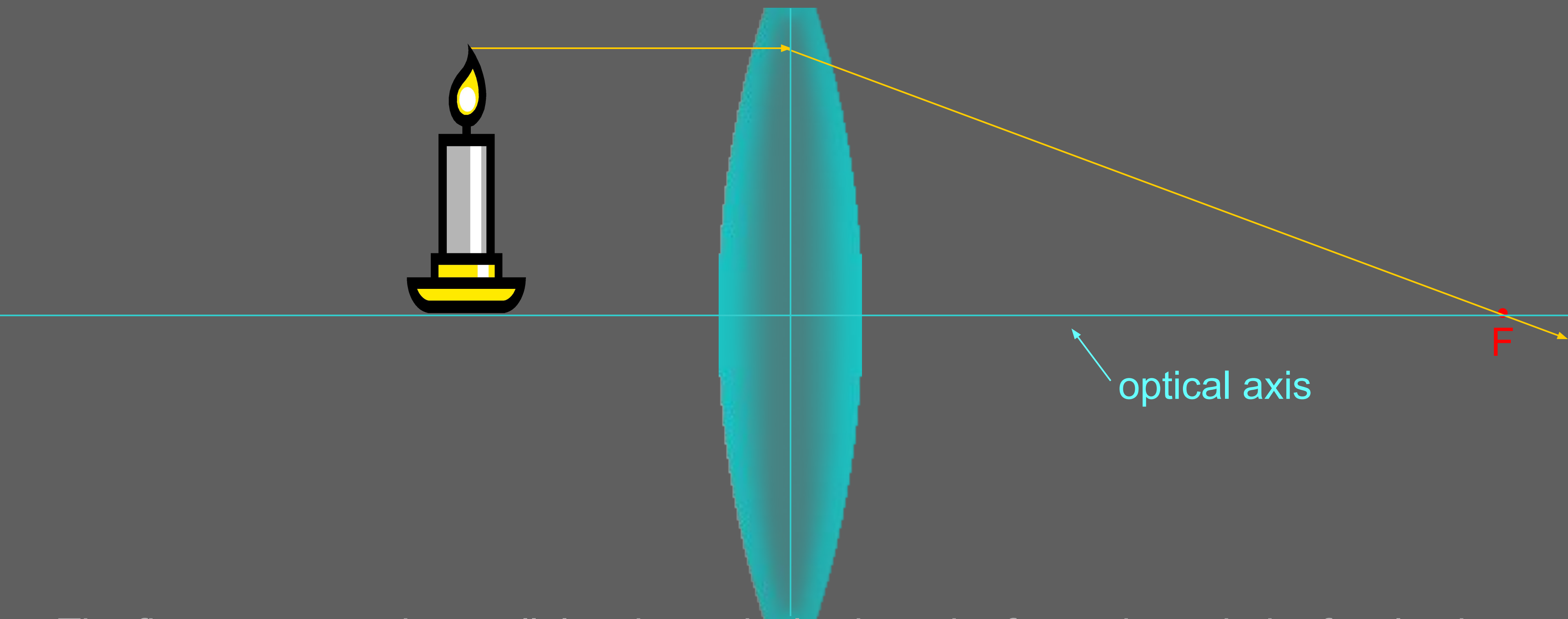
Convex Lens

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts through the focal point.

The second ray goes straight through the center of the lens.

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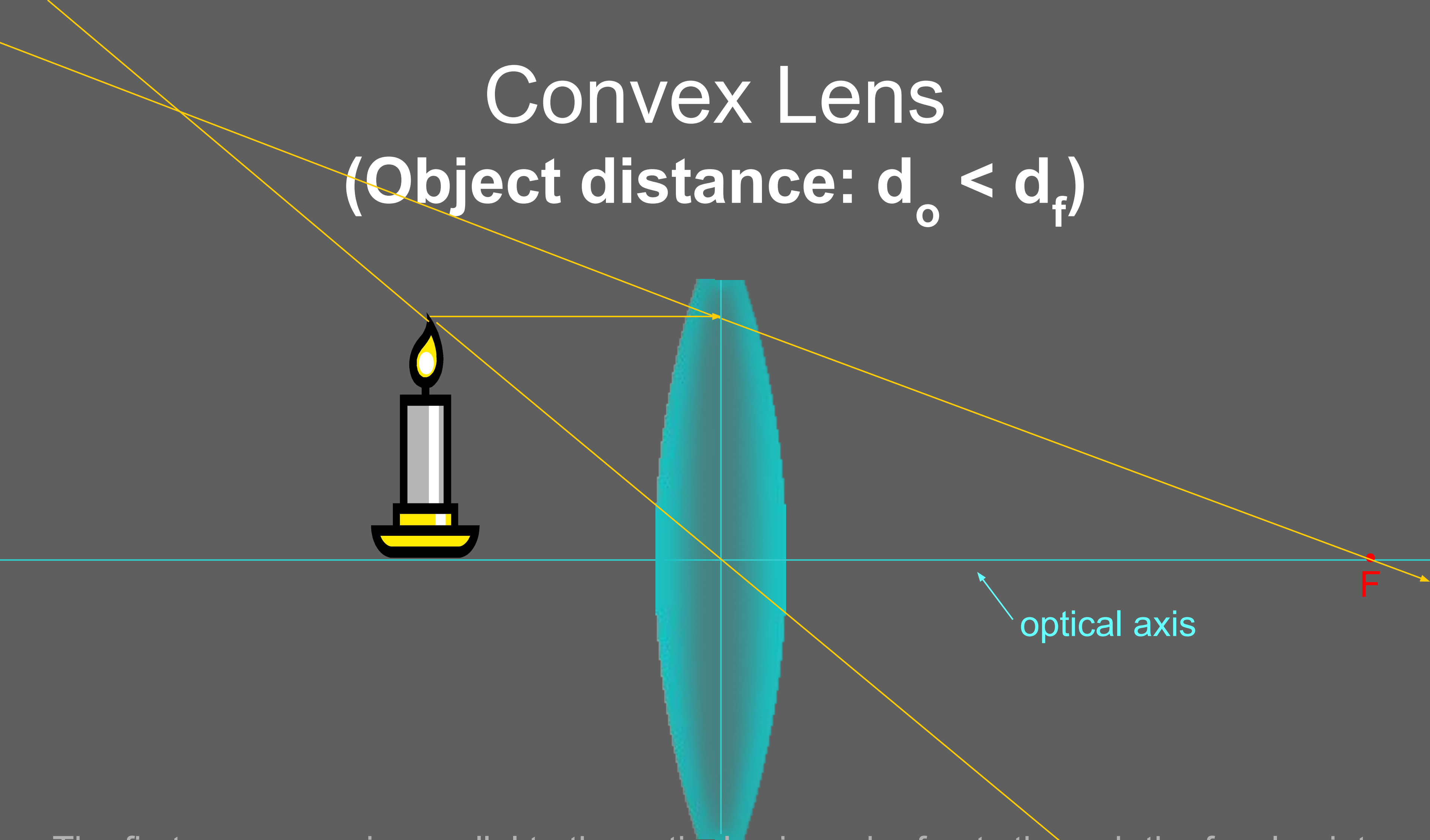
Convex Lens

(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts through the focal point.

The second ray goes straight through the center of the lens.

The light rays don't converge, but the sight lines do.

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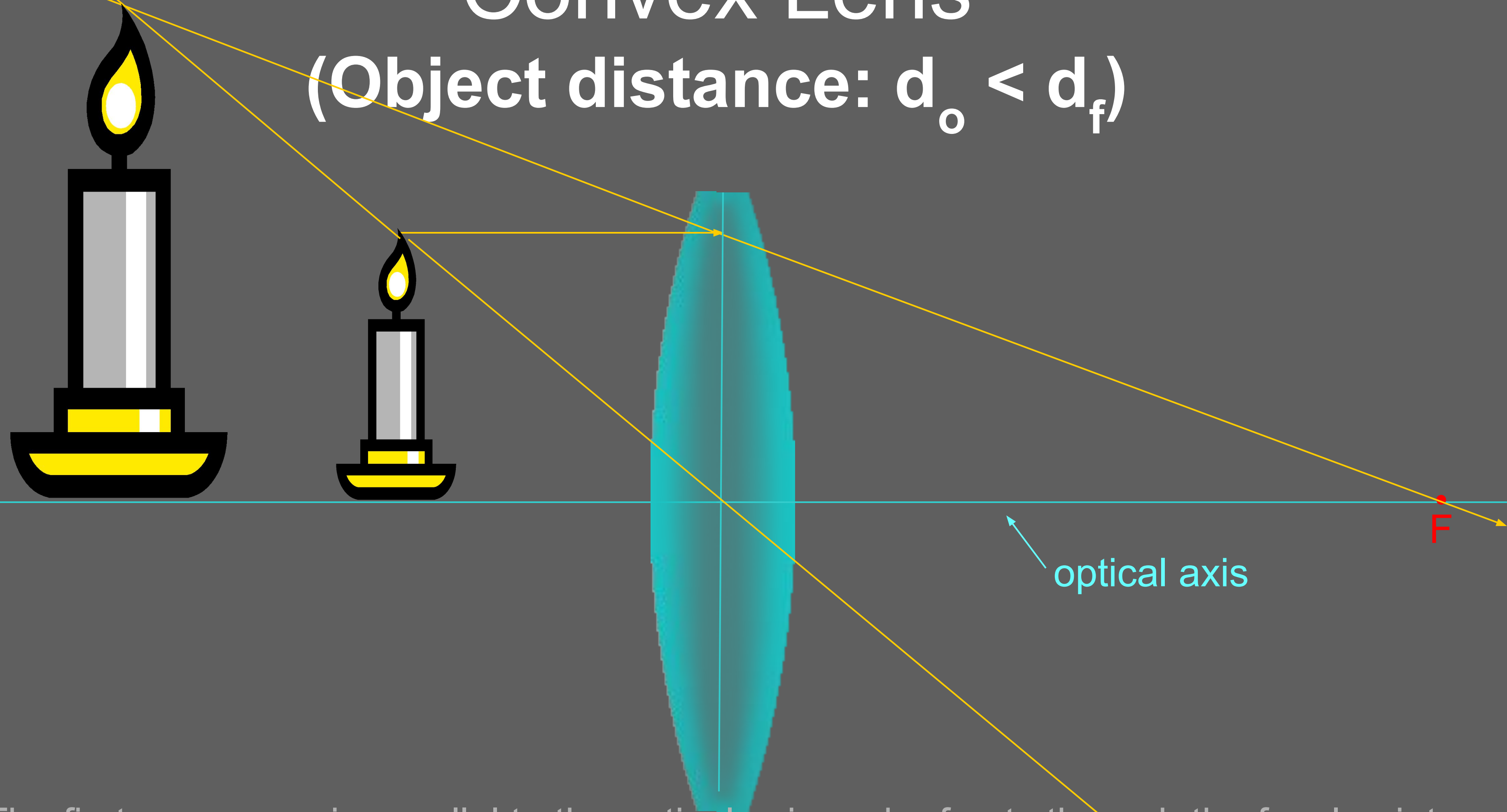
Convex Lens
(Object distance: $d_o < d_f$)



The first ray comes in parallel to the optical axis and refracts through the focal point.

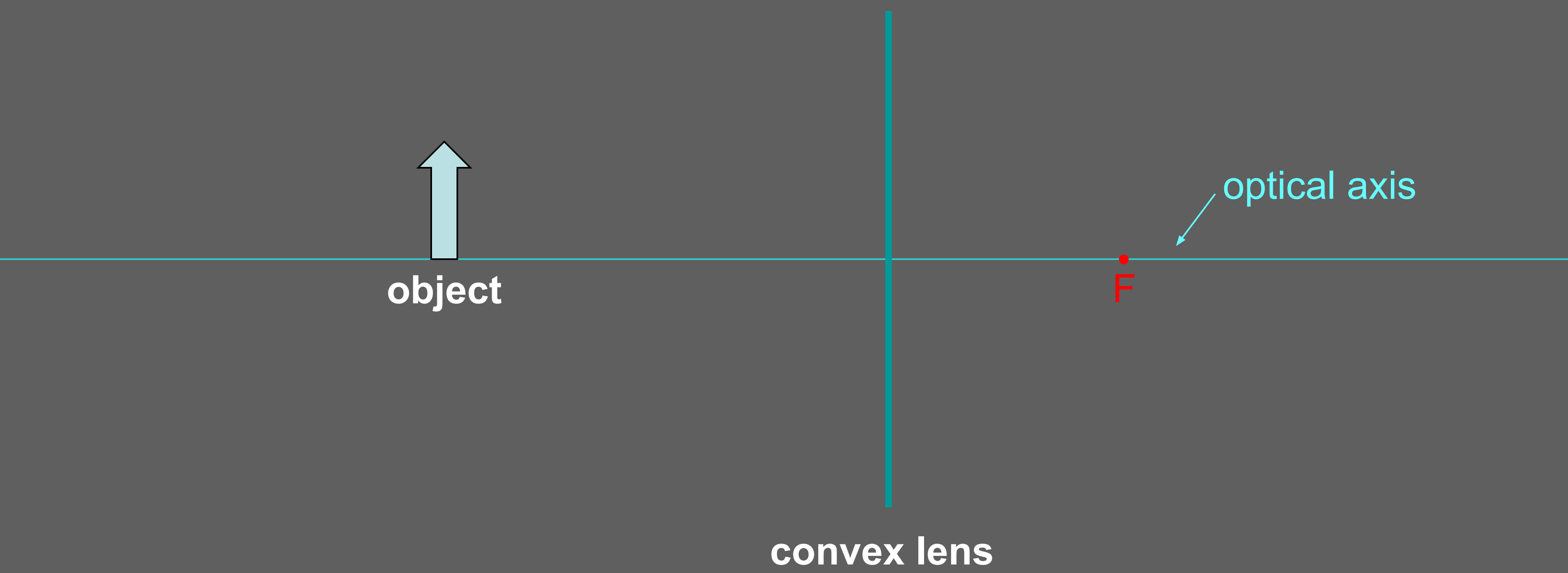
The second ray goes straight through the center of the lens.

The light rays don't converge, but the sight lines do.

A **virtual, upright, magnified image** forms where the sight lines converge.

J.M. Gabrielse

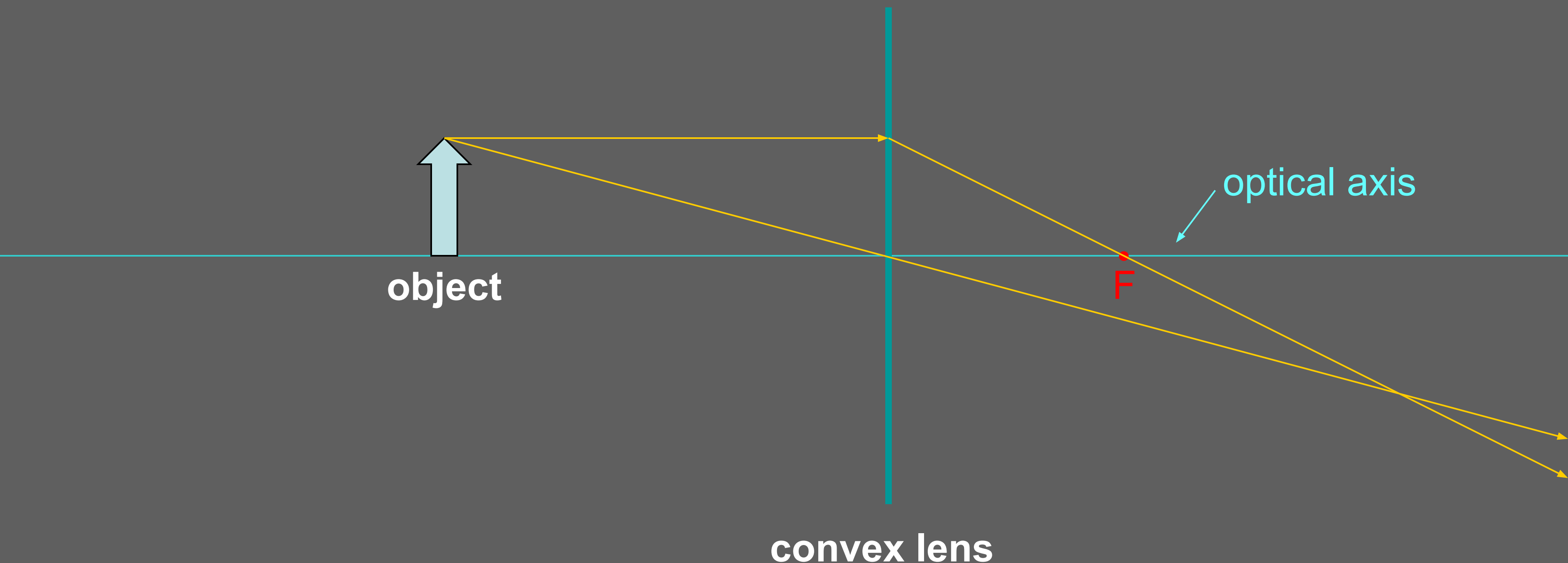
Your Turn
(Object distance: $d_o > 2d_f$)



- Note: lenses are thin enough that you just draw a line to represent the lens.
- **Locate the image of the arrow.**

J.M. Gabrielse

Your Turn
(Object distance: $d_o > 2d_f$)



- Note: lenses are thin enough that you just draw a line to represent the lens.
- **Locate the image of the arrow.**

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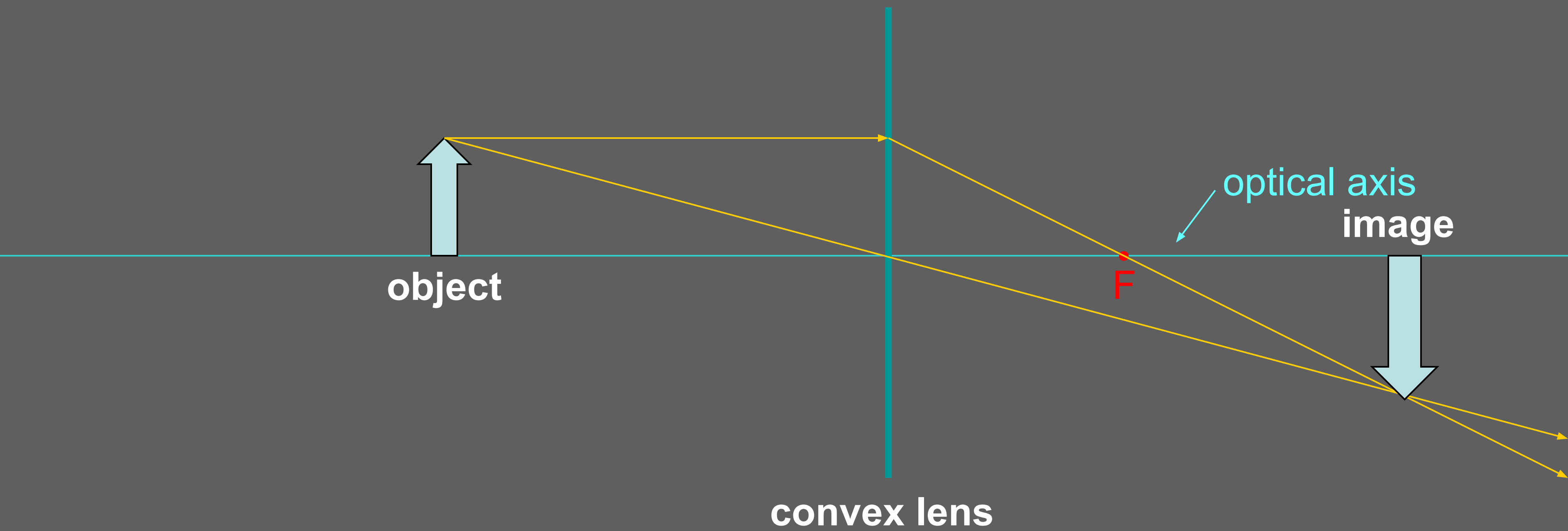
Your Turn
(Object distance: $d_o = 2d_f$)



- Note: lenses are thin enough that you just draw a line to represent the lens.
- **Locate the image of the arrow.**

A **real, inverted, same size image** forms where the light rays converge.

J.M. Gabrielse

Thanks/Further Info

- **Faulkes Telescope Project: Light & Optics** **by Sarah Roberts**
- **Fundamentals of Optics: An Introduction for Beginners** **by Jenny Reinhard**
- **PHET Geometric Optics (Flash Simulator)**
- **Thin Lens & Mirror (Java Simulator)** **by Fu-Kwun Hwang**