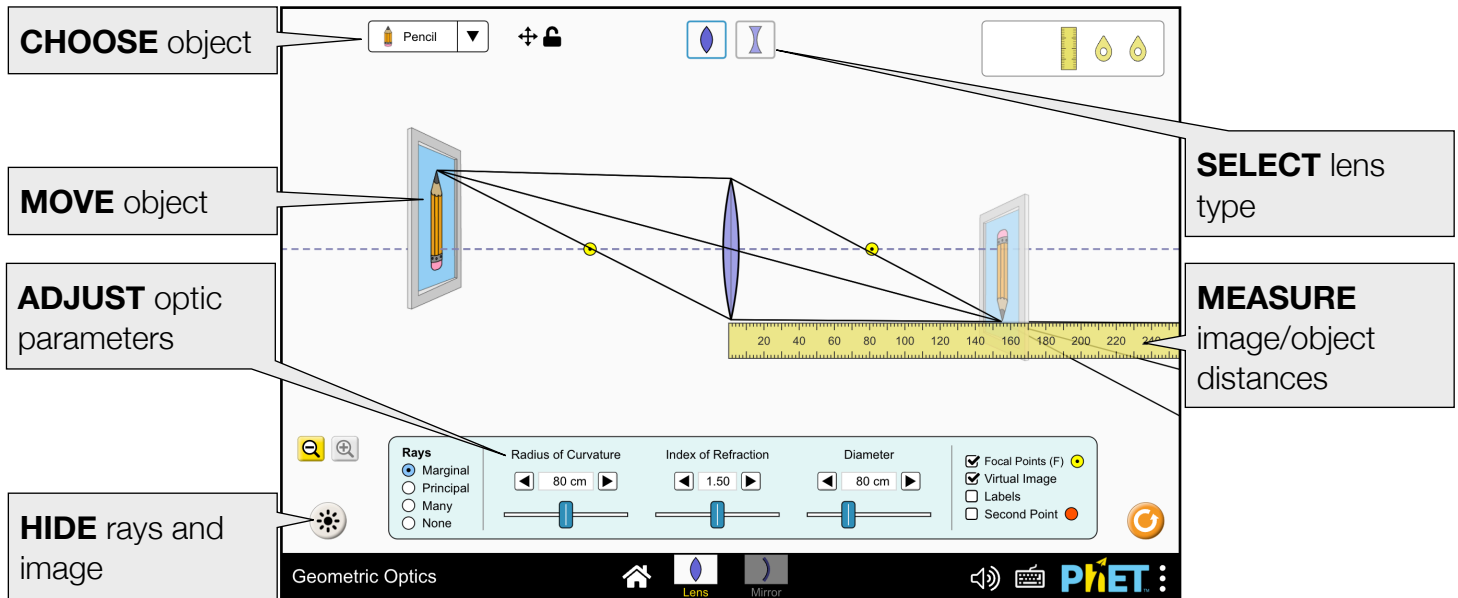# Geometric Optics

In **Geometric Optics**, students discover how an image is formed by a lens or mirror using ray diagrams.
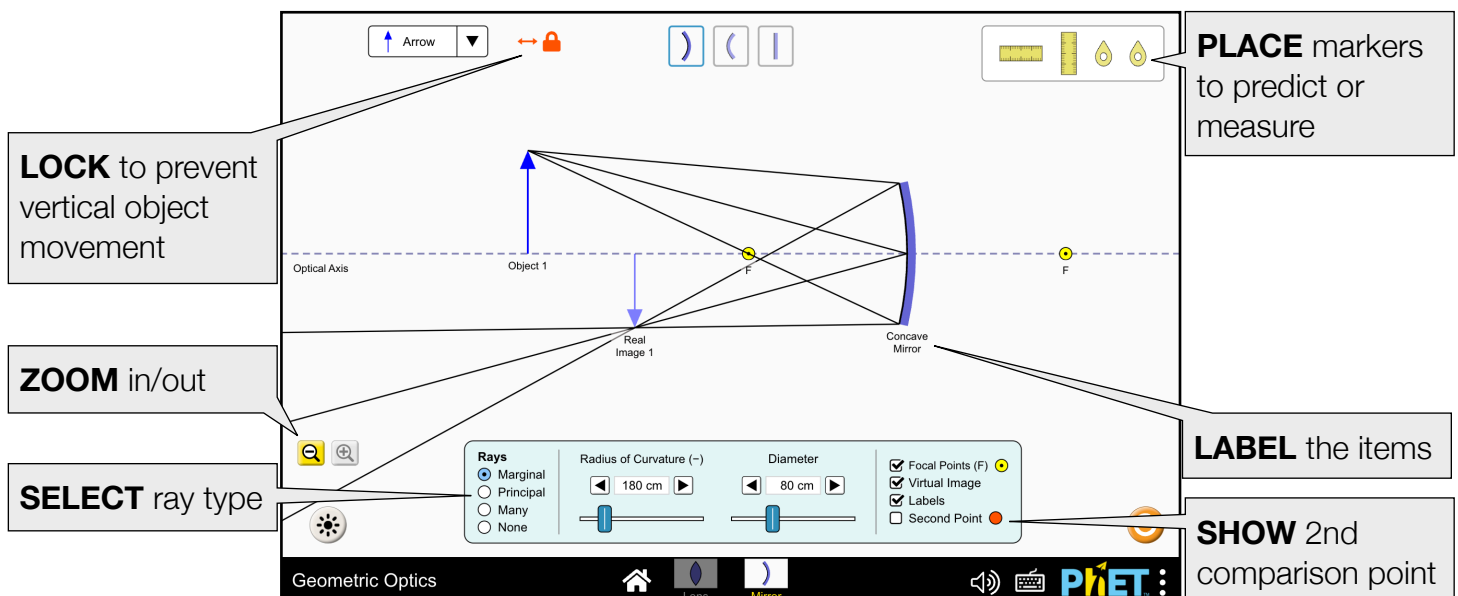
Lens Screen

Determine how radius of curvature and index of refraction affect the focal length of a lens. Create real and virtual images and experiment with a spotlight.

CHOOSE object

MOVE object

ADJUST optic parameters

HIDE rays and image

SELECT lens type

MEASURE image/object distances

Mirror Screen

Explore spherical and flat mirrors. Adjust the radius of curvature and diameter of the mirror and observe the effects on the image position, magnification, and brightness.

LOCK to prevent vertical object movement

ZOOM in/out

SELECT ray type

PLACE markers to predict or measure

LABEL the items

SHOW 2nd comparison point

Rouinfar, April 2022

Customization Options

The following query parameters allow for customization of the simulation, and can added by appending a '`?`' to the sim URL, and separating each query parameter with a '`&`'.

Query Parameter and Description	Examples
`focalLengthControl` - specifies how the focal length is controlled, and can be either `direct` (focal length slider) or `indirect` (radius of curvature and index of refraction sliders). Default is indirect.	`focalLengthControl=direct`
`add2FPointsCheckbox` - when true, adds a checkbox to the control panel to display the 2F points. Default is false.	`add2FPointsCheckbox=true`
`addGuidesCheckbox` - when true, adds a checkbox to the control panel to display the Guides, see Complex Controls below. Default is false.	`addGuidesCheckbox=true`

`screens` - specifies which screens are included in the sim and their order. Each screen should be separated by a comma. For more information, visit the Help Center.	`screens=1`
	
	`screens=2,1`

`audio` - if muted, audio is muted by default. If disabled, all audio is permanently turned off.	`audio=muted`
	
	`audio=disabled`

`supportsPanAndZoom` - when true, enables panning and zooming of the simulation using pinch-to-zoom or browser zoom controls.	`supportsPanAndZoom=false`

Complex Controls

- The Options menu can be used to change the focal length controls and enable the 2F Points checkbox. Click on the PhET logo and select Options.
- The light propagation toggle button which hides the rays/image/light spot and can be used for predictions or triggering the ray tracing animation.
- To constrain the movement of the object to horizontal motion only, use the lock button next to the object selection menu.
- The Guides feature can be enabled using the `addGuidesCheckbox` query parameter. The Guides indicate the extent to which light refracts through a lens, and the angle between the guide arms is proportional to the focal length. The Guides may be useful when predicting the location of the image, or can be used to emphasize the way light is focused. The Guides will align to the Marginal Rays when the object distance is twice the focal length.
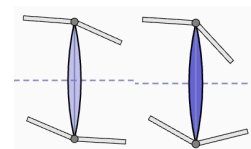
Insight into Student Use

- Students may experiment with placing the object at the focal point. However, this is not possible for all optics, as the minimum object distance is 40 cm.
- Students may need scaffolding to interpret the image brightness when the image is smaller than the object. When |M|<1 the light forming the image is more intense, so changes in object distance and optic diameter will appear to have less of an effect on image brightness.

Model Simplifications

- The focal length, f, of the lenses is calculated using the Lens-Maker's Equation, assuming thin lenses and an equal radius of curvature, R, on both faces, $f = R/(2(1 - n))$ where n is the index of refraction. The focal length of the spherical mirror assumes the paraxial approximation, $f = R/2$.
- The Focal Length and Radius of Curvature sliders control the magnitude, and (-) is appended to the title of the control when the value is negative.
- The perspective of the picture frames implies that the observer is looking from the side. However, an observer would only see an image from this vantage point if there was a screen at the image location. This perspective was chosen to make the ray tracing and inversion/mirroring of the image clearer.
- For consistency, labels appear below the item. For objects, this means that the "Object" label may not be immediately next to the origin of the point source.
- There is a singularity when an object is placed exactly at the focal point, which may result in a flash or stutter.
- The opacity of the framed images is used to indicate its intensity, and depends on the object distance, optic diameter, and magnification of the image. An image will appear dimmer when the object is far from the optic, the optic diameter is small, or the magnification is large.
- In general, the intensity of the light spot on the projector screen is inversely proportional to its diameter. However, intensity will remain constant when the diameter of the lens changes.
- Marginal Rays and Many Rays refract/reflect only at the first point of contact with the optic. For the diverging lens, it's possible that a ray will exit through the top or bottom surface of the lens without refracting a second time.
- Principal Rays are a model used to identify the location of an image. However, due to the size of the object, these rays may not always physically reach the optic, so we extend the central axis of the optic to make the ray behavior clearer.
- Many Rays consists of a 120-degree fan of rays. The number of rays will increase with the distance of the object from the optics, so that there are always at least 2 rays incident on the optic.
- In the Light scene, rays that do not interact with the lens will not cast any light on the projection screen, because we are not modeling ambient light.
- We do not model the physics of reflected rays and they may pass over the object (rather than being blocked). However, framed objects are constrained to horizontal dragging above the optical axis so that the rays forming a real image are never obscured by the object. This same restriction is not applied to the Arrow, because it is a representation of point source, not a physical extended object.
- For a flat mirror, the radius of curvature and focal length controls disappear, as the values are infinite.
- The flat mirror is intended for comparison purposes. Deeper exploration of flat mirrors will be supported in an upcoming simulation, Geometric Optics: Basics, which has a centered mirror and allows for freely-moving objects.

Suggestions for Use

Sample Challenge Prompts

- Sketch the formation of an image using principal rays.
- Determine the relationship between radius of curvature, index of refraction, and focal length of a lens.
- Describe the relationship between the radius of curvature and focal length of a mirror.
- Explain the difference between a real and virtual image.
- Find all the ways to change the brightness of the image.
- Predict where an image will be formed given the object distance and optic parameters.

See all published activities for Geometric Optics here.
For more tips on using PhET sims with your students, see Tips for Using PhET.