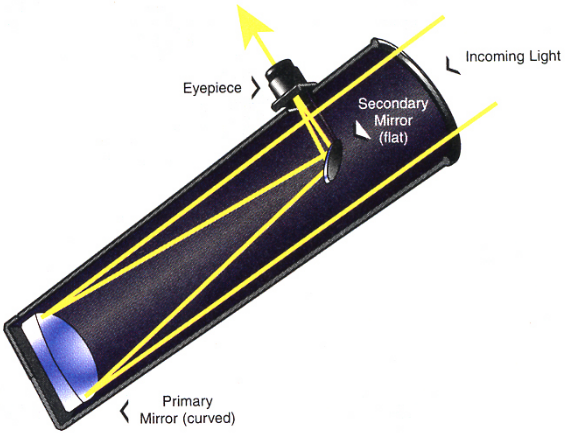
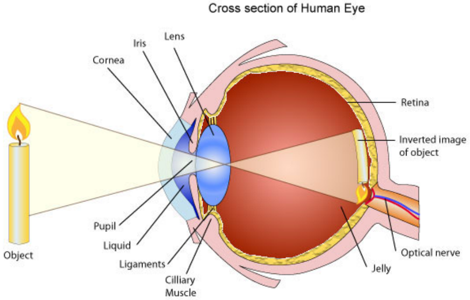
Chapter 2 - Geometric Optics



David J. Starling
Penn State Hazleton
PHYS 214

Images and Plane Mirrors

The human eye is a visual system that collects light and forms an image on the retina.



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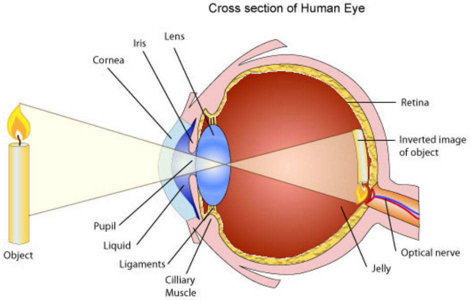
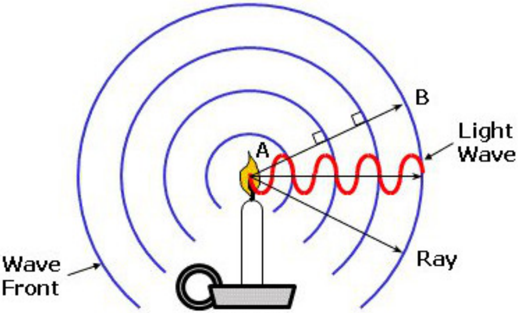


The lens changes shape to to image objects at different distances.

Images and Plane Mirrors

Without a visual system, light spreads out in all directions.



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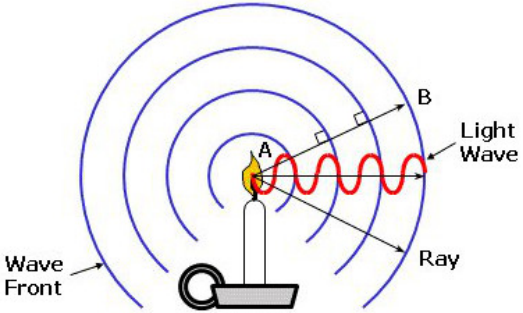

Wavefronts propagate spherically from the source unless blocked or collected and imaged with a lens or mirror.

Images and Plane Mirrors

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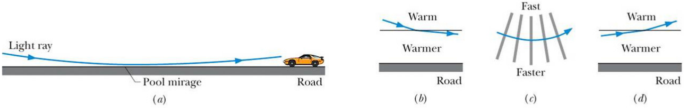
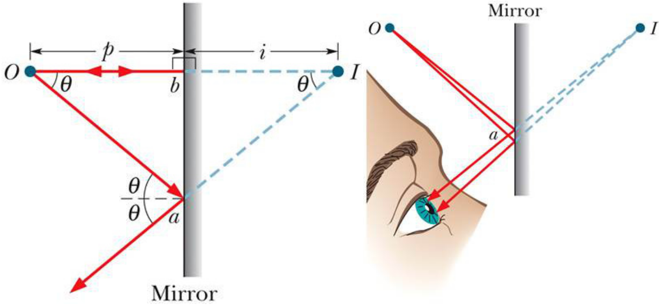
- A **real image** faithfully reproduces the object without a visual system.
- A **virtual image** requires a visual system to reproduce the object.



Images and Plane Mirrors

Plane (flat) mirrors form virtual images.



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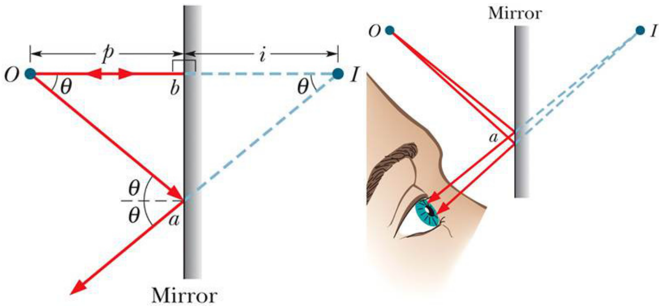
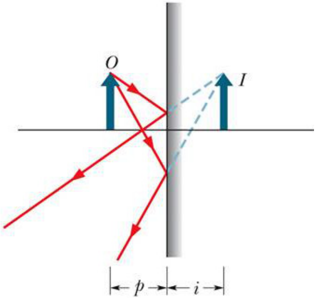


Using the eye to form the real image, the object appears to be on the opposite side of the mirror. (note: $i = -p$)

Images and Plane Mirrors

We often draw objects (O) and images (I) as arrows.



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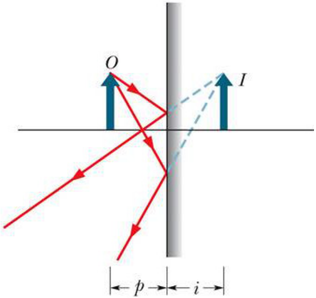
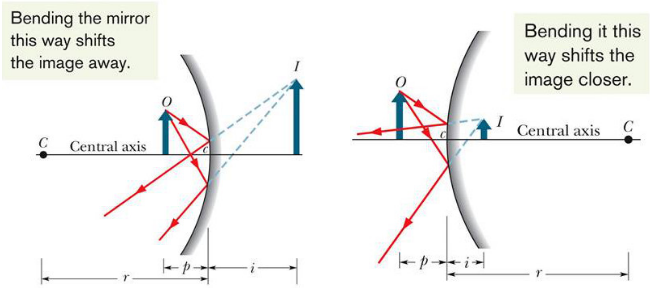


- magnification: the size of the arrow
- inversion: direction of arrow
- location: distance from mirror ($p > 0$ and $i < 0$)

Spherical Mirrors

Spherical mirrors make the rays diverge either more quickly or more slowly compared to a plane mirror.



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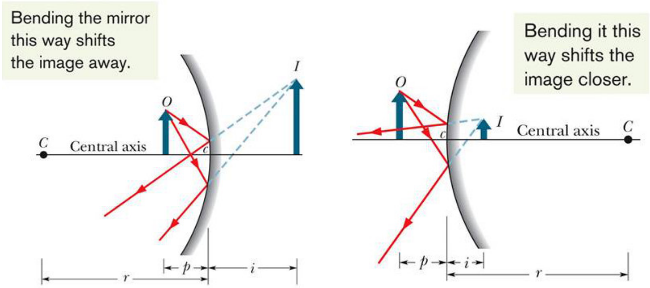
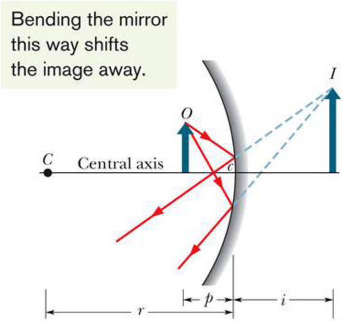


The radius of curvature of the mirror *r* determines how the virtual image will form.

Spherical Mirrors

A concave mirror "caves in" toward the object and forms a virtual image that is magnified but appears far away.



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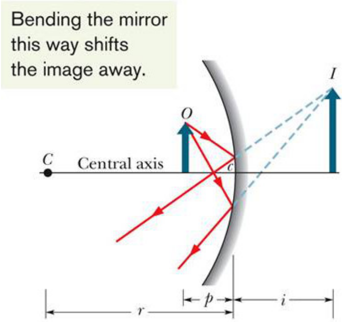
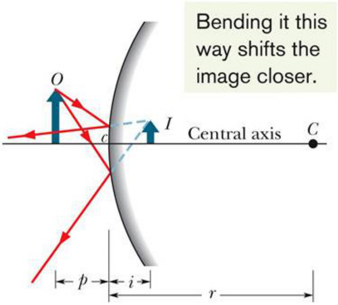


C is the center of curvature. Distances are measured from the face of the mirror with $p > 0$ and $i < 0$.

Spherical Mirrors

A convex mirror bends away from the object and forms a virtual image that is shrunk but appears closer.



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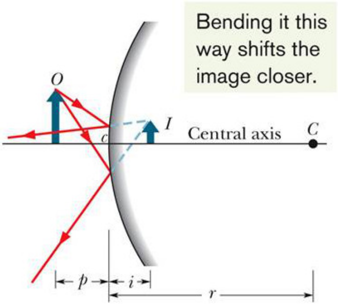
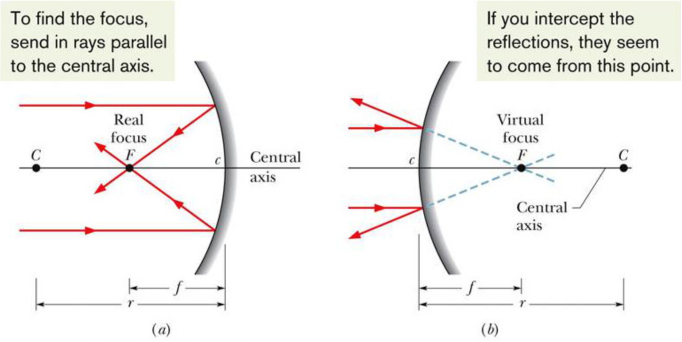


This gives the viewer a larger "field of view" and is how rear-view and side-view mirrors for cars are made.

Spherical Mirrors

Spherical mirrors have a focus at a distance $f = \pm r/2$.



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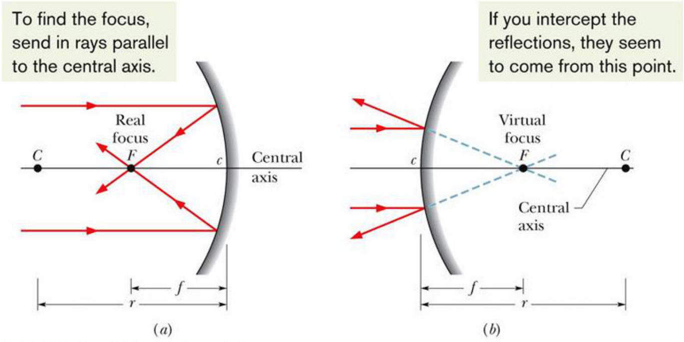
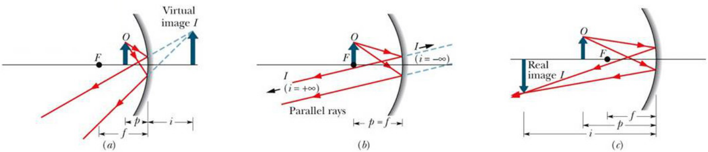


A concave mirror focuses parallel rays to a point. A convex mirror produces a virtual focus.

Spherical Mirrors

Convex mirrors always form virtual images (the rays always diverge). But a concave mirror can form a real image.



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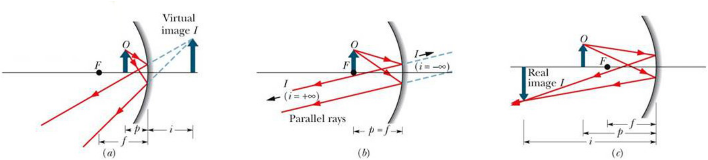
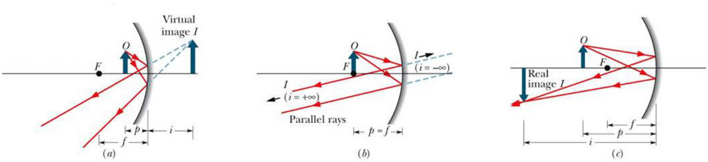


How can we predict the location and size of the image?

Spherical Mirrors

For a mirror or lens, the focal length, image and object distances are related by:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} \qquad (1)$$



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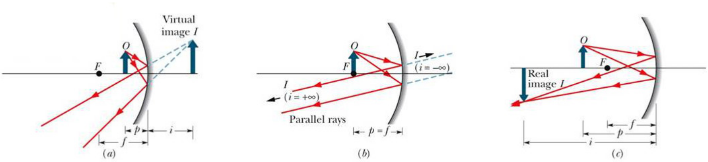
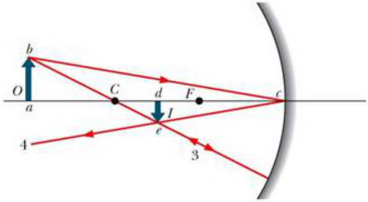


From this, we can predict i given f and p [$i = fp/(p-f)$].

Spherical Mirrors

The magnification is the ratio of the image size to the object size:

$$m = \frac{h'}{h}$$



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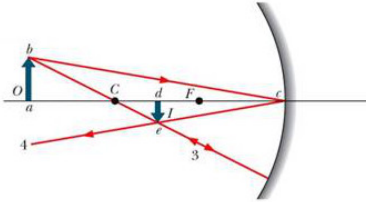
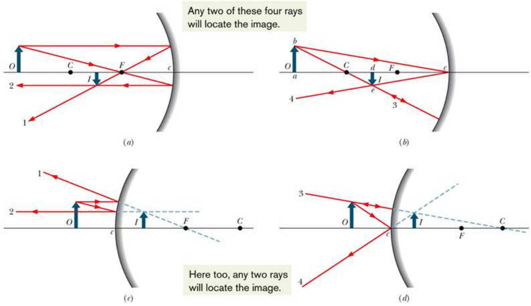


Using similar triangles, we find that $m = -i/p$.

Spherical Mirrors

There are four rays that can be used to locate the image.



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There are four rays that can be used to locate the image.

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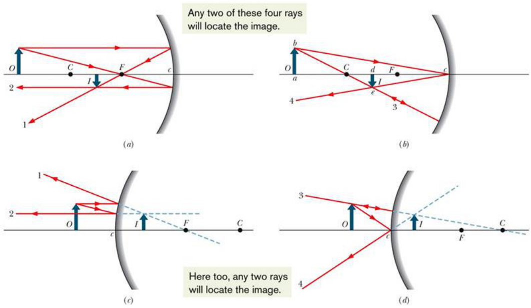

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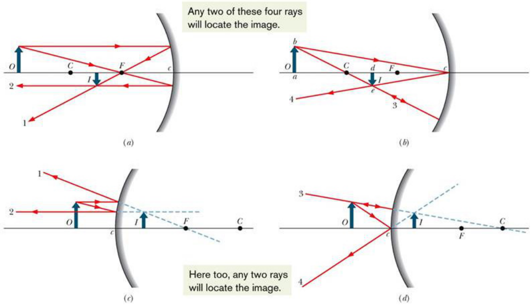
There are four rays that can be used to locate the image.

- Incoming parallel ray reflects through focus.
- Incoming focal ray reflect parallel.



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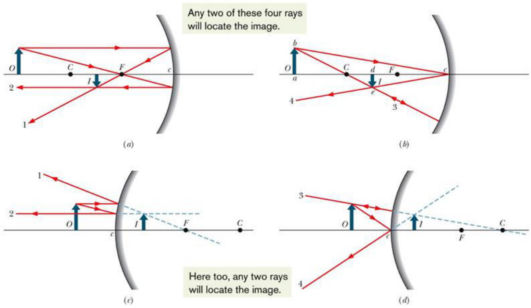
- Incoming central ray reflects on itself.



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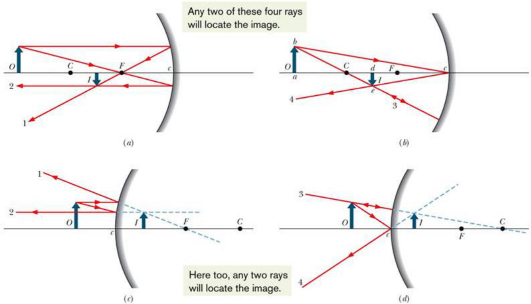
- Incoming parallel ray reflects through focus.
- Incoming focal ray reflect parallel.
- Incoming central ray reflects on itself.
- Incoming centered ray reflects symmetrically.



Spherical Mirrors

Lecture Question 2.1

An object is placed at the center of curvature of a concave spherical mirror. Which of the following descriptions best describes the image produced in this situation?

(a) upright, larger, real

(b) inverted, same size, real

(c) upright, larger, virtual

(d) inverted, smaller, real

(e) inverted, larger, virtual

Lenses

A lens is a transparent object used to shape light.

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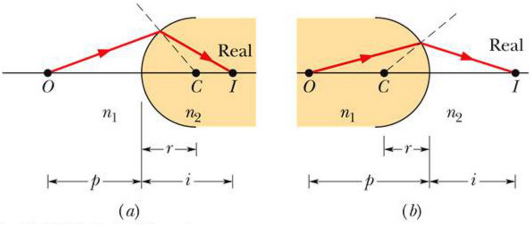
The material and shape of the object determine how it behaves.

Lenses

Consider a simplified lens with only one refracting surface.



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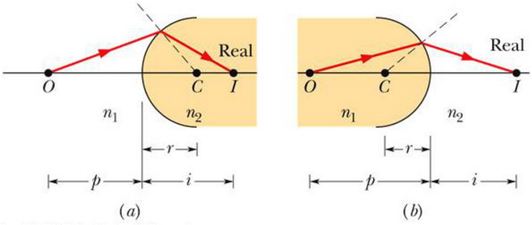
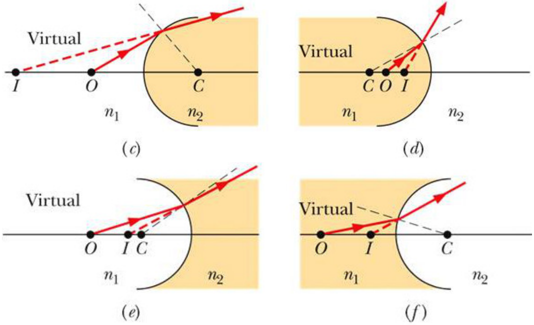


This system is governed by

$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r} \tag{2}$$

Lenses

There are other possible geometries:



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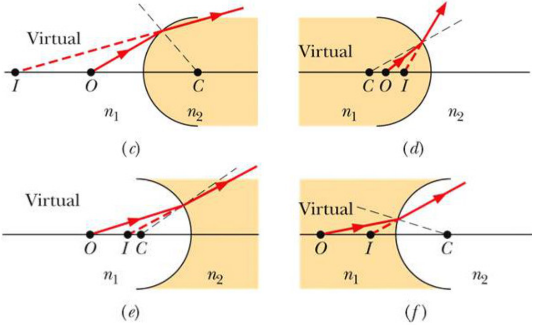
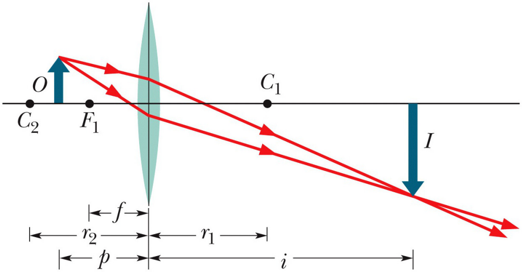


$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}$$

Lenses

The lens maker's equation determines the focal length given the lens's physical properties.

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad (3)$$



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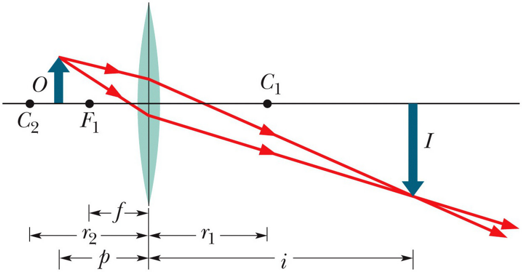
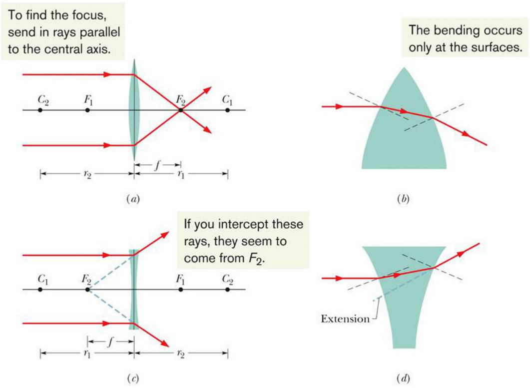


Here, the radii are r_1 and r_2 and index of refraction is n.

Lenses

The focal point can be found using parallel rays.



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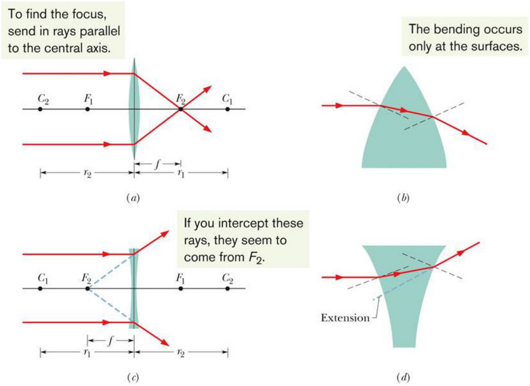
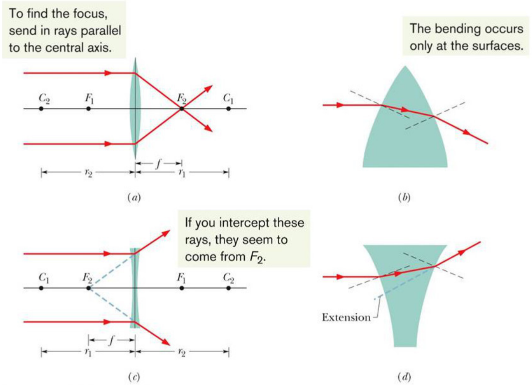


A convex lens has a real focal point, but a concave lens has a virtual focal point.

Lenses

Converging lenses have positive focal lengths, but diverging lenses have negative focal lengths.



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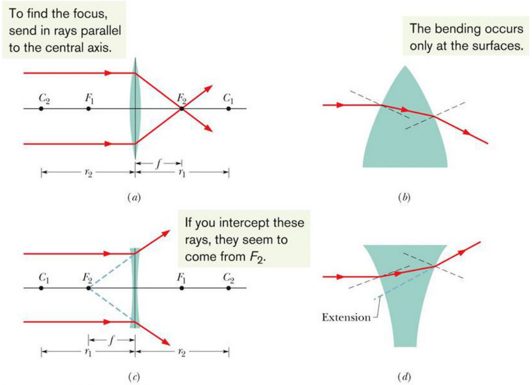
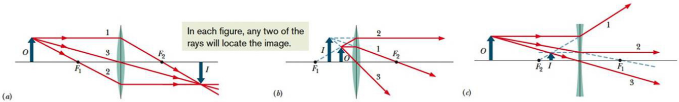


This is important in applications of the thin lens equation $(\frac{1}{p} + \frac{1}{i} = \frac{1}{f})$.

Lenses

Three rays (parallel, focal and central) can be used to find the image of an object with a thin lens.



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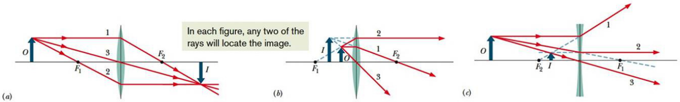

- **Parallel ray:** moves parallel to the central axis, then passes through the focal point
- **Focal ray:** reversed (first through the focus, then parallel)
- **Central ray:** passes through the center of the lens unaffected.

Lenses

When imaging with two lenses, apply the thin lens equation

(a) on the first lens, ignoring lens two;

(b) then on the second lens, ignoring lens one.

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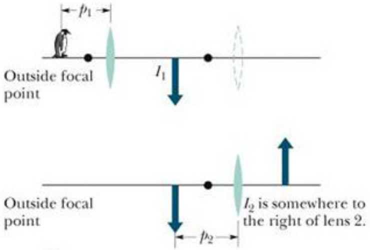

(a)

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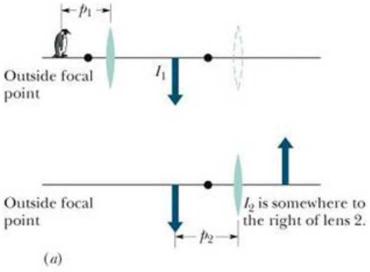
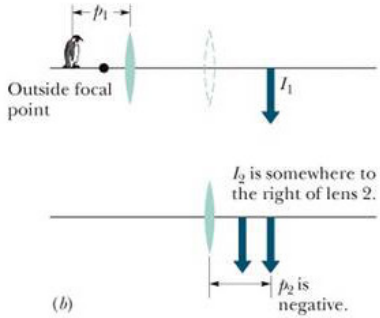


The *image* of lens 1 is an *object* for lens 2.

Lenses

The image of lens 1 can be past lens 2 entirely.



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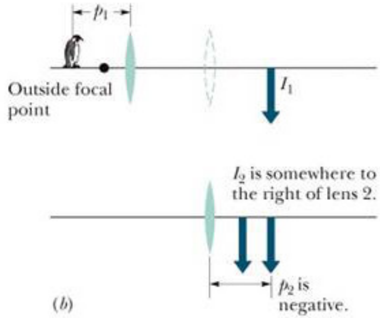
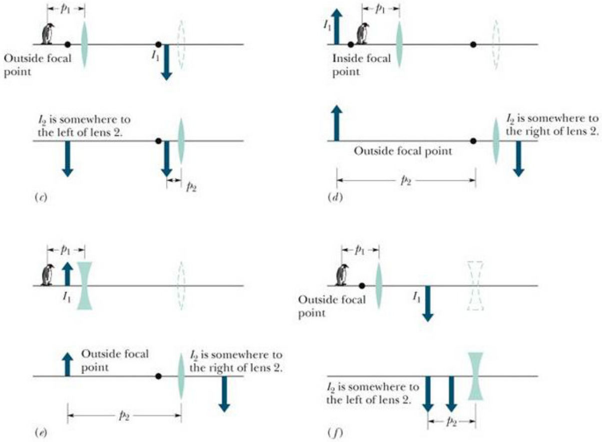


In this case, the object distance p_2 for lens 2 is negative.

Lenses

There are many other arrangements.



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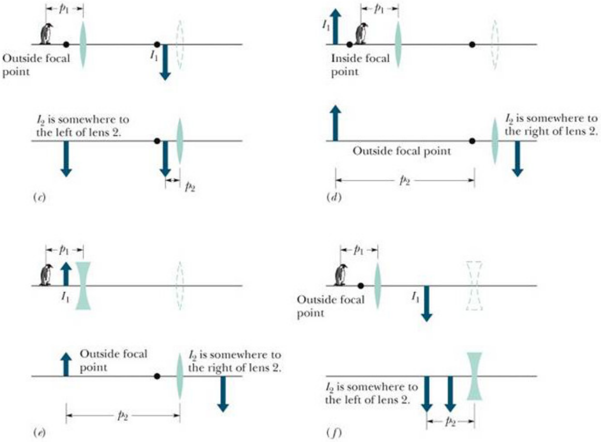


When finding the resulting image, it's important to note whether the image is inverted or not by tracing the rays.

Lecture Question 2.2

An object is located 25 cm to the left of a converging lens that has a focal length of 12 cm, producing a real image. If you wanted to produce a larger real image without changing the distance between the object and lens, you should replace the lens with a

(a) 4 cm focal length diverging lens.

(b) 4 cm focal length converging lens.

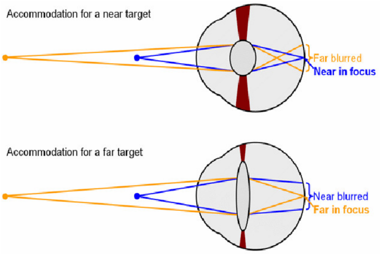
(c) 12 cm focal length diverging lens.

(d) 20 cm focal length converging lens.

(e) 20 cm focal length diverging lens.

Optical Instruments

The near point P_n of the eye is the closest distance the eye can bring into focus (about 25 cm).



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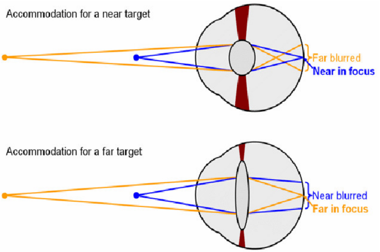
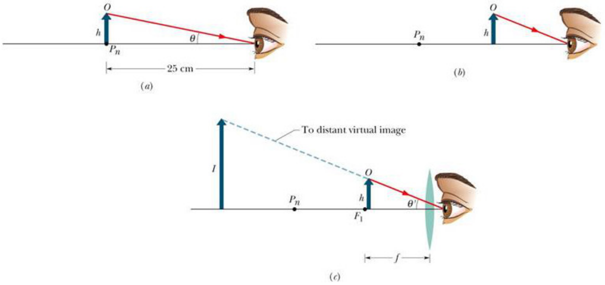


However, using a magnifying glass, objects can be brought closer than 25 cm while appearing to be much father away.

Optical Instruments

The magnifying glass creates a virtual image outside the near point, allowing the eye to focus on the object despite its proximity.



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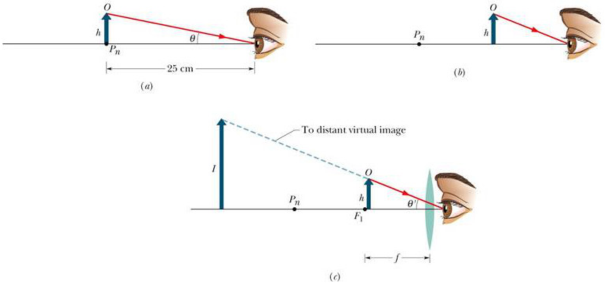
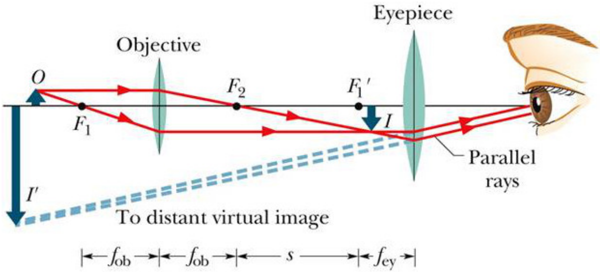


The magnification is approximately $m_\theta = 25/f$ where the focal length is in centimeters.

Optical Instruments

The compound microscope uses two lenses to magnify an object.



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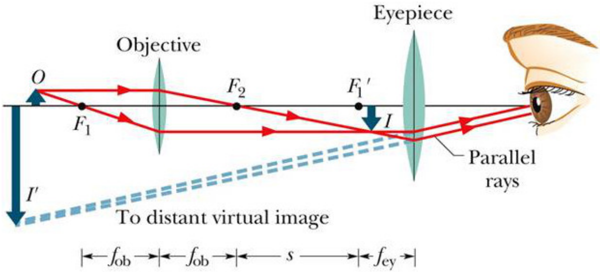
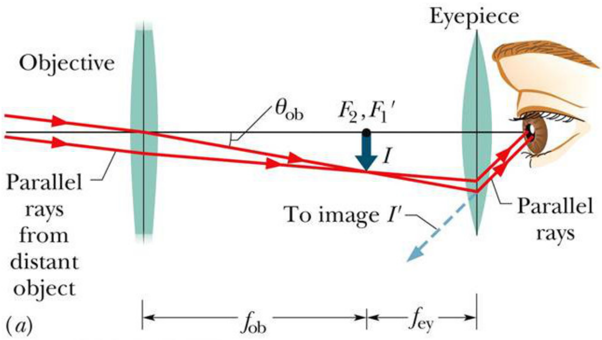


The overall magnification is given by the magnification of the two lenses: $M = m_{ob} m_{ey} \approx -\frac{s}{f_{ob}} \frac{25\text{ cm}}{f_{ey}}$.

Optical Instruments

A telescope images very large objects at very large distances (opposite of a microscope).



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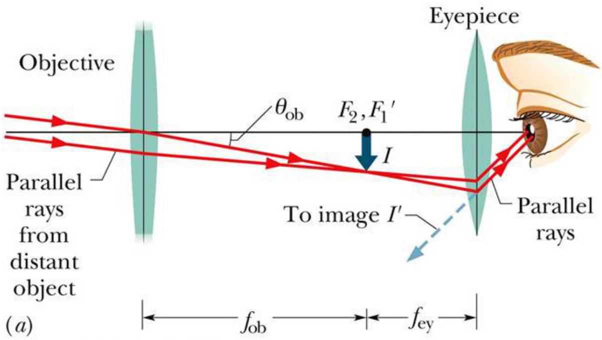

Here, the magnification is just the ratio of the focal lengths, $m = -f_{ob}/f_{ey}$.

Lecture Question 2.3

To see the rings of Saturn, you need to resolve close to 1 arcsec (0.000278°) of angle. Since, the human eye can only resolve about 60 arcsec of angle (0.0167°), a telescope must be used. If your telescope has a 1200 mm focal length objective lens, focal length eyepiece is required to see the rings of Saturn?

(a) 80 mm

(b) 48 mm

(c) 20 mm

(d) 19 mm

(e) 17 mm