Optics
Lenses
Wave Behavior in Optics

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Last time

- magnification and refracting surfaces
- images formed by lenses

Overview

- images formed by lenses
- images formed by lens combinations
- wave behavior in optics
- diffraction effects
- Rayleigh criterion

Converging Lens Example, 36.8

A converging lens has a focal length of 10.0 cm.

(a) An object is placed 30.0 cm from the lens. Construct a ray diagram, find the image distance, and describe the image.

(b) An object is placed 5.00 cm from the lens. Find the image distance and describe the image.

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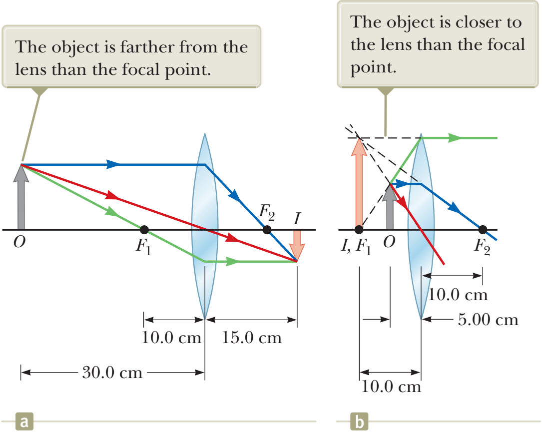

Converging Lens Example

(a) An object is placed 30.0 cm from the lens.

$$q = +15.0\text{cm}$$

$$M = -0.500$$

(b) An object is placed 5.00 cm from the lens.

$$q = -10.0\text{cm}$$

$$M = +2.00$$

(c) An object is placed 10.0 cm from the lens. Find the image distance and describe the image.

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$$q = \infty$$

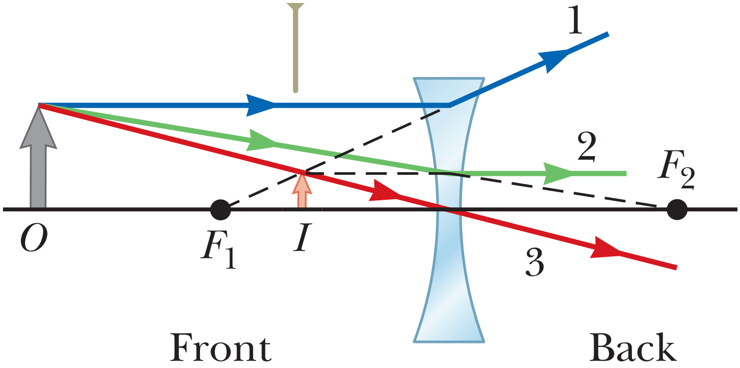
No image is formed!

Ray Diagrams for Diverging Lenses

For Diverging Lenses:

1. Draw a ray from the top of the object parallel to the principle axis refracted outward directly away focal point F on the front side of the lens.
2. Draw a ray from the top of the object toward the focal point on the back side of the lens and refracted parallel to the principal axis.
3. Draw a ray from the top of the object through the center of the lens, and continuing in a straight line.

Ray Diagrams for Diverging Lenses



The image formed is upright, virtual, and smaller in size.

Diverging Lenses

The image formed is upright, virtual, and smaller in size.

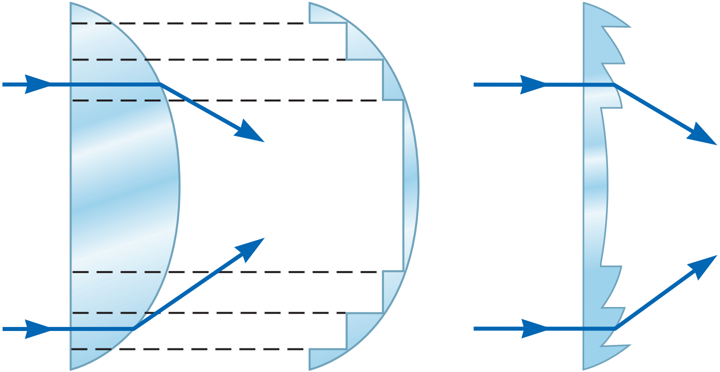
[0]Photo from the Capilano University Physics Dept. webpage.

Cases for Lenses

type of lens	object dist	image		
$f > 0$, converging, convex	$p > 2f$	real	inverted	diminished
	$f < p < 2f$	real	inverted	enlarged
	$p < f$	virtual	upright	enlarged
$f < 0$, diverging, concave	any p	virtual	upright	diminished

[1] Notice that this table is actually identical to the one for mirrors, except that the words "convex" and "concave" have been swapped.

Fresnel Lenses



Combinations of Lenses

Two or more lenses can be used in series to produce and image.

This is used in

- eyeglasses (your eyeball lens is the second lens)
- refracting telescopes
- microscopes
- camera zoom lenses

Lenses can also be used together with curved mirrors, for example in reflecting telescopes.

Combinations of Lenses

Two thin lenses placed right up against each other (touching) will act like one lens with a focal length

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

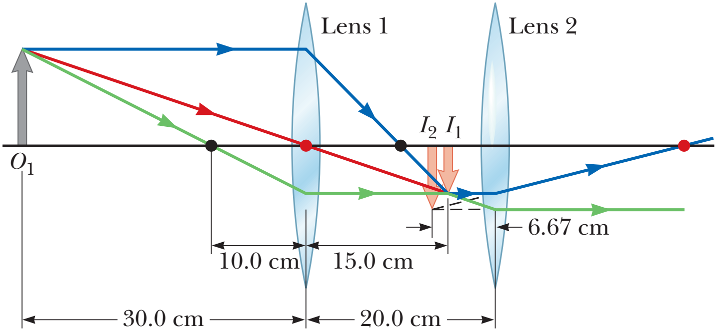
In other cases, the intermediate image formed by the first lens must be found, and imaged again in the second lens to find the final image.

The magnification of a series of lenses is the product of the magnification produced by each one.

Combinations of Lenses Example 36.10

Two thin converging lenses of focal lengths $f_1 = 10.0$ cm and $f_2 = 20.0$ cm are separated by 20.0 cm as illustrated. An object is placed 30.0 cm to the left of lens 1.

Find the position and the magnification of the final image.



Combinations of Lenses Example 36.10

The second lens makes an image of the image formed by the first lens. The object for the second lens is I_1.

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Use the lens equation twice in series.

Moving beyond Ray Optics

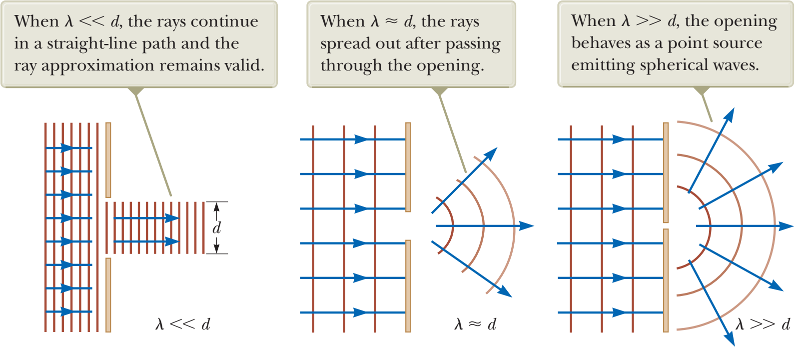
Ray optics can tell us about the formation of images, but it cannot tell us about the behavior of light that is specific to waves.

The ray approximation assumes that light will travel out from a source in straight lines, unless it encounters a change of medium.

However light does also behave a wave and can change direction at apertures: diffraction and interference.

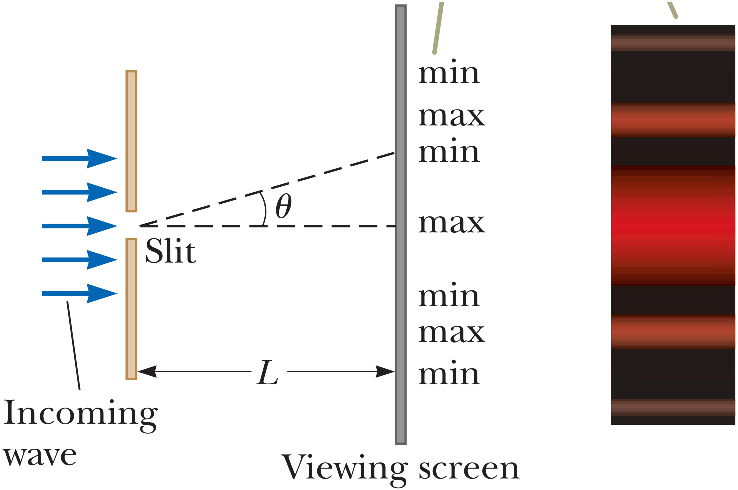
Diffraction

We already know that light and other waves that travel through a small gap ($< \lambda$) diverge, and that the smaller the gap, the more divergence.

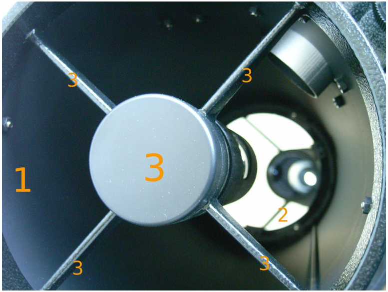


The intensity of light in each direction is not the same however.

Diffraction Patterns



Diffraction Spikes

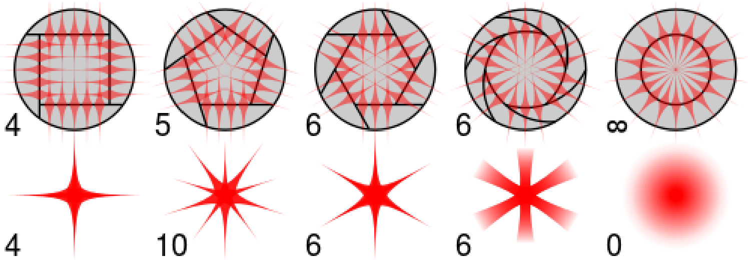


[1]NASA, ESA, and H. Richer (University of British Columbia); Svon Halenbach

Diffraction Spikes in Camera Apertures

Iris diaphragms adjust the amount of light allowed into a camera body.

They cause characteristic diffraction patterns on photos taken of bright lights.

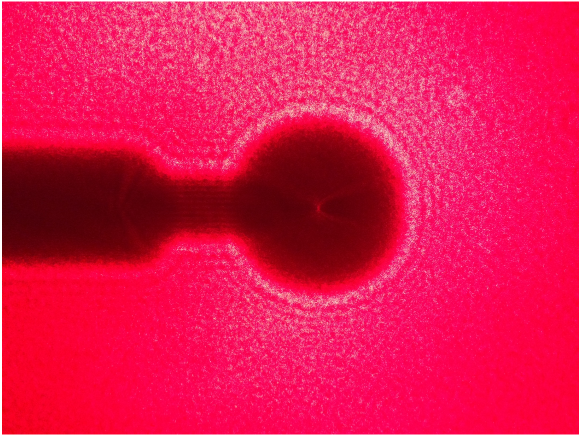


[1]Wikipedia user Cmglee

Diffraction Patterns: Arago Spot

Directly in the center of the shadow produced by a round object lit with coherent light, a spot of light can be observed!

This is called the Arago spot, Fresnel bright spot, or Poisson spot.



[1]Photo taken at Exploratorium in SF, own work.

Resolution and the Rayleigh criterion

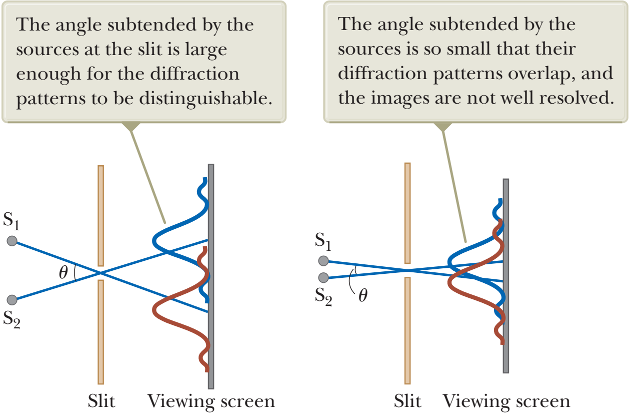
Diffraction effects mean that we cannot perfectly resolve objects.

We use optical systems like our eyes, a camera, or a telescope to view distant objects and interpret them.

Imagine two distant stars. If they are very close together, or so far away that they make a very small angle to each other in the sky, they may look like only one star.

When can we distinguish them as two separate points?

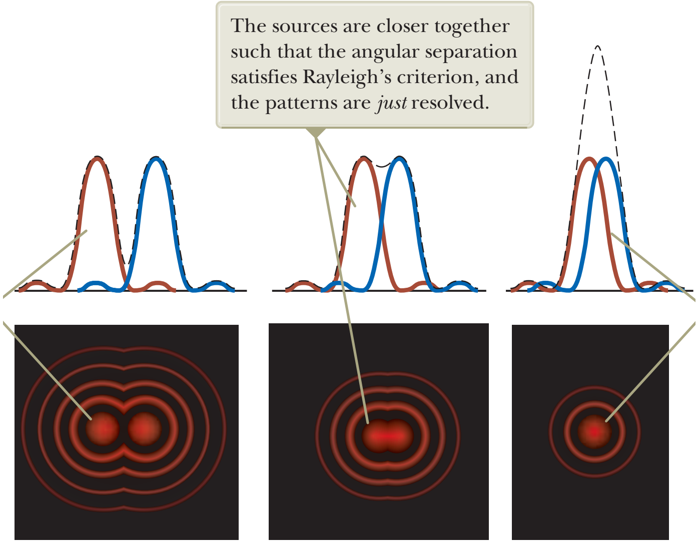
Resolution and the Rayleigh criterion



When the central maximum of one falls on the first dark fringe of the other, the two images begin to look like they came from one object.

$$\theta_{\min} \approx \sin\theta_{\min} = \frac{\lambda}{a}$$

Resolution and the Rayleigh criterion



Resolution and the Rayleigh criterion

For circular points being resolved, the Rayleigh Criterion is:

$$\theta_{\text{min}} = 1.22\frac{\lambda}{D}$$

where D is the diameter of the aperture.

The 1.22 factor comes from a full analysis of the 2-dimensional diffraction pattern for a circular aperture.

Summary

- images formed by lenses
- images formed by lens combinations
- wave behavior in optics
- diffraction effects
- Raleigh criterion

Final Exam 9:15-11:15am, Tuesday, June 23.

Homework Serway & Jewett: (suggested)

- Ch 37, onward from page 1150. OQs: 3, 9; CQs: 3, 5; Probs: 19, 21 (Young's experiment)
- Ch 38, onward from page 1182. Probs: 10, 15, 21 (diffraction and resolution)