

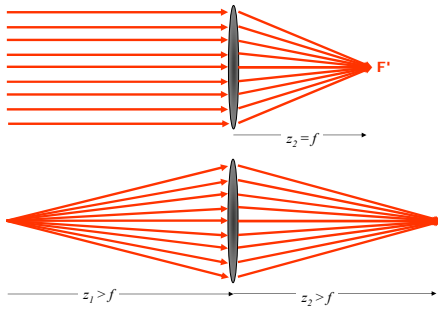
Imaging with Lenses

- Distance from Object to Lens is z_1
- Distance from Lens to Image is z_2
- Relate f to z_1 and z_2 through the *Imaging Equation*

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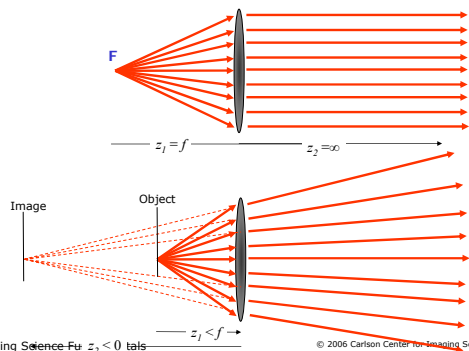
Imaging with Positive Lens



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Imaging with Positive Lens



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Observations for Positive Lens

Object Distance z_1	Image Distance z_2
∞	$f > 0$ (real image)
$> f$	$> f$ (real image)
$f > 0$	∞ ("real image")
$< f$	< 0 (virtual image)

Imaging Equation
for Lens

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

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Example:

- Where is the image if $z_1 = 2f$?

$$\frac{1}{2f} + \frac{1}{z_2} = \frac{1}{f} = \frac{2}{2f}$$

$$\frac{1}{z_2} = \frac{2}{2f} - \frac{1}{2f} = \frac{1}{2f}$$

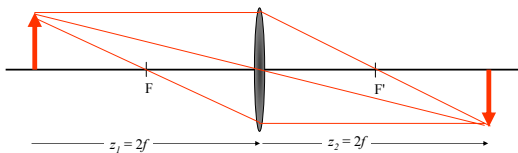
$$z_2 = 2f = z_1$$

Image Distance = Object Distance
("Equal Conjugates")

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Diagram of Lens at Equal Conjugates



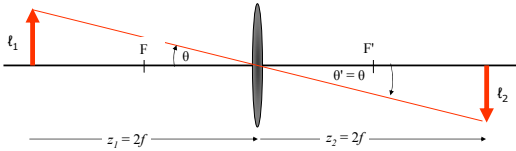
- Cast two rays from tip of object
 - parallel to axis of symmetry, refracts through "rear" focal point
 - through center of lens, not refracted
- Also May Cast Third Ray
 - through "front" focal point, refracts parallel to axis
- These rays "converge" at the image point

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Imaging at Equal Conjugates

- Image size is identical to object size, but "upside down" ("inverted")



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Image Magnification

- Ratio of the *size* of the output image compared to the input object?

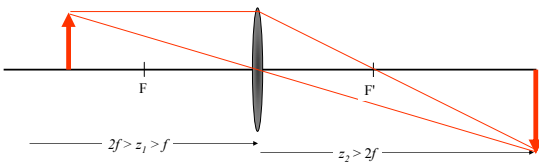
$$\theta = \frac{l_1}{z_1} = -\frac{l_2}{z_2}$$

$$M_t = \frac{l_2}{l_1} = -\frac{z_2}{z_1}$$

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Diagram of Lens with $2f > z_1 > f$



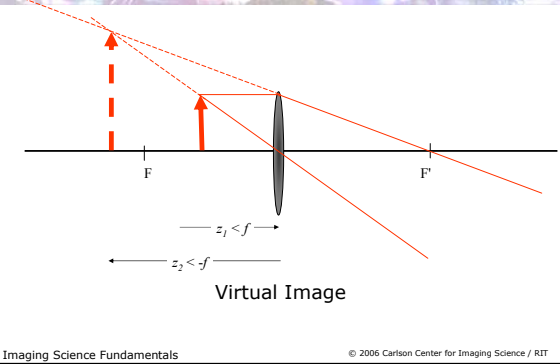
Example: $z_1 = 1.5f$

$$\frac{1}{\left(\frac{3}{2}f\right)} + \frac{1}{z_2} = \frac{1}{f} \Rightarrow z_2 = 3f \Rightarrow M_t = -\frac{z_2}{z_1} = -\frac{3f}{\left(\frac{3}{2}f\right)} = -2$$

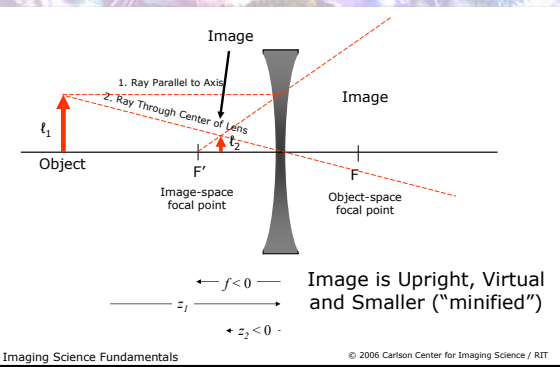
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Diagram of Lens with $z_1 < f$



Tracing Rays for Negative Lens



Imaging with a Negative Lens

- Focal length f is negative: $f = -|f|$
- Place object at distance $z_1 = 2|f|$

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f} = -\frac{1}{|f|}$$

$$z_1 = 2|f| \Rightarrow z_2 = -\frac{2|f|}{3}$$

$$M_r = -\frac{z_2}{z_1} = -\frac{-\frac{2|f|}{3}}{2|f|} = +\frac{1}{3}$$

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Imaging Chain Link #4

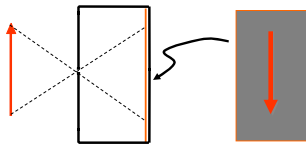
Energy Sensors

- Convert energy propagated from object to a measurable physical parameter
 - e.g., number of silver atoms or number of electrons

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Image Capture = Detection = Sensing



- Image captured by sensor, e.g., photographic emulsion, CCD
 - Emulsions must be *processed* to yield a permanent visible image
 - CCDs must be *read out* to produce an array of numbers that may be interpreted as an image

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Most Common Sensors

- Human Eye
- Photographic Emulsion
 - film
 - plates
- Electronic Sensors
 - "Charge-Coupled Devices" = CCDs
 - "Complementary Metal-Oxide Semiconductors" = CMOS
 - "Charge-Injection Devices" = CIDs

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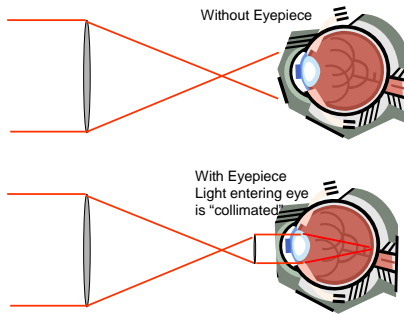
Eye as Detector

- Eye includes its own lens
 - focuses light on retina ("sensor")
- When used with an optical device (e.g., telescope), must add yet another lens
 - redirect rays from primary optic
 - make them parallel ("collimated")
 - ▶ rays appear to come from "infinity" (infinite distance away)
 - reimaging is performed by "eyepiece"

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Eye with Telescope



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Photographic Emulsions

- More difficult to quantify



- Light-sensitive "grains" of silver halide in the emulsion
- Placed "randomly" in emulsion
- "Random" sizes
- "large" grains are more sensitive (respond to few photons)
- "small" grains produce better resolution

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