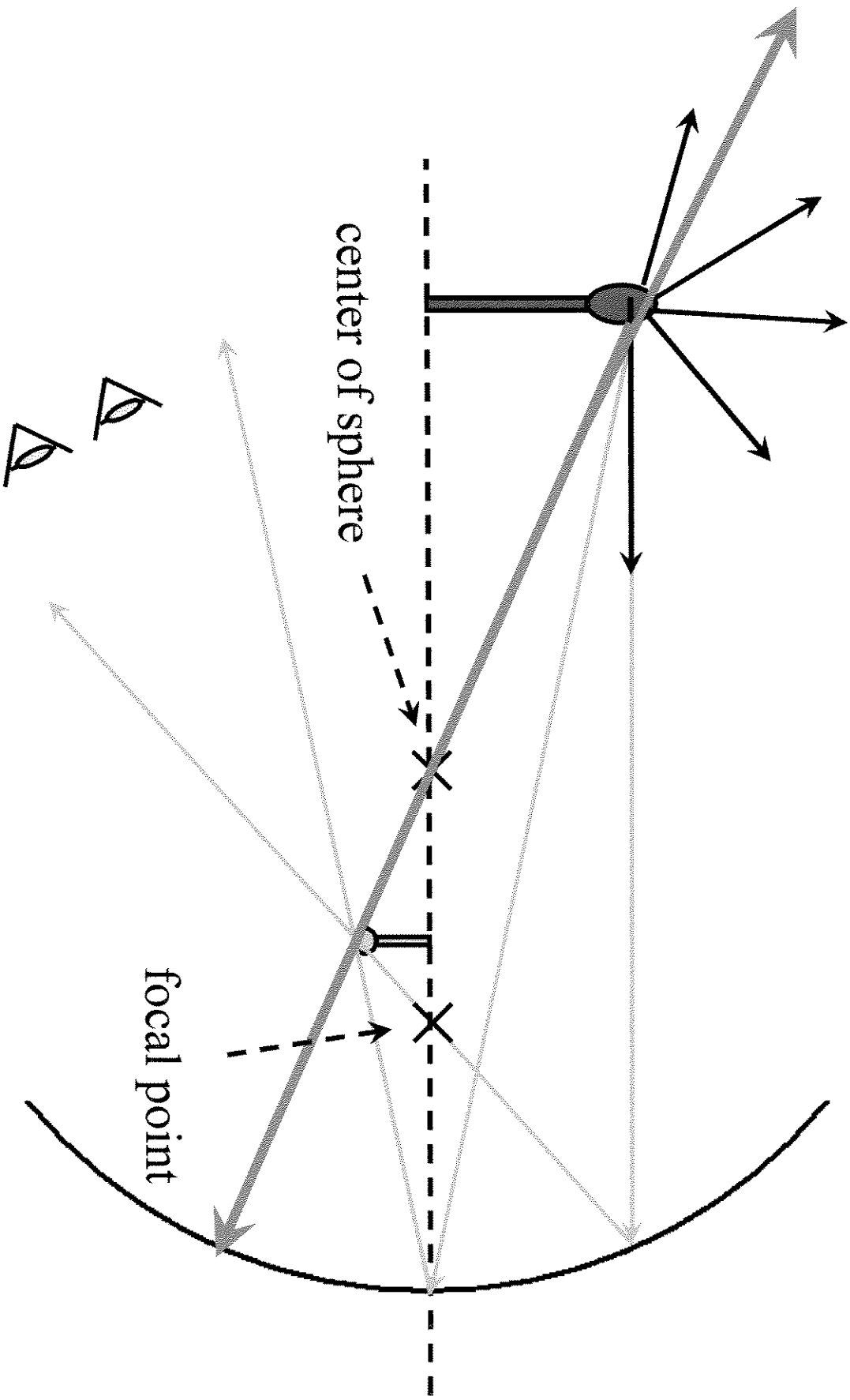


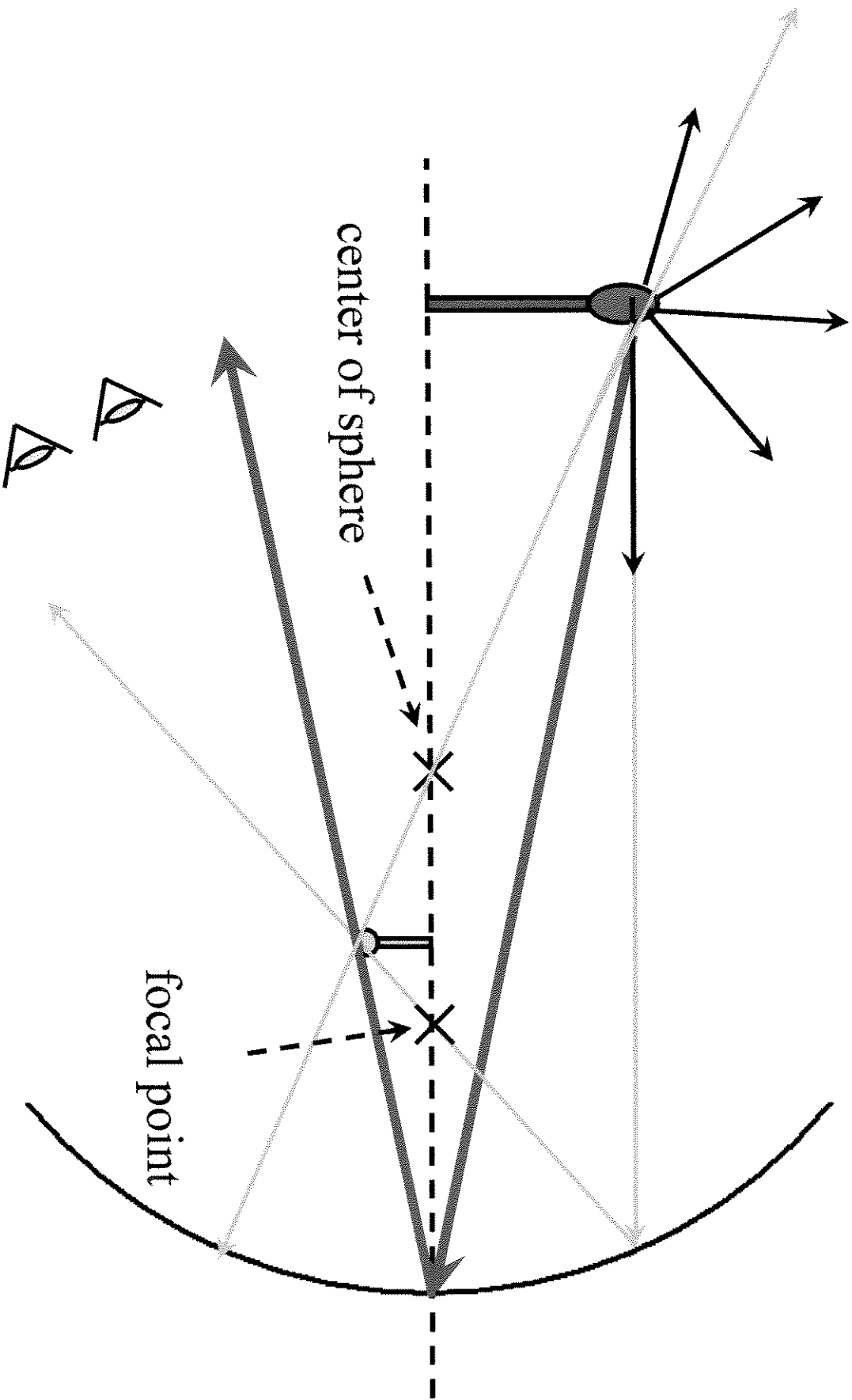
Lecture

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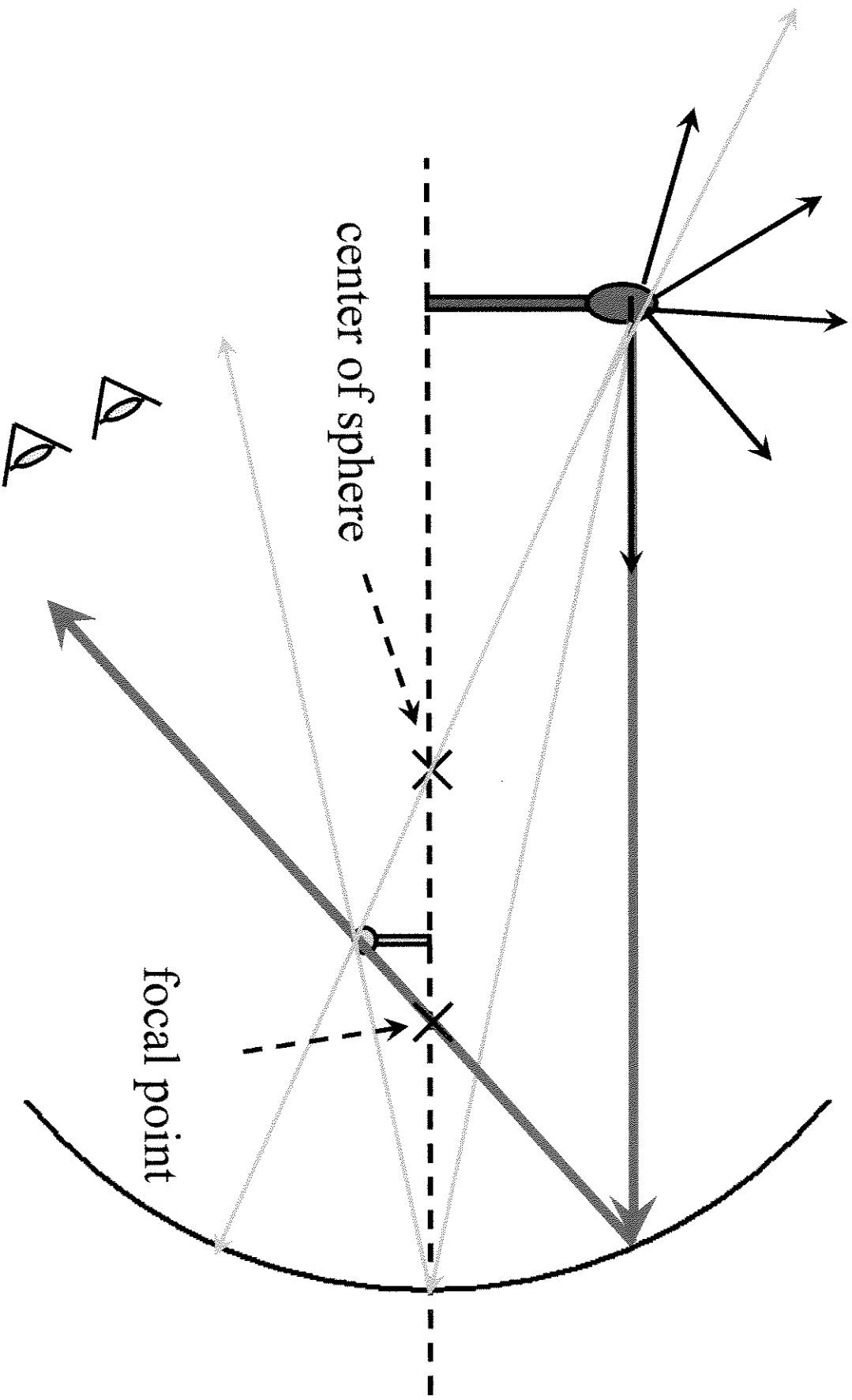
# Images in a Spherical Mirror: 1

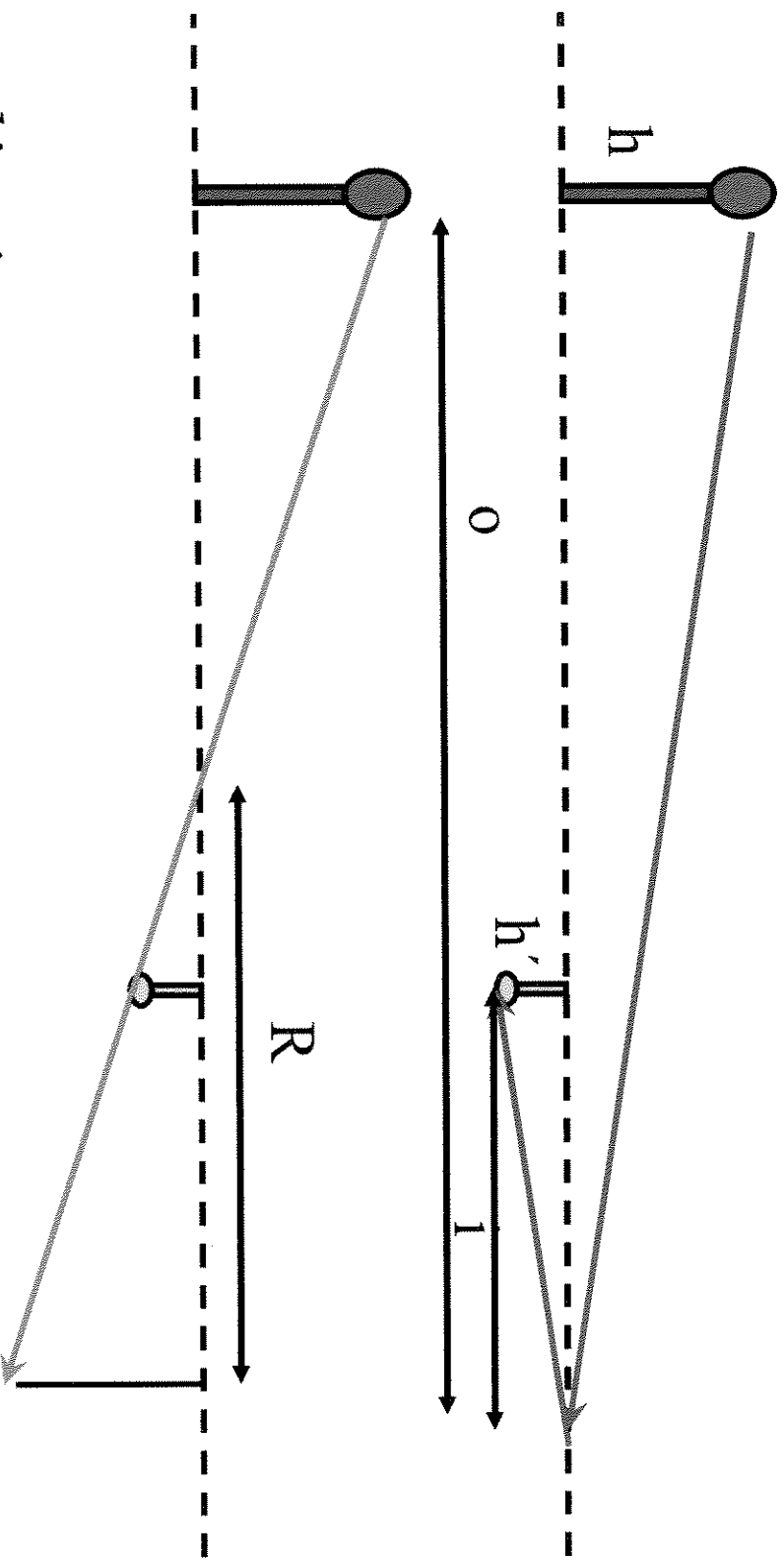


# Images in a Spherical Mirror: 1



# Images in a Spherical Mirror: 1

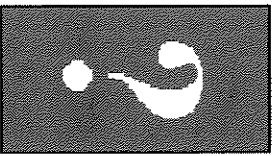




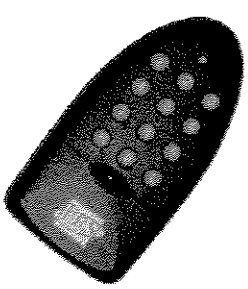
$$\frac{h'}{h} = \frac{i}{o} = \frac{R-i}{o-R}$$



$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o} \quad f = R/2$$

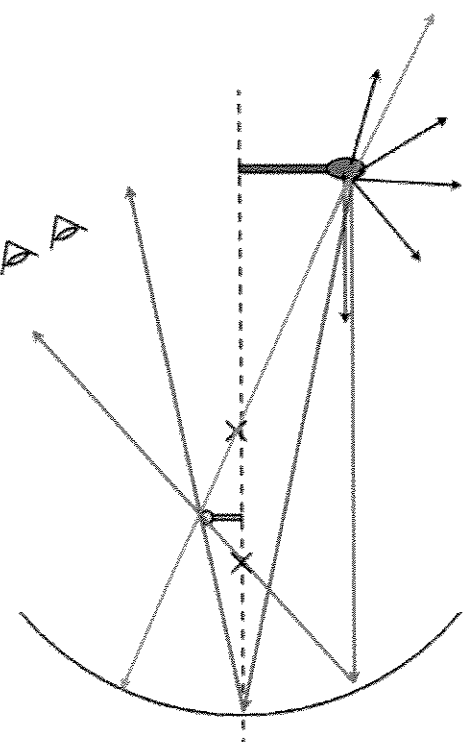


# Puzzle

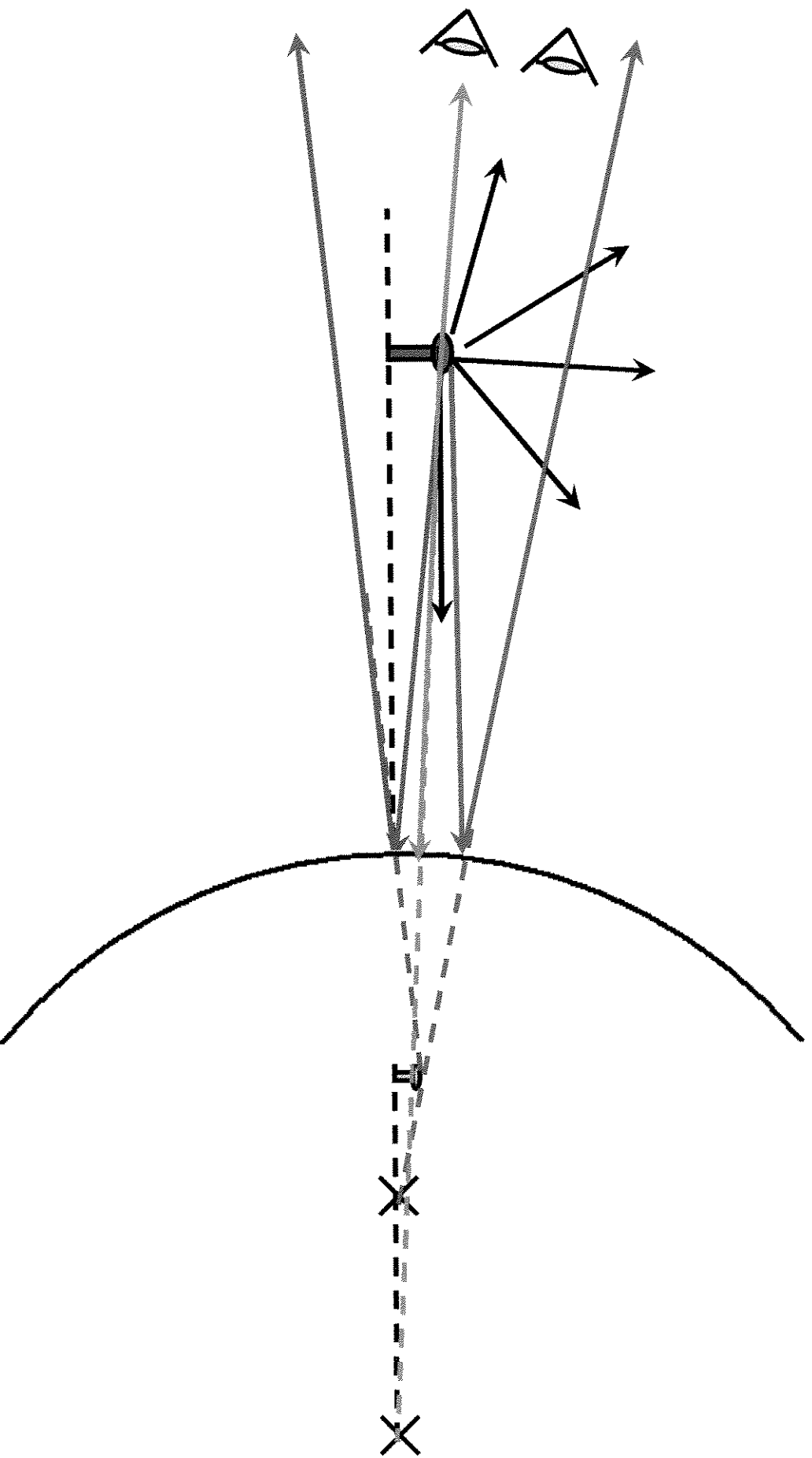


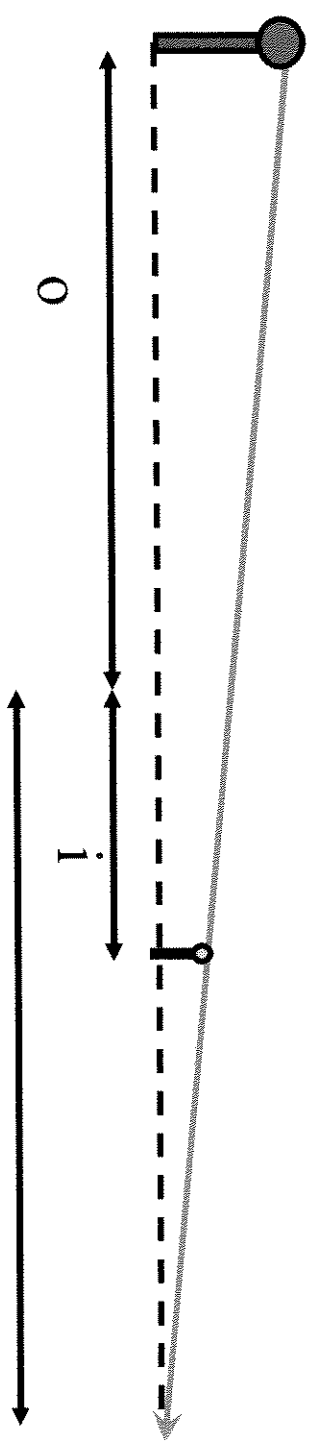
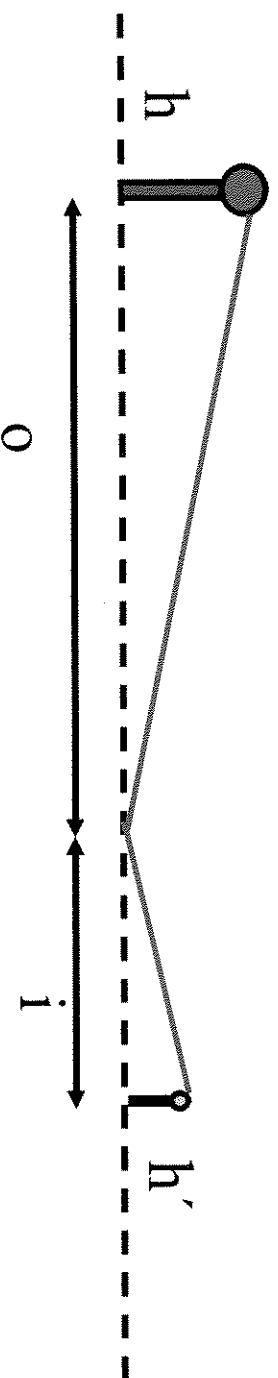
■ In class on Wednesday, we showed a curved mirror that produced a real image at the same distance from the mirror as the object. What distance does that have to be?

- 1.  $R$
- 2.  $R/2$
- 3. less than  $R/2$
- 4. greater than  $R$



# Images in a Spherical Mirror: 2



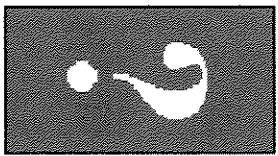


$$\frac{h'}{h} = \frac{i}{0}$$

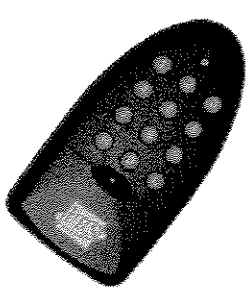
$$\frac{h'}{h} = \frac{R-i}{R+0}$$



$\frac{1}{f}$	$=$	$\frac{1}{i}$	$+$	$\frac{1}{0}$	
					$f = R/2$

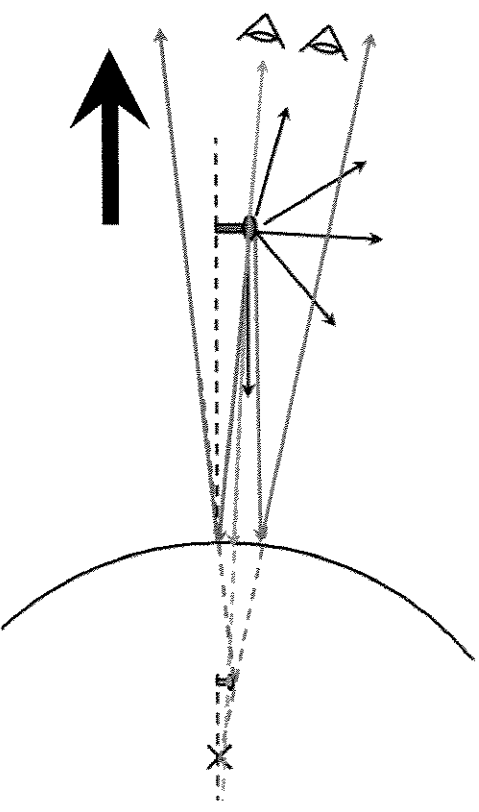


# Puzzle



- If we get very far away from the back of a curved mirror, where does the image appear to go?

1. R behind the mirror
2.  $R/2$  behind the mirror
3. at the mirror (just behind it)
4. very far behind the mirror



# Unifying Equation for Mirrors

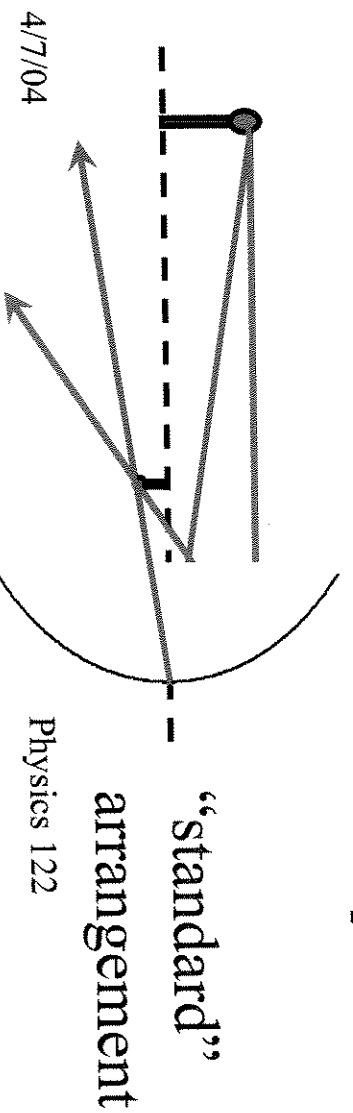
- If we treat our mirror quantities as “signed” and let the signs carry directional information, we can unify all the situations in a single set of equations.

$\frac{1}{f}$	$=$	$\frac{1}{i}$	$+$	$\frac{1}{o}$		$\frac{h'}{h}$	$=$	$\frac{i}{o}$		$f = R/2$
---------------	-----	---------------	-----	---------------	--	----------------	-----	---------------	--	-----------

$h > 0$	$h' < 0$	$o > 0$	$i > 0$	$i < 0$
$h < 0$	$h' > 0$	$o < 0$	$i < 0$	$i > 0$

)  $f < 0$

)  $f > 0$



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# Refraction

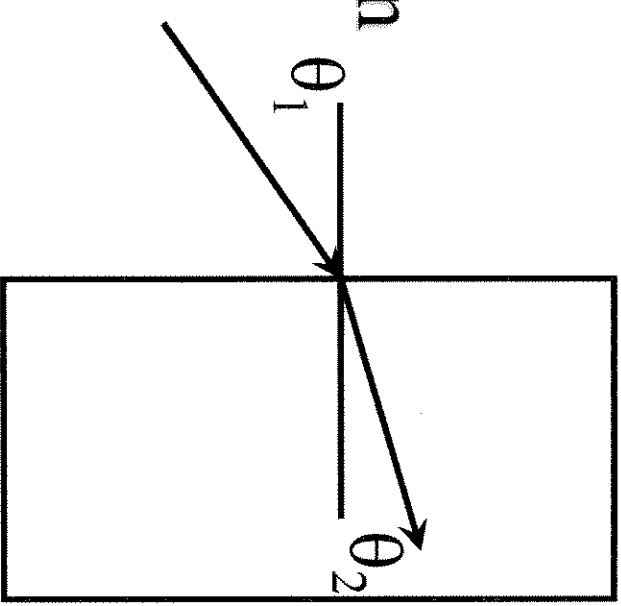
- When a ray of light enters a transparent medium at an angle, it appears to bend.
- Newton suggested that this was because light was made up of little particles and different media were like different (uniform) PEs for these particles.
- Light would speed up in a dense medium according to

$$\frac{1}{2}mv_1^2 + U_1 = \frac{1}{2}mv_2^2 + U_2$$

- Newton proposed that denser media had more negative PEs.

# Snell's Law

- Entering a dense medium is like rolling off a cliff.
- You only speed up in the direction perpendicular to the surface.
- Your speed in the direction parallel to the surface stays the same.



Why?

$$v_1 \sin \theta_1 = v_2 \sin \theta_2$$

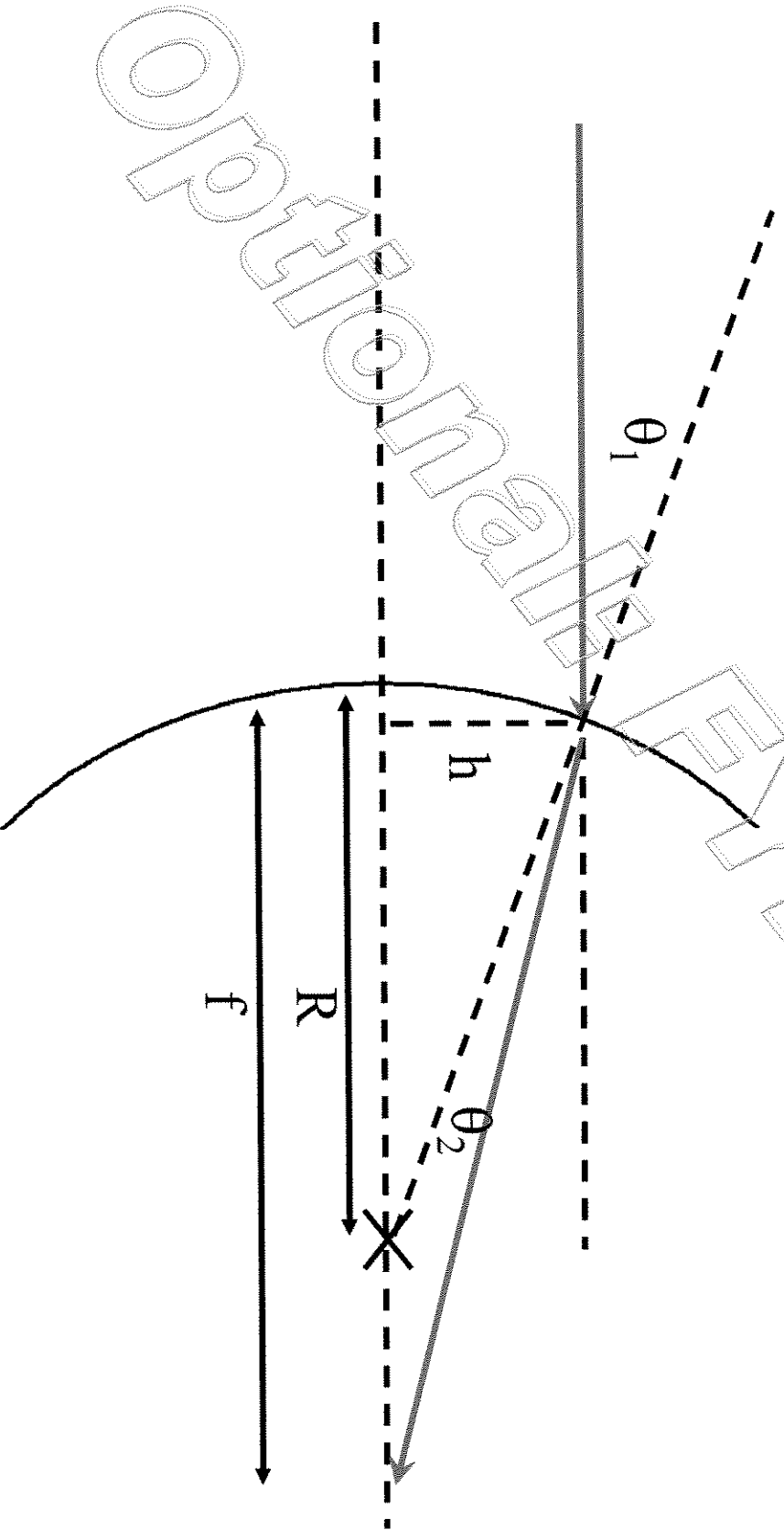
$$n_{\text{Newton}} = \frac{v}{c}$$

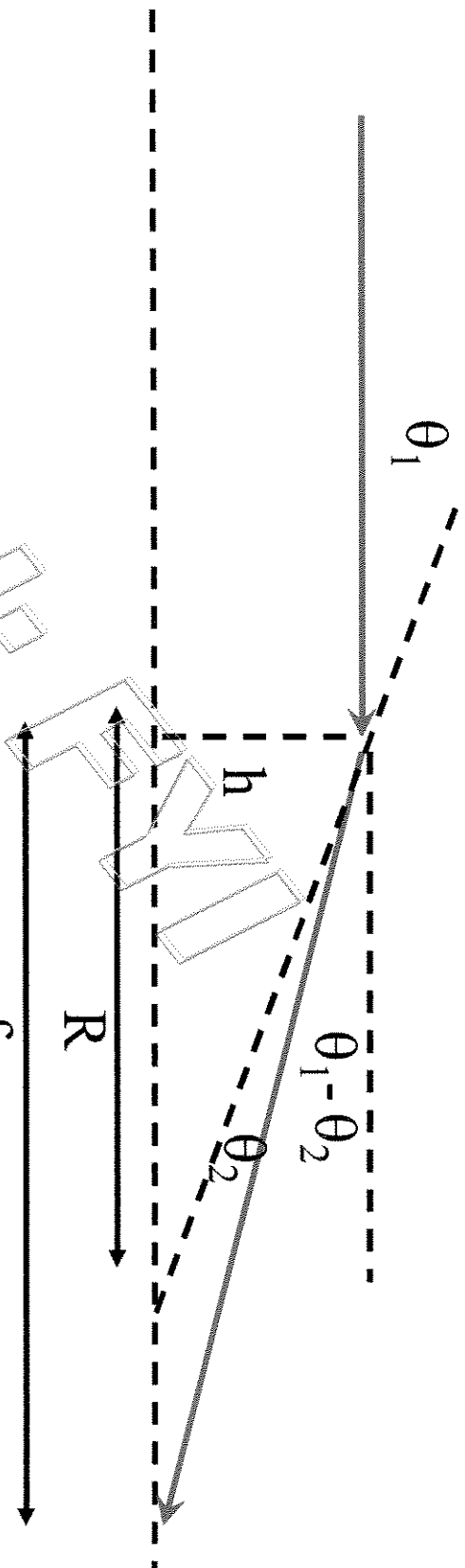
Speed of light in vacuum

# Index of Refraction

- Light propagating into a material with a larger  $n$  bends towards the normal.
- Light propagating into a material with a smaller  $n$  bends away from the normal.
- The property  $n$  is called *the index of refraction* of a material.
- The  $n$  of empty space (vacuum) is taken to be 1.
- The index of refraction of a material can depend on the color (frequency) of the light.

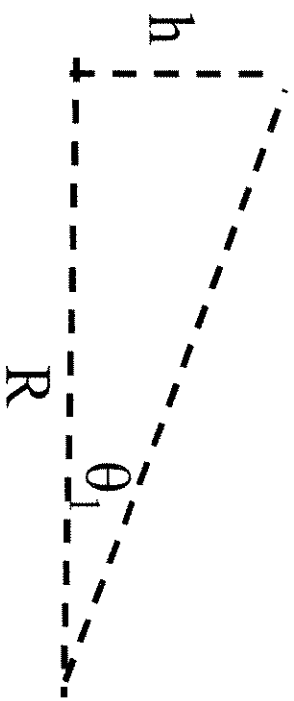
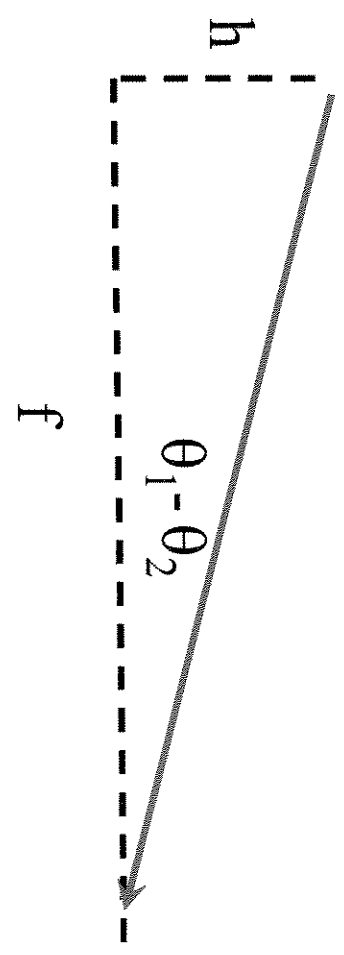
# Refraction at a spherical surface





$$\frac{h}{f} = \tan(\theta_1 - \theta_2)$$

$$\frac{h}{R} = \tan \theta_1$$



# The Lensmaker's Equation

$$\frac{h}{f} = \tan(\theta_1 - \theta_2)$$
$$\frac{h}{R} = \tan \theta_1$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

For small angles ( $\theta$  in radians)

$$\sin \theta \approx \theta$$

$$\tan \theta \approx \theta$$

$$h = f(\theta_1 - \theta_2)$$

$$h = R\theta_1$$

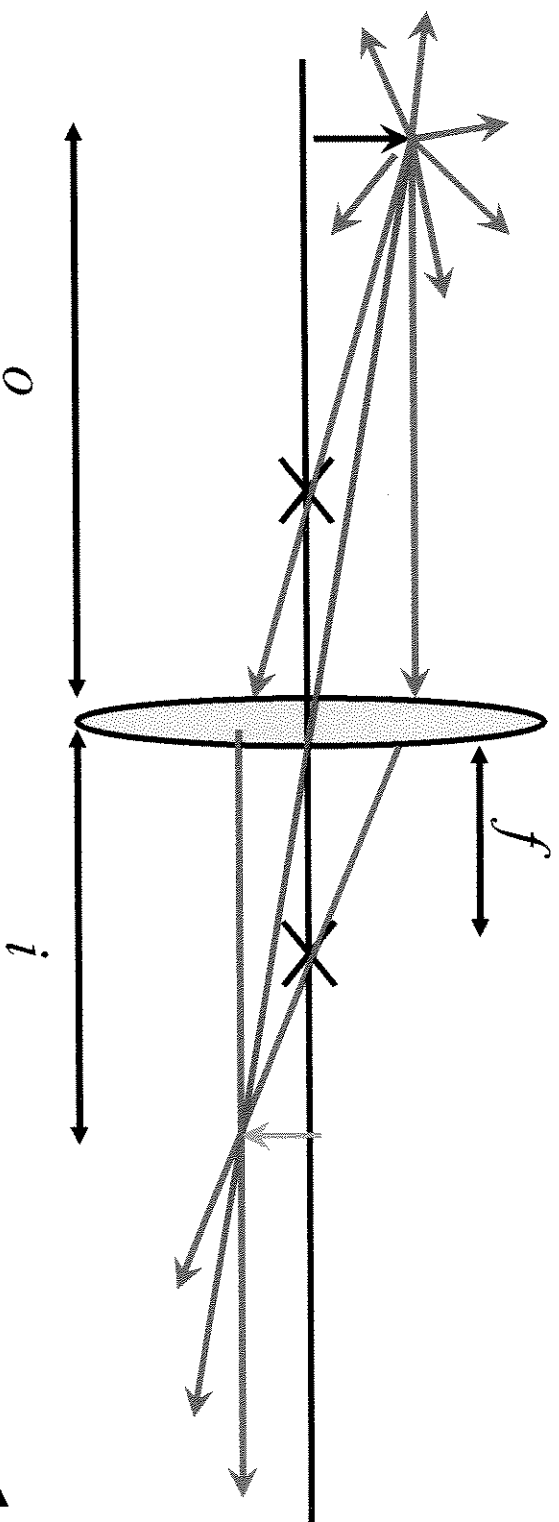
$$n_1 \theta_1 = n_2 \theta_2$$

$$f = \frac{R}{n_1 - n_2}$$

# The Lens Equation

- For a thin lens

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i} \quad \frac{h'}{h} = -\frac{i}{o}$$



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## SIGN CONVENTIONS FOR MIRRORS

<u>Quantity</u>	<u>In Front</u>	<u>In Back</u>	<u>Image</u>	
			<u>Upright</u>	<u>Inverted</u>
<b>o</b>	+	-		
<b>i</b>	+	-		
<b>f</b>	+	-		
<b>h'</b>			+	-
<b>M</b>			+	-