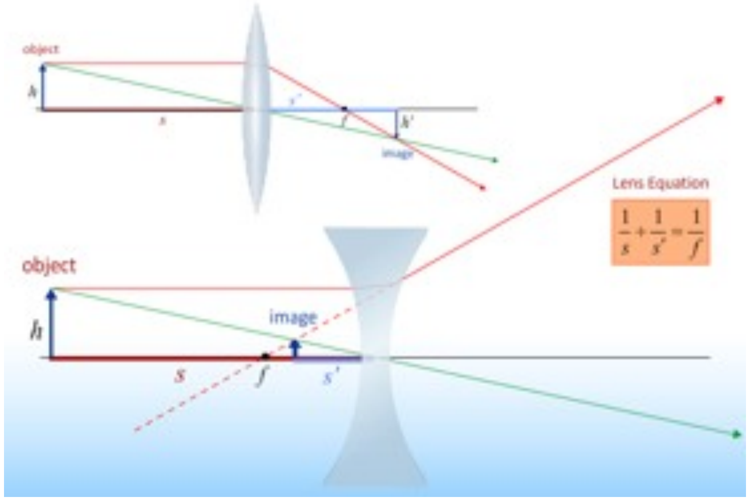
Physics 141
Lecture 26

Today's Concept:

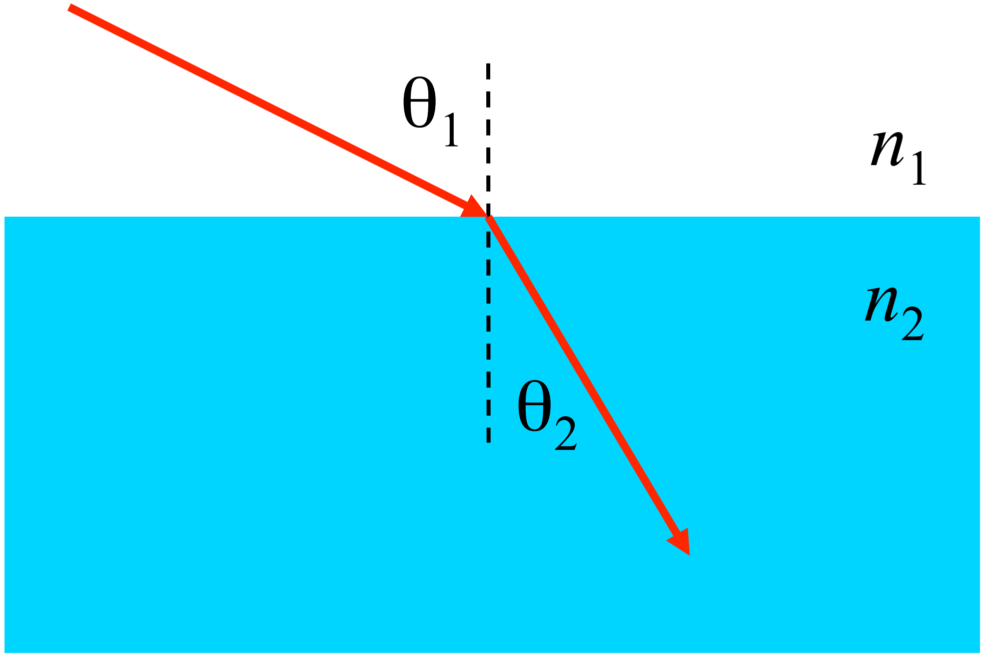
A) Lenses



Refraction

Snell's Law

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



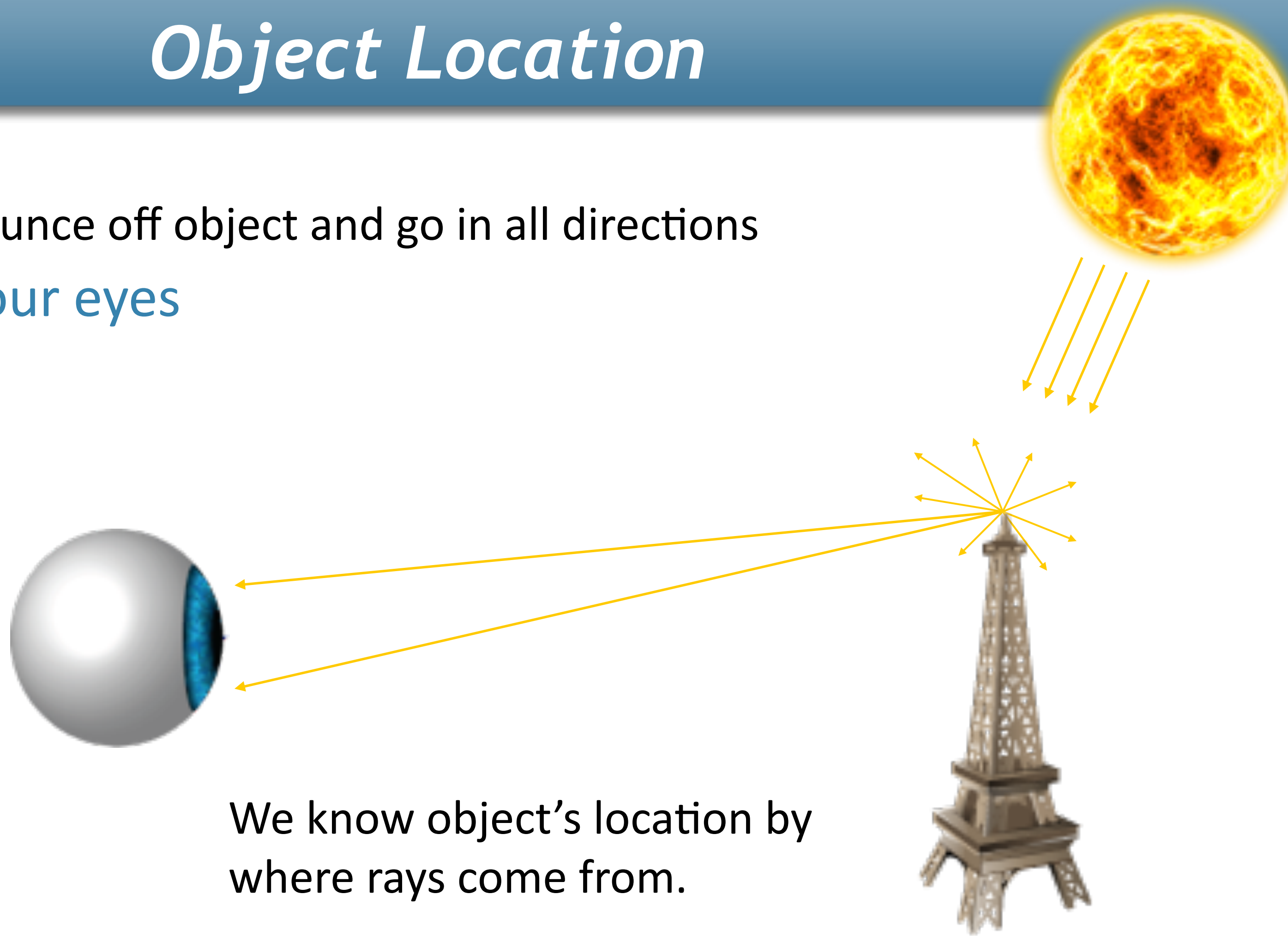
That's all of the physics –

everything else is just geometry!

Object Location

Light rays from sun bounce off object and go in all directions

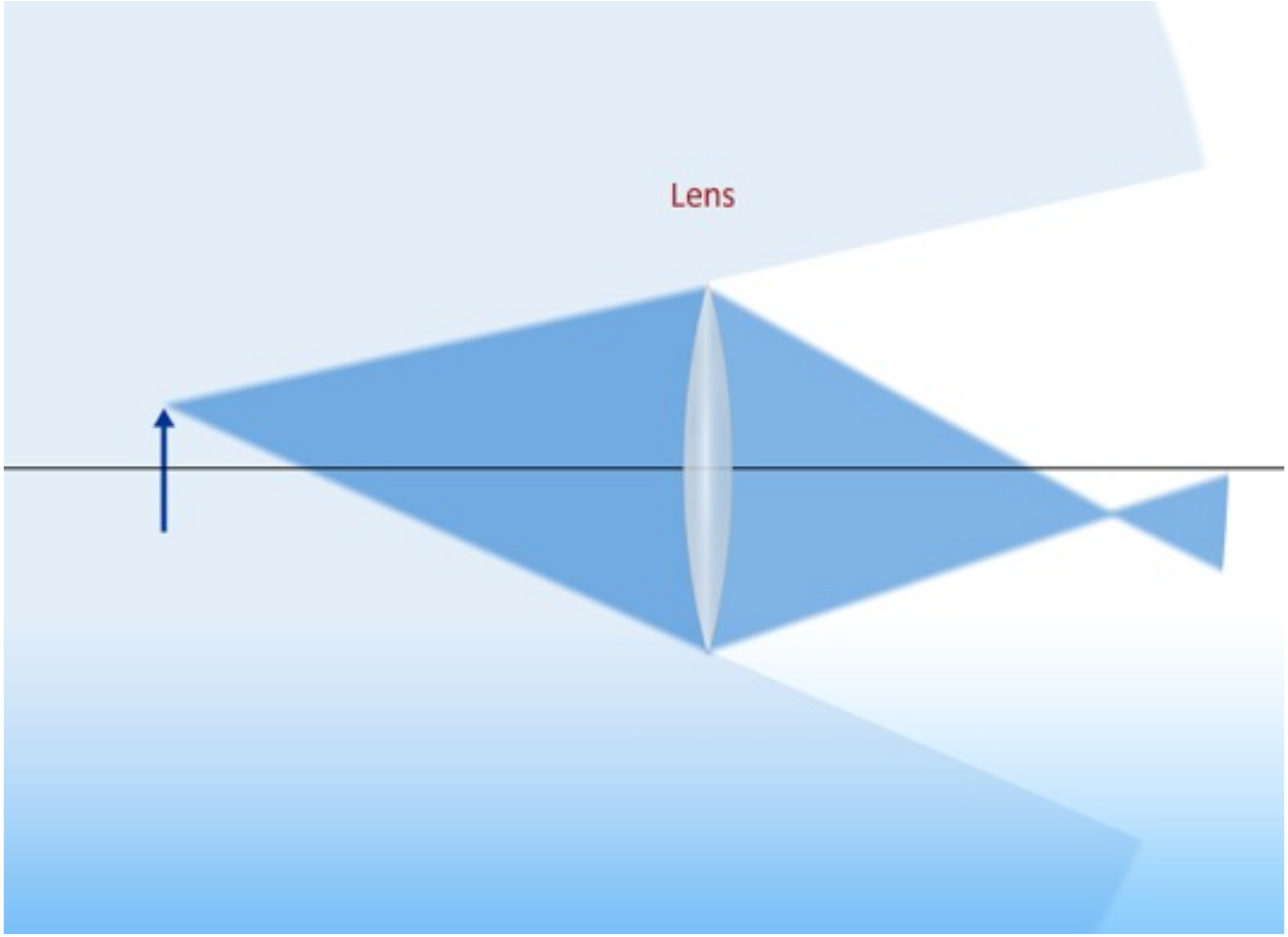
- Some hits your eyes



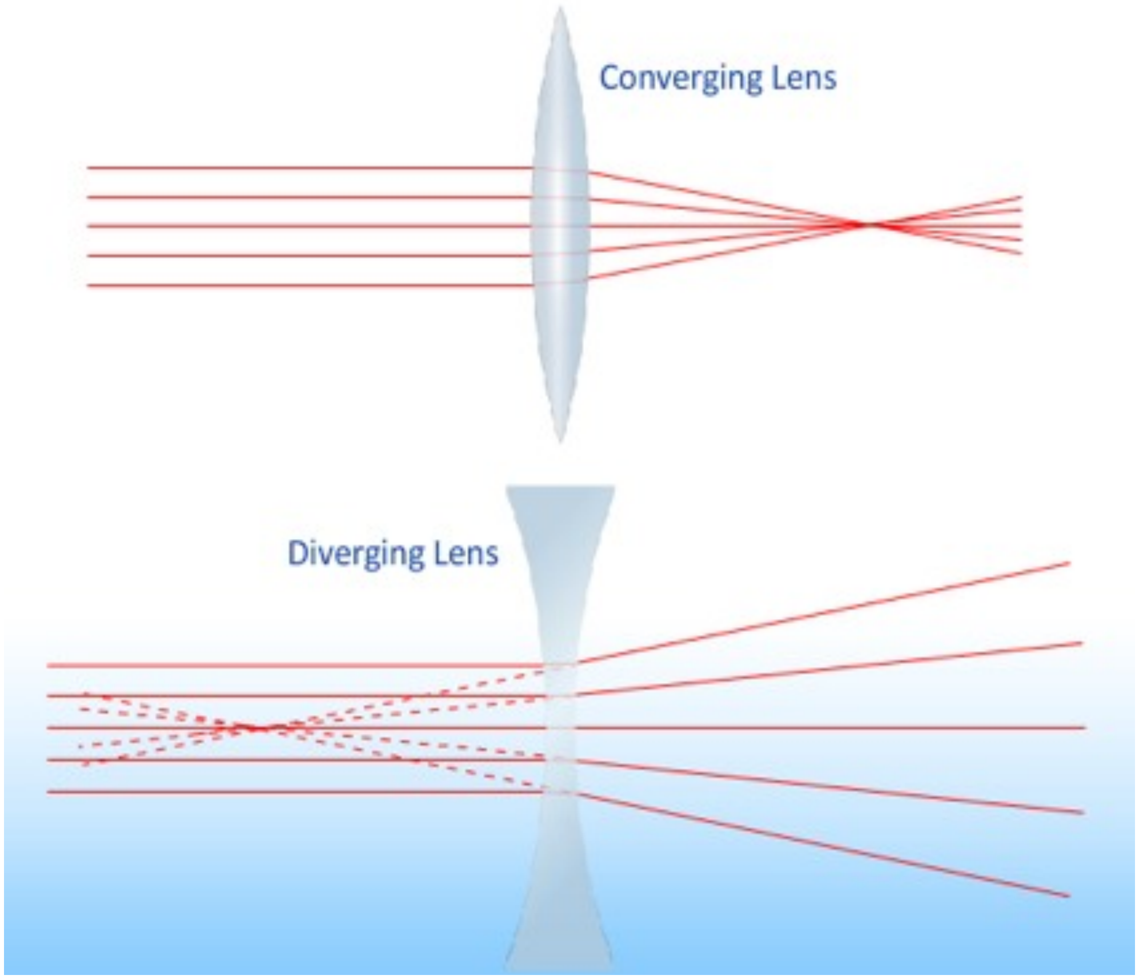
We know object's location by where rays come from.

We will discuss eyes in lecture 28…

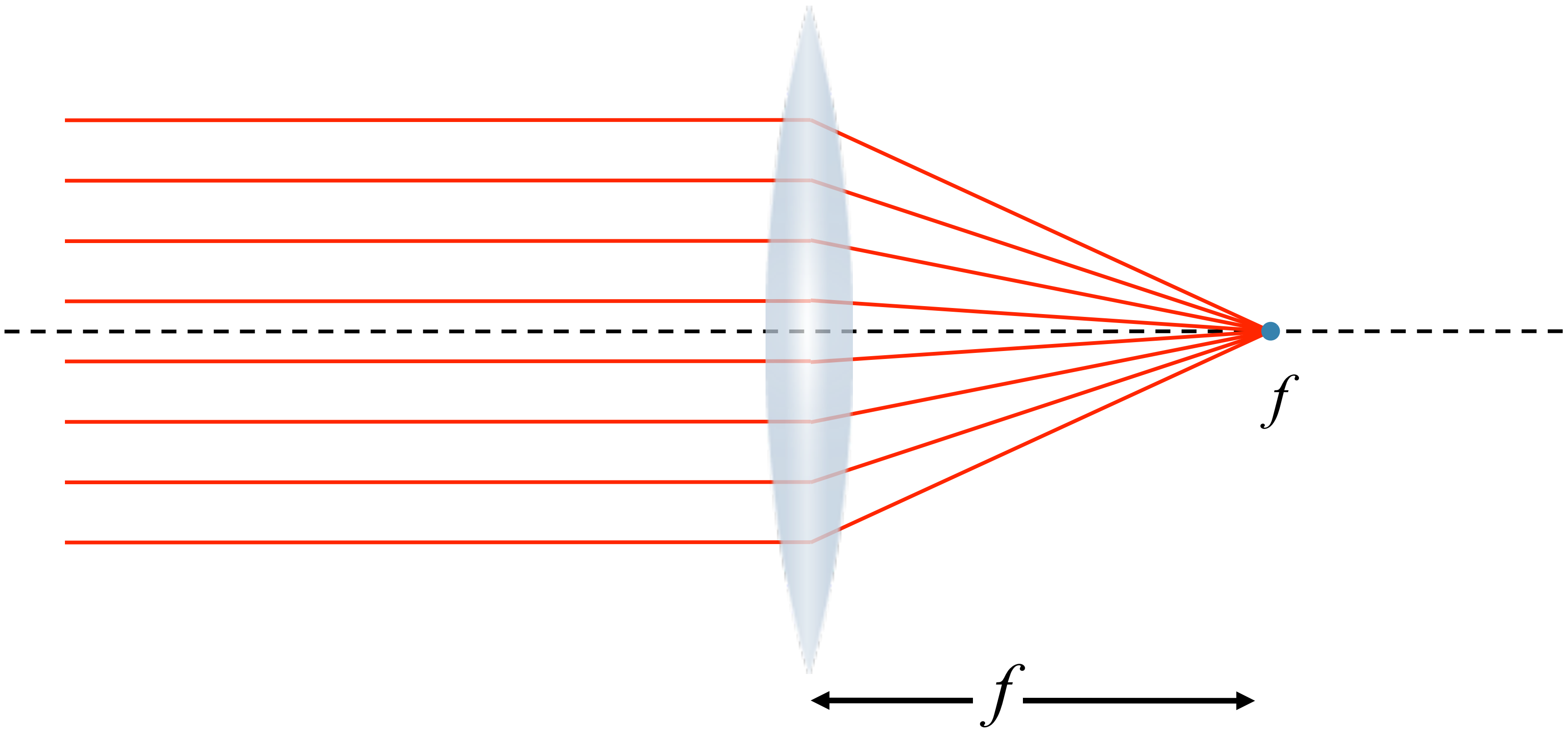
Waves from Objects are Focused by Lens



Two Different Types of Lenses



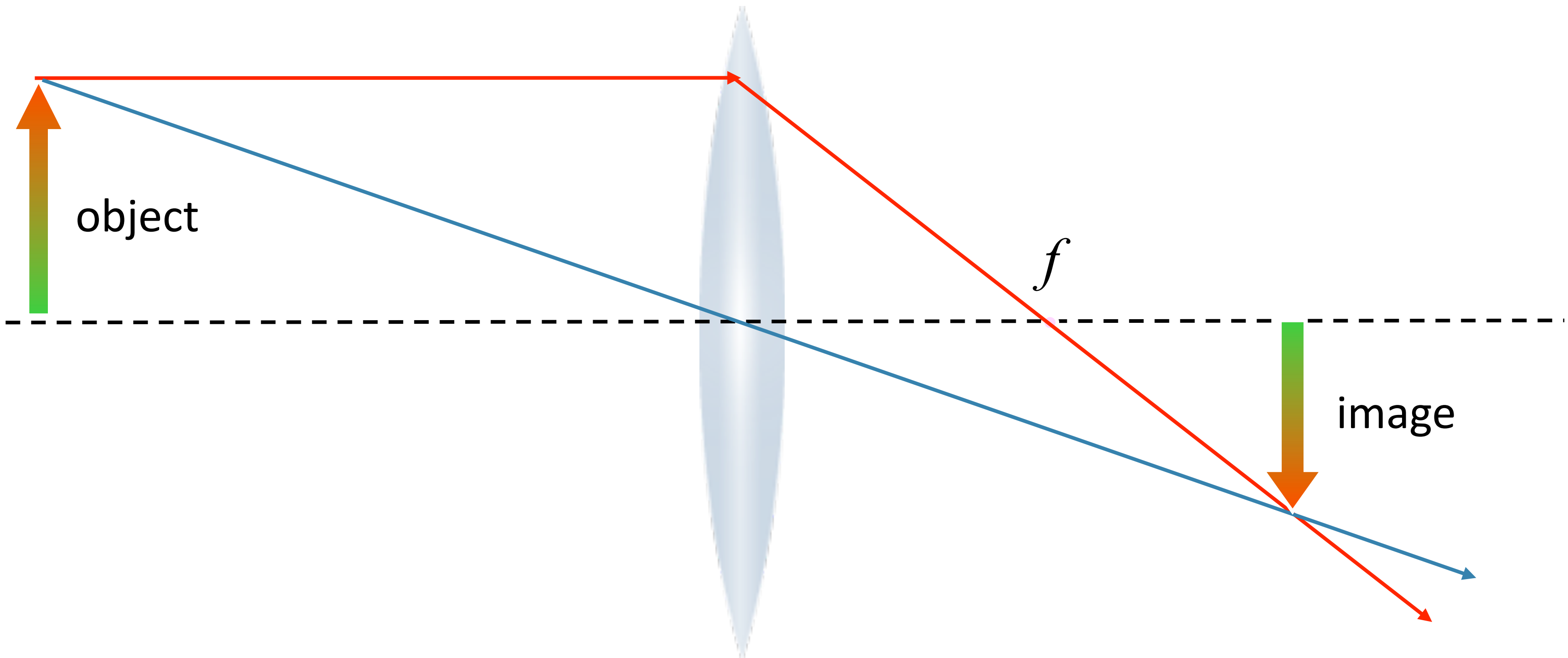
Converging Lens: Consider the case where the shape of the lens is such that light rays parallel to the axis of the mirror are all "focused" to a common spot a distance f behind the lens:



Recipe for Finding Image:

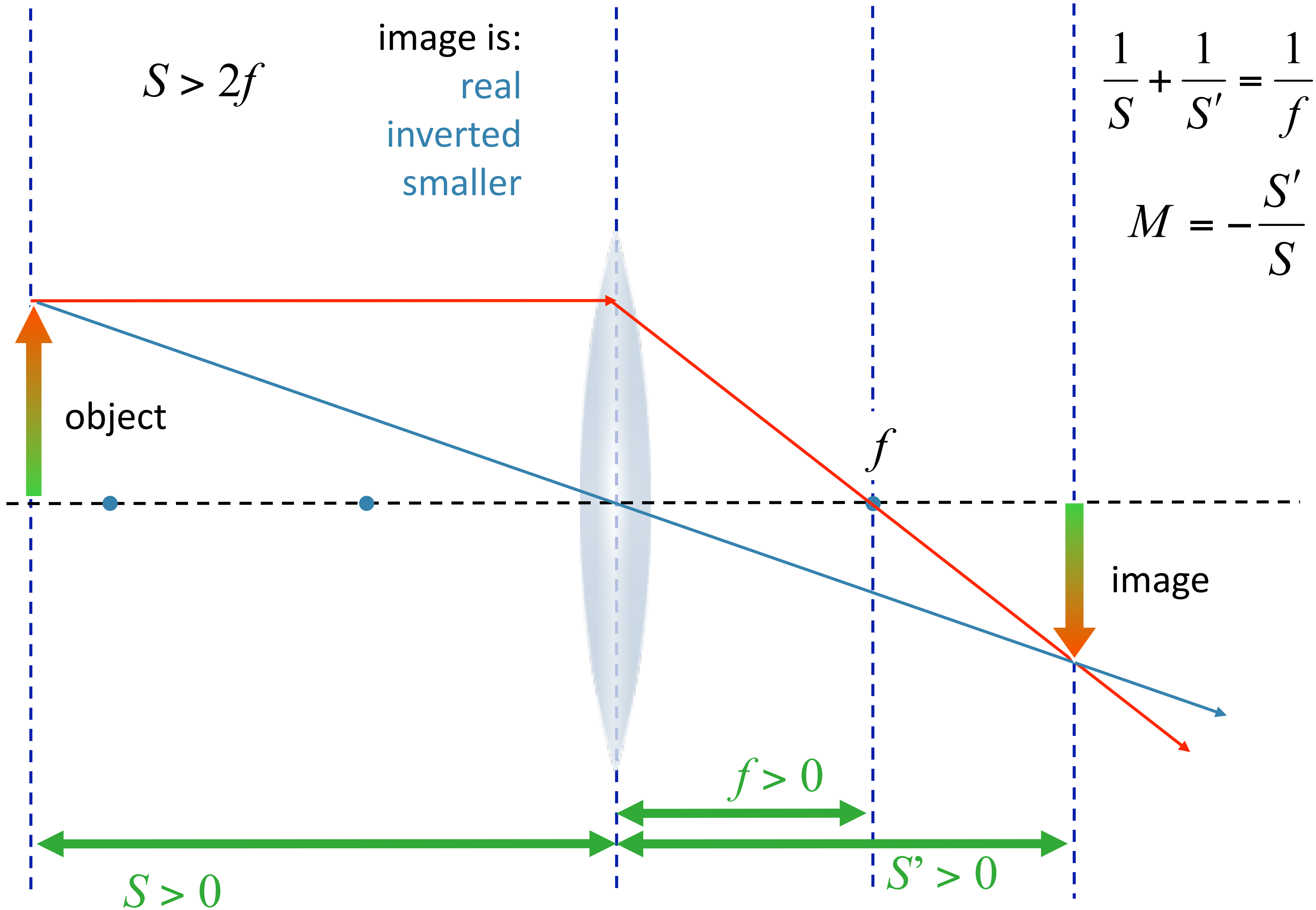
1) Draw ray parallel to axis — refracted ray goes through focus

2) Draw ray through center — refracted ray is symmetric



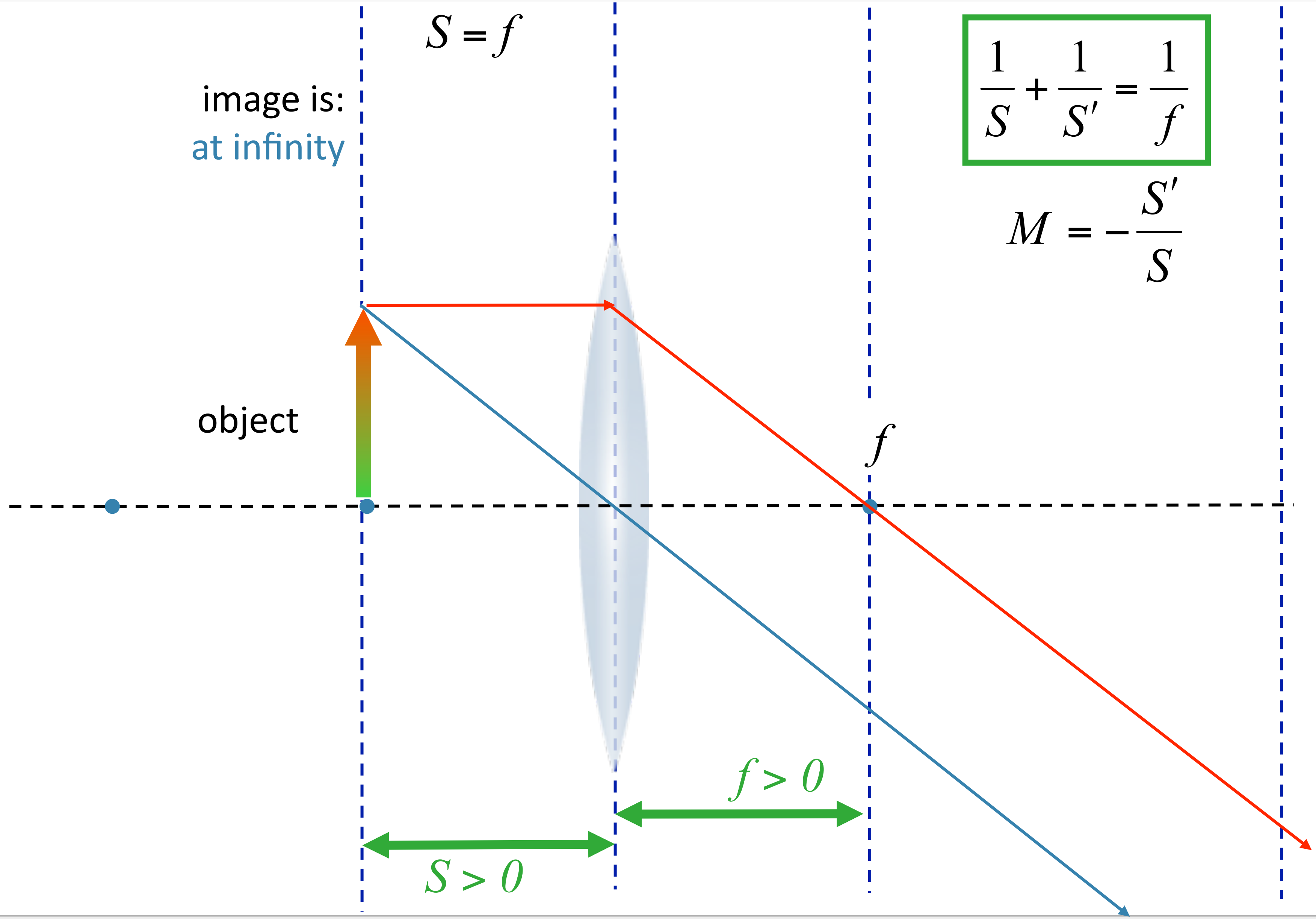
You now know the position of the same point on the image

Example



$S > 2f$
image is:
real
inverted
smaller
$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$
$M = -\frac{S'}{S}$
object
f
image
$f > 0$
$S > 0$
$S' > 0$

Example



$S = f$
image is:
at infinity
$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$
$M = -\frac{S'}{S}$
object
f
$f > 0$
$S > 0$

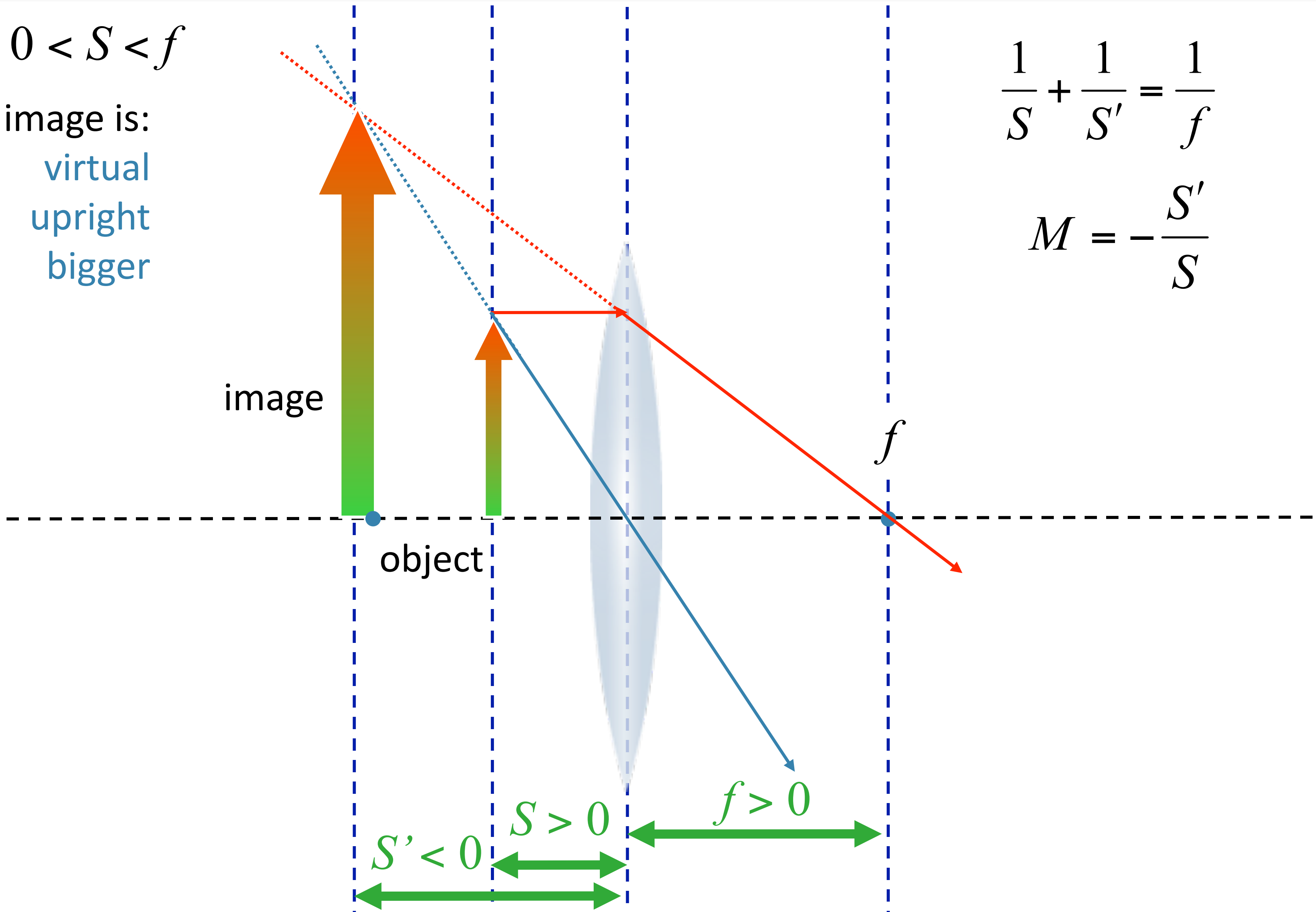
Example

$0 < S < f$

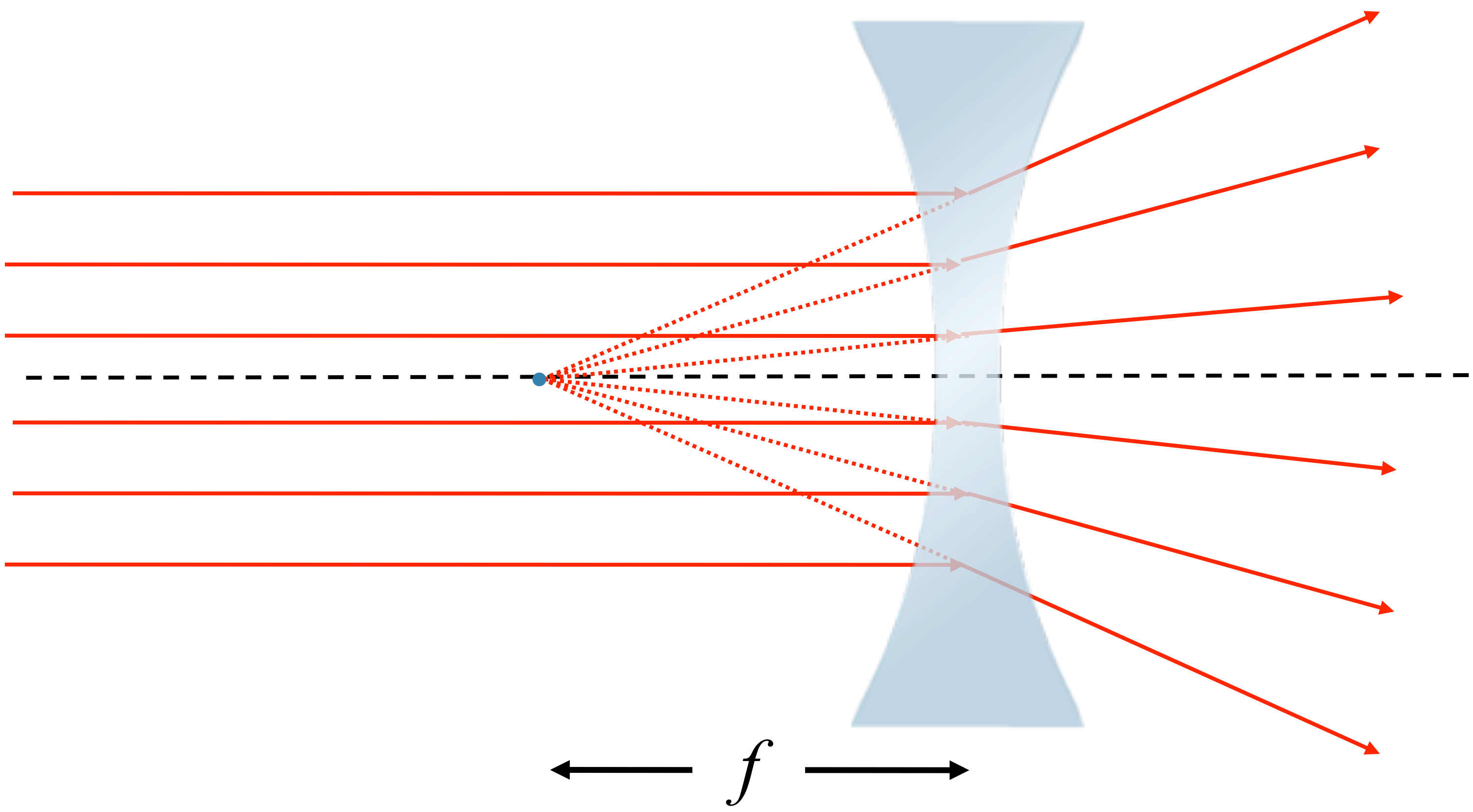
image is:
virtual
upright
bigger

$$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$$

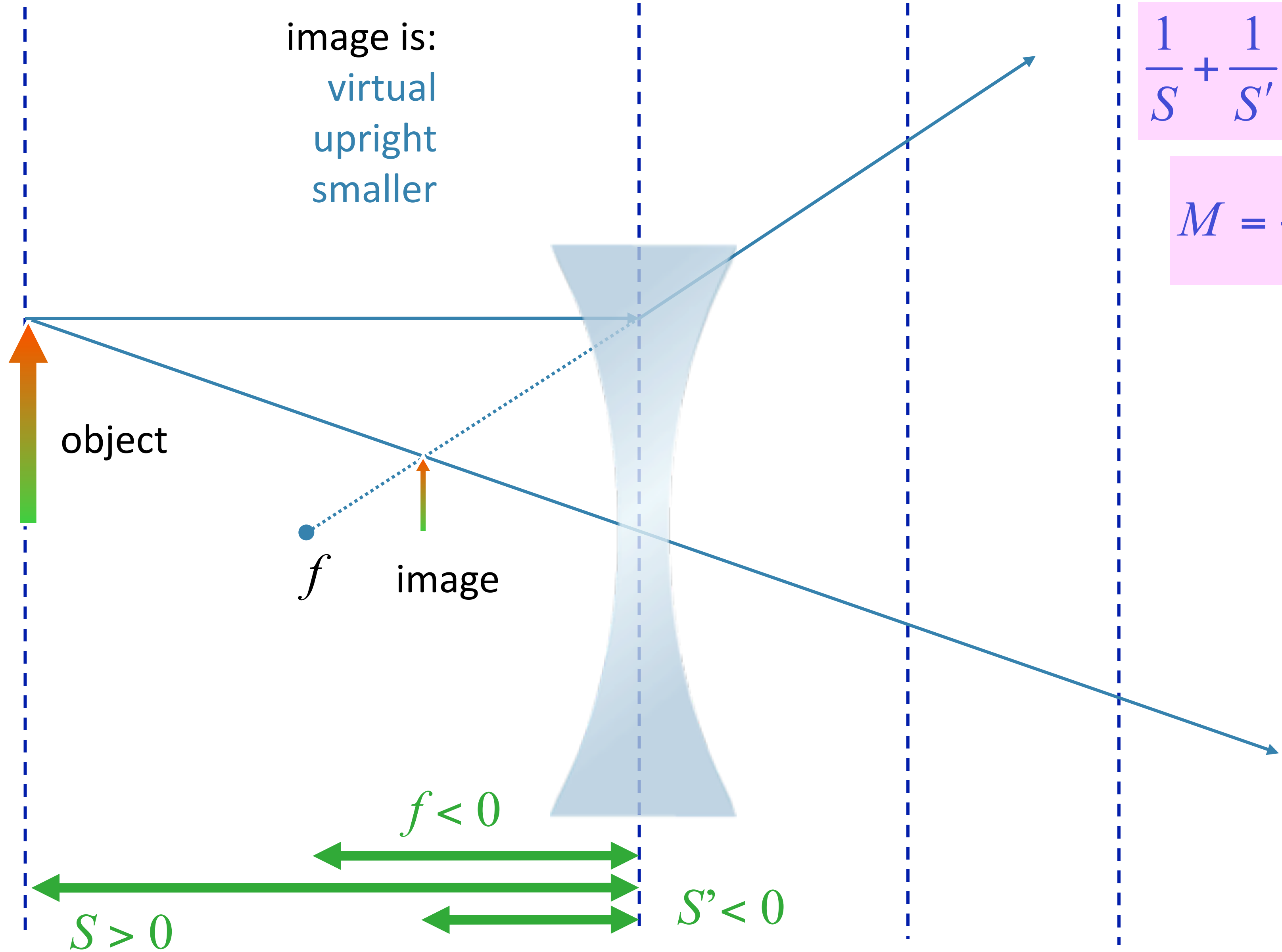
$$M = -\frac{S'}{S}$$



Diverging Lens: Consider the case where the shape of the lens is such that light rays parallel to the axis of the lens all diverge but appear to come from a common spot a distance f in front of the lens:



Example

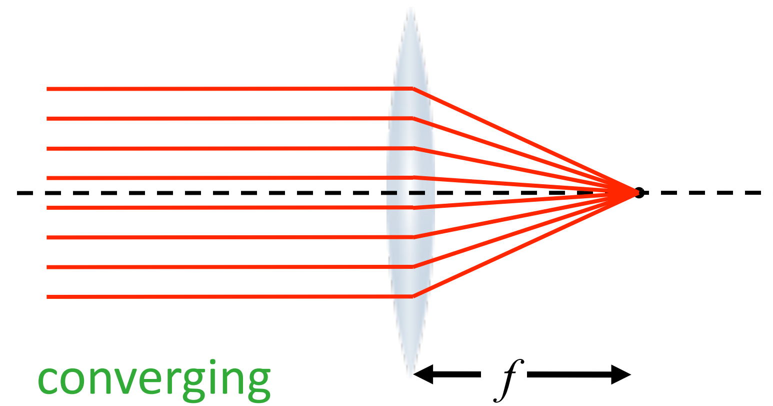


$$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$$

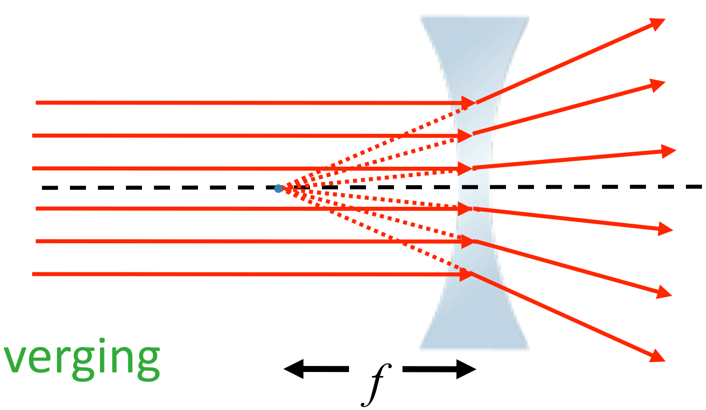
$$M = -\frac{S'}{S}$$

Executive Summary - Lenses

$S > 2f$	real inverted smaller
$2f > S > f$	real inverted bigger
$f > S > 0$	virtual upright bigger
$S > 0$	virtual upright smaller



$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad M = -\frac{s'}{s}$$



It's Always the Same:

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f} \quad M=-\frac{s'}{s}$$

You just have to keep the signs straight:

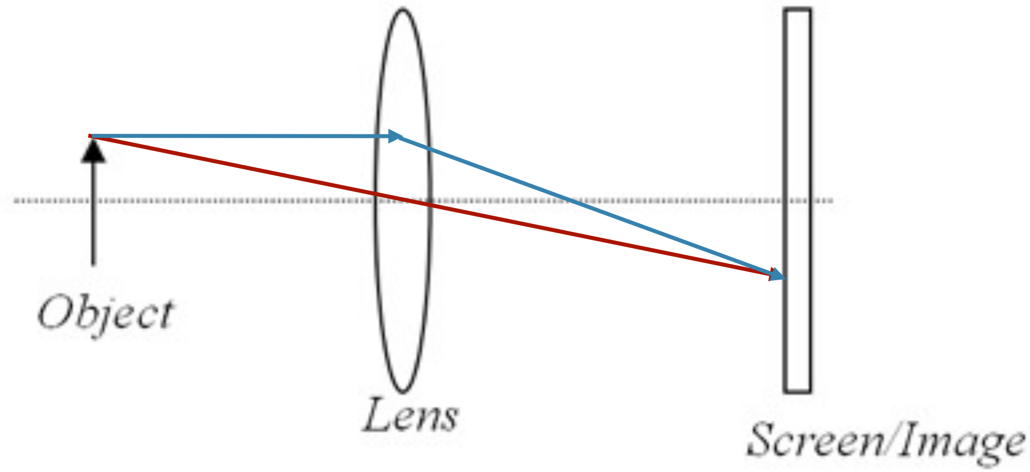
The sign conventions

S: positive if object is "upstream" of lens

S': positive if image is "downstream" of lens

f: positive if converging lens

CheckPoints 2 & 3



A converging lens is used to project the image of an arrow onto a screen as shown above.

The image is
- ○ real
- ○ virtual

The image is
- ○ inverted
- ○ upright

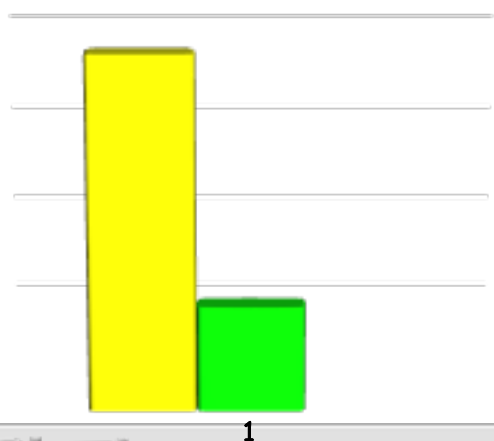
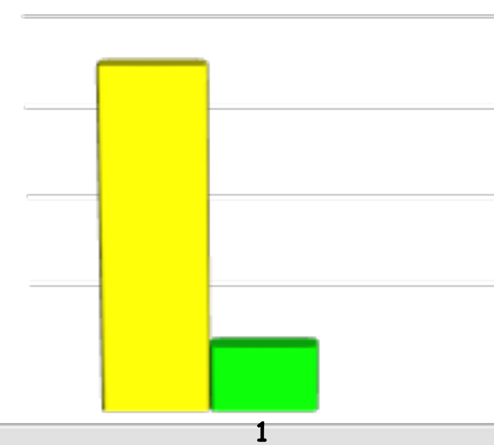


Image on screen

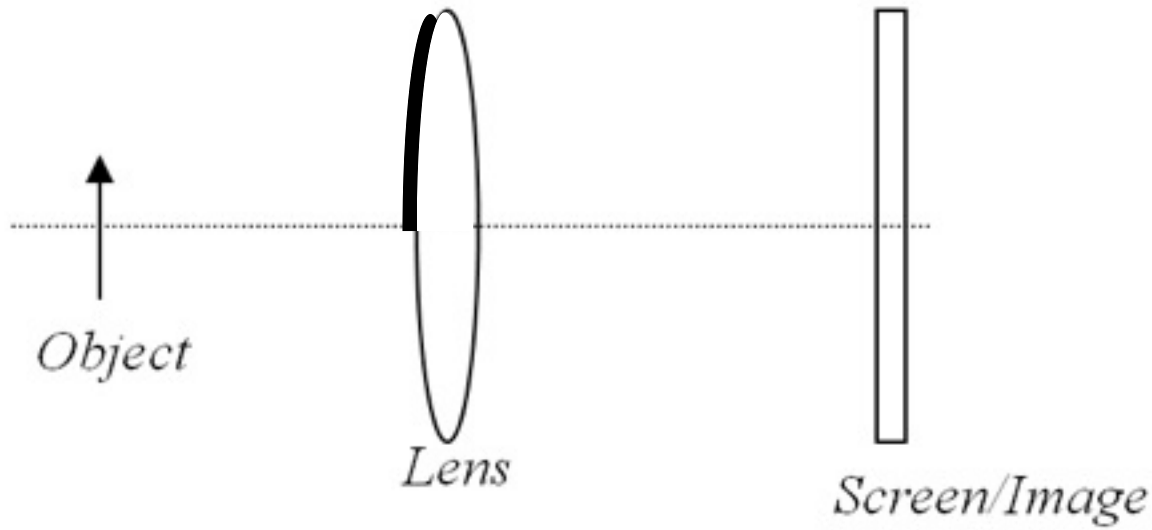
MUST BE REAL

→ $s' > 0$

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad M = -\frac{s'}{s}$$



CheckPoint 5



A converging lens is used to project the image of an arrow onto a screen as shown above.

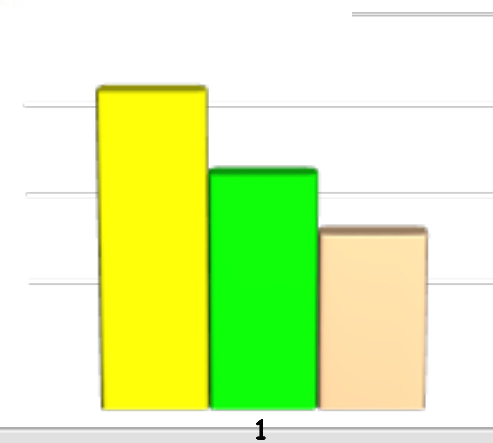
A piece of black tape is now placed over the upper half of the lens. Which of the follow is true.

- ○ Only the lower half of the object (i.e. the arrow tail) will show on the screen.
- ○ Only the upper half of the object (i.e. the arrow head) will show on the screen.
- ○ The whole object will still show on the screen.

"No light from the top of the object can be transmitted through the lens, so it will not be seen. "

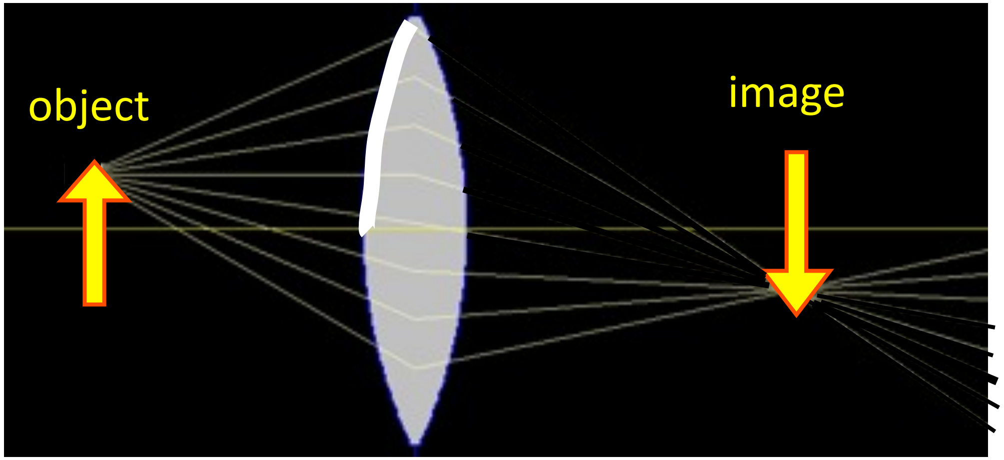
"the image is reversed so only the upper half of the image will show"

"The rays from the bottom half still focus The image is there, but it will be dimmer !! "



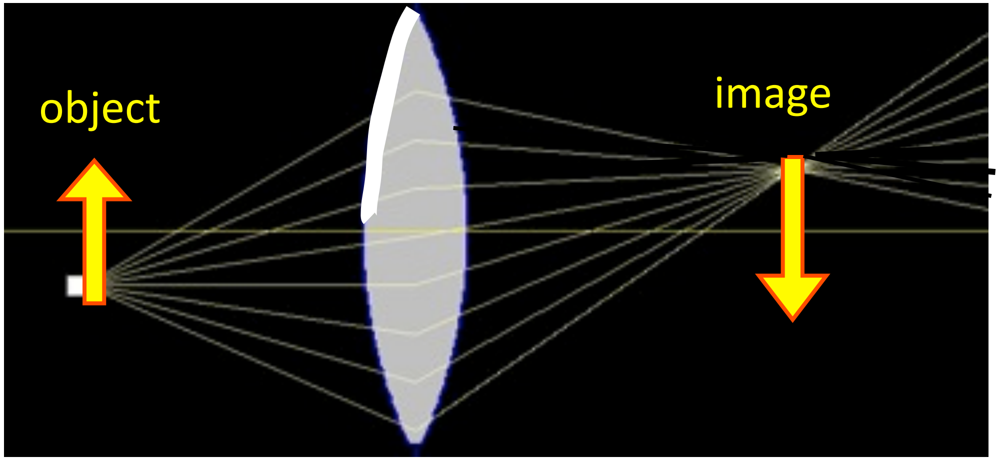
Cover top half of lens

Light from top of object



Cover top half of lens

Light from bottom of object



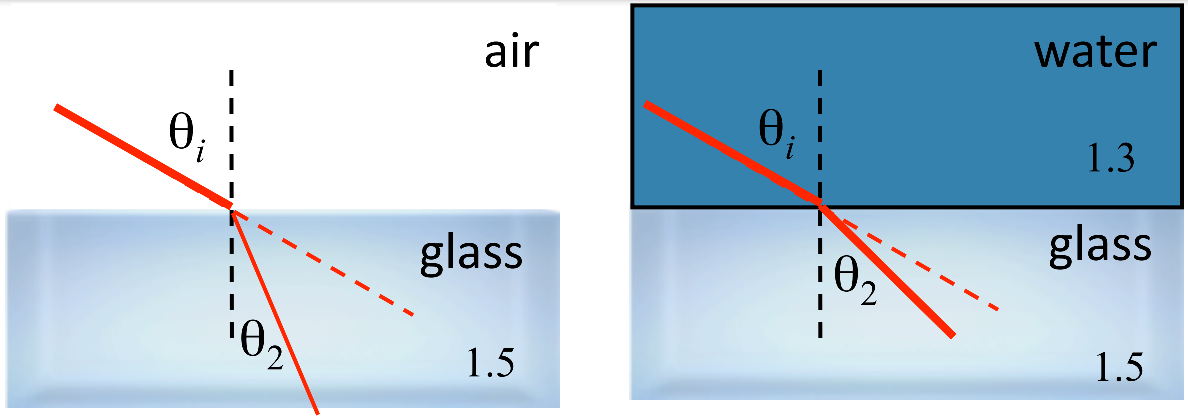
What's the Point?

The rays from the bottom half still focus
The image is there, but it will be dimmer!

3) A piece of black tape is now placed over the upper half of the lens. Which of the follow is true.

- ○ Only the lower half of the object (i.e. the arrow tail) will show on the screen.
- ○ Only the upper half of the object (i.e. the arrow head) will show on the screen.
- ○ The whole object will still show on the screen.

Case A



Case B

In Case A light in air heads toward a piece of glass with incident angle θ_i

In Case B, light in water heads toward a piece of glass at the same angle.

In which case is the light bent most as it enters the glass?

A) Case A
B) Case B
C) Same

The angle of refraction in bigger for the water – glass interface:

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \quad \longrightarrow \quad \sin(\theta_2)/\sin(\theta_1) = n_1/n_2$$

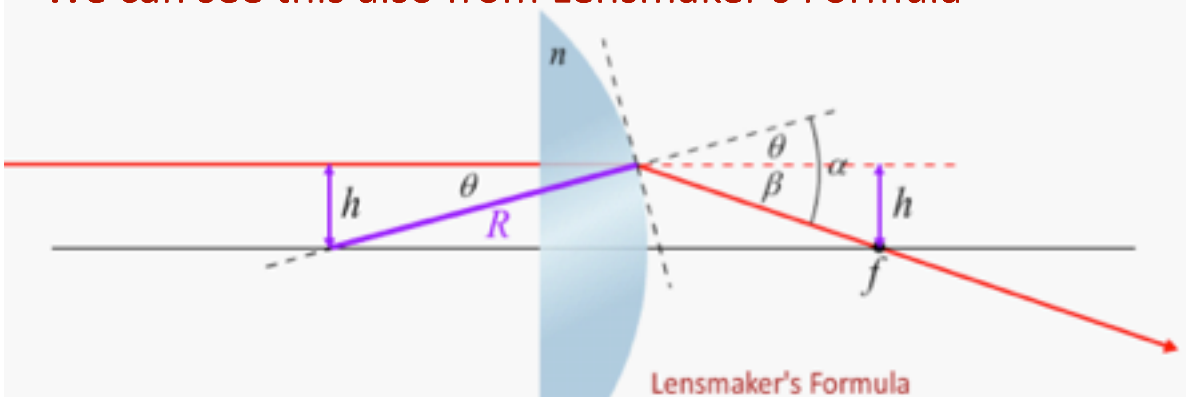
Therefore the BEND ANGLE ($\theta_1 - \theta_2$) is BIGGER for air – glass interface

CheckPoint 7

What happens to the focal length of a converging lens when it is placed under water?

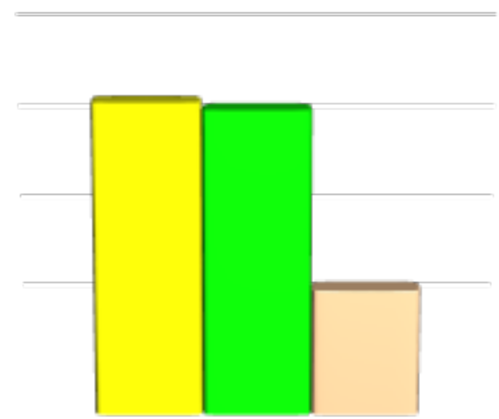
- ○ increases
- ○ decreases
- ○ stays the same

We can see this also from Lensmaker's Formula



$$\frac{1}{f} = (n-1)\frac{1}{R}$$

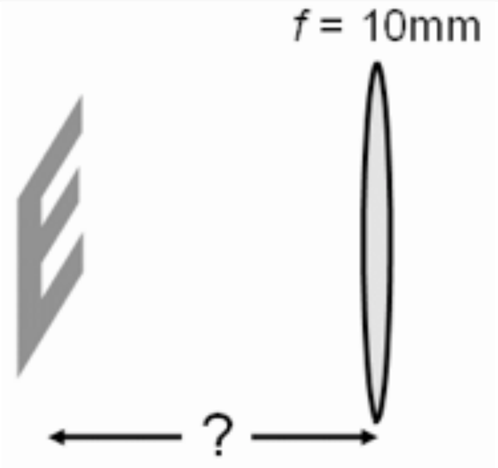
n_{lens} n_{air}



Calculation

A magnifying glass is used to read the fine print on a document. The focal length of the lens is 10mm.

At what distance from the lens must the document be placed in order to obtain an image magnified by a factor of 5 that is not inverted?



Conceptual Analysis

Lens Equation: $1/s + 1/s' = 1/f$

Magnification: $M = -s'/s$

Strategic Analysis

Consider nature of image (real or virtual?) to determine relation between object position and focal point

Use magnification to determine object position

A magnifying glass is used to read the fine print on a document. The focal length of the lens is 10mm.

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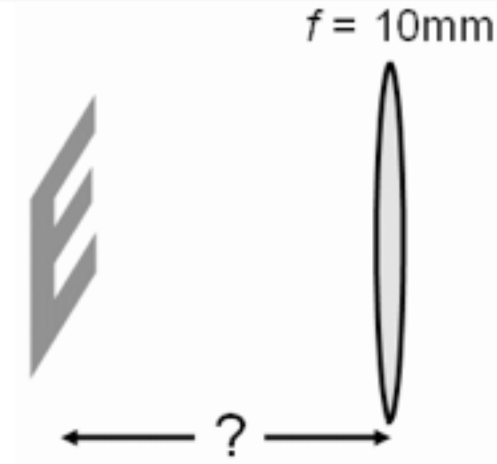
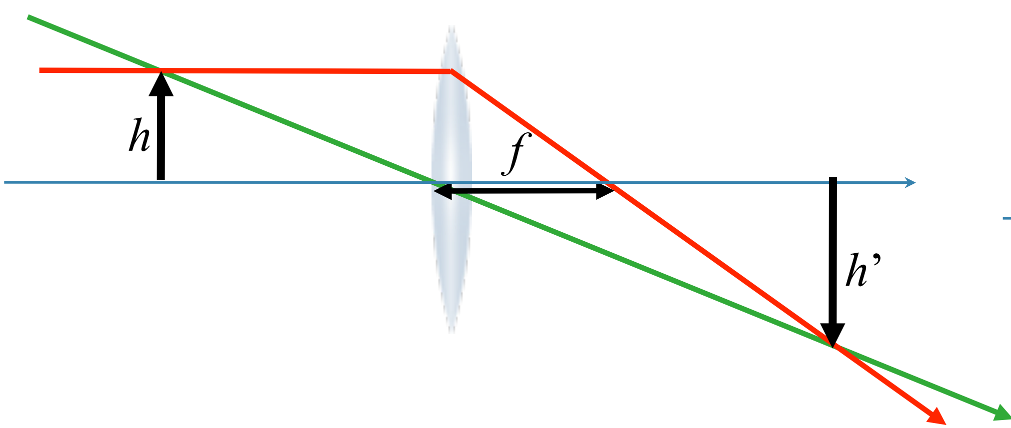


Is the image real or virtual?

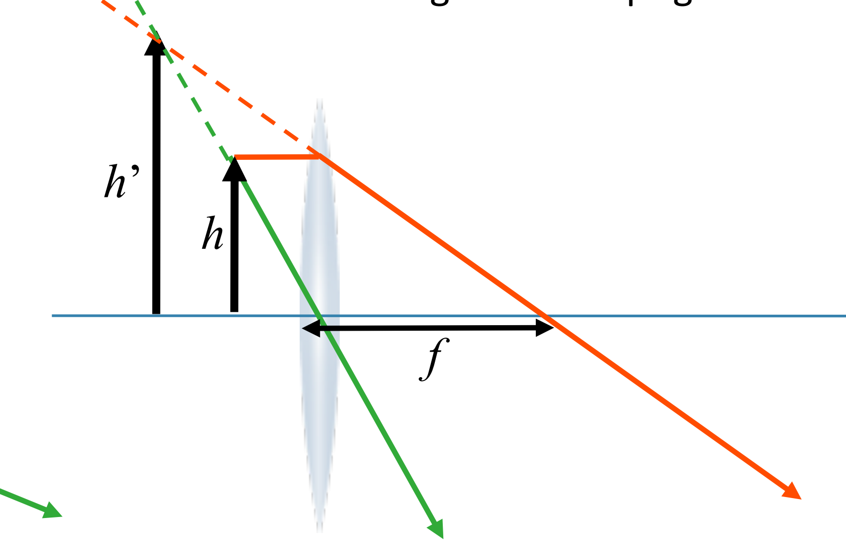
A) REAL

B) VIRTUAL

A real image would be inverted



A virtual image will be upright



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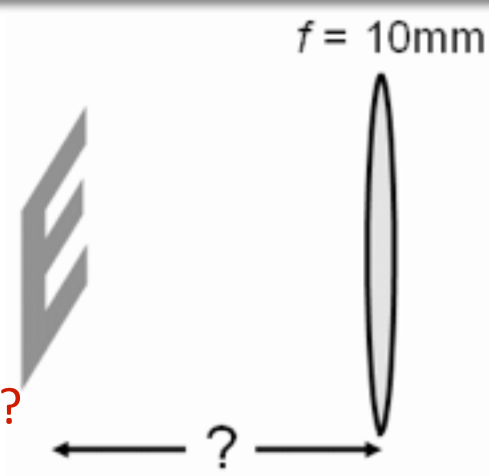
At what distance from the lens must the document be placed in order to obtain an image magnified by a factor of 5 that is not inverted?



How does the object distance compare to the focal length?

A) $|s| < |f|$

B) $|s| = |f|$

C) $|s| > |f|$

Lens equation → $$\frac{1}{S'} = \frac{1}{f} - \frac{1}{S}$$

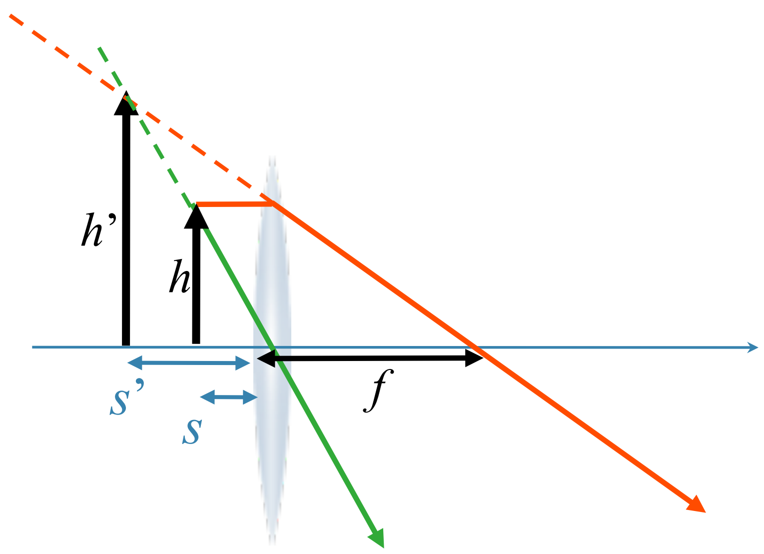
→ $$S' = \frac{f\,S}{S - f}$$

Virtual Image Þ $s' < 0$

Real object Þ $s > 0$

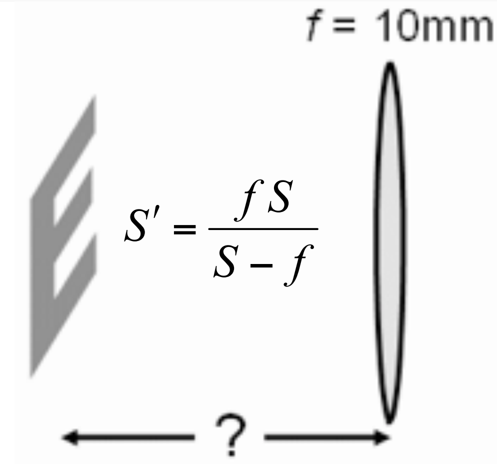
Converging lens Þ $f > 0$

$$S - f < 0$$



A magnifying glass is used to read the fine print on a document. The focal length of the lens is 10mm.

At what distance from the lens must the document be placed in order to obtain an image magnified by a factor of 5 that is not inverted?



What is the magnification M in terms of s and f?

A) $M = \frac{s-f}{f}$

B) $M = \frac{f-s}{f}$

C) $M = \frac{-f}{s-f}$

D) $M = \frac{f}{s-f}$

Lens equation:

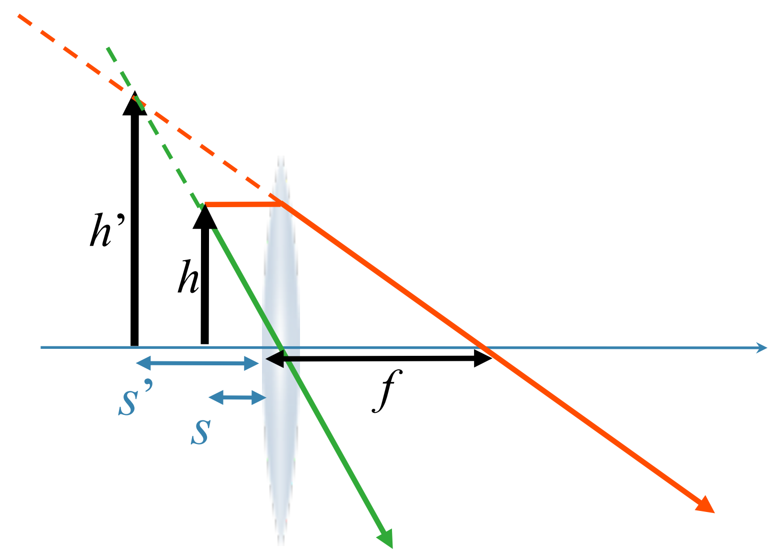
$$\frac{1}{S'} = \frac{1}{f} - \frac{1}{S}$$

$$S' = \frac{fS}{S-f}$$

Magnification equation:

$$M = -\frac{s'}{s}$$

$$M = \frac{-f}{s-f}$$



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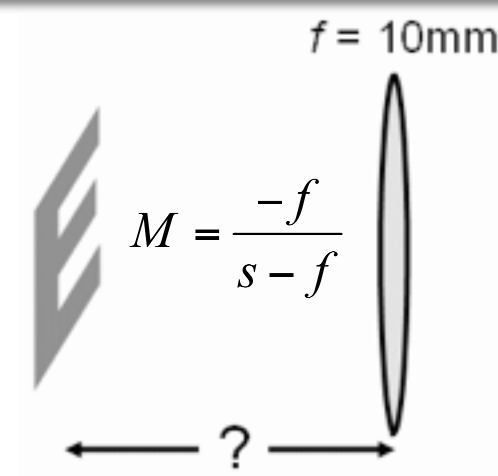
At what distance from the lens must the document be placed in order to obtain an image magnified by a factor of 5 that is not inverted?



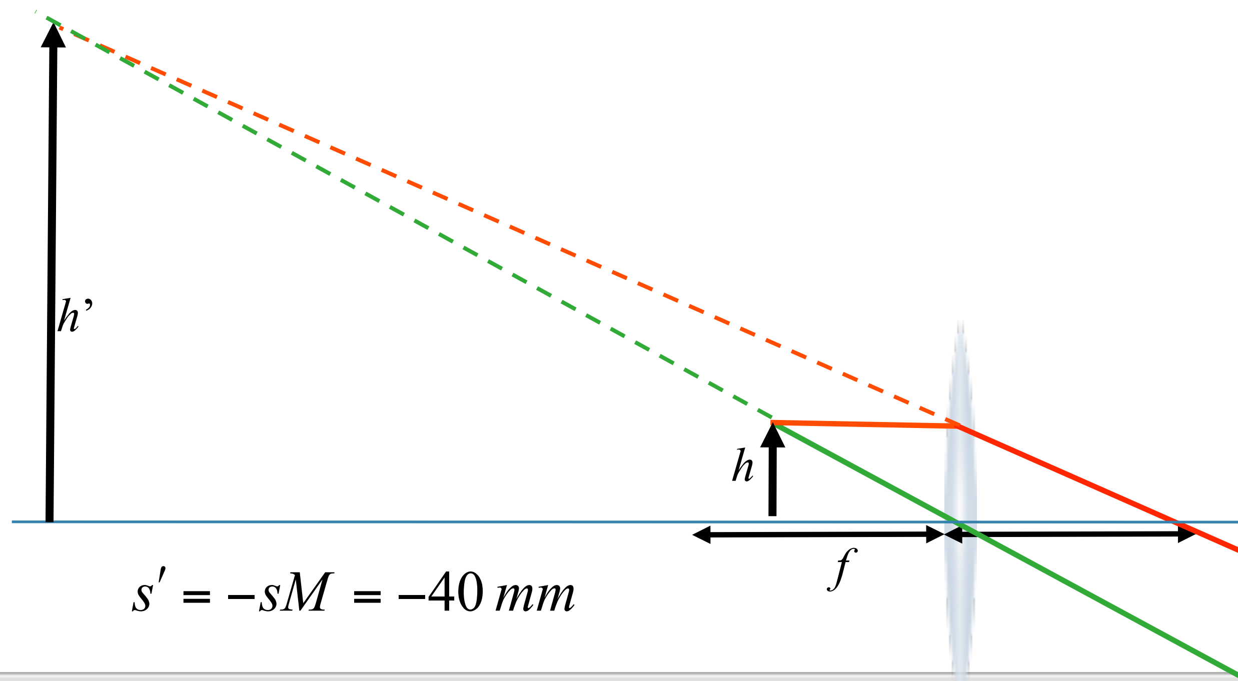
A) 1.7mm B) 6mm **C) 8mm** D) 40 mm E) 60 mm

$$M = +5$$

$$f = +10\,mm$$

$$M = \frac{-f}{s-f} \rightarrow s = f\frac{(M-1)}{M}$$

$$\rightarrow s = \frac{4}{5}f = 8\,mm$$



$$s' = -sM = -40\,mm$$

Follow Up

Suppose we replace the converging lens with a diverging lens with focal length of 10mm.

If we still want to get an image magnified by a factor of 5 that is not inverted, how does the object s_{div} compare to the original object distance s_{conv}?

A) $s_{div} < s_{conv}$

B) $s_{div} = s_{conv}$

C) $s_{div} > s_{conv}$

D) s_{div} doesn't exist

EQUATIONS

$$M = \frac{-f}{s-f} \rightarrow s = f\frac{(M-1)}{M}$$

$$M = +5$$
$$f = +10\,mm \rightarrow s = \frac{4}{5}f = 8\,mm$$

s negative Þ not real object

PICTURES

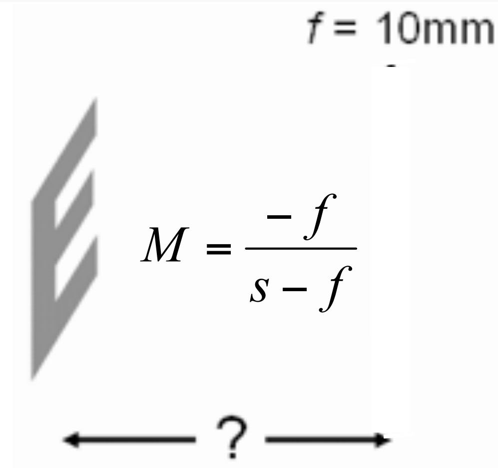
Draw the rays: s' will always be smaller than s

Magnification will always be less than 1

Follow Up

Suppose we replace the converging lens with a diverging lens with focal length of 10mm.

What is the magnification if we place the object at $s = 8\text{mm}$?



$$M = \frac{-f}{s-f}$$

A) $M = \frac{1}{2}$ B) $M = 5$ C) $M = \frac{3}{8}$ **D) $M = \frac{5}{9}$** E) $M = \frac{4}{5}$

EQUATIONS

$$M = \frac{-f}{s-f}$$

$$s = 8\,mm$$

$$f = -10\,mm$$

$$M = -\frac{-10}{8-(-10)} = \frac{10}{18} = \frac{5}{9}$$

PICTURES