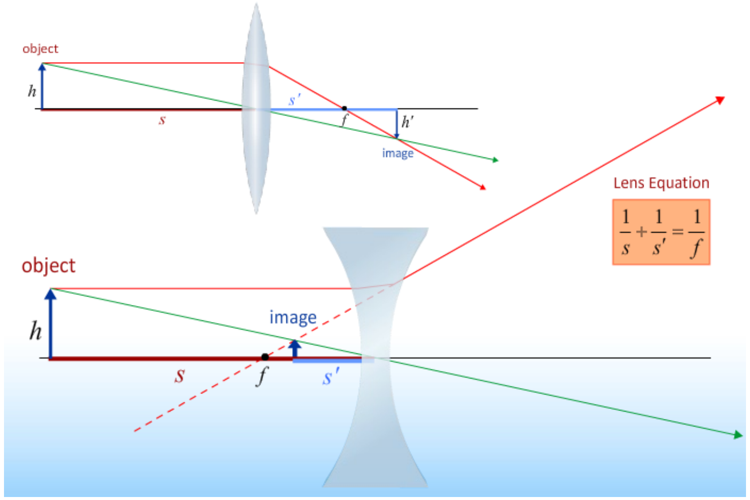
Physics 121
Lecture 26

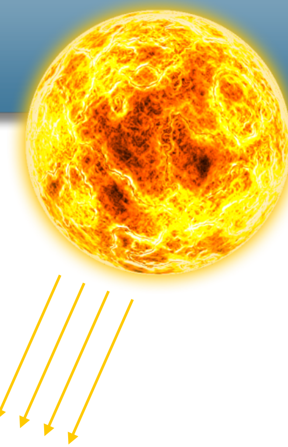
Today's Concept:

A) Lenses

B) Mirrors

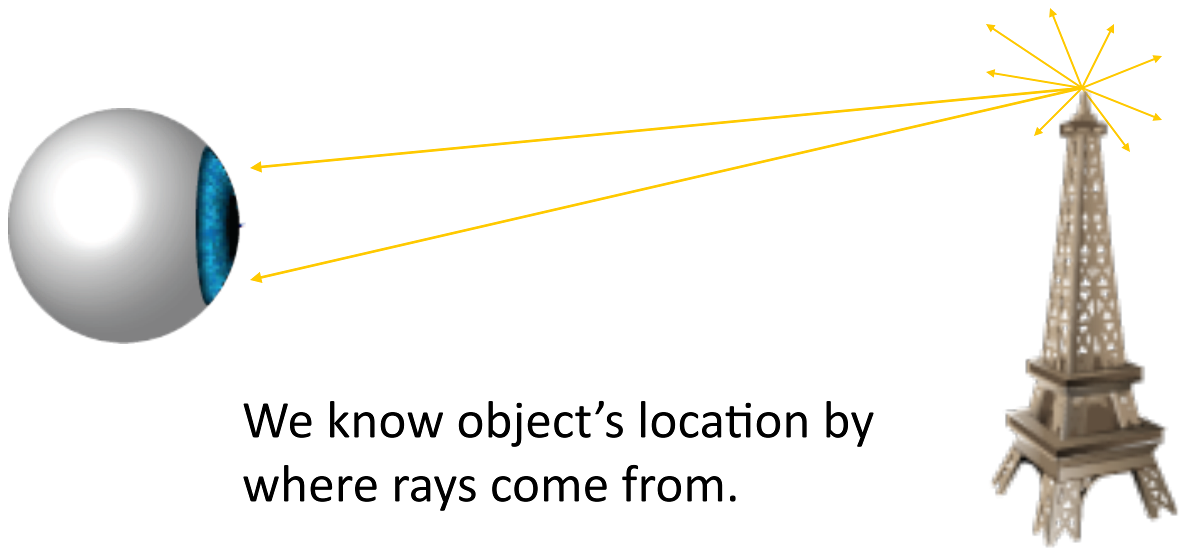


Object Location



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

- Some hits your eyes



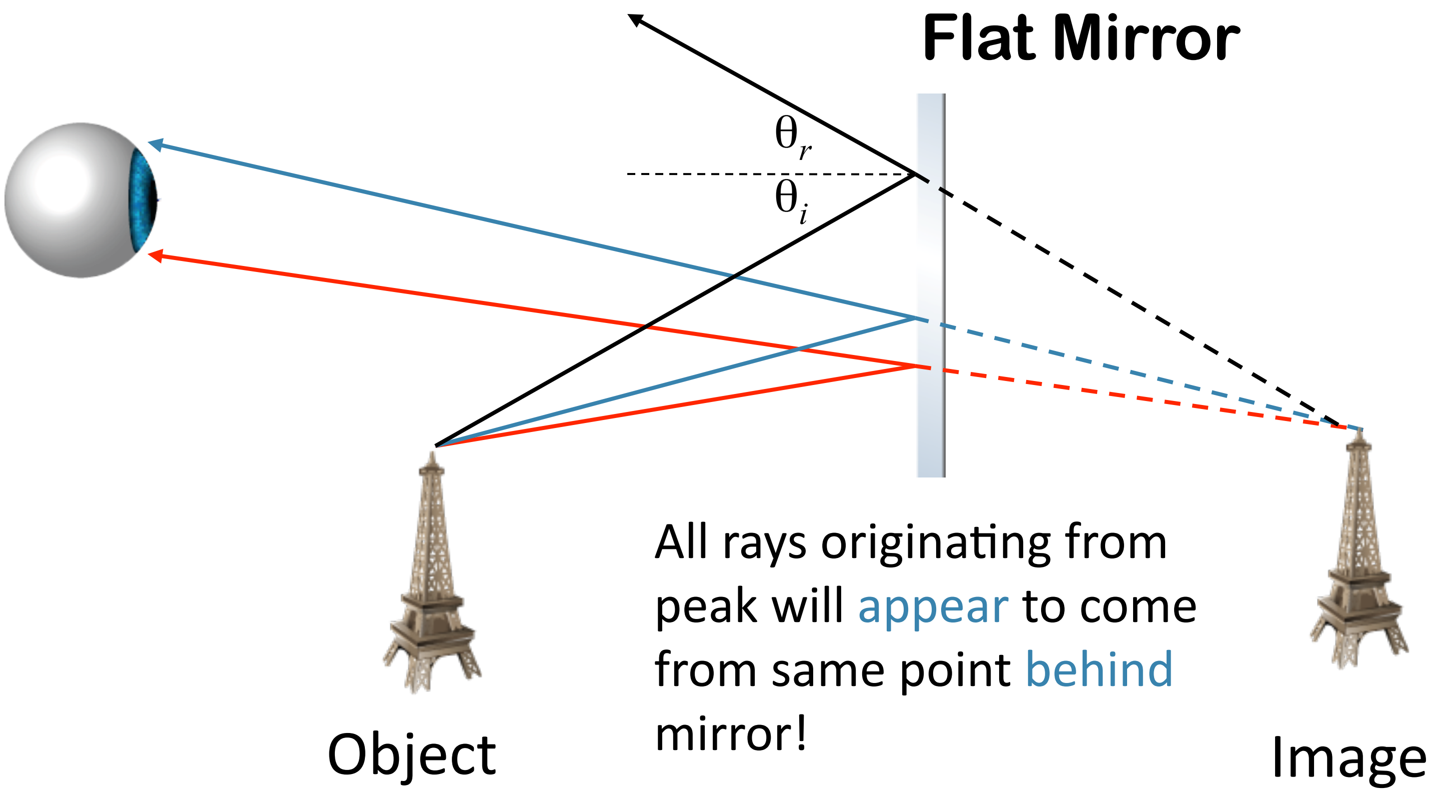
We know object's location by where rays come from.

We will discuss eyes in lecture 28…

Flat Mirror

All you see is what reaches your eyes

You think object's location is where rays appear to come from.



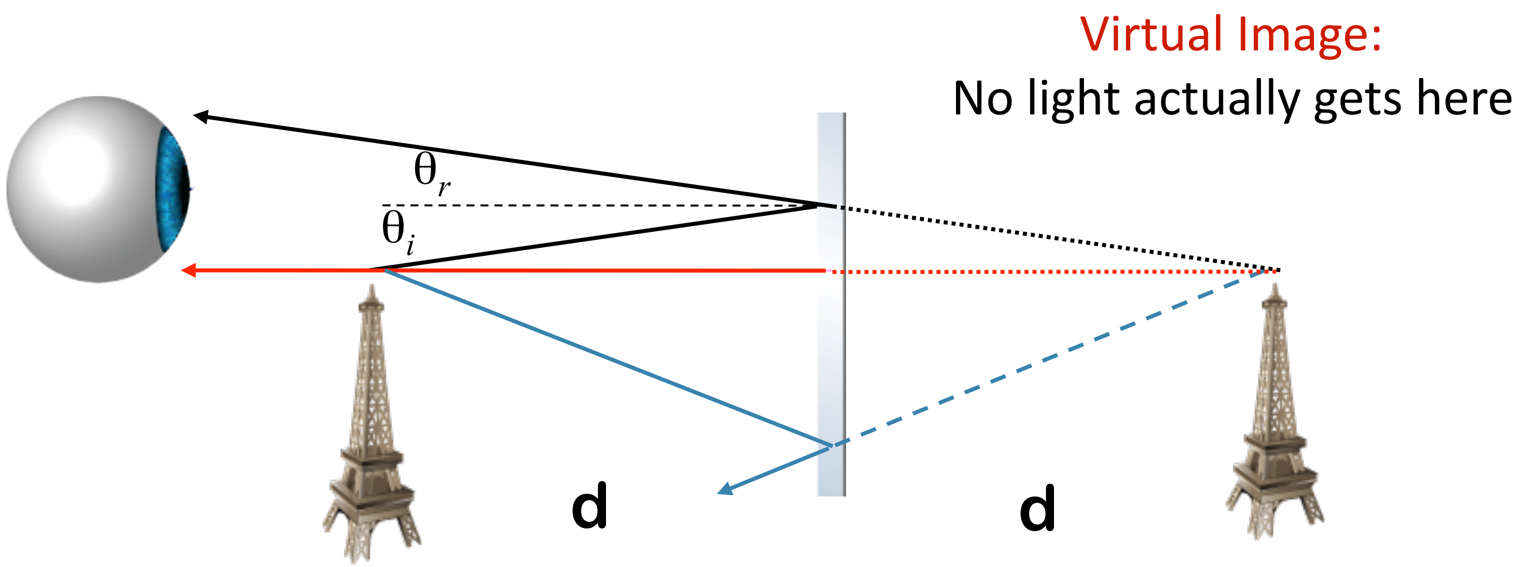
All rays originating from peak will appear to come from same point behind mirror!

Flat Mirror

1) Draw first ray perpendicular to mirror $0 = \theta_i = \theta_r$

2) Draw second ray at angle. $\theta_i = \theta_r$

3) Lines appear to intersect a distance d behind mirror. This is the image location.



Mirrors

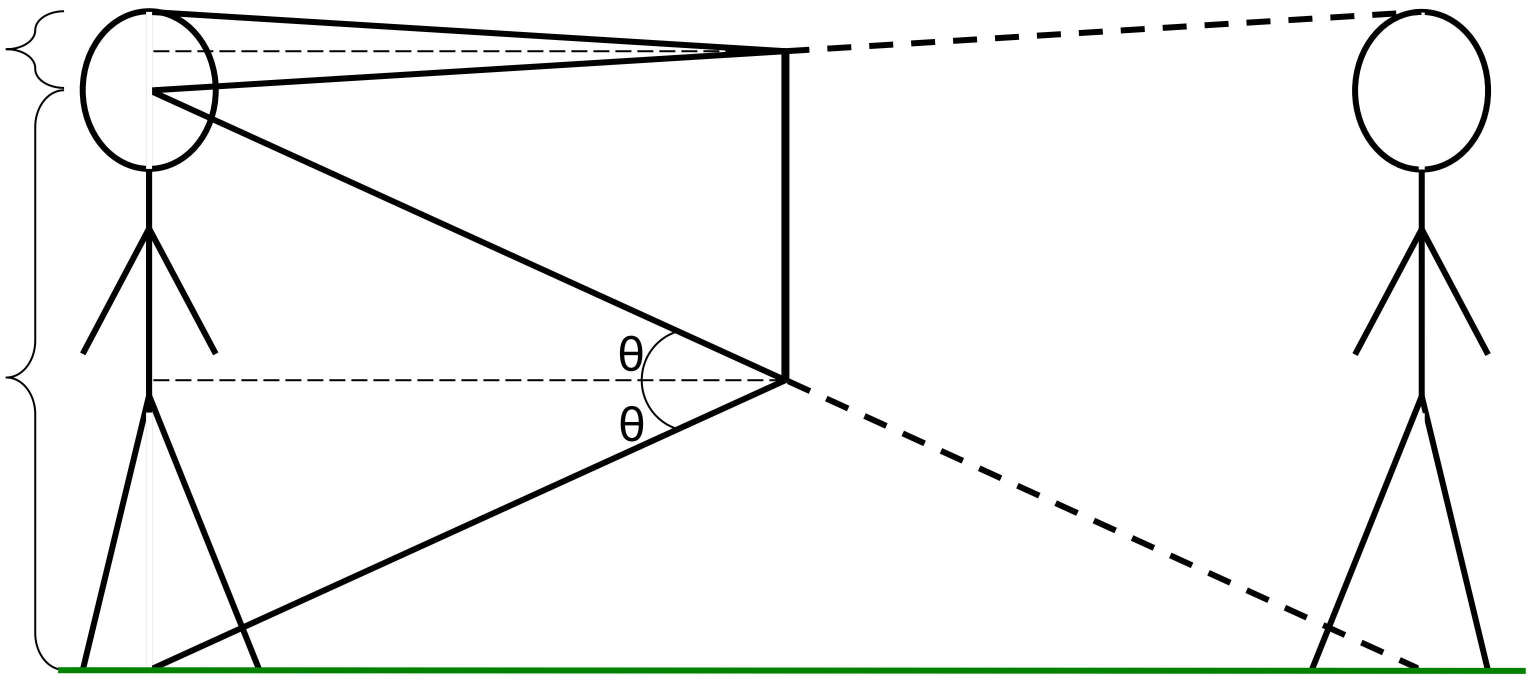
You are trying to buy a new mirror for your bedroom, and you want to get one that will allow you to see your entire body at one time.

What is the minimum length the mirror must be so that you can see your entire body?

A. Whole height
B. Three quarter height
C. Half height
D. Quarter height

A. H
B. ¾H
C. ½H
D. ¼H

Mirrors



In order to see your whole body, a mirror half your height is needed.

Mirrors

Two plane mirrors are joined at 90 degrees to create a right angle mirror.

How many images are produced when an object is placed between them?

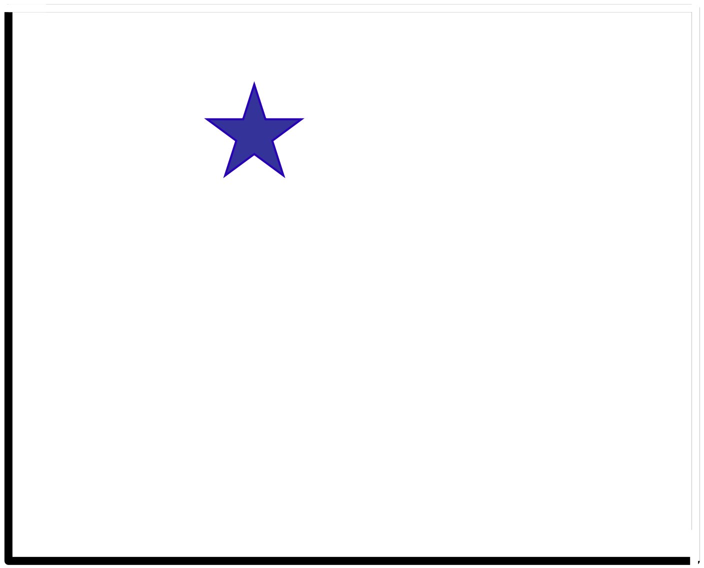
A. 1

B. 2

C. 3

D. 4

E. Infinitely many

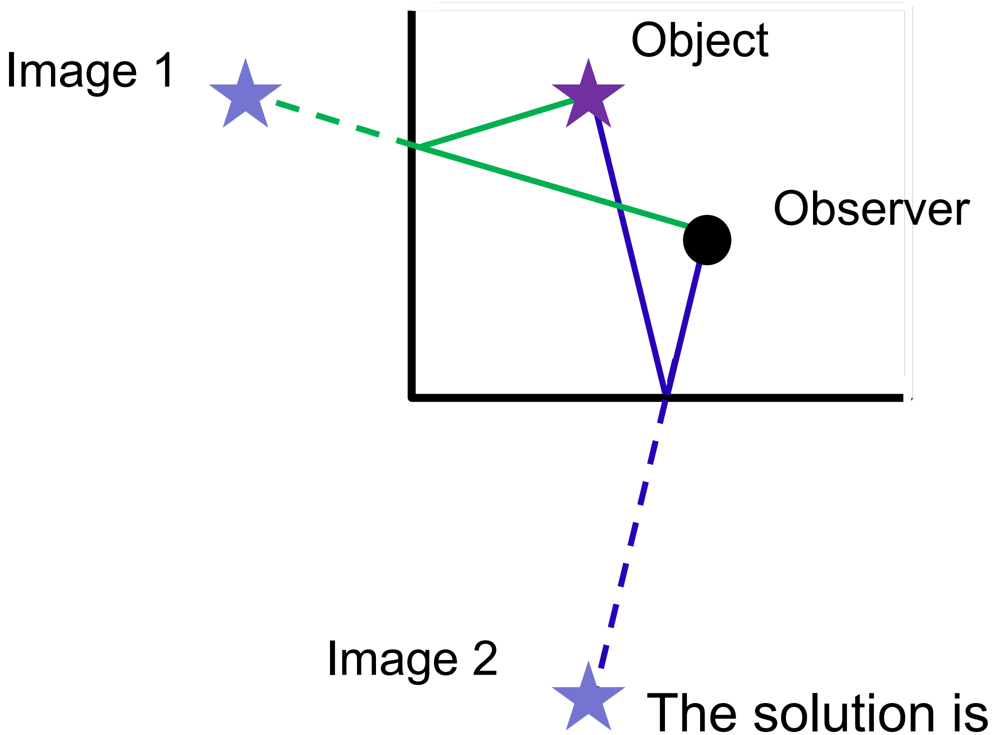


Note: This is one example of an object location, this occurs for all locations.

Mirrors

Answer: C

Justification: There is one virtual image directly behind each mirror (images 1 and 2). The light entering your eyes that appears to come from these images has undergone one reflection.



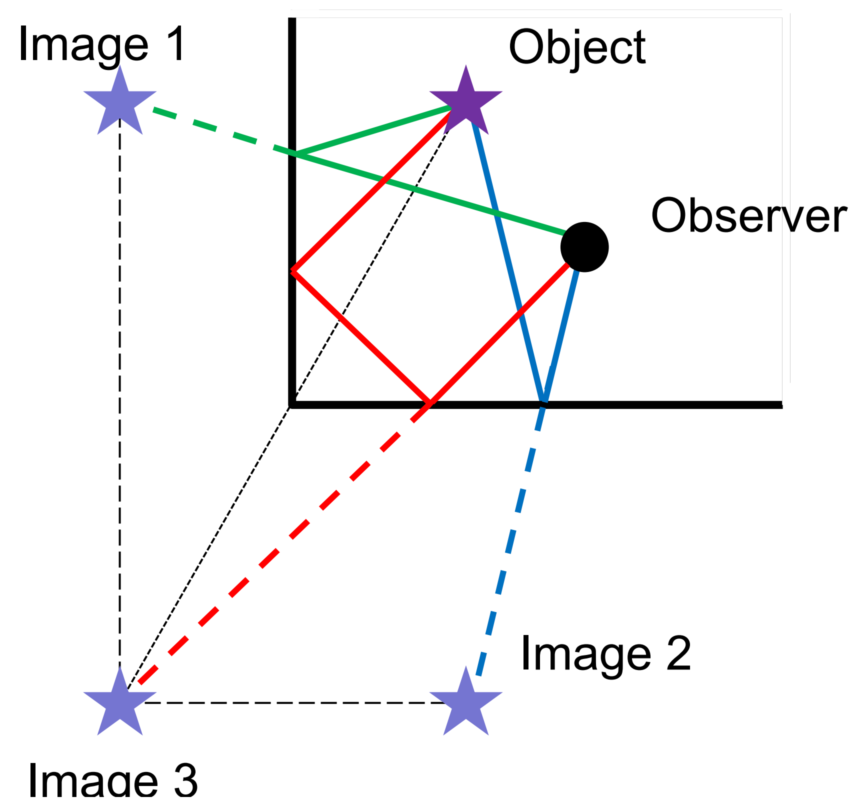
The solution is continued on the next slide.

Mirrors

The light that enters the eye that appears to come from the center image has undergone two reflections, one from each mirror.

The third image is created here by the red rays. Light travels from the object to the mirror. It then reflects to the second mirror. Image 3 forms behind this second reflection.

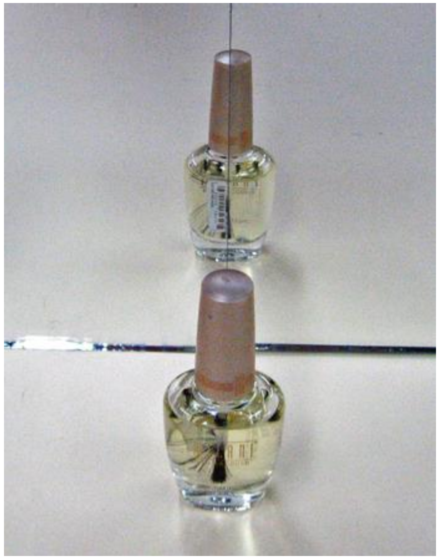
An imaginary line exists between the image and the object, which passes through the vertex of the mirror.



Mirrors

When two mirrors are parallel to each other (maybe you have seen this in an elevator), the image is continuously reflected from mirror to mirror, and an infinite number of images are created.

One mirror



Two mirrors at a right angle

Two mirrors at a 60° angle

Two parallel mirrors

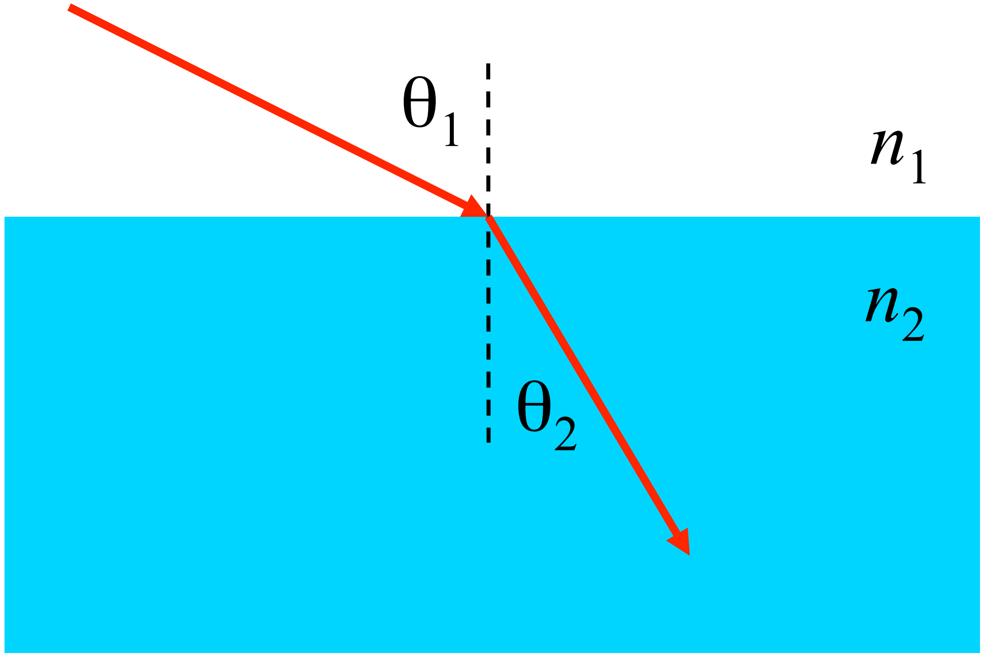
By angling one of the mirrors slightly, the path of images will curve

http://scienceres-edcp-educ.sites.olt.ubc.ca/files/2015/01/sec_phys_optics_planeMirrors.pdf

Refraction

Snell's Law

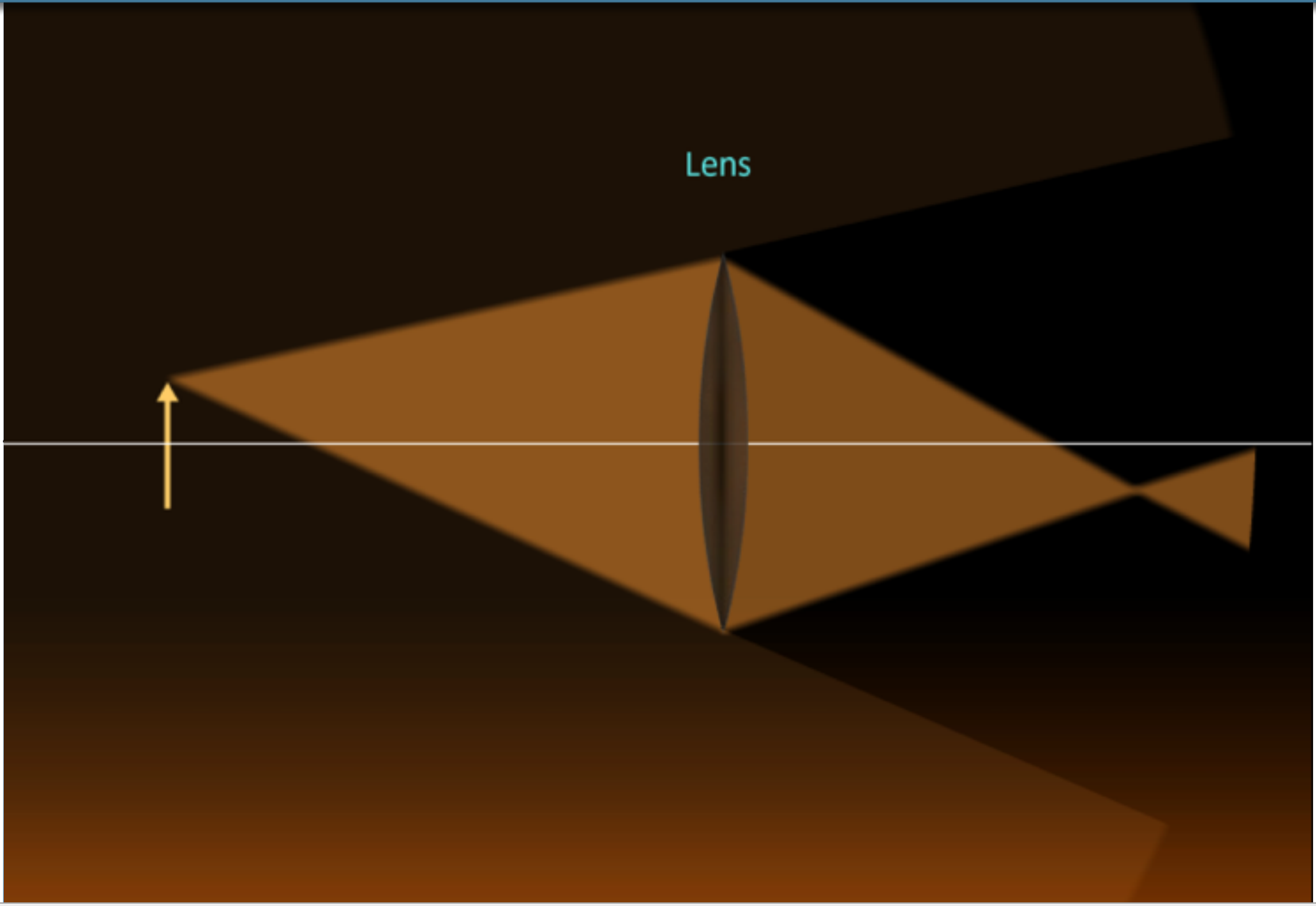
$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$



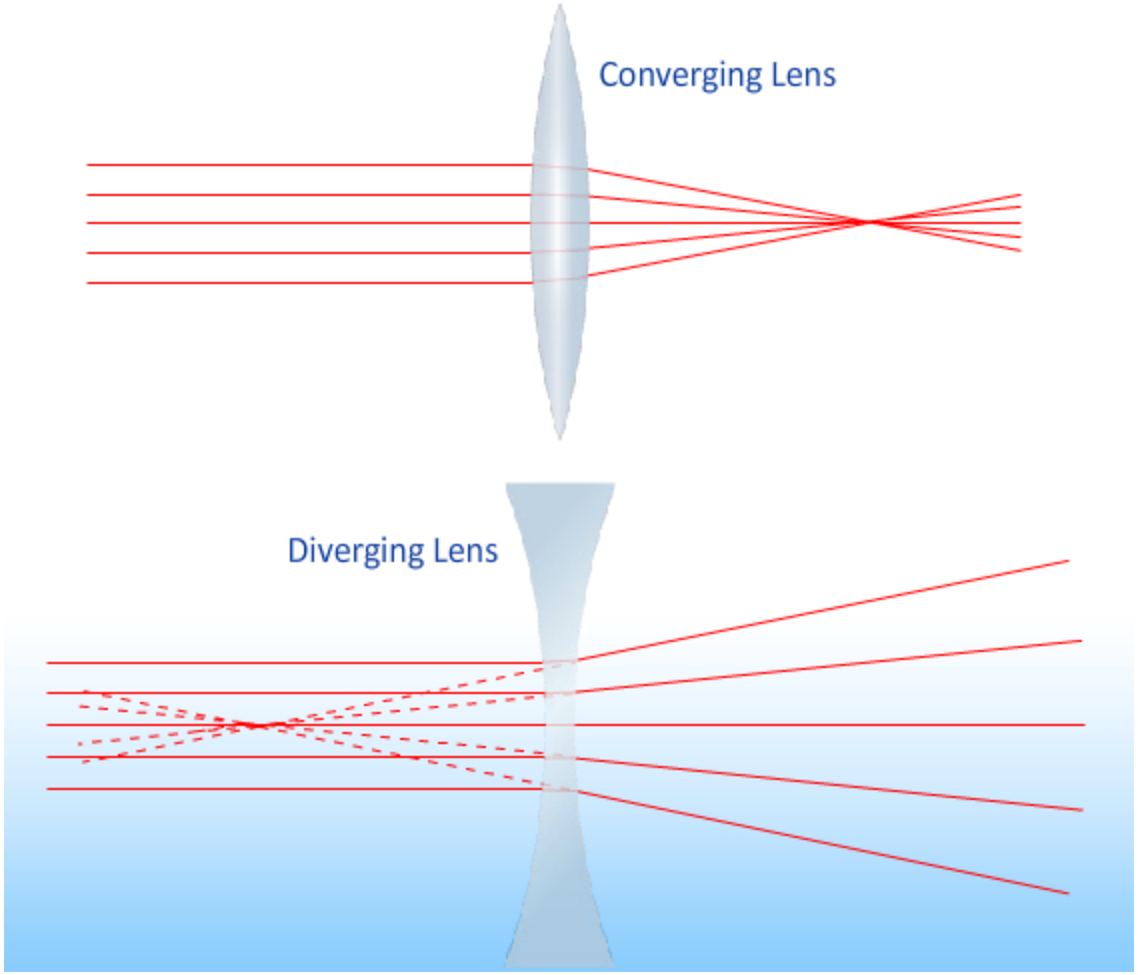
That's all of the physics –

everything else is just geometry!

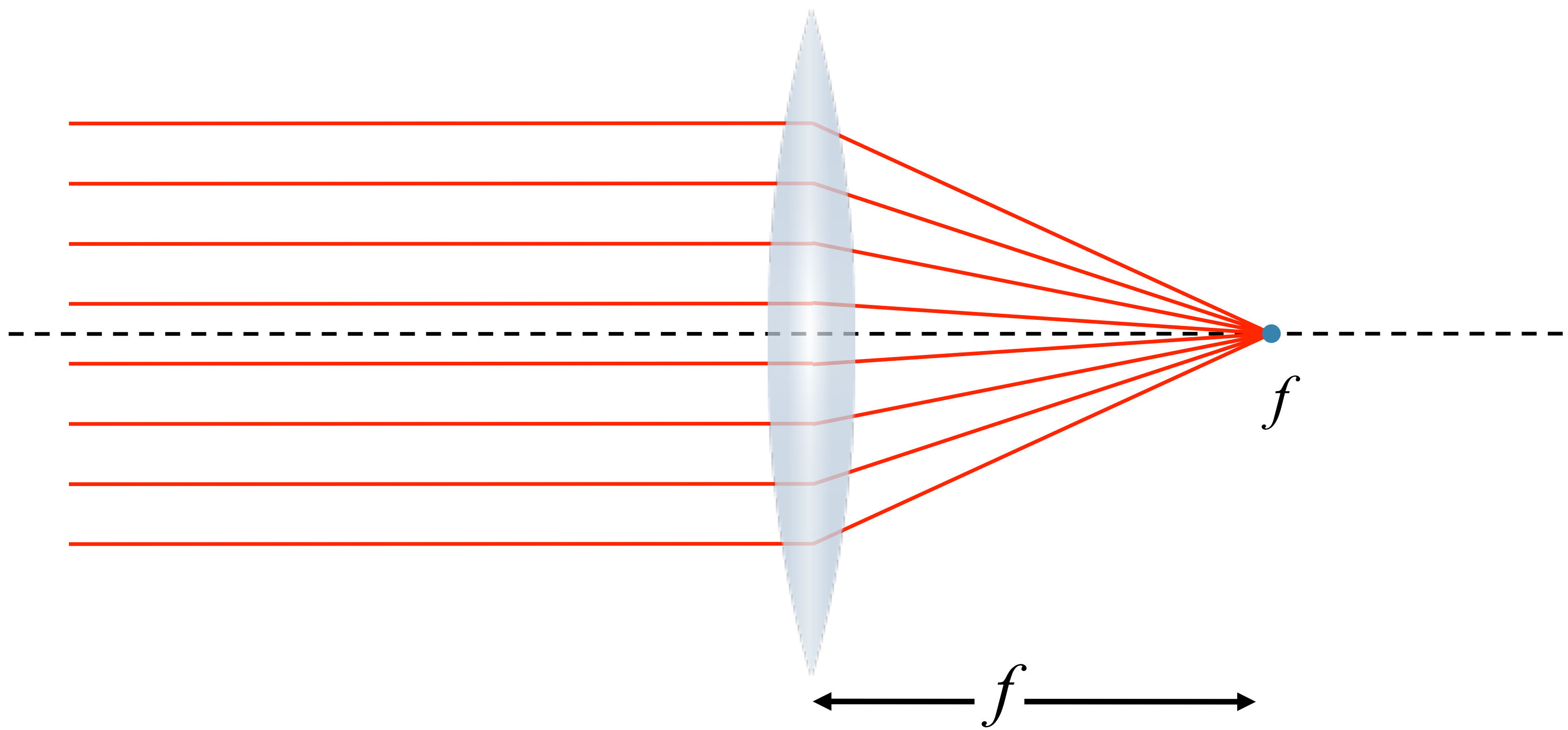
Waves from Objects are Focused by Lens



Two Different Types of Lenses



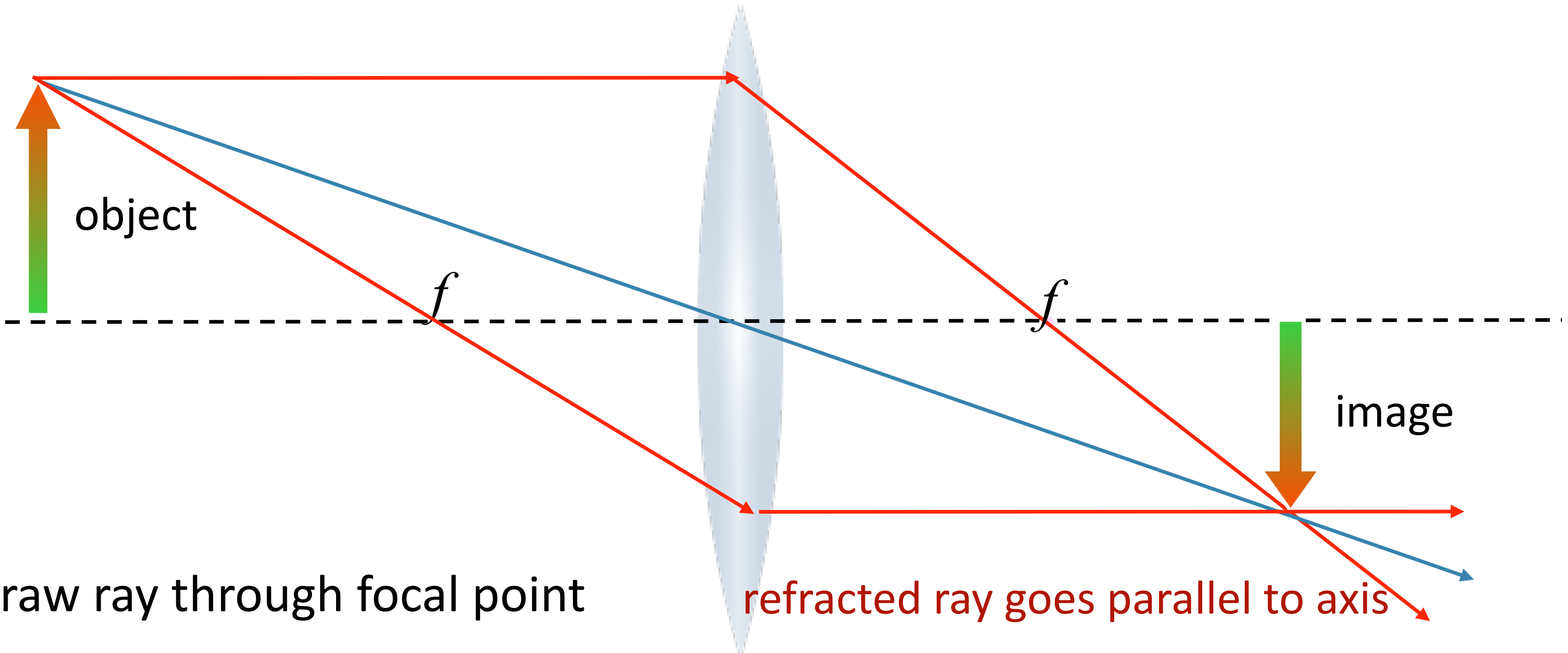
Converging Lens: Consider the case where the shape of the lens is such that light rays parallel to the axis of the mirror are all "focused" to a common spot a distance f behind the lens:



Recipe for Finding Image:

1) Draw ray parallel to axis — refracted ray goes through focal point

2) Draw ray through center — refracted ray is symmetric

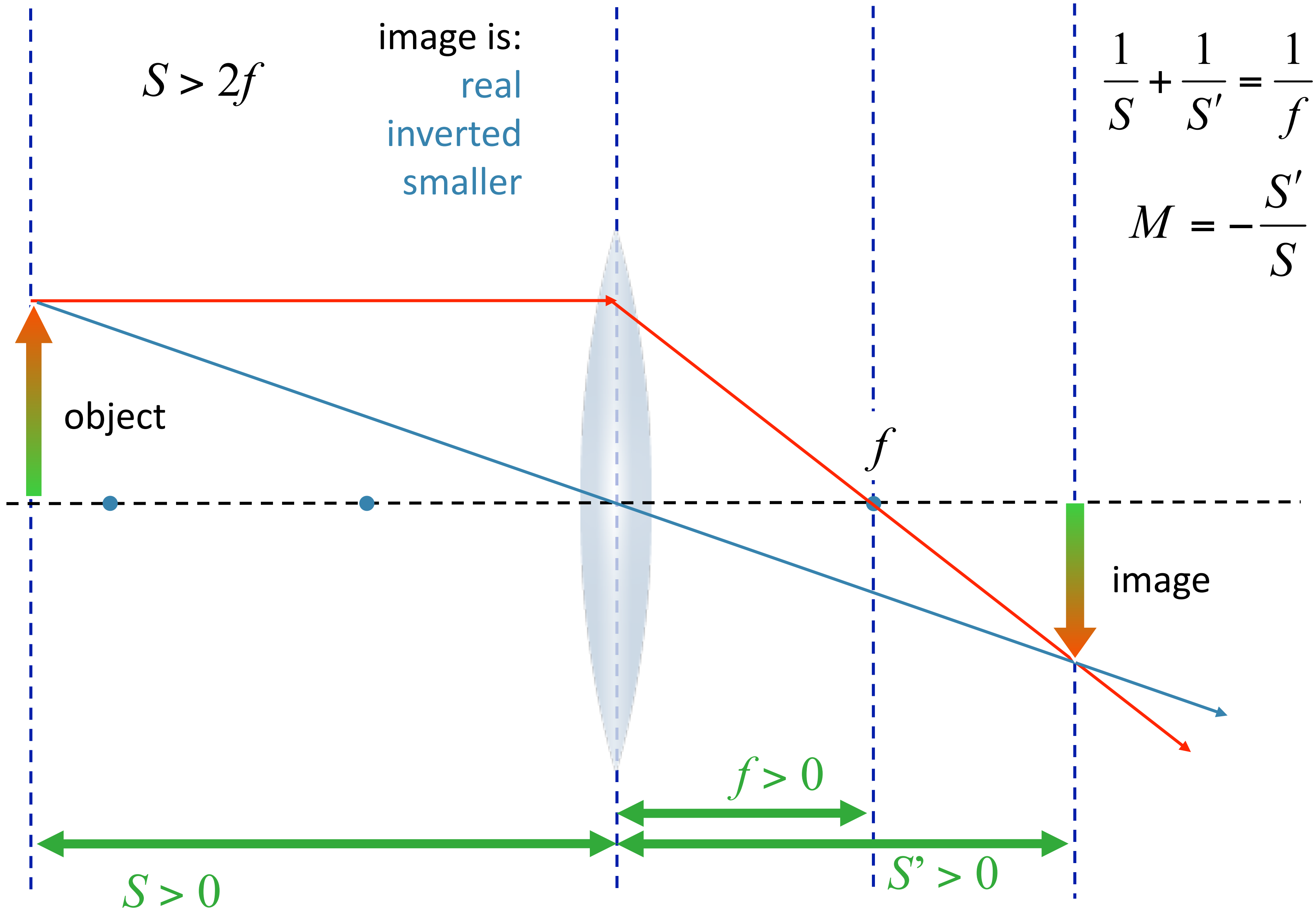


3) Draw ray through focal point — refracted ray goes parallel to axis

alternate or check

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

Example



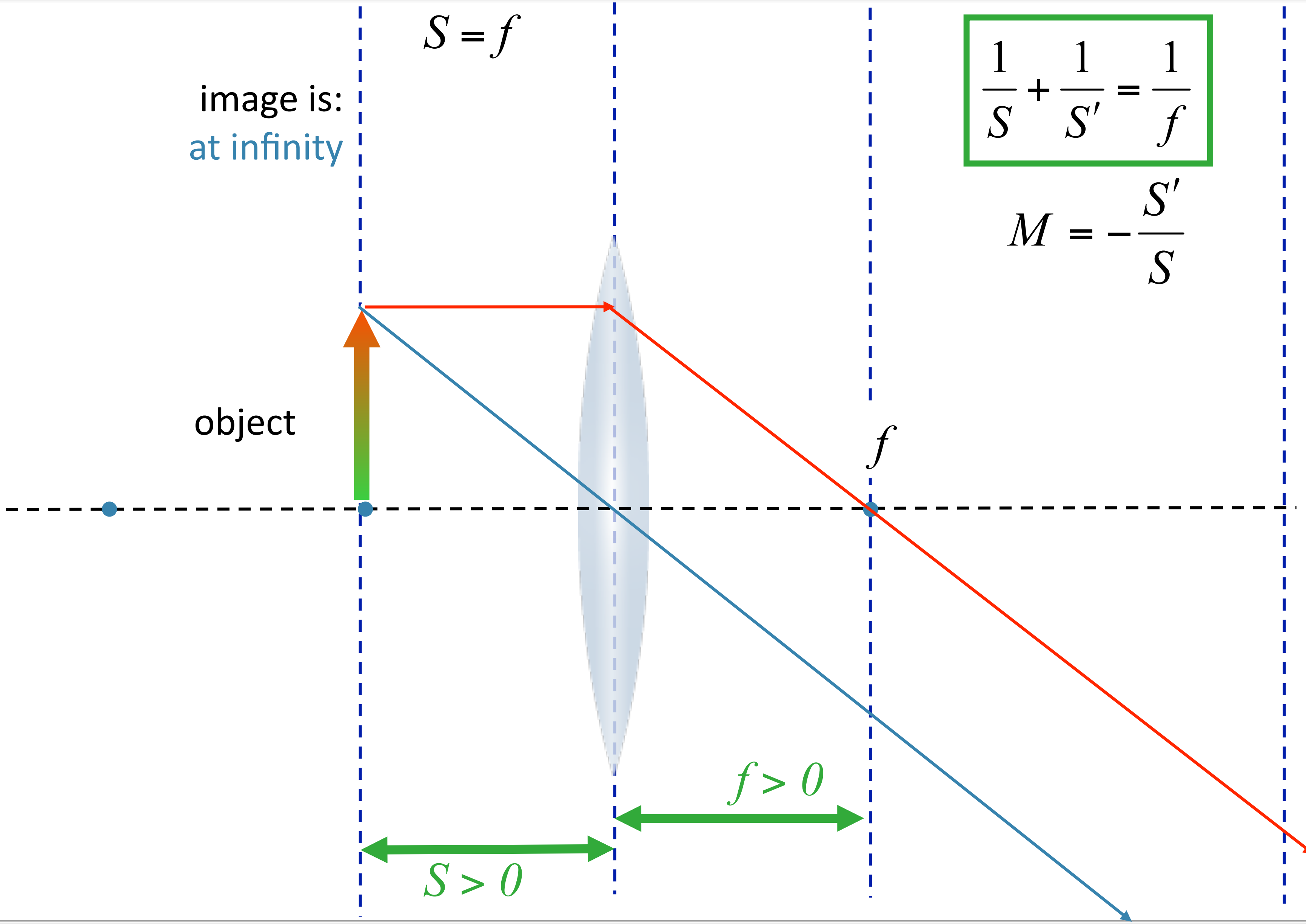
$S > 2f$
image is:
real
inverted
smaller
$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$
$M = -\frac{S'}{S}$
object
f
image
$f > 0$
$S > 0$
$S' > 0$

Example

image is:
at infinity

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

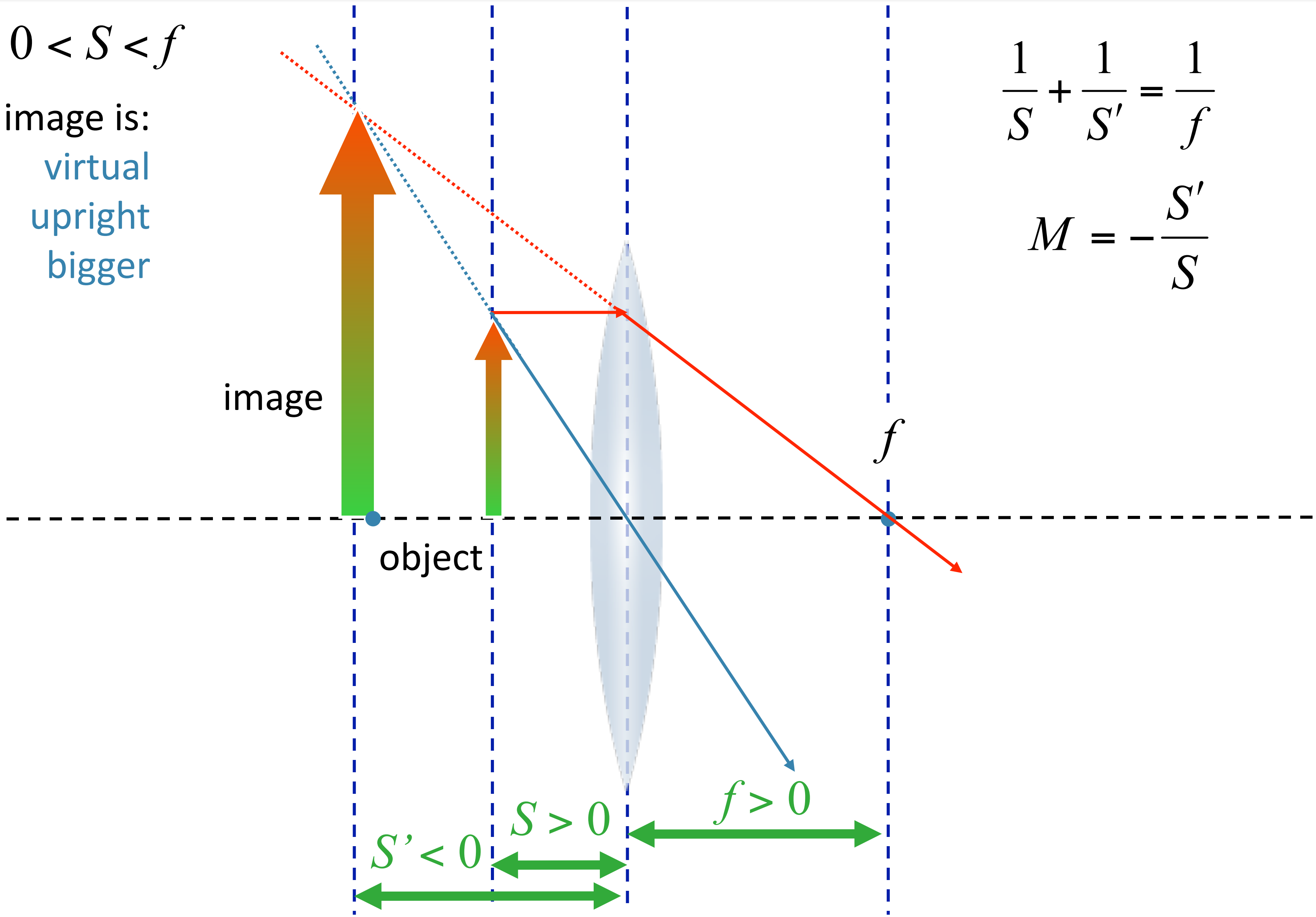
$$M = -\frac{S'}{S}$$



Example

$0 < S < f$

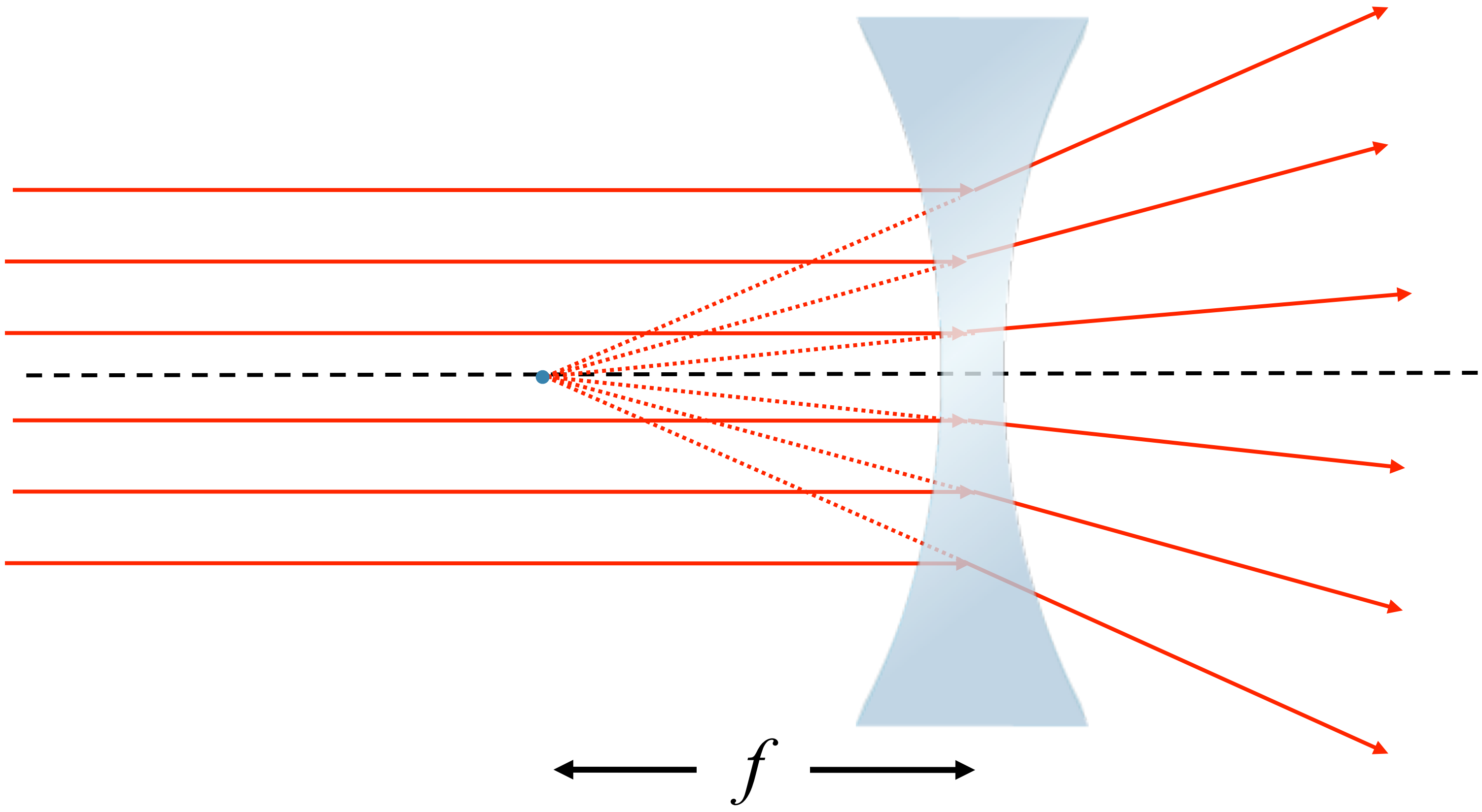
image is:
virtual
upright
bigger



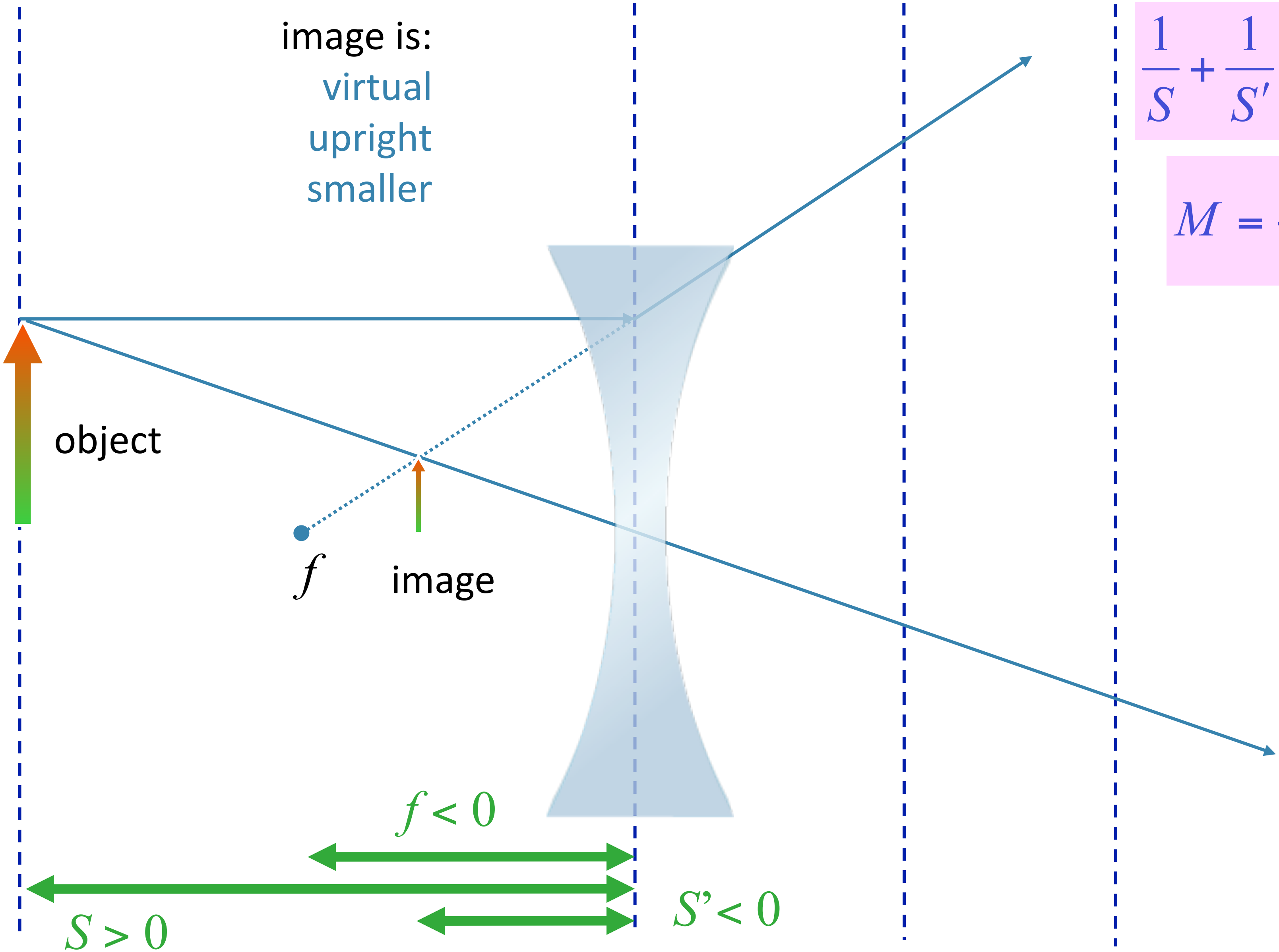
$$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$$

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

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



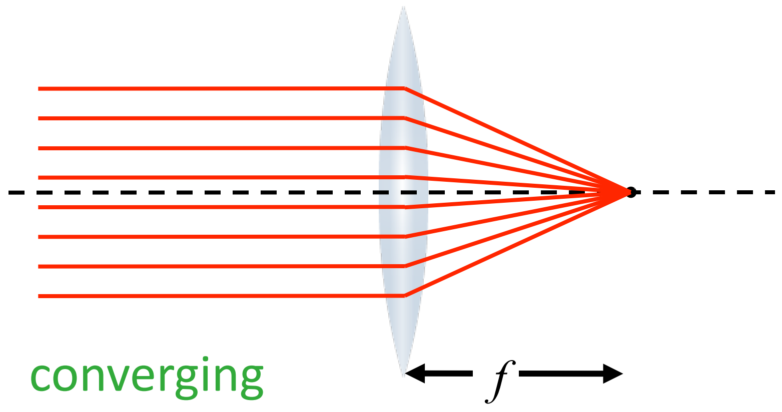
$$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$$

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

Executive Summary - Lenses

$S > 2f$ — real, inverted, smaller

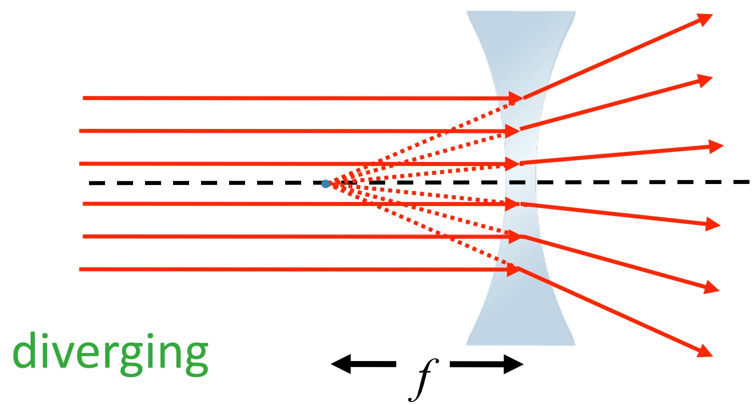
$2f > S > f$ — real, inverted, bigger



$f > S > 0$ — virtual, upright, bigger

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

$S > 0$ — virtual, upright, smaller



It's Always the Same:

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

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

You just have to keep the signs straight:

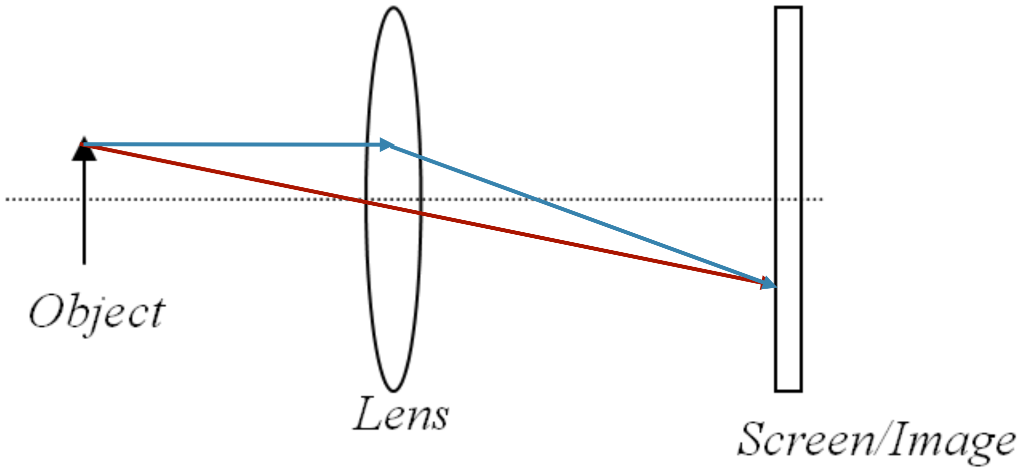
The sign conventions

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

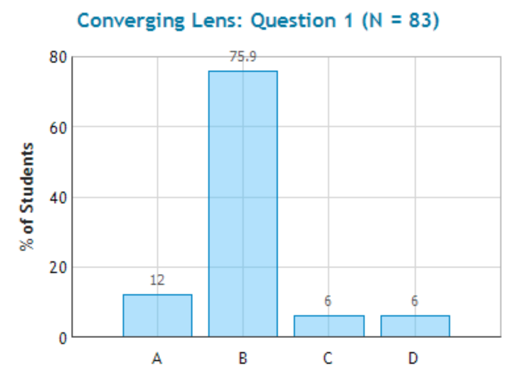


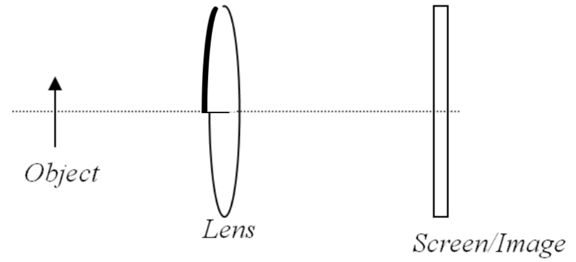
Image on screen

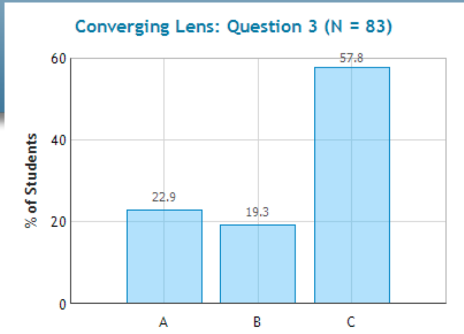
MUST BE REAL

$\rightarrow \; s' > 0$

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

Checkpoint





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 following will be seen

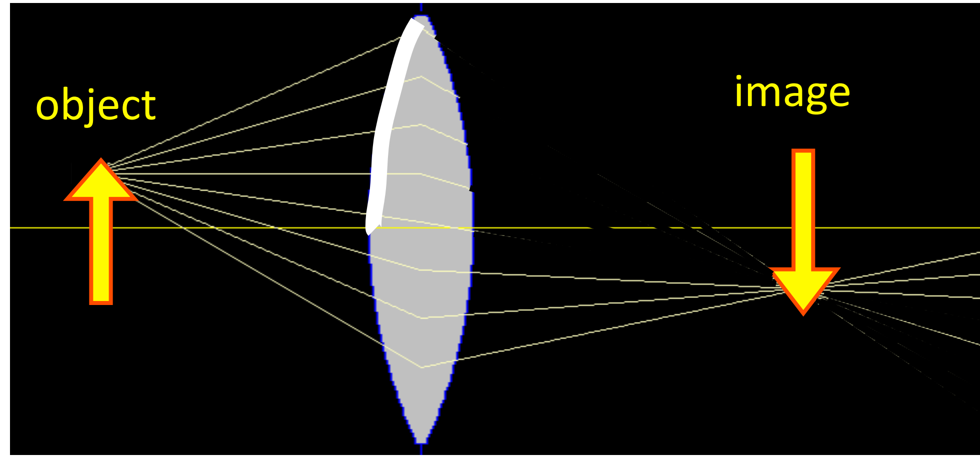
A) Only the lower half of the object

B) Only the upper half of the object

C) The whole object will still show on the screen.

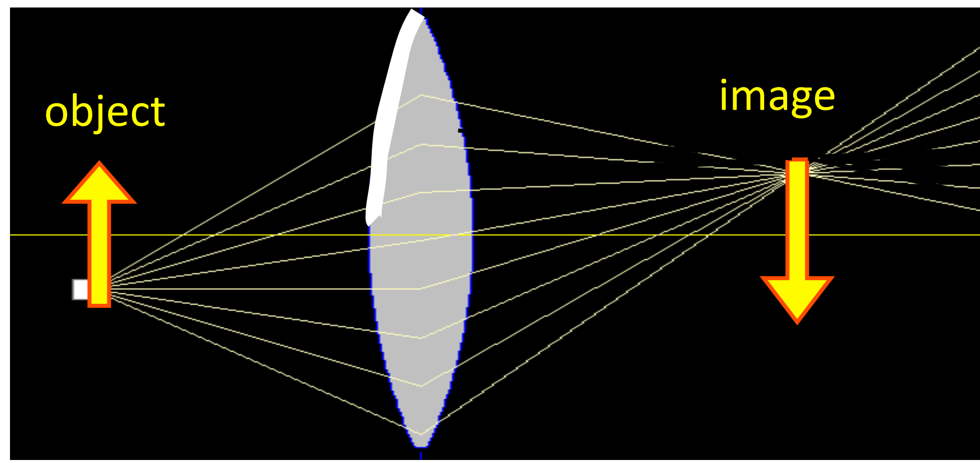
Cover top half of lens

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!

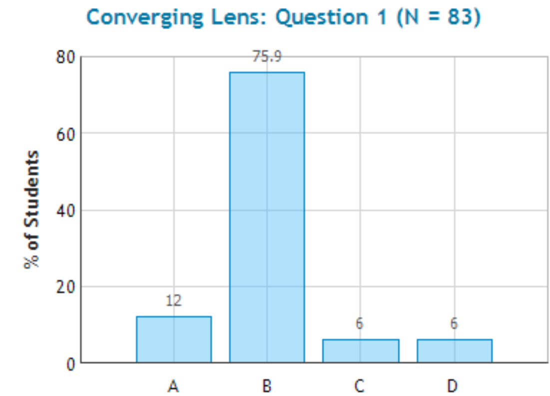
3) A piece of black tape is now placed over the upper half of the lens. Which of the follow is true.

- ○ 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.

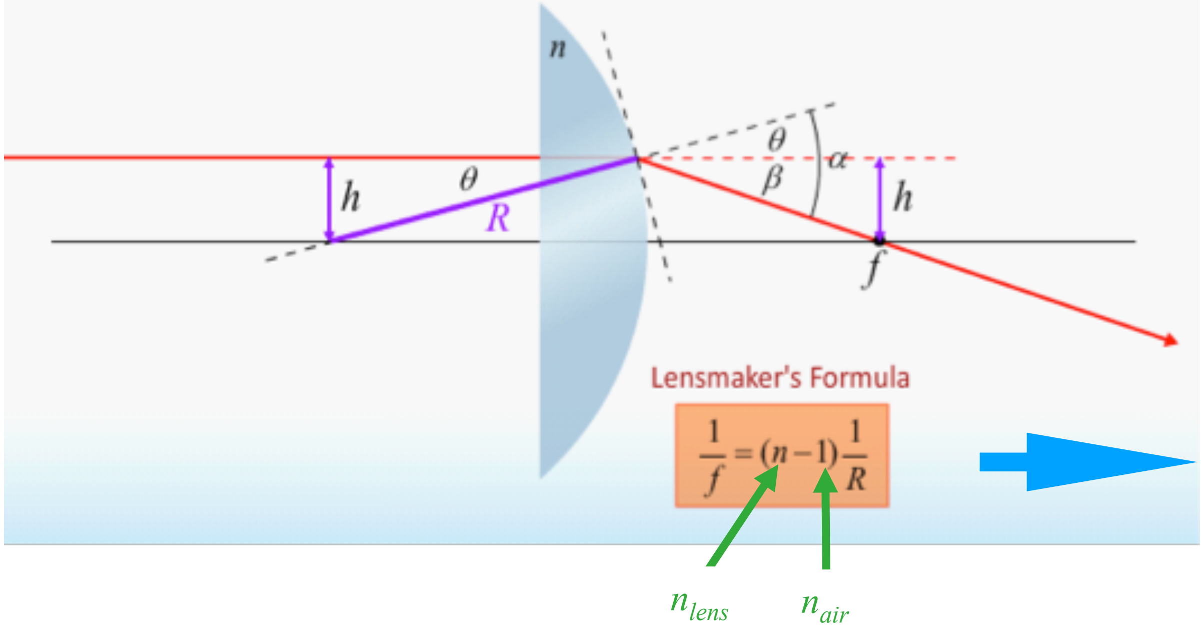
CheckPoint 7

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



$$\frac{1}{f} = (n_{\text{lens}} - 1.33)\frac{1}{R}$$

n water

Air Bubble in water

A Converging

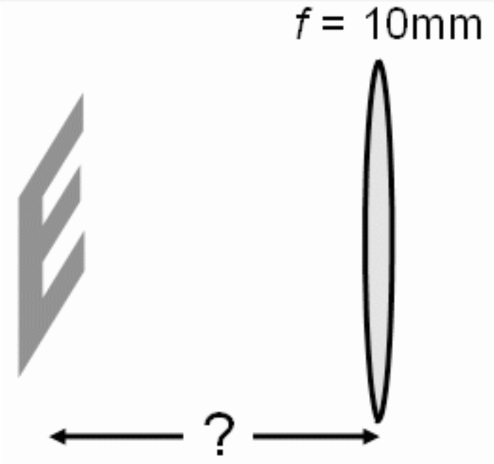
B Diverging

C not a lens

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: $M = -s'/s$

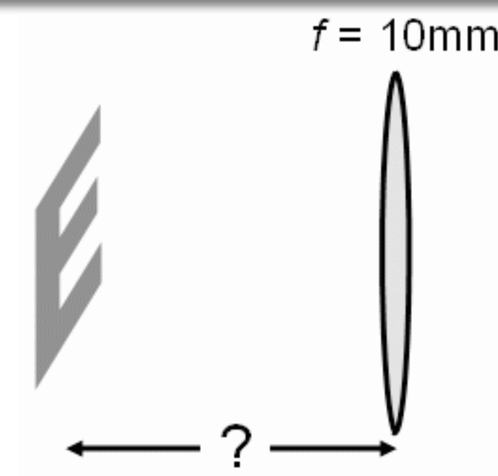
Strategic Analysis

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.

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?

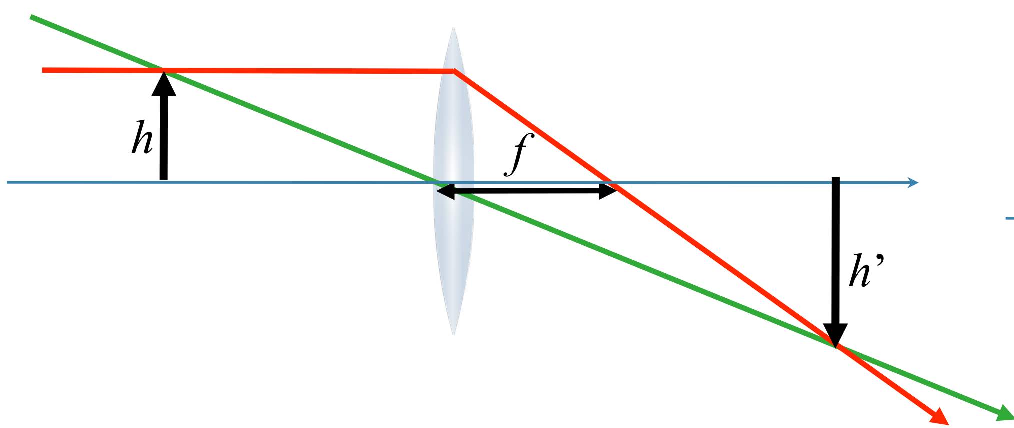


Is the image real or virtual?

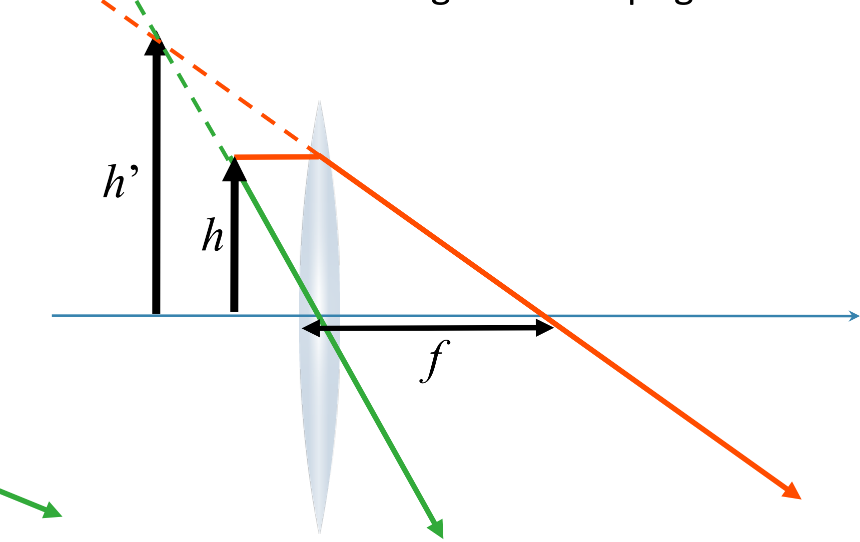
A) REAL

B) VIRTUAL

A real image would be inverted

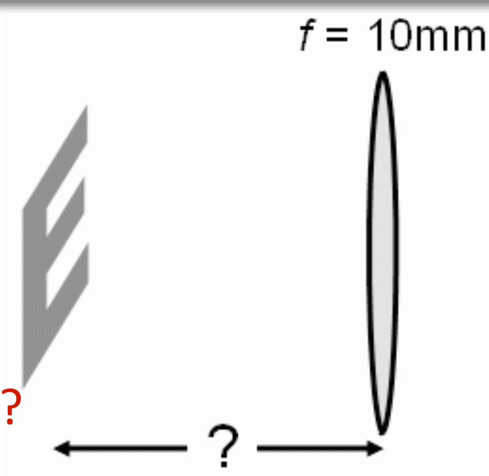


A virtual image will be upright



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?



How does the object distance compare to the focal length?

A) $|s| \leq |f|$

B) $|s| = |f|$

C) $|s| > |f|$

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

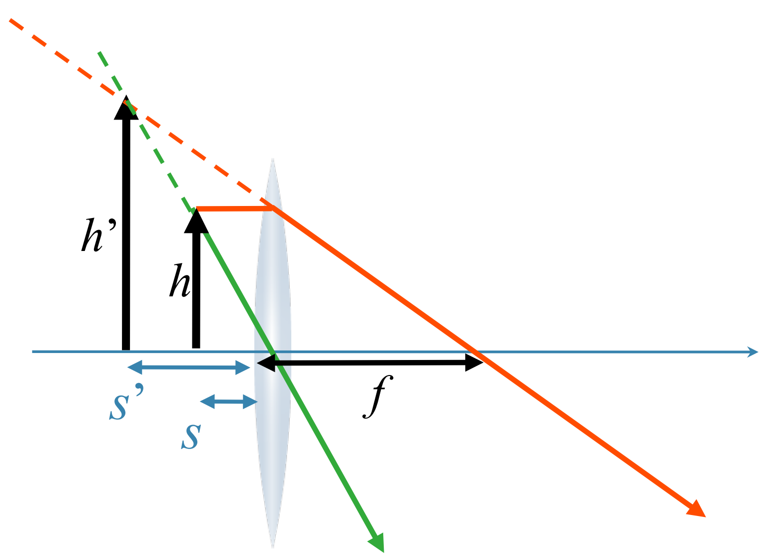
→ $$S' = \frac{fS}{S-f}$$

Virtual Image Þ $s' < 0$

Real object Þ $s > 0$

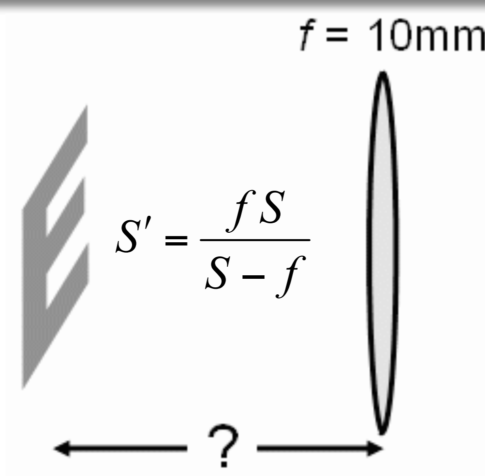
Converging lens Þ $f > 0$

$$S - f < 0$$



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) $M = \dfrac{s-f}{f}$

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

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

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

Lens equation:

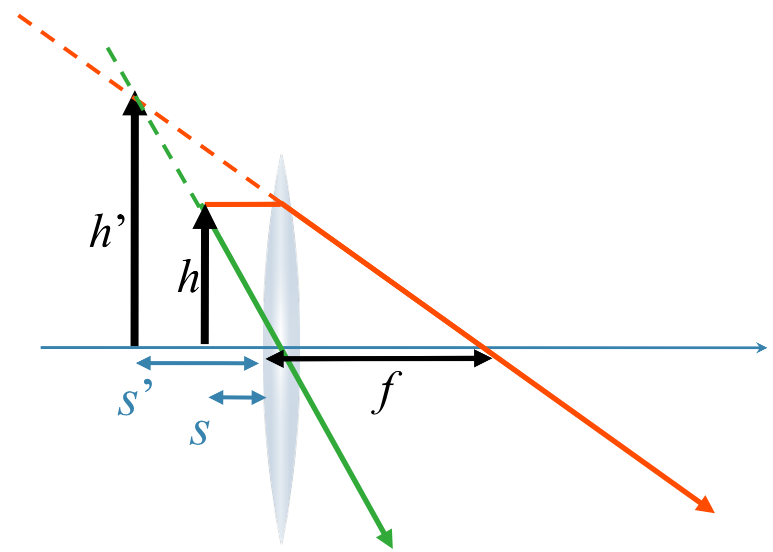
$$\frac{1}{S'} = \frac{1}{f} - \frac{1}{S}$$

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

Magnification equation:

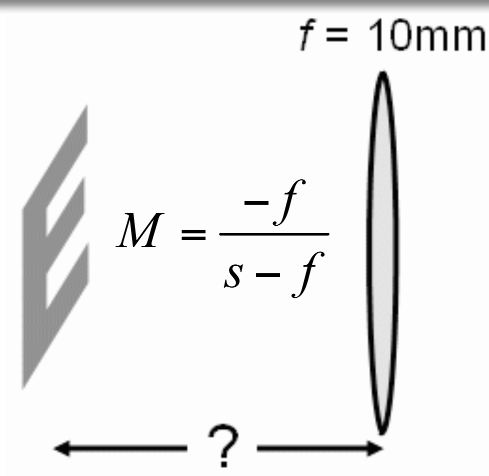
$$M = -\frac{s'}{s}$$

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



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?



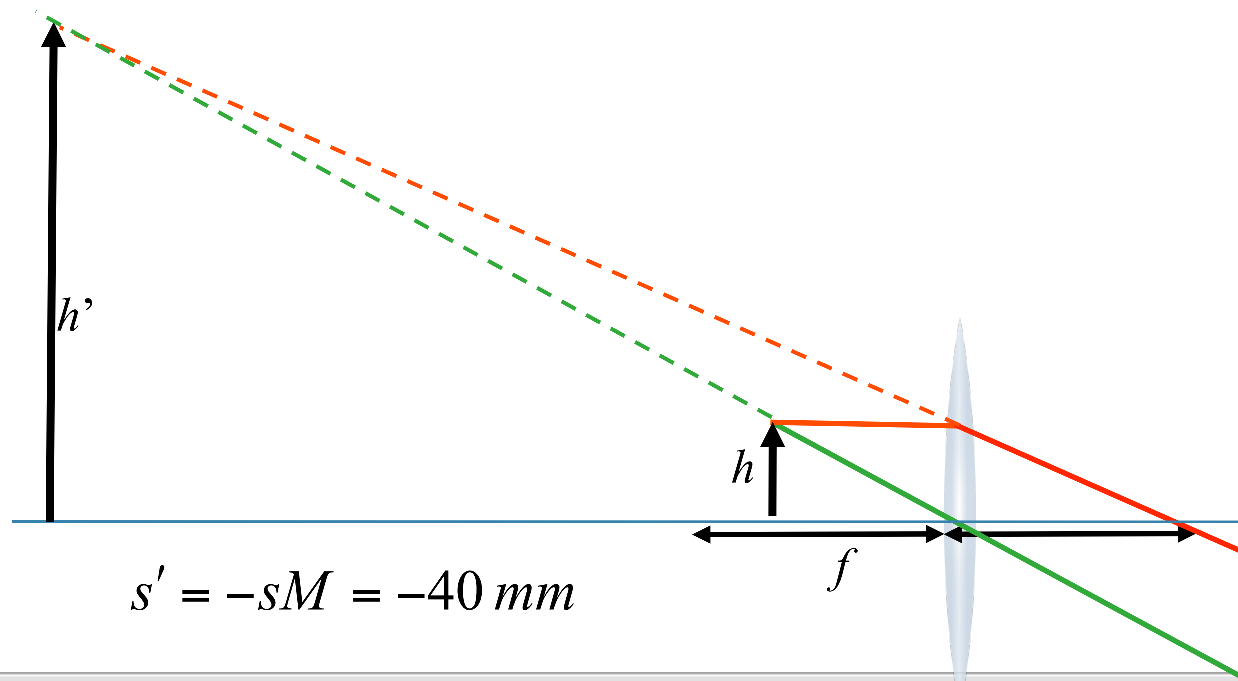
A) 1.7mm B) 6mm C) 8mm D) 40 mm E) 60 mm

$$M = +5$$

$$f = +10\,mm$$

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

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

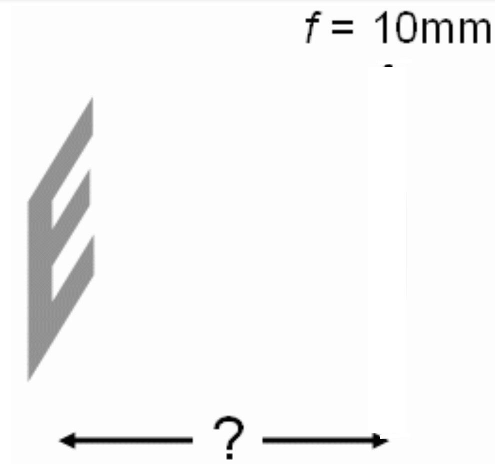


$$s' = -sM = -40\,mm$$

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

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

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

s negative —> not real object

PICTURES

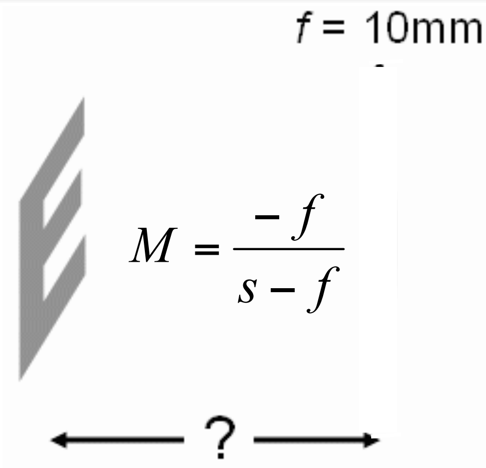
Draw the rays: s' will always be smaller than s

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 $s = 8\text{mm}$?



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

EQUATIONS

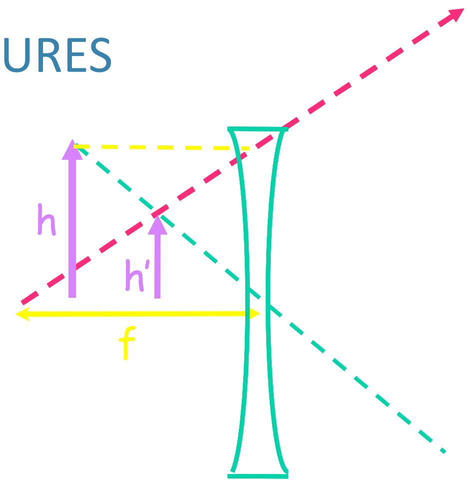
$$M = \frac{-f}{s-f}$$

$$s = 8\,mm$$

$$f = -10\,mm$$

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

PICTURES

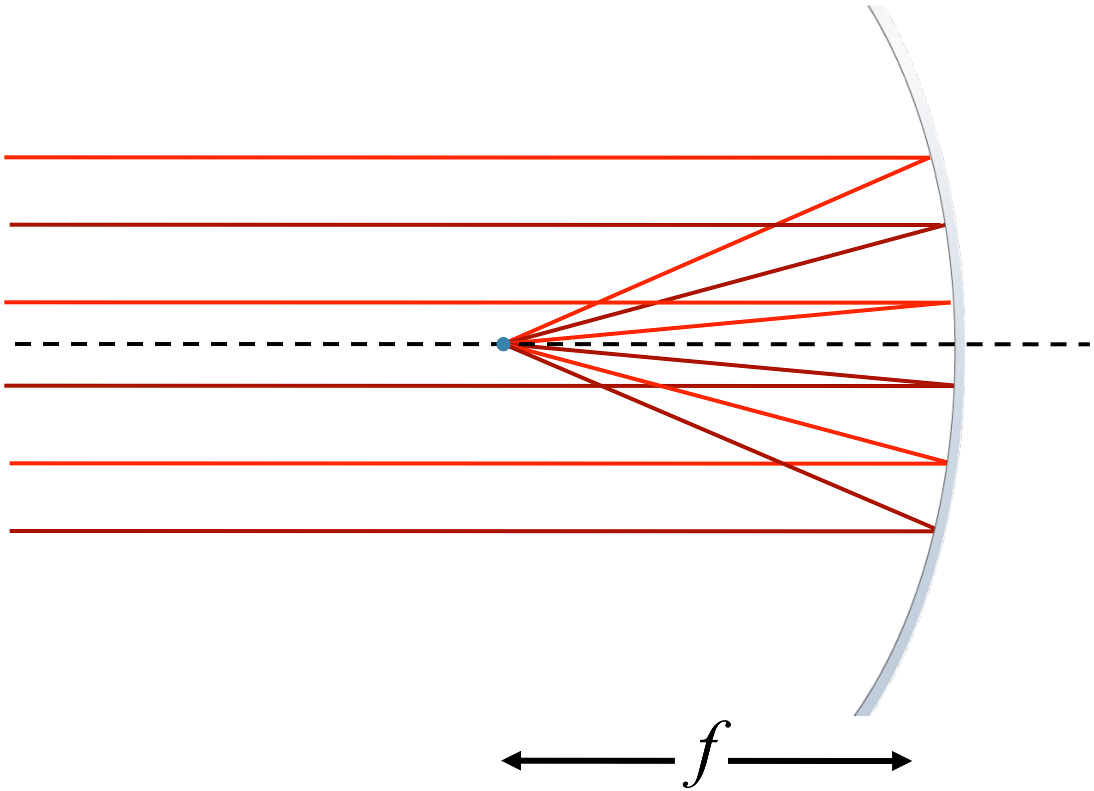


You will also get Images from Curved Mirrors:

Curved Mirrors

Concave: Consider the case where the shape of the mirror is such that light rays parallel to the axis of the mirror are all "focused" to a common spot a distance f in front of the mirror:

Note: analogous to "converging lens"
Real object can produce real image

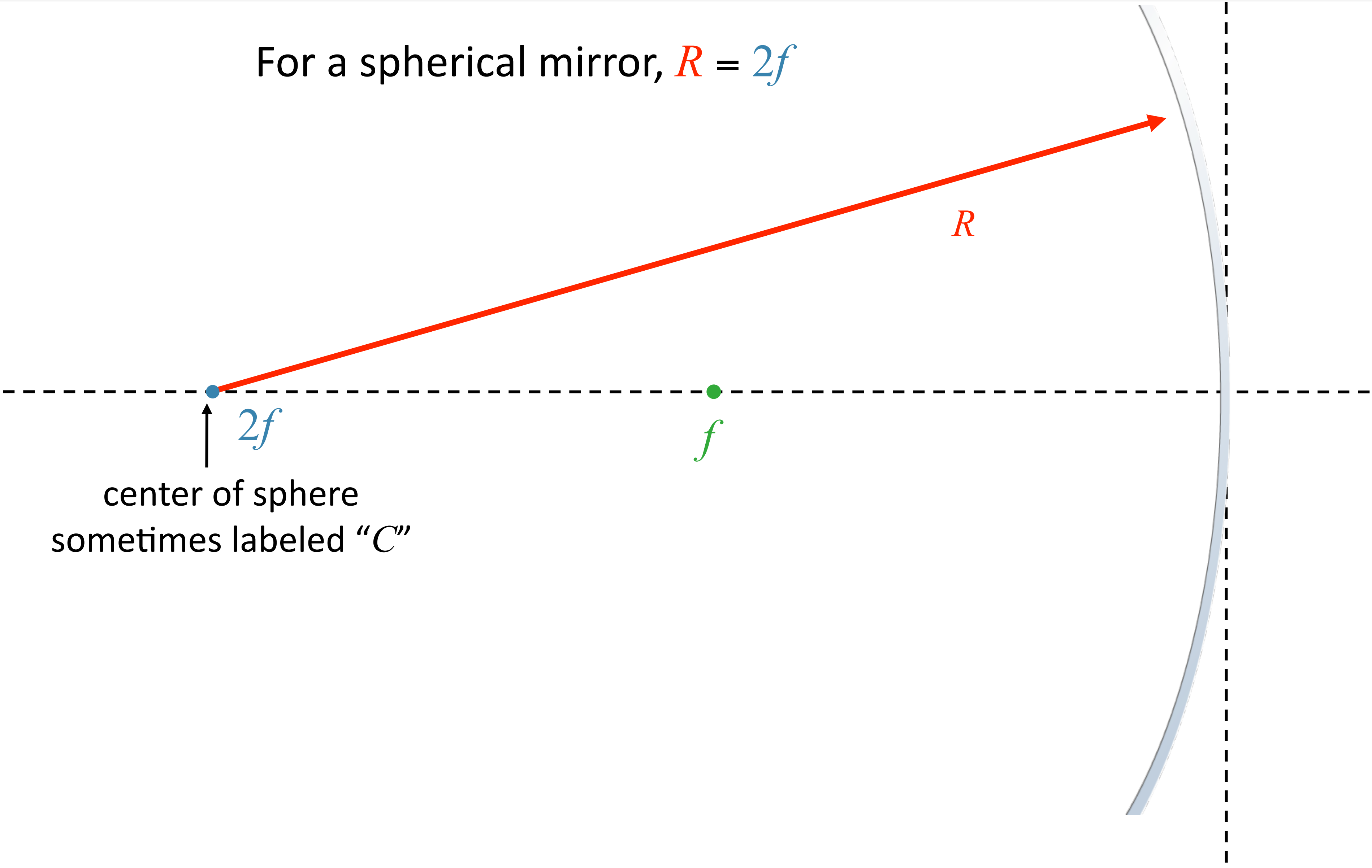


These mirrors are often sections of spheres (assumed in this class).

For such "spherical" mirrors, we assume all angles are small even though we draw them big to make it easy to see…

Curved Mirrors

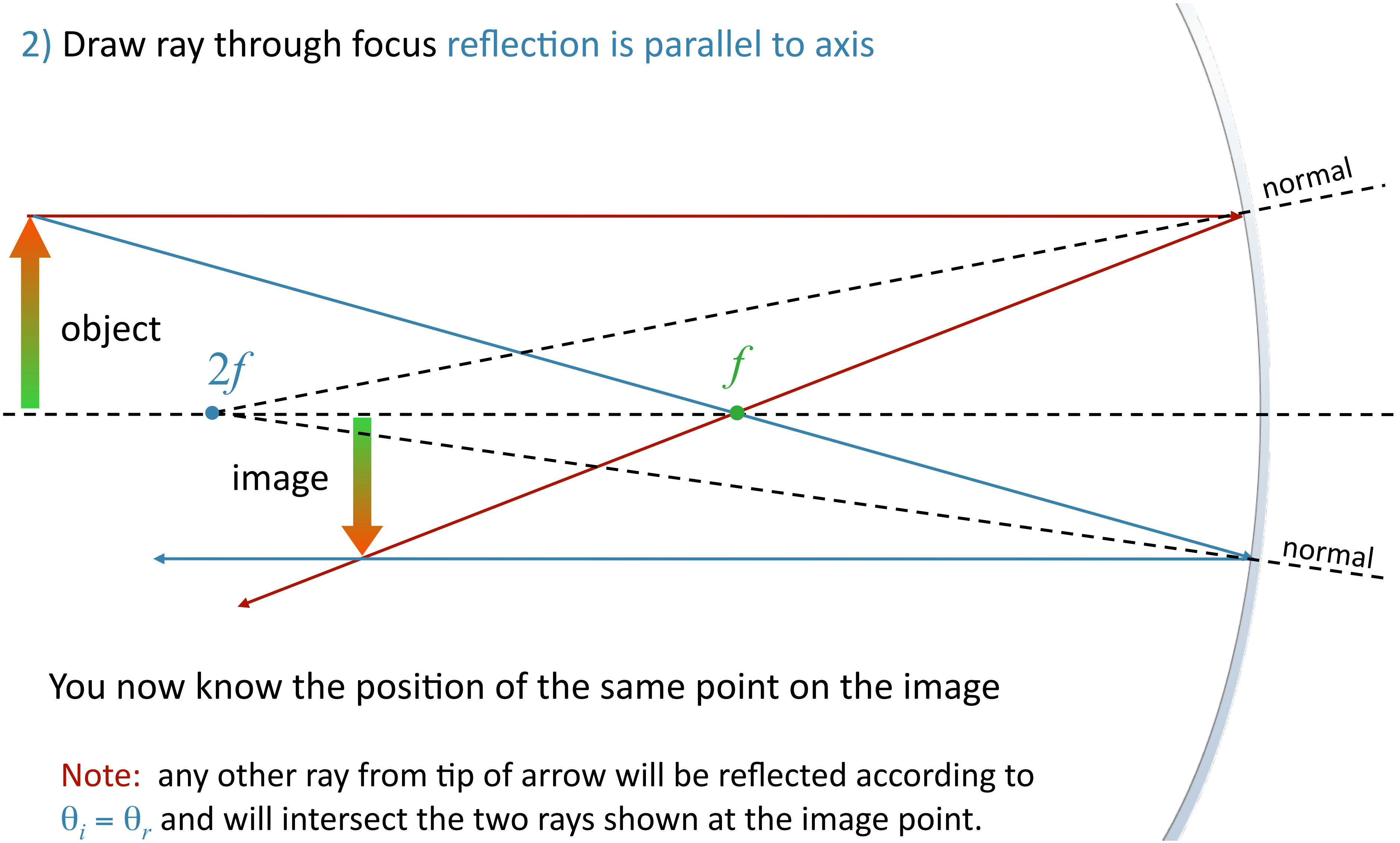
For a spherical mirror, $R = 2f$



Recipe for Finding Image:

1) Draw ray parallel to axis reflection goes through focus

2) Draw ray through focus reflection is parallel to axis



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

Note: any other ray from tip of arrow will be reflected according to $\theta_i = \theta_r$ and will intersect the two rays shown at the image point.

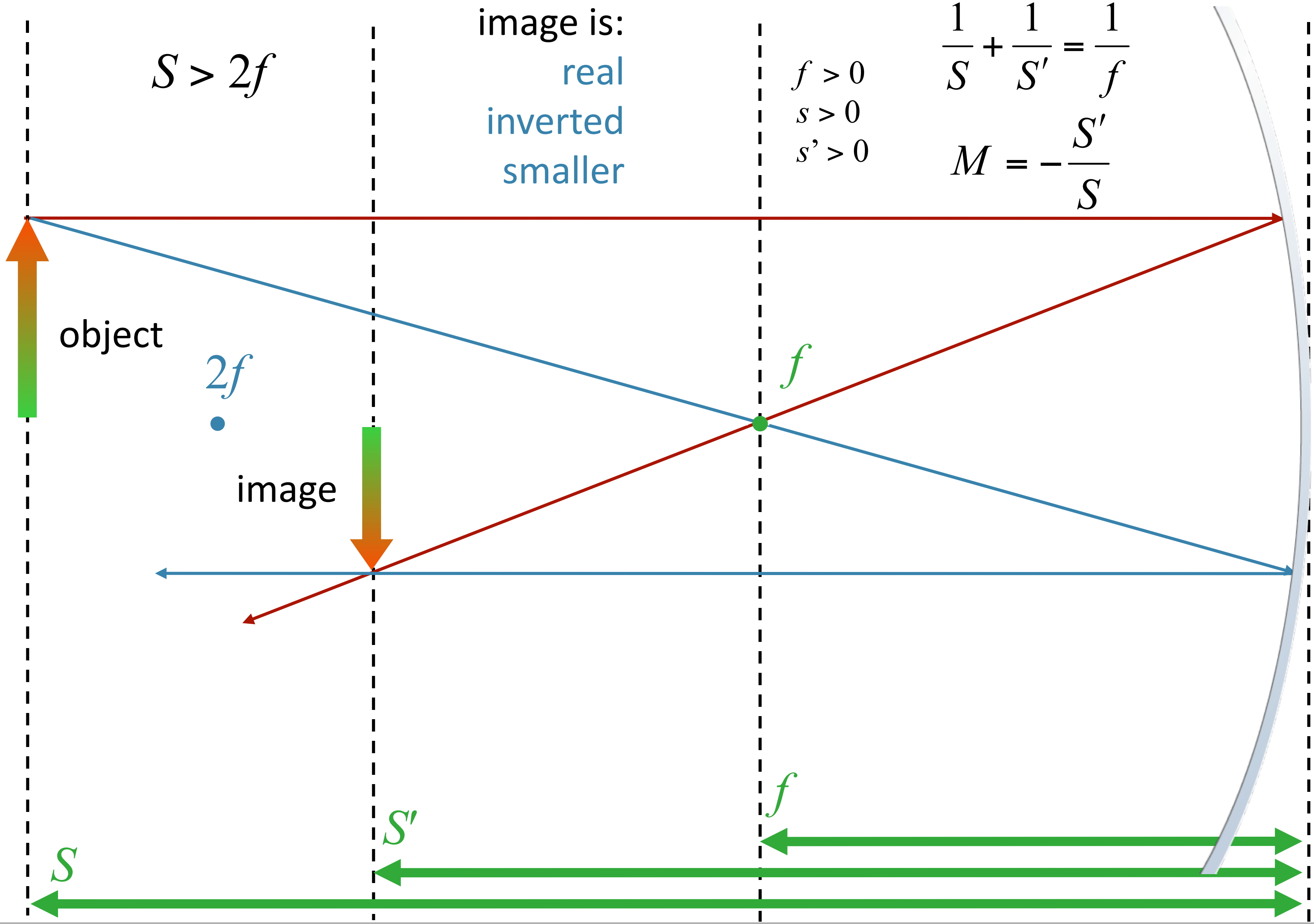
$S > 2f$

image is:
real
inverted
smaller

$f > 0$
$s > 0$
$s' > 0$

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

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



$S = 2f$

image is:

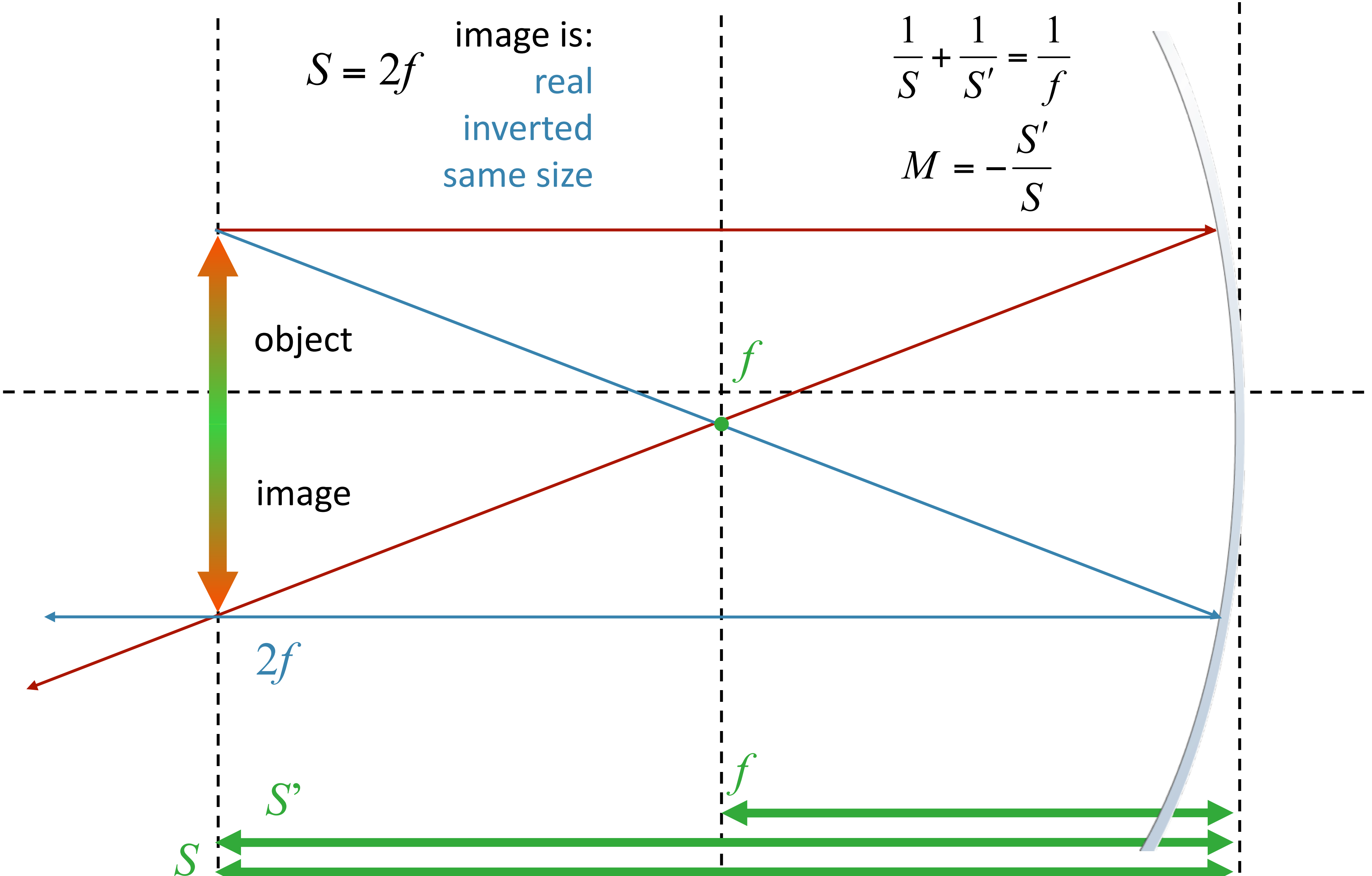
real

inverted

same size

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

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



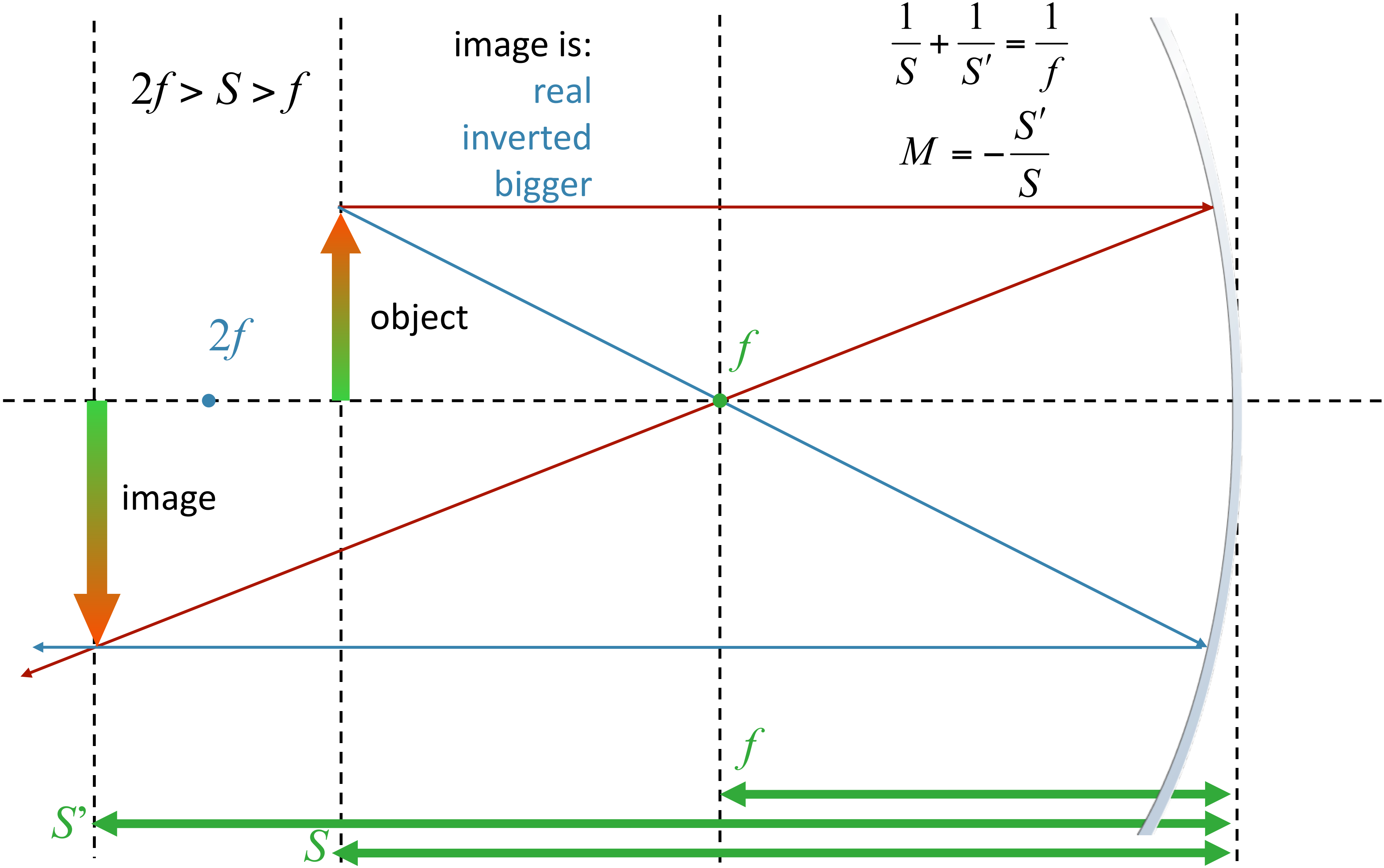
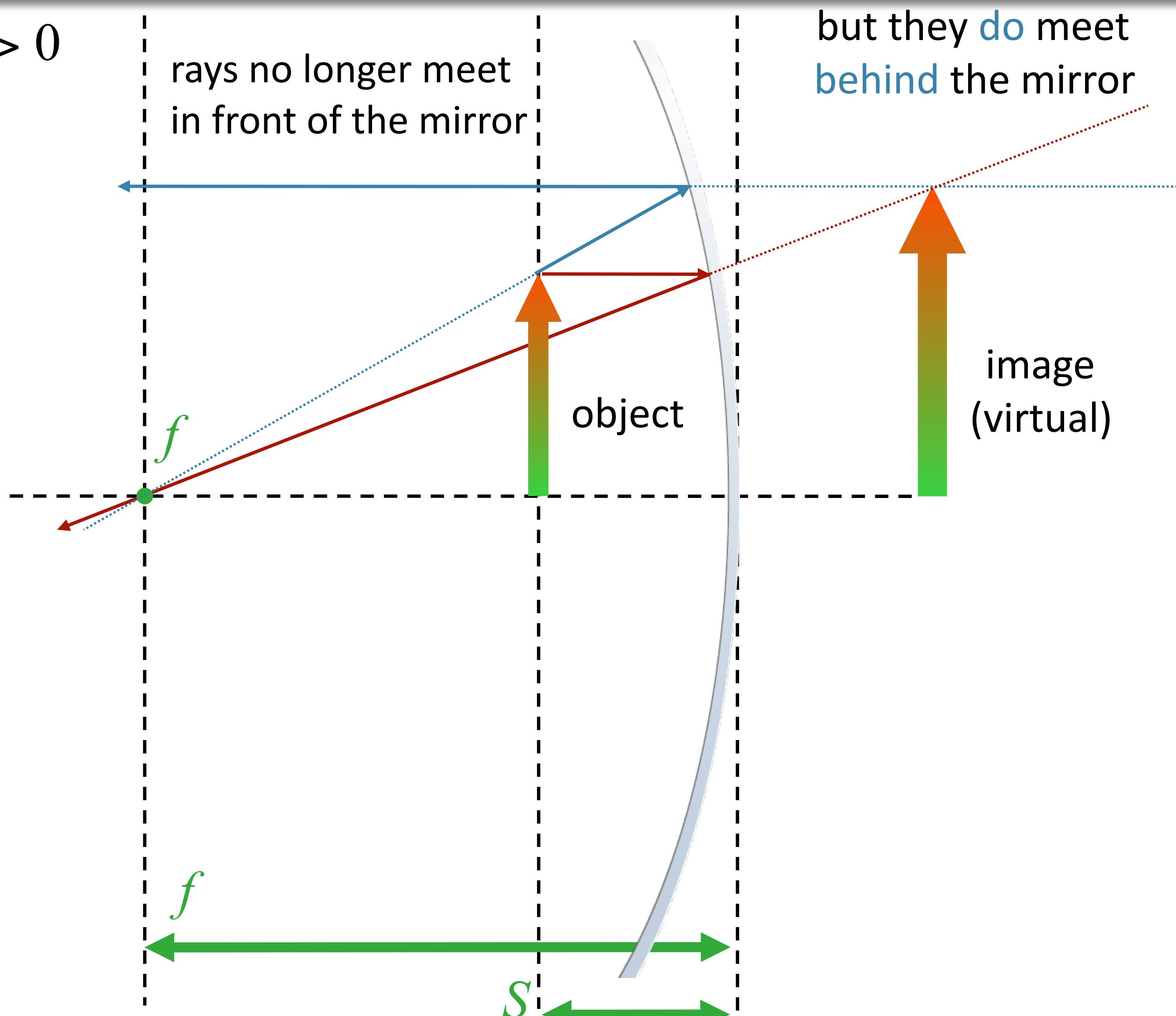


image is:
real
inverted
bigger
$2f > S > f$
$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f}$
$M = -\frac{S'}{S}$
object
image
$2f$
f
f
S'
S

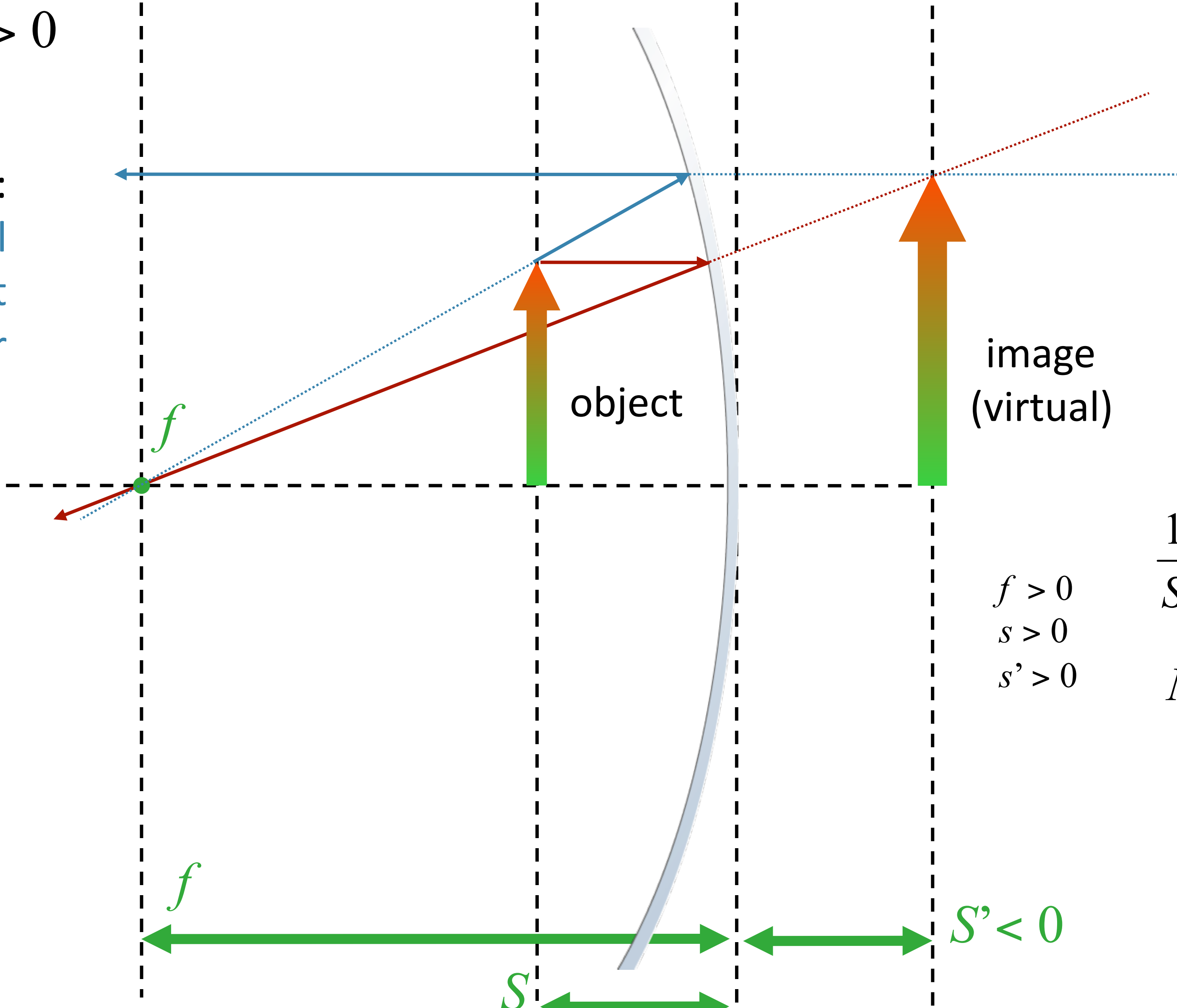
$f > S > 0$



rays no longer meet
in front of the mirror
but they do meet
behind the mirror
object
image
(virtual)
f
f
S

$f > S > 0$

image is:
virtual
upright
bigger



$f > 0$
$s > 0$
$s' > 0$

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

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

Convex: Consider the case where the shape of the mirror is such that light rays parallel to the axis of the mirror are all “focused” to a common spot a distance f behind the mirror:

Note: analogous to “diverging lens”
Real object will produce virtual image