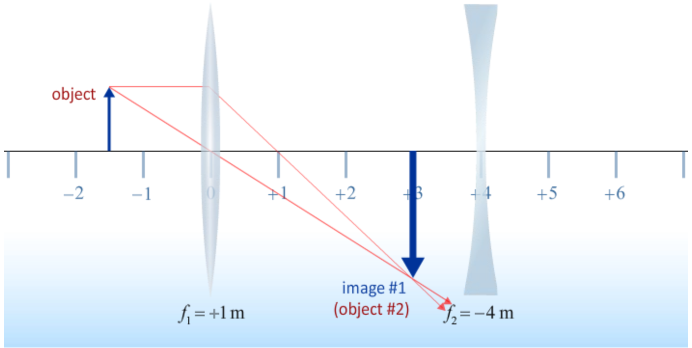
Physics 121
Lecture 28

Today's Concept:

A) Optical Devices



Executive Summary - Mirrors & Lenses:

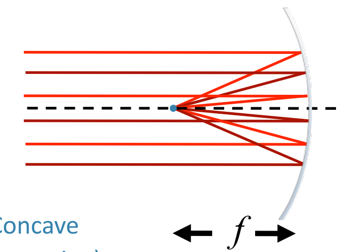
$S > 2f$ — real, inverted, smaller

$2f > S > f$ — real, inverted, bigger

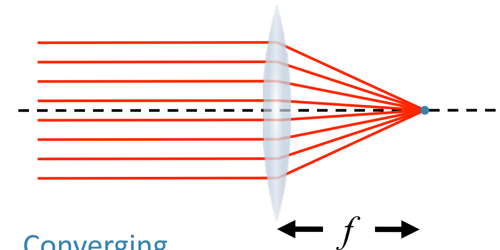
$f > S > 0$ — virtual, upright, bigger

$S > 0$ — virtual, upright, smaller

$f > 0$



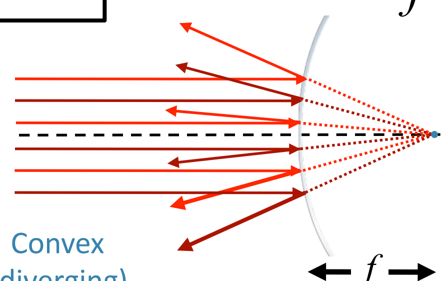
Concave (Converging)



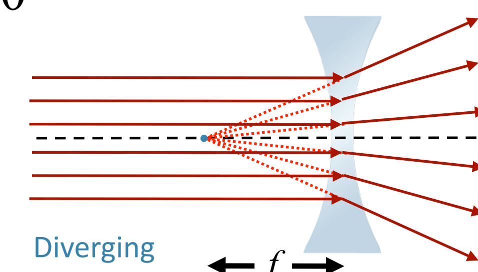
Converging

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

$f < 0$



Convex (diverging)



Diverging

It's Always the Same:

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

You just have to keep the signs straight:

s' is positive for a real image

f is positive when it can produce a real image

Lens sign conventions

S: positive if object is "upstream" of lens

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

f: positive if converging lens

Mirrors sign conventions

S: positive if object is "upstream" of mirror

S': positive if image is "upstream" of mirror

f: positive if converging mirror (concave)

System of Lenses

Trace rays through lenses, beginning with most upstream lens

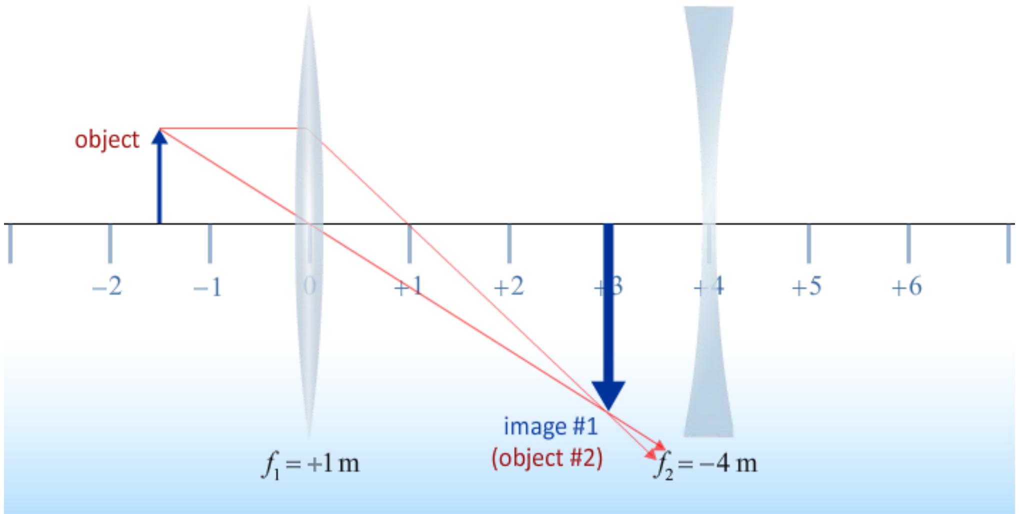
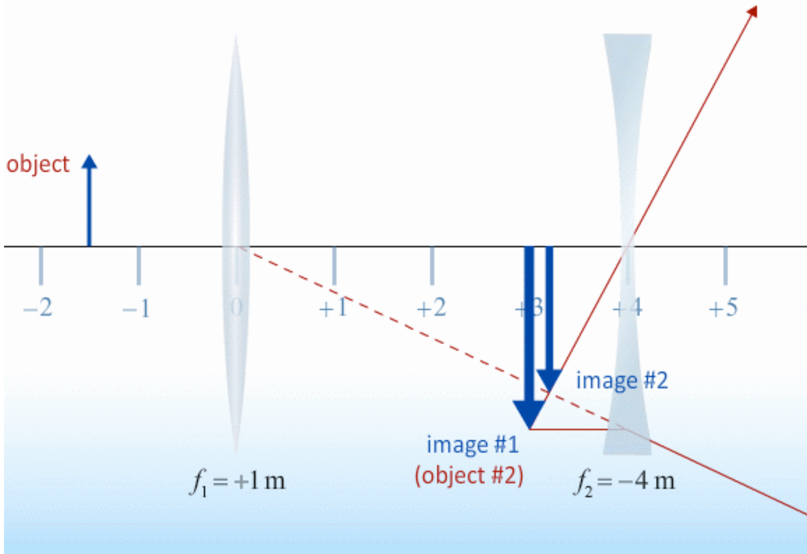
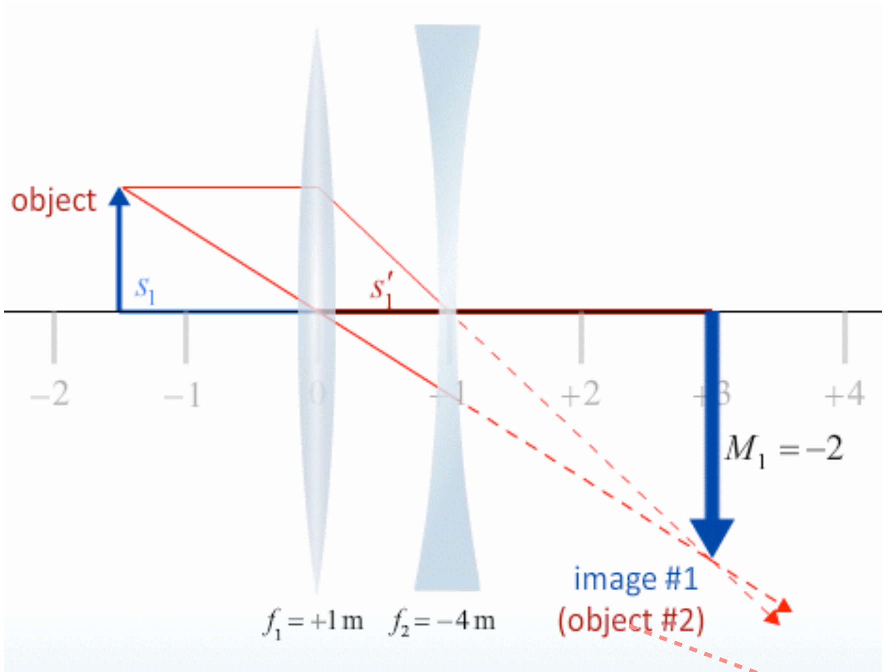


Image from first lens
Becomes object for second lens



System of Lenses

Virtual Objects are Possible !!



Object Distance is Negative!

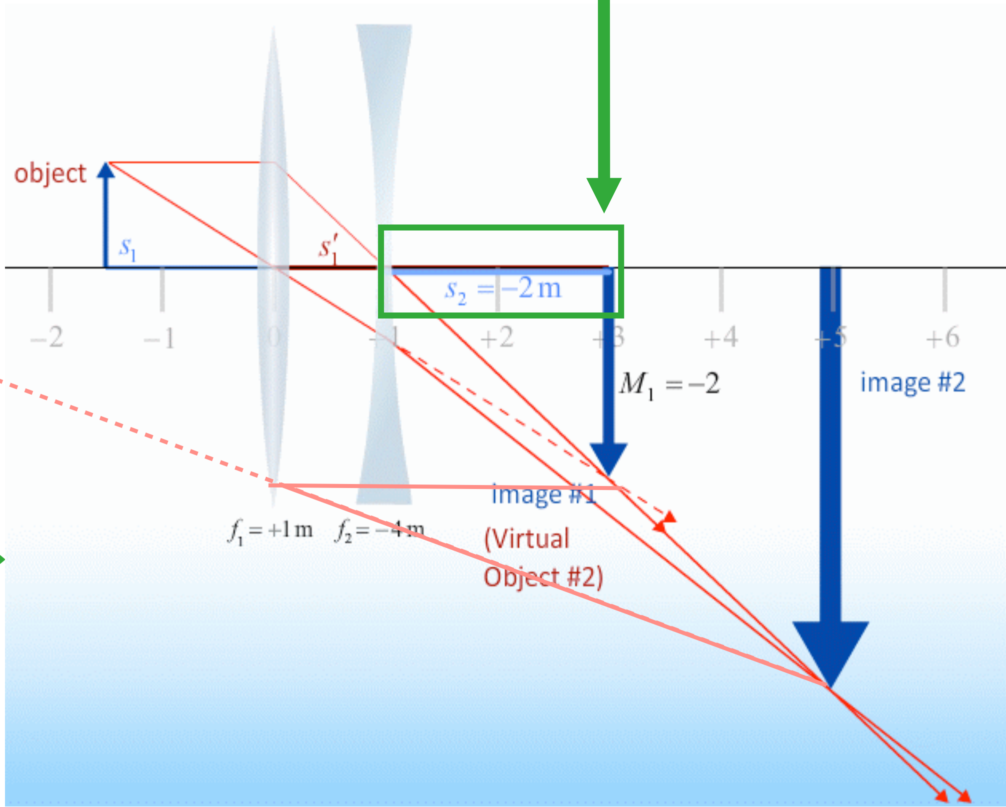
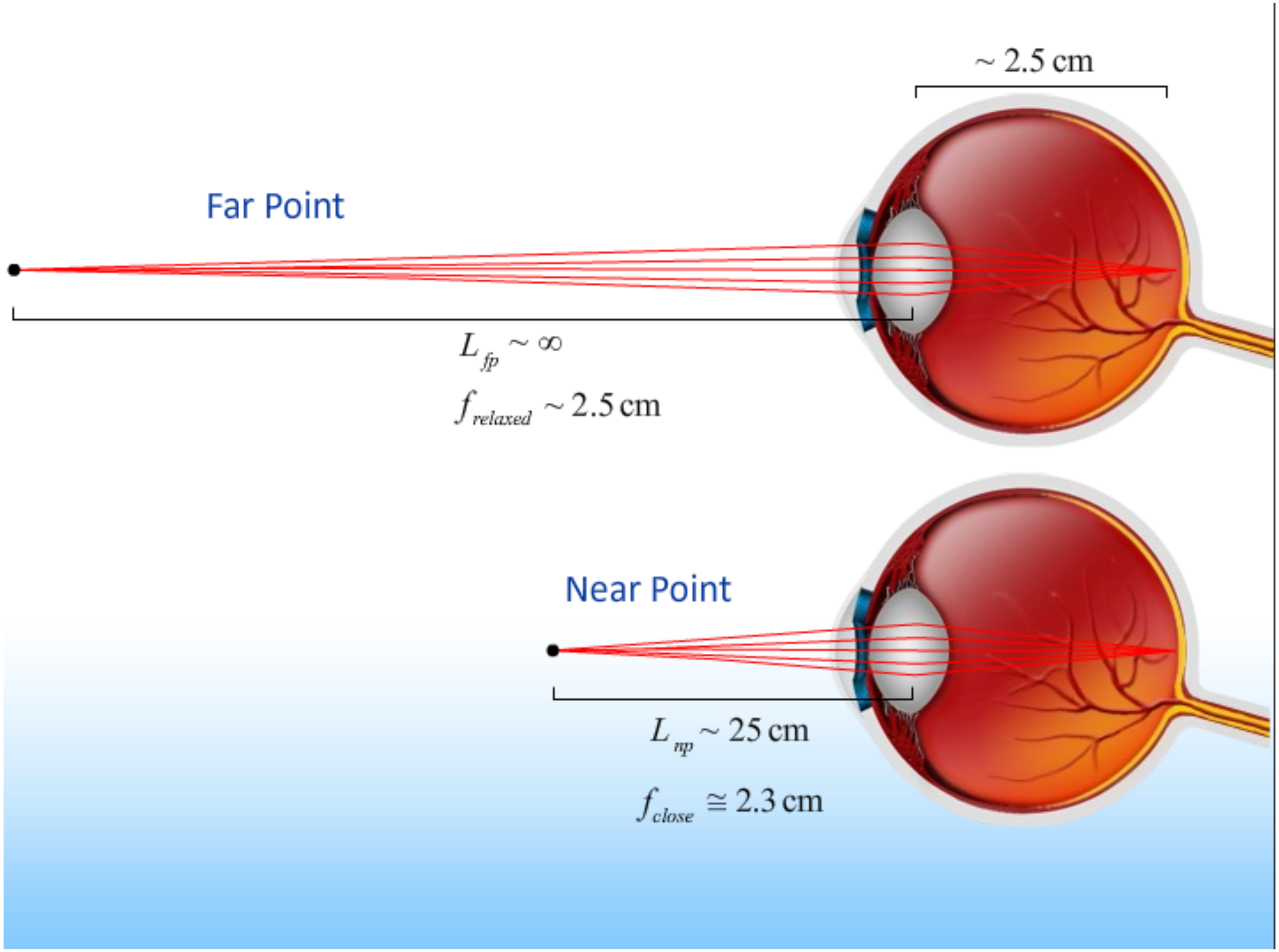


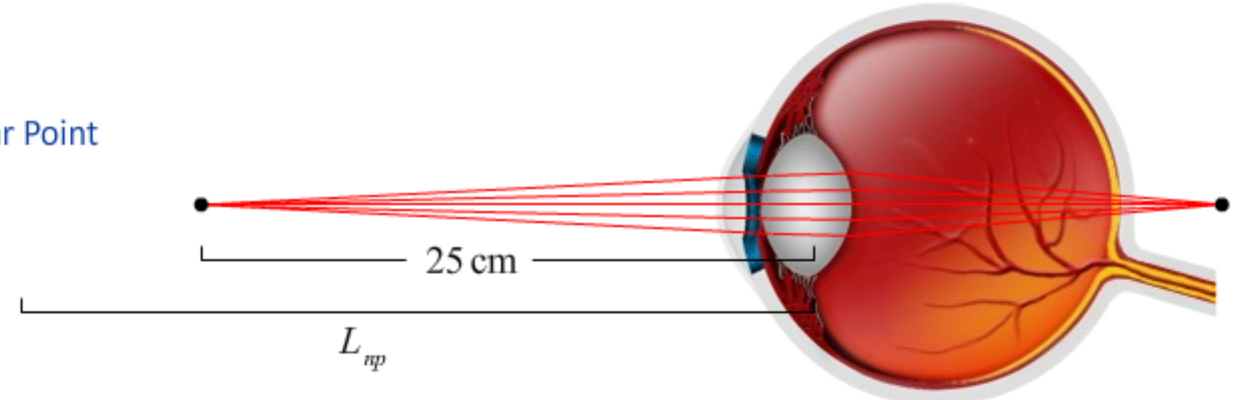
Image from first lens
Becomes object for second lens

Normal Eye

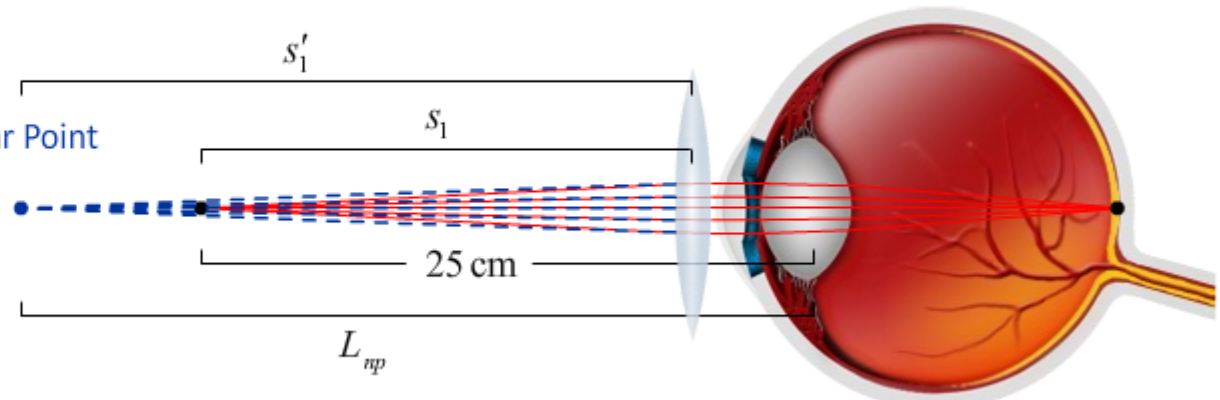

~ 2.5 cm
Far Point
$L_{fp} \sim \infty$
$f_{relaxed} \sim 2.5\,\text{cm}$
Near Point
$L_{np} \sim 25\,\text{cm}$
$f_{close} \cong 2.3\,\text{cm}$

Far-Sighted

actual Near Point

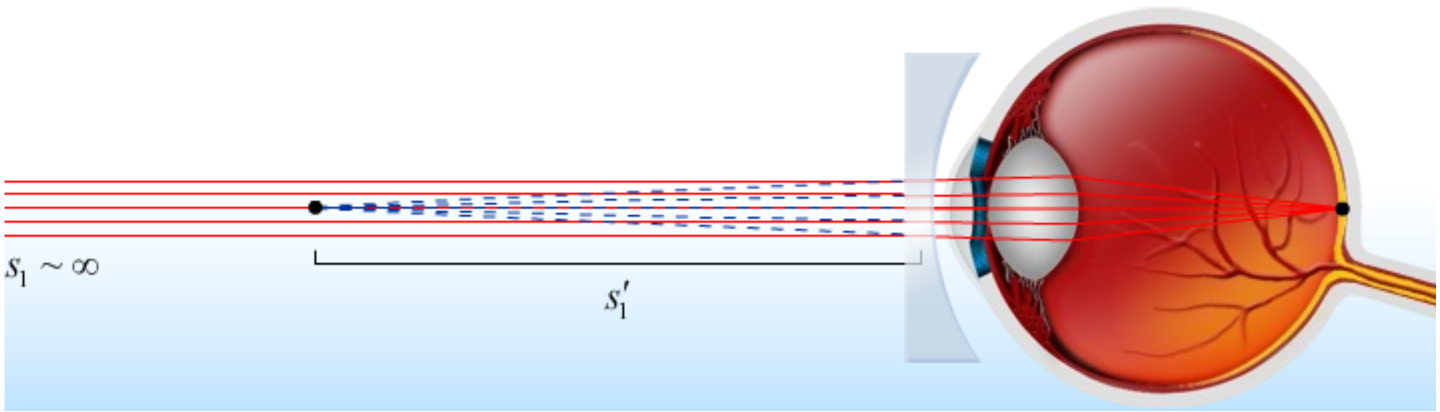


actual Near Point



Converging Lens creates virtual image at person's actual near point

Near-Sighted



Fix with diverging lens that creates virtual image at far point.

Question

"Are contact lenses just tiny lenses? Or are they something different. The size of the lenses can't really change too much for different perscriptions"

Yes!

The size variations are actually very small

CheckPoint 2

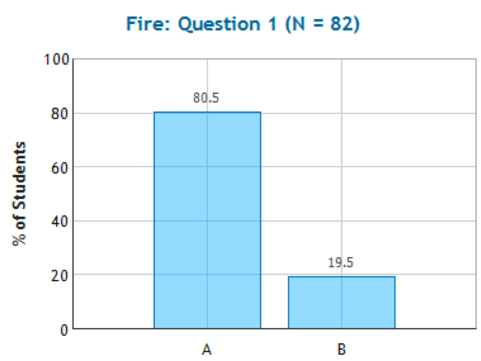
2) Two people who wear glasses are camping. One of them is nearsighted and the oth

Which person's glasses will be useful in starting a fire with the sun's rays?

A ◯ the farsighted person's glasses

B ◯ the nearsighted person's glasses

Farsighted = Converging Lens
Only Converging Lens can produce a real image!

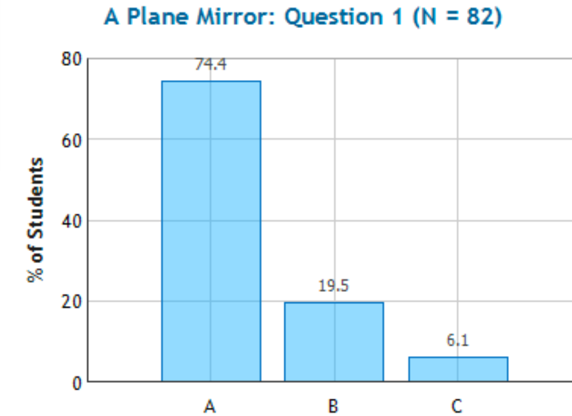


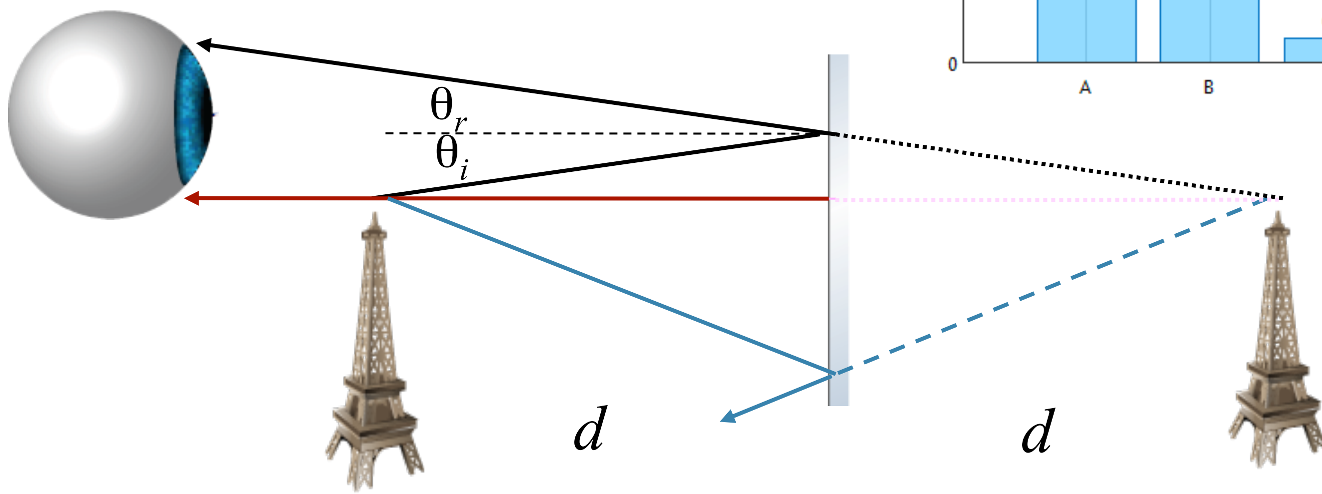
CheckPoint 4

4) A person with normal vision (near point 28cm) is standing in front of a plane mirror.

What is the closest distance to the mirror the person can stand and still see himself in focus?

A ◯ 14cm
B ◯ 28cm
C ◯ 56cm

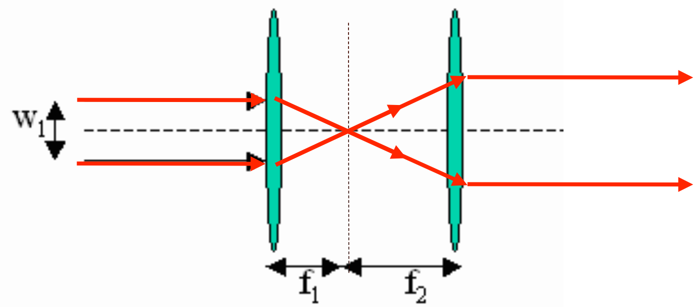




The image is formed an equal distance behind the mirror
Therefore, if you stand a distance = ½ of your near point, the distance to the image will be the near point distance.

CheckPoint 6

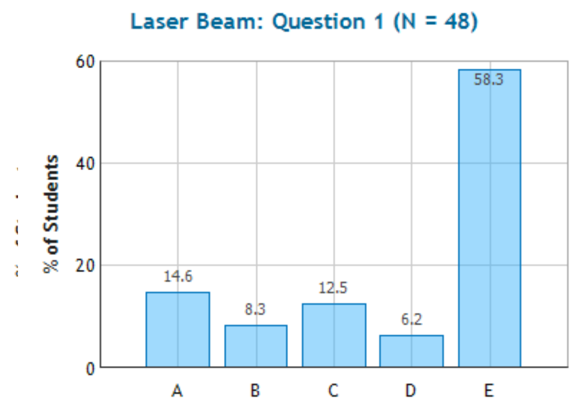
6) A parallel laser beam of width w_1 is incident on a two lens system as shown below.



Each lens is converging. The second lens has a larger focal length than the first ($f_2 > f_1$).

What does the beam look like when it emerges from the second lens?

A ○ The beam is converging
B ○ The beam is diverging
C ○ The beam is parallel to the axis with a width < w_1
D ○ The beam is parallel to the axis with a width = w_1
E ○ The beam is parallel to the axis with a width > w_1



1. Parallel rays are transmitted and pass through focal point (f_1)
2. Those rays also pass through focal point of second lens (f_2) and therefore are transmitted parallel to the axis.
3. $f_2 > f_1$ implies that the width > w_1

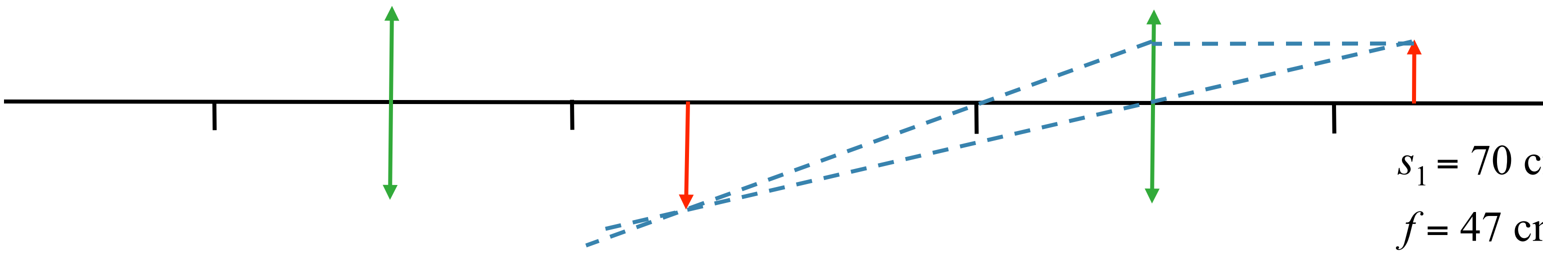
"Do we get the formulas for microscope, telescope, etc. on the final?"

Note

But you can write them on the formula sheet.

Multiple Lenses Exercises

Two converging lenses are set up as shown. The focal length of each lens is 47 cm. The object is a light bulb located 70 cm in front of the first lens.



What is the nature of the image from the first lens alone?

A) REAL UPRIGHT

B) REAL INVERTED

C) VIRTUAL UPRIGHT

D) VIRTUAL INVERTED

EQUATIONS

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

$s > f \rightarrow s' > 0 \rightarrow$ real image

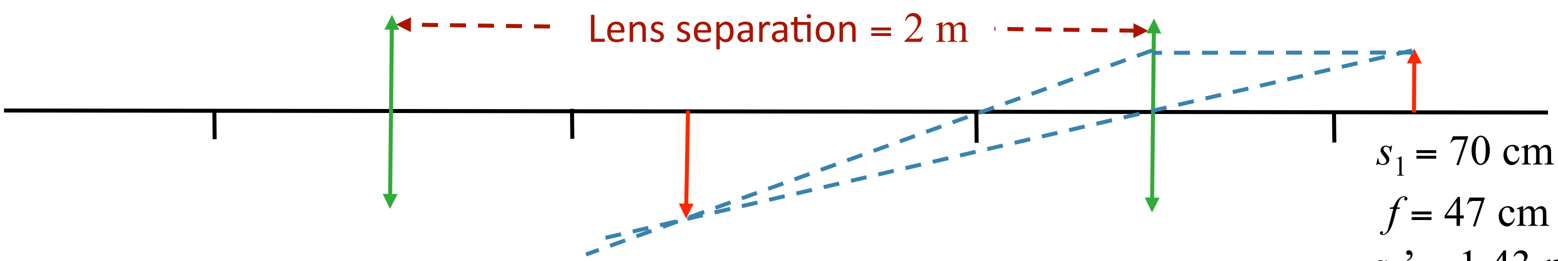
$$M = -\frac{S'}{S} \rightarrow M < 0 \rightarrow \text{inverted image}$$

PICTURES

Draw Rays as above.

Multiple Lenses Exercises

Two converging lenses are set up as shown. The focal length of each lens is 47 cm. The object is a light bulb located 70 cm in front of the first lens.



$s_1 = 70$ cm

$f = 47$ cm

$s_1' = 1.43$ m

What is the object distance s_2 for lens 2?

A) $s_2 = -1.43$ m B) $s_2 = +1.43$ m C) $s_2 = -0.57$ m D) $s_2 = +0.57$ m E) $s_2 = +2.7$ m

THE OBJECT FOR THE SECOND LENS IS THE IMAGE OF THE FIRST LENS

~~$s_2 = -0.57$~~

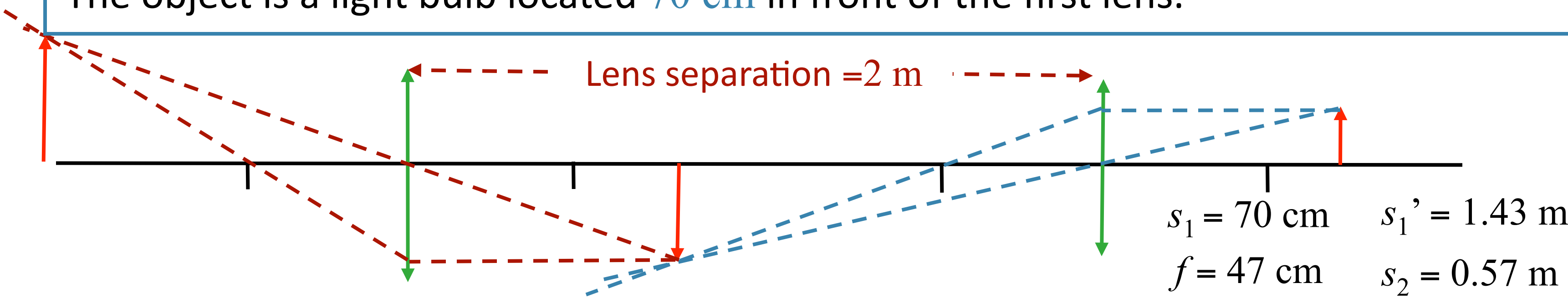
OR

$s_2 = +0.57$

Image of first lens is a REAL object for the second lens

Multiple Lenses Exercises

Two converging lenses are set up as shown. The focal length of each lens is 47 cm. The object is a light bulb located 70 cm in front of the first lens.



What is the nature of the FINAL image in terms of the ORIGINAL object?

A) REAL UPRIGHT

B) REAL INVERTED

C) VIRTUAL UPRIGHT

D) VIRTUAL INVERTED

EQUATIONS

$$S_2' = \frac{fs_2}{s_2 - f}$$

$s_2 > f$ → $s_2' > 0$ → real image

$$M_2 = -\frac{S_2'}{S_2}$$

→ $M_2 < 0$ → $M = M_1 M_2 > 0$

→ upright image

PICTURES

Draw Rays as above.

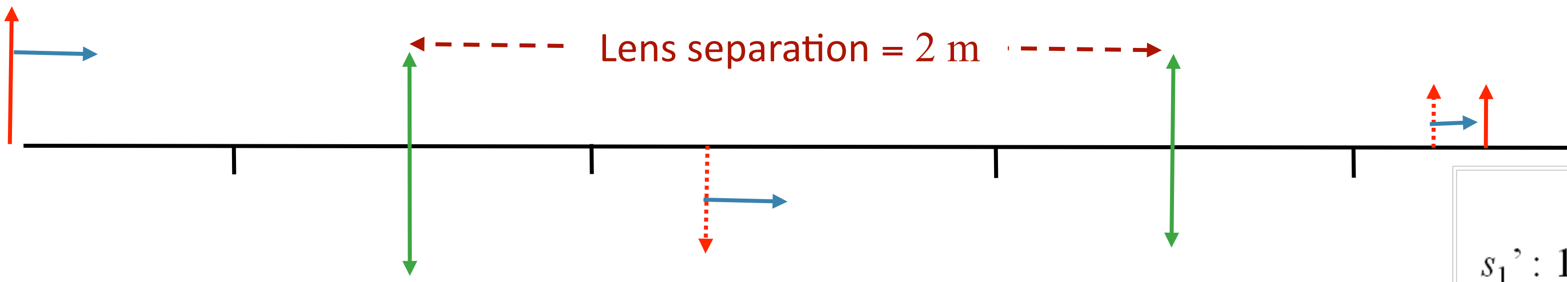
RESULTS

$s_2' = 2.69$ m

$M = 9.6$

Multiple Lenses Exercises

Suppose we increase the initial object distance to 74 cm.



$s_1 = 74$ cm
$f = 47$ cm

RESULTS

s_1' : 1.43 m ✸ 1.29 m

s_2' : 2.69 m ✸ 1.38 m

How does the L, the distance to the final image, change?

A) L increases

B) L decreases

C) L remains the same

Step through images, one at a time

WORDS

Increasing s_1 will decrease s_1' (moving closer to focal point would increase the image distance)

Decreasing s_1' will increase s_2 Increasing s_2 will decrease s_2'

EQUATIONS

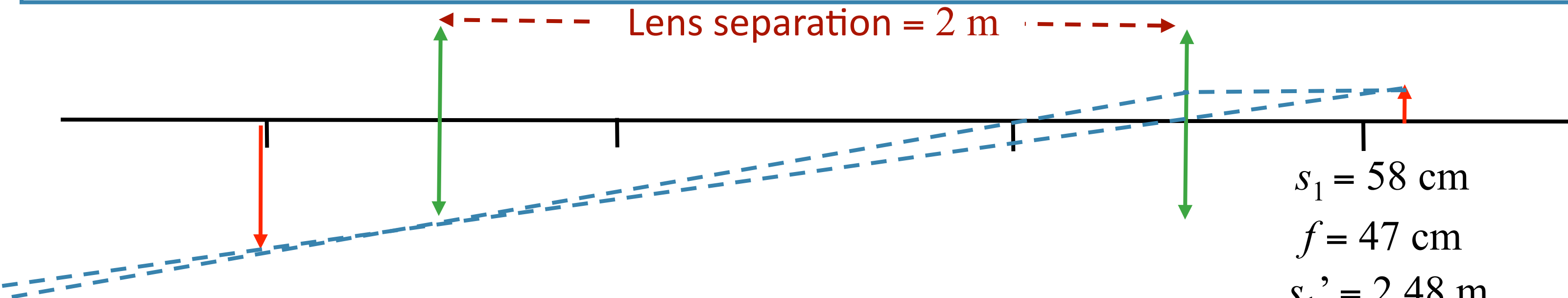
$$\frac{1}{S_1'} = \frac{1}{f} - \frac{1}{S_1} \rightarrow \frac{1}{S_1'} \text{ increases}$$

$$S_2 = 2m - s_1' \rightarrow s_2 \text{ increases}$$

$$\frac{1}{s_2'} = \frac{1}{f} - \frac{1}{s_2} \rightarrow \frac{1}{S_2'} \text{ increases}$$

Multiple Lenses Exercises

Suppose we now decrease the initial object distance to 58 cm. Applying the lens equation, we find $s_1' = 2.48\text{m}$



What is the object distance s_2 for lens 2?

A) $s_2 = -0.48$ m B) $s_2 = +0.48$ m C) $s_2 = -2.48$ m D) $s_2 = +2.48$ m E) $s_2 = +2.58$ m

THE OBJECT FOR THE SECOND LENS IS THE IMAGE OF THE FIRST LENS

$s_2 = -0.48$

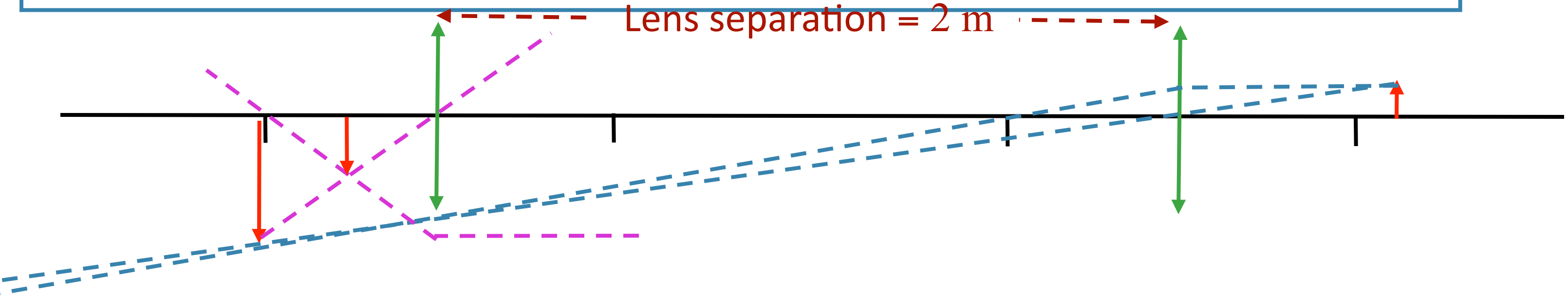
OR

~~$s_2 = +0.48$~~

Image of first lens is a VIRTUAL object for the second lens

Multiple Lenses Exercises

Suppose we now decrease the initial object distance to 58 cm. Applying the lens equation, we find $s_1' = 2.48\text{m}$



$s_1 = 58\ \text{cm}$

$f = 47\ \text{cm}$

$s_1' = 2.48\ \text{m}$

$s_2 = -0.48\ \text{m}$

What is the nature of the final image in terms of the original object?

A) REAL UPRIGHT

B) REAL INVERTED

C) VIRTUAL UPRIGHT

D) VIRTUAL INVERTED

EQUATIONS

$$S_2' = \frac{fs_2}{s_2 - f}$$

$s_2 < 0$ → $s_2' > 0$ → real image

$$M_2 = -\frac{S_2'}{S_2}$$

→ $M_2 > 0$ → $M = M_1 M_2 < 0$

→ inverted image

PICTURES

Draw Rays as above.

RESULTS

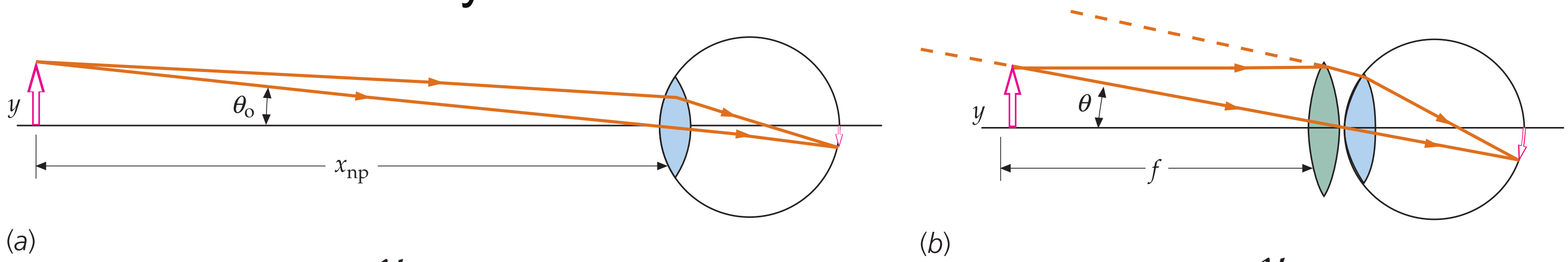
$s_2' = 0.24\ \text{m}$

$M = -2.1$

Magnifying Glass

The Magnifying Glass is just a lens that creates a virtual image!.

"Naked" eye

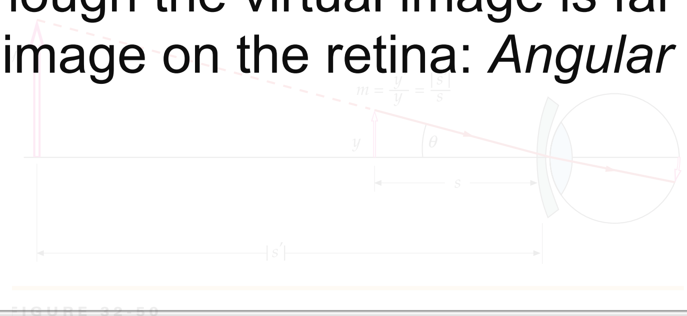


$$\theta_o = \frac{y}{x_{np}}$$

$$\theta = \frac{y}{f}$$

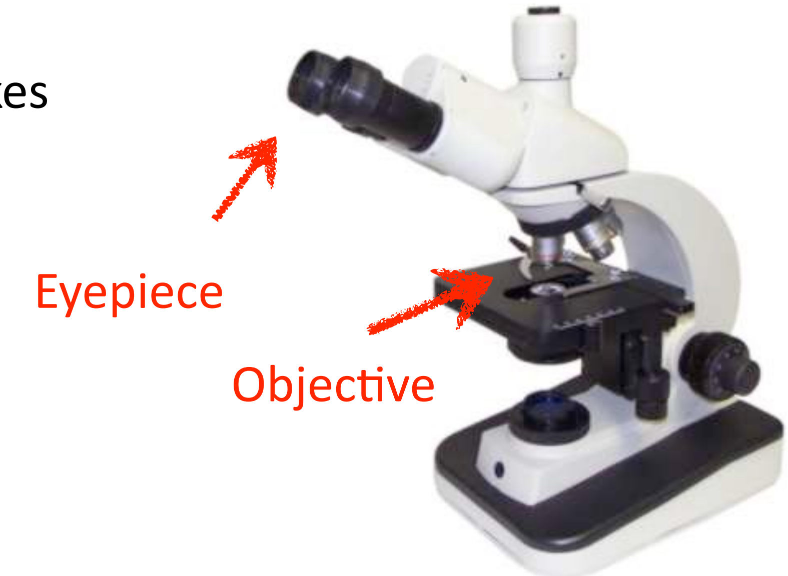
$$M = \frac{\theta}{\theta_o} = \frac{x_{np}}{f}$$

Even though the virtual image is far away, θ is bigger and makes a bigger image on the retina: *Angular magnification*



The Compound Microscope

A combination of two converging lens makes a Microscope.

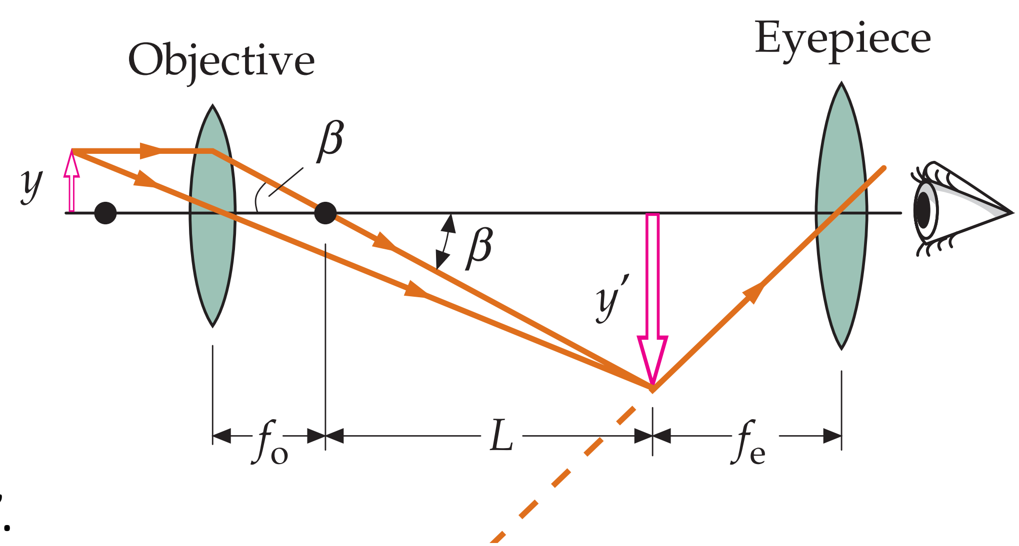


The first lens is the Objective lens, the second one called Eyepiece.

$$m_o = \frac{y'}{y} = -\frac{L}{f_o}$$

$$M_e = \frac{x_{np}}{f_e}$$

$$M = m_o M_e = -\frac{L}{f_o}\frac{x_{np}}{f_e}$$



L is called the "tube length".

In the prefecture L is shown as the distance between the lenses. The formula for M was a little different.

How to Make a Big Telescope Mirror

Melt it & Spin it.

Telescope

Like microscope, a Keplerian telescope is also made of two converging lenses.

$$\tan\theta_o = \frac{y}{s} = -\frac{y'}{f_o} \approx \theta_o$$

Both object and image in telescope are at infinity.

$$\tan\theta_e = \frac{y'}{f_e} \approx \theta_e$$

$$M = \frac{\theta_e}{\theta_o} = -\frac{f_o}{f_e}$$