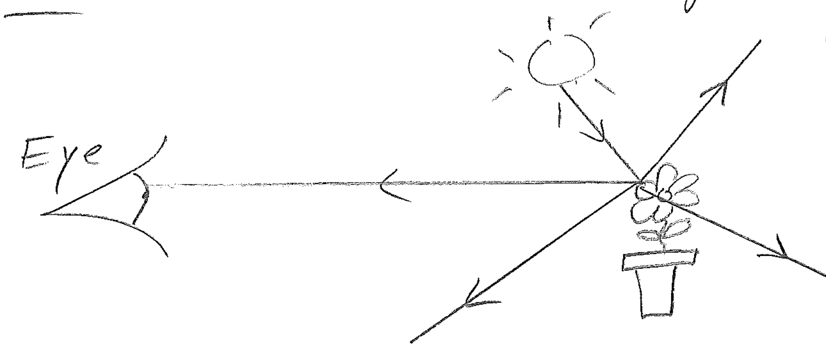
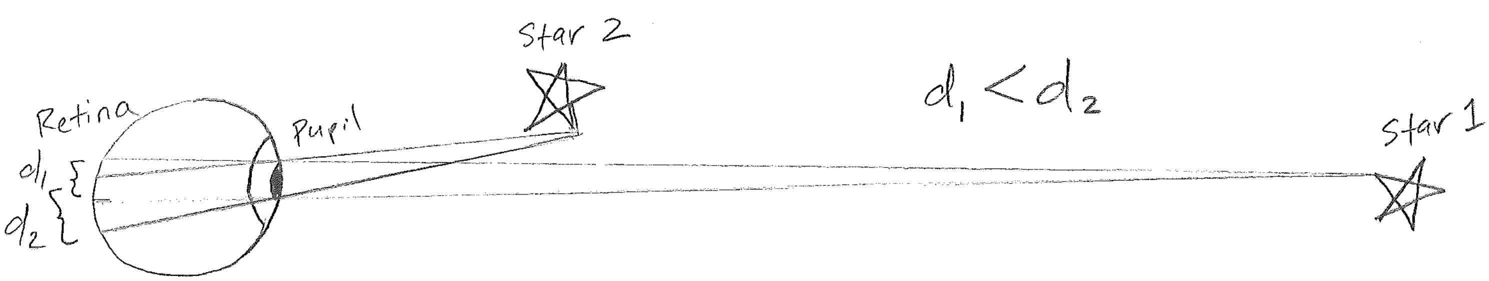
Geometric Optics

Light is reflected many different directions. Some of the reflected light rays reach your eyes.

Most rays do not reach your eyes.



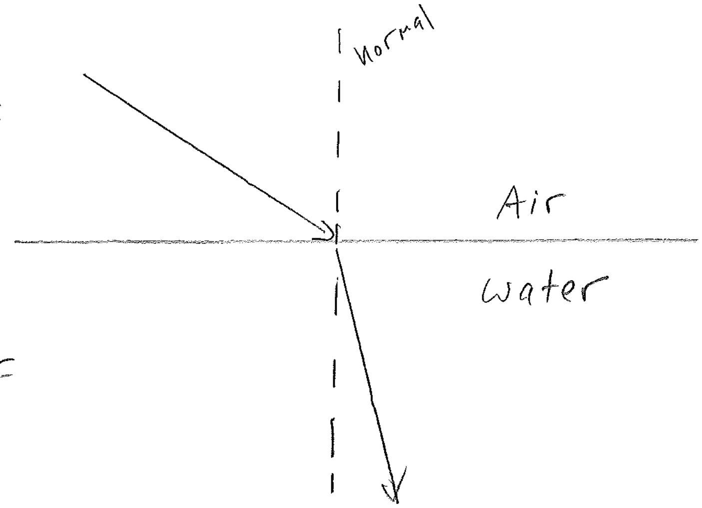


Objects closer to your eye result in reflected rays that diverge more compared to reflected rays from objects further away. Objects closer to your eye take up more space on your retina and your brain interprets this information appropriately. When objects are very far away, light rays from the objects are essentially parallel.

Mirror Types: Plane Concave Convex

Refraction - bending of light from one medium to another

$c = \lambda \cdot f$

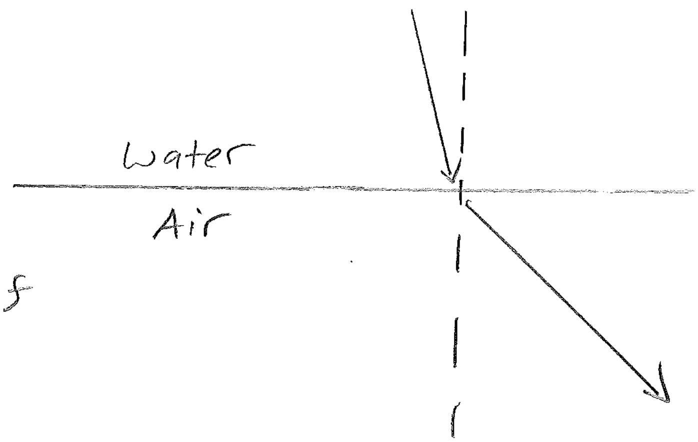


Bends toward the normal

$c = \lambda \cdot f$
↓ ↓

Light travels slower in more dense materials.

The frequency of light stays the same but wavelength decreases.



Bends away from the normal.

$c = \lambda \cdot f$
↑ ↑

Water is a slower medium compared to air.

When light enters a slower medium it bends toward the normal.

When light enters a faster medium it bends away from the normal.

Index of refraction is a number that indicates the ratio of the speed of light in a vacuum to that of a second medium of greater density. $n = \frac{c}{v}$

The greater the index of refraction, the slower the medium.

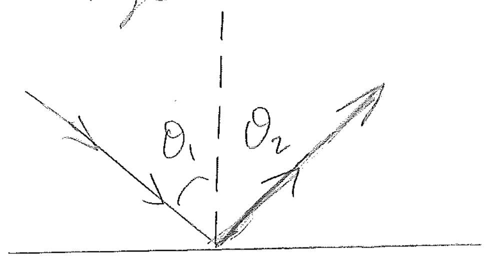
Larger index of refraction leads to a smaller focal length.

Geometric Optics – Mirrors

How long must a mirror be to see your reflection?

a) full length b.) 1/2 length c.) 1/4 length d.) 1/8 length

Law of Reflection – the angle of incidence is equal to the angle of reflection. $\theta_1 = \theta_2$



θ_1 = angle of incidence

θ_2 = angle of reflection

Measure angles from the normal.

* Curved surfaces have normal lines.

Geometric Optics Terminology for Mirrors

d_i The distance between the mirror and the image.

d_o The distance between the mirror and the object.

h_i The height of the image

h_o The height of the object.

* Real images have a positive d_i while virtual images have a negative d_i.

M is Magnification. The size of the image compared to the object.

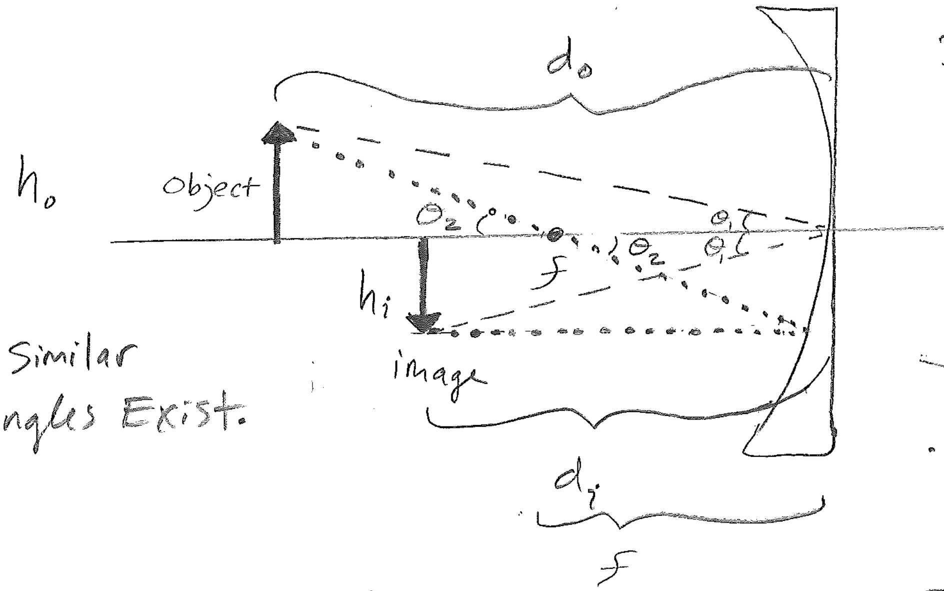
* If $M > 1$ the image is bigger than the object. If $M < 1$ the image is smaller than the object. If $M = 1$ they are the same size.

Formulas

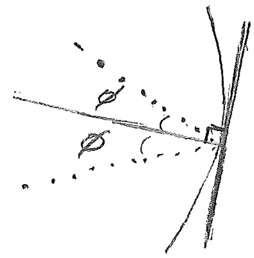
$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \qquad M = \frac{-d_i}{d_o} \text{ or } \frac{h_i}{h_o} \qquad f = \frac{1}{2} R_{curvature}$$

real images occur when rays converge, virtual images occur when rays appear to diverge.

Derivation of the Mirror Equation



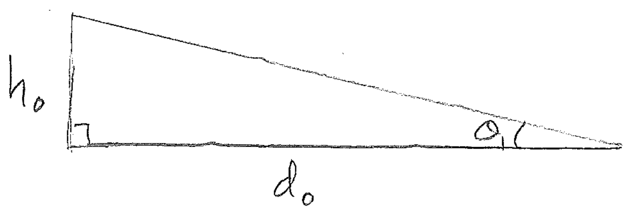
It is possible to have a normal line to a curved surface:



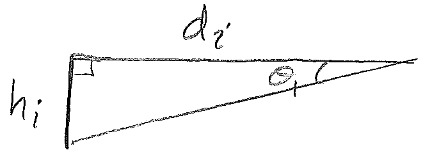
Law of Reflection still applies.

Many Similar Triangles Exist.

Measure from the back of the mirror for f, d_i and d_o.



$$\tan\theta_1 = \frac{opp}{adj}$$



$$\tan\theta = \frac{h_i}{d_i} = \frac{h_o}{d_o}$$

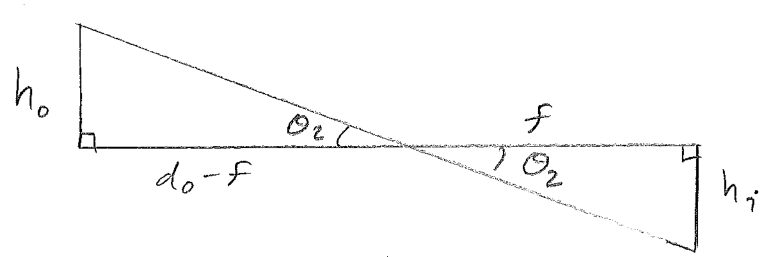
$$\frac{h_o}{h_i} = \frac{d_o}{d_i}$$

$h_i = h_o\left(\frac{d_i}{d_o}\right)$ but h_i is flipped over

so $$h_i = -h_o\left(\frac{d_i}{d_o}\right)$$ Magnification Equation

$$\tan\theta_2 = \frac{opp}{adj}$$

$$\tan\theta_2 = \frac{h_o}{d_o - f} = \frac{h_i}{f}$$



$$\frac{h_o}{h_i} = \frac{d_o - f}{f} = \frac{d_o}{d_i}$$

$$\frac{d_o - f}{f} = \frac{d_o}{d_i} \quad \text{or} \quad \frac{d_o}{f} - \left(\frac{f}{f}\right) = \frac{d_o}{d_i}$$

$$\frac{d_o}{f} - 1 = \frac{d_o}{d_i}$$

$$\frac{1}{d_o}\left(\frac{d_o}{f} - 1\right) = \left(\frac{d_o}{d_i}\right)\frac{1}{d_o}$$

$$\frac{1}{f} - \frac{1}{d_o} = \frac{1}{d_i}$$

$$+\frac{1}{d_o} \qquad +\frac{1}{d_o}$$

$$\boxed{\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}}$$

Mirror Equation

Focal length is positive for concave mirrors.

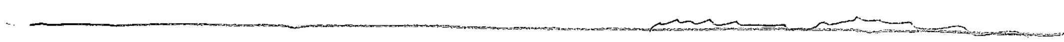
Focal length is negative for convex mirrors.

image distances are positive if they are on the same side of the mirror as your eye.

image distances are negative if they are behind the mirror.

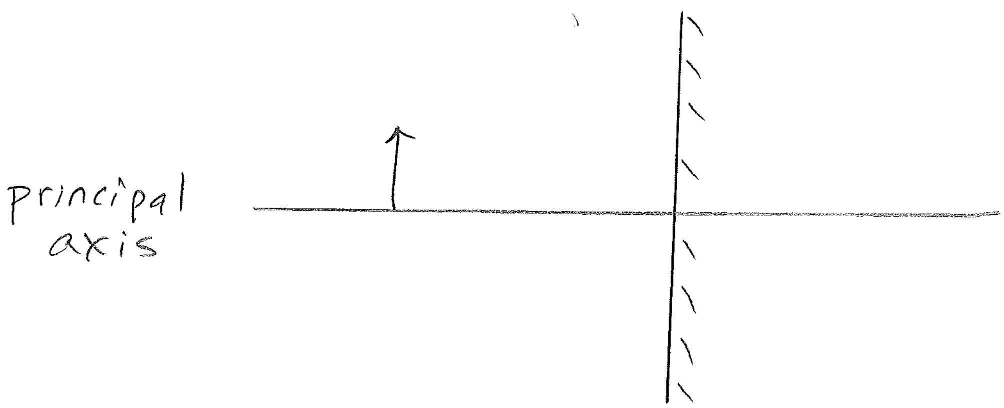
<u>But</u> there are other sign conventions.

Ray Model & Geometric Optics – Mirrors



Specular reflection — diffuse reflection

Plane Mirror

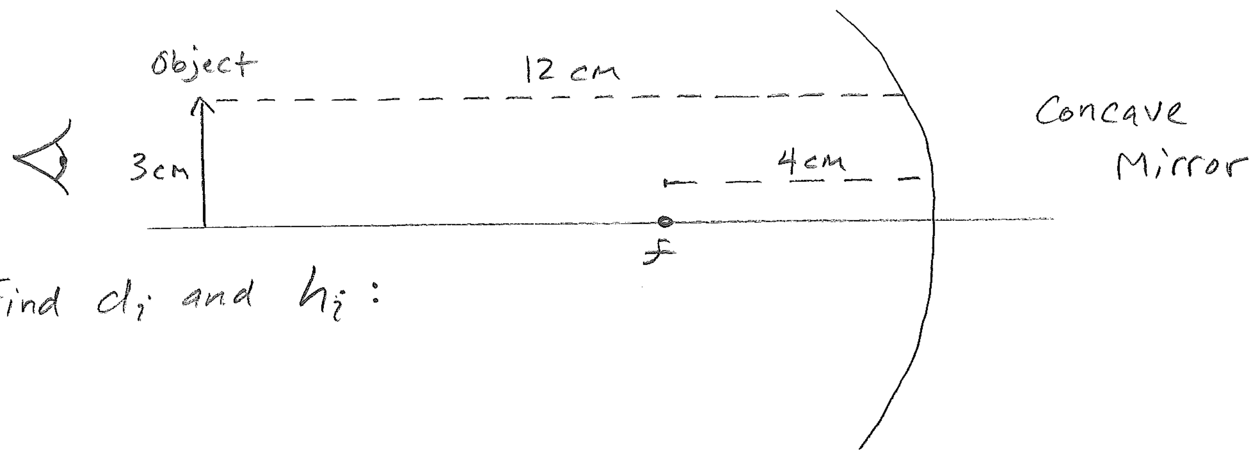


Overview of Mirrors & Lenses

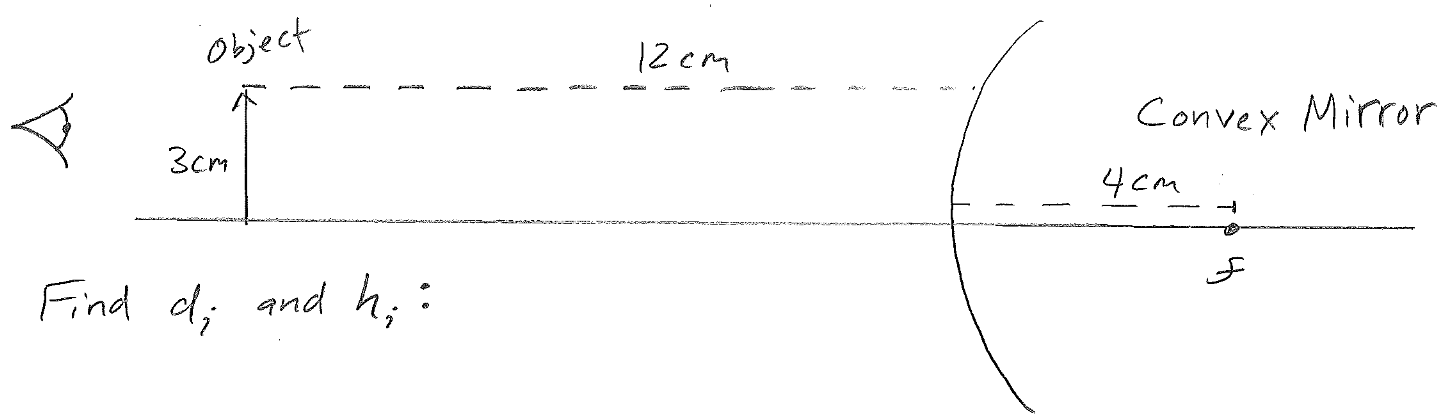
Convex Lens | Concave Mirror | Concave Lens | Convex Mirror

Convex Lens	Concave Mirror	Concave Lens	Convex Mirror
Upside down image	Upside down image	Right side up image	Right side up Image
Converging Rays	Converging rays	Diverging Rays	Dievererging Rays

Mirror Equation Example problems



Find d_i and h_i:



Find d_i and h_i:

Convex mirrors

- The focal point is negative.
- Only one kind of image formed.
- The image is always virtual, upright and smaller.

Concave Mirrors

- The focal point is positive.
- Several kinds of images can be formed:

Upright, enlarged, virtual.... d_o between f and mirror.

Inverted, enlarged, real .... d_o between f and $2f$.

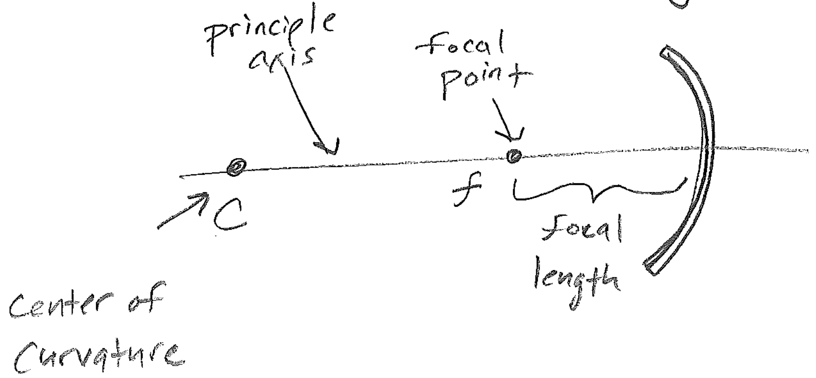
Inverted, same size, real.... d_o at $2f$

Inverted, smaller, real.... d_o beyond $2f$

No image at all.... d_o at f

Notes

Concave Mirror (Converging Mirror)

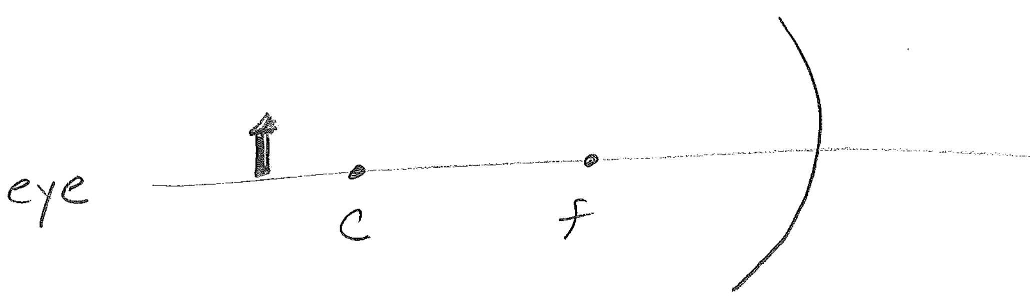


$f = \frac{1}{2} C$

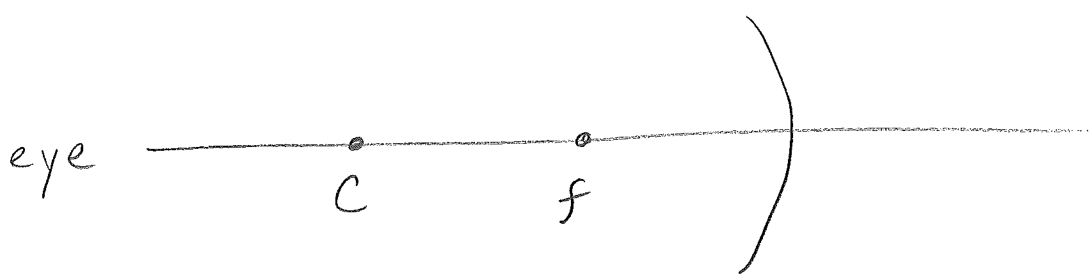
Image Descriptors: Location
Size
Orientation
Type

Rules: Parallel f, f parallel.
Parallel rays do not converge to form an image.
Diverging rays intersect to form a virtual image.

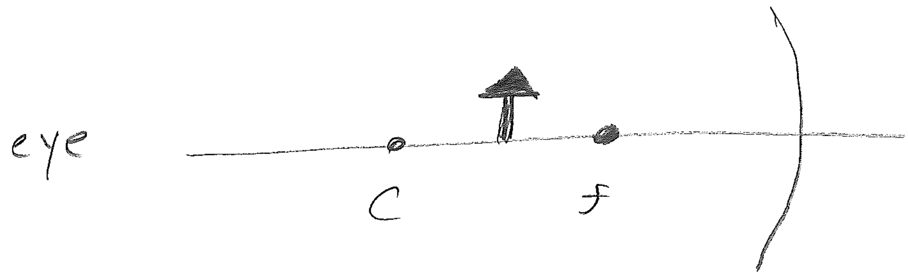
1. $d_o > C$



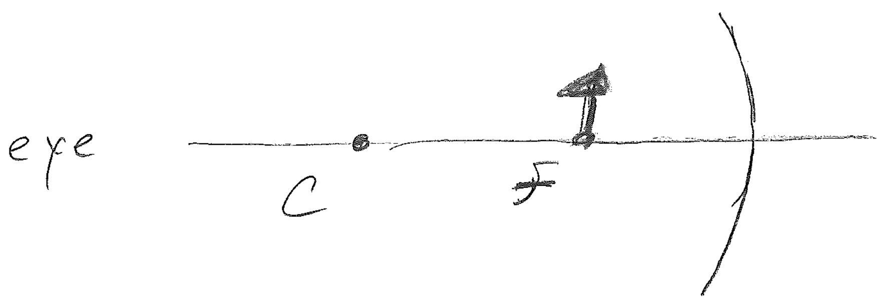
2. $d_o = C$



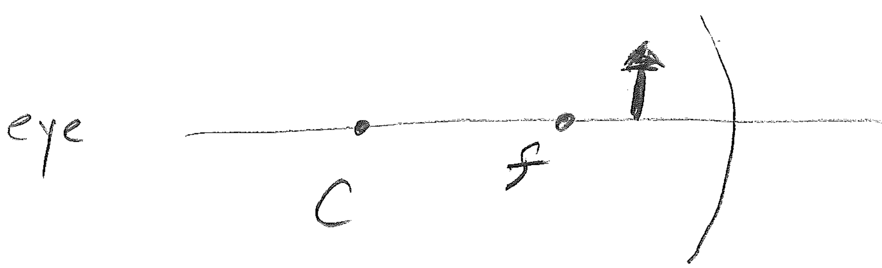
3. d_o between C & f



4. $d_o = f$



5. $d_o < f$



Lenses: Vocab (similar to mirrors)

h_i : image height h_o : object height

d_i : distance for the lens to the image

d_o : distance for the lens to the object

f : distance from lens to the focal point

- Negative for concave / diverging lenses
- Positive for convex / converging lenses

M: Magnification. Image size compared to object size.

Virtual image: lines don't intersect, can't be projected on a screen

Real image: lines intersect, can be projected on a screen

Same formulas as mirrors:

Thin Lens Equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$|M| = \left|\frac{-d_i}{d_o}\right| = \frac{h_i}{h_o}$$

Magnification Equation

Geometric optics of lenses.

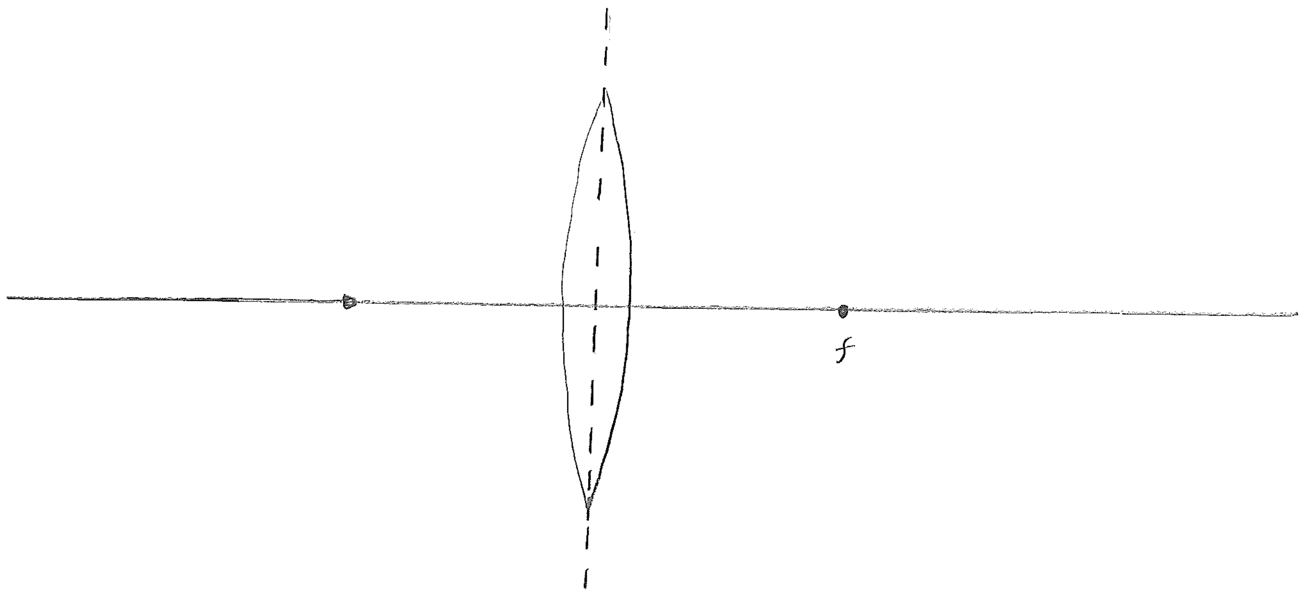
How to draw ray diagrams

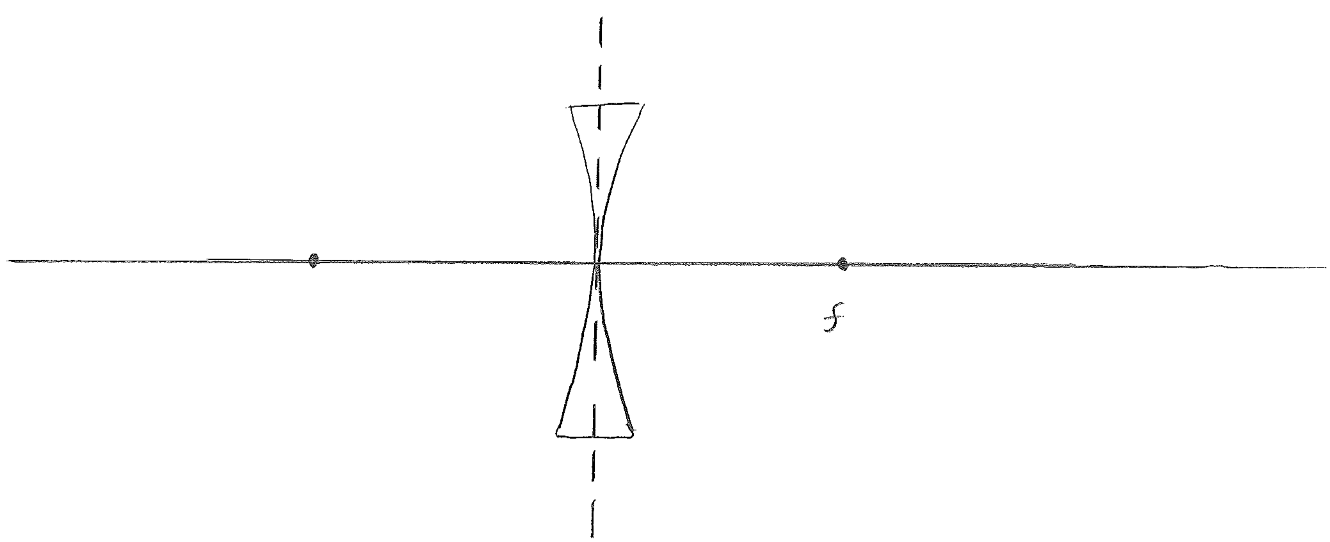
Step 1: Draw a line parallel to the principle axis. It goes through the lens it either converges to the focus or diverges from the focus.

Step 2: Draw a line to the other focus, when it goes through the lens it will be parallel to the priciple axis.

Step 3: Draw a line to where the principle axis meets the lens (optical center). The line passes directly through.

Thin Lens Equation Problem Solving





Magnifying Lens Problem & Thin Lens Problem

When a lens is held 10 cm from paper, the image of words on paper appears to be upright and magnified 2 times. Find

a.) the location of the image

b.) the type of lens used

c.) the focal length of the lens

An object 50 cm in front of a certain lens is imaged 20 cm in front of the lens (on the same side as the object).

a.) what type of lens is this and f=?

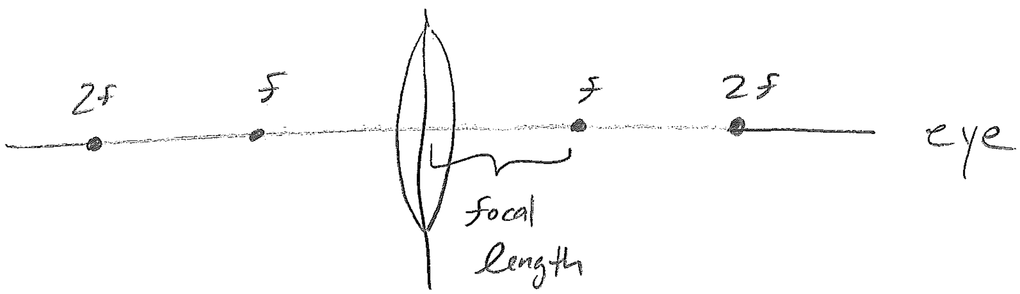
b.) Is the image real or virtual?

c.) What is the magnification of the image?

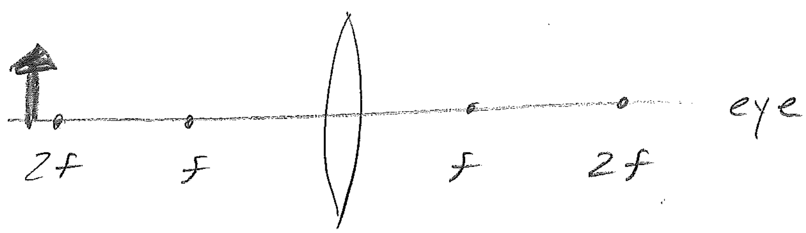
d.) If the object is 10 cm high, what is the height of the image?

Notes

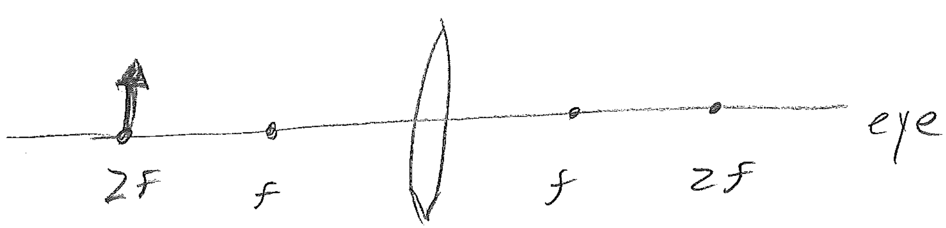
Convex Lens (Converging Lens)



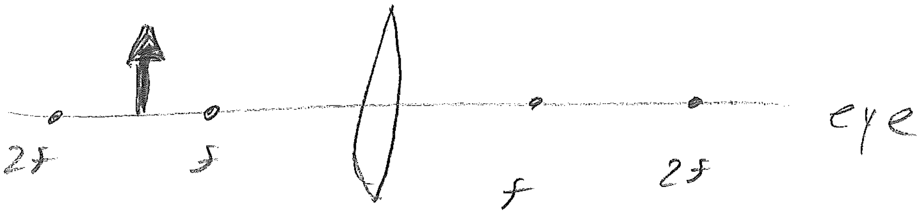
1. $d_o > 2f$



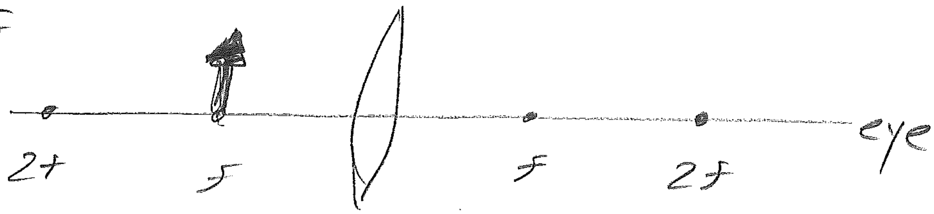
2. $d_o = 2f$



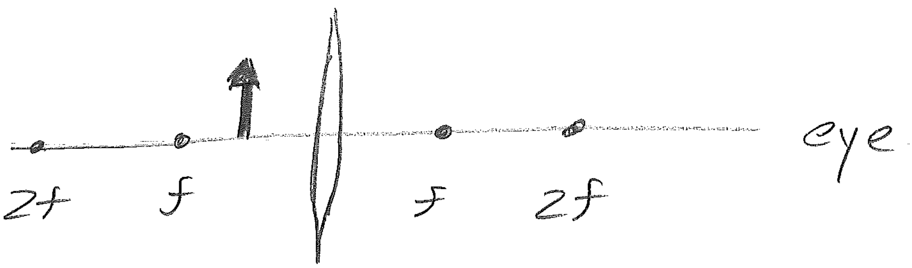
3. d_o between $2f$ & f



4. $d_o = f$



5. $d_o < f$

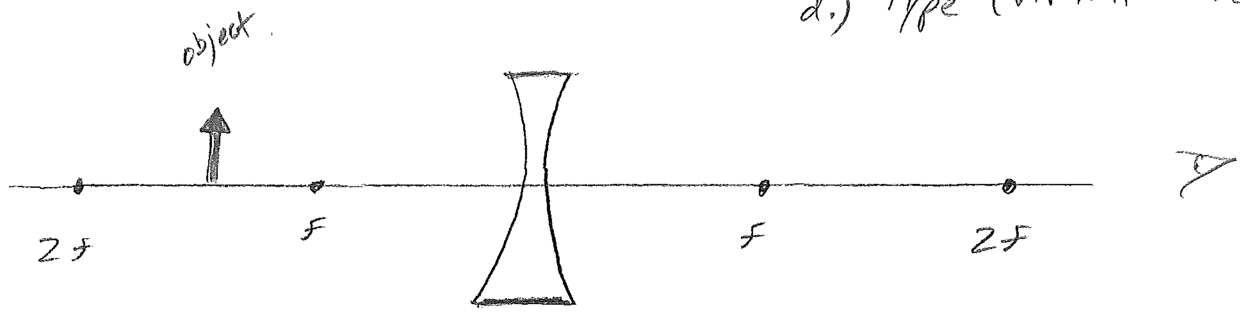


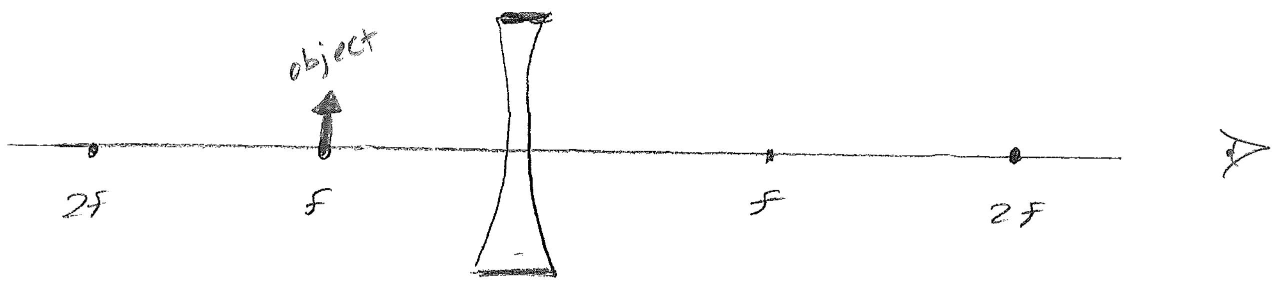
Ray Diagrams for Converging Lenses

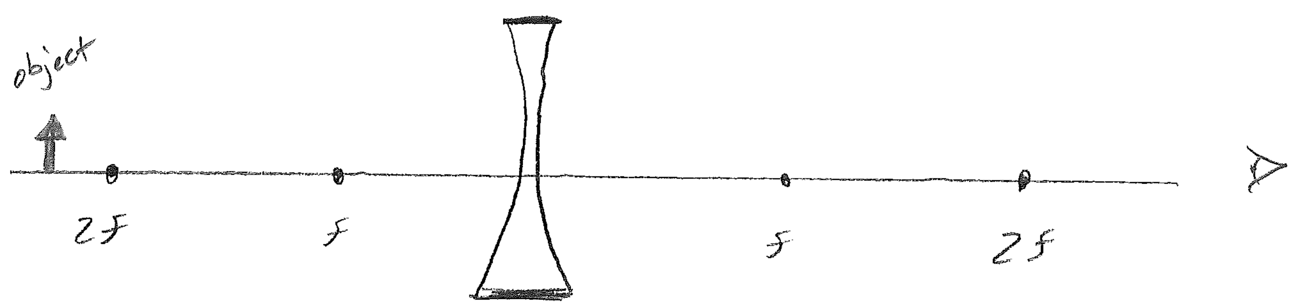
Ray Diagrams for Diverging Lenses

Concave Lens (Diverging Lens)

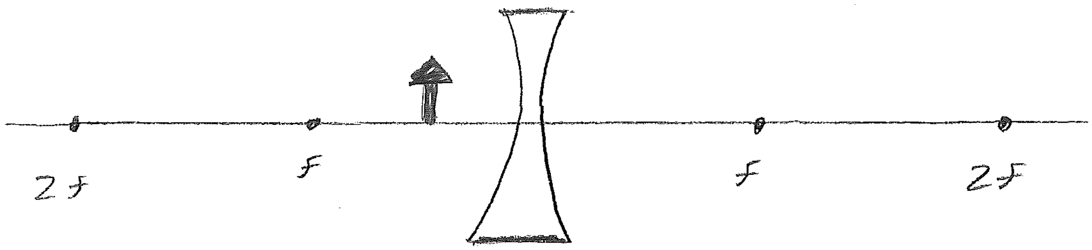
Determine the image's :
a.) Location
b.) size
c.) orientation
d.) Type (virtual or real)

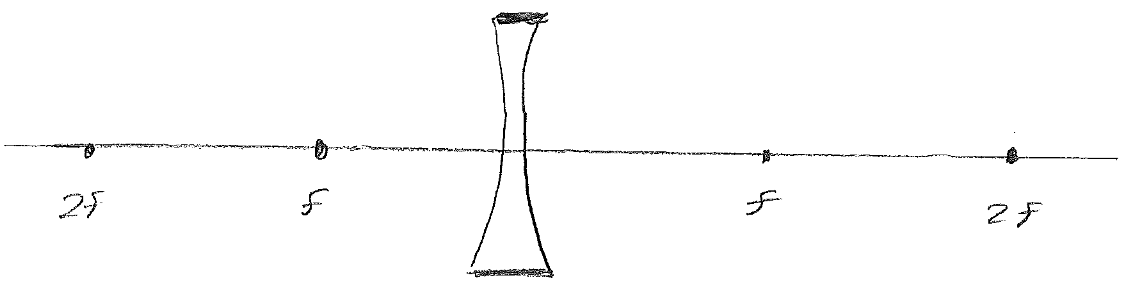


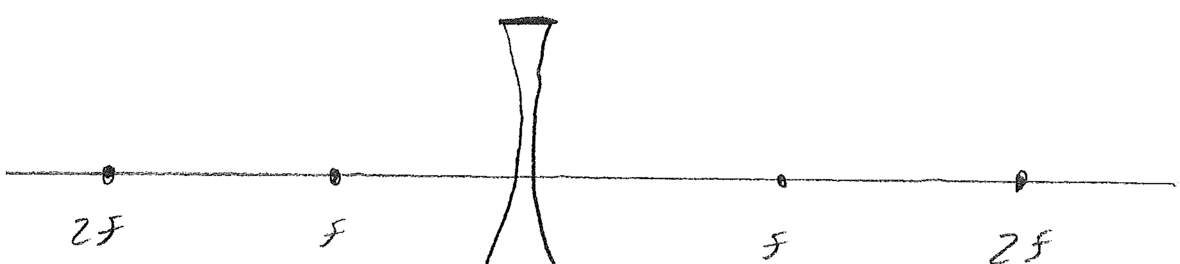




Concave Lens (Diverging Lens)

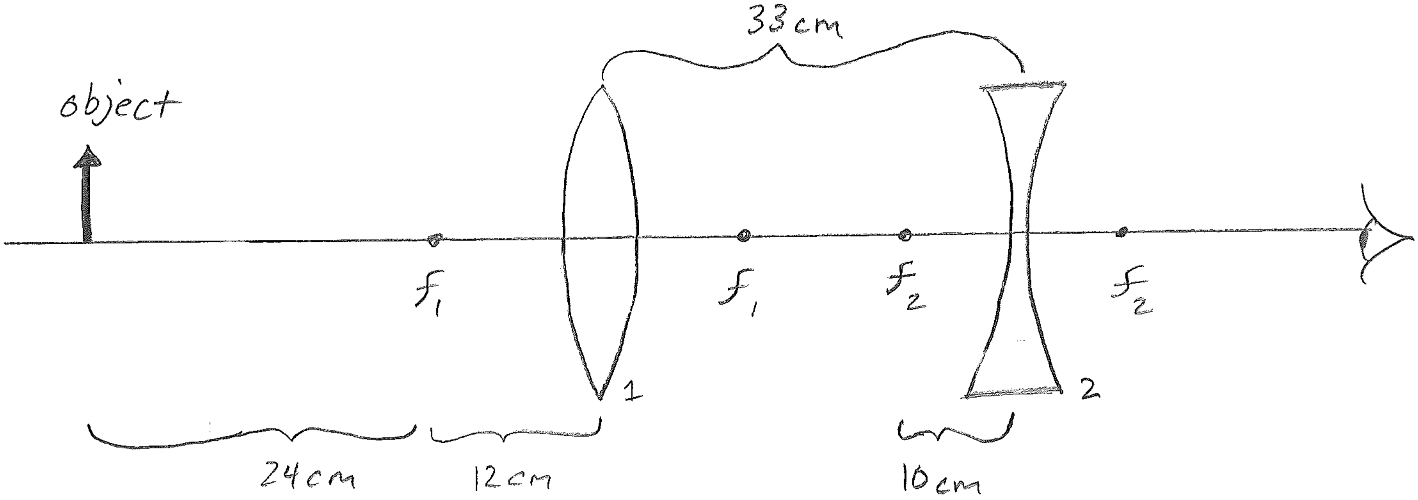




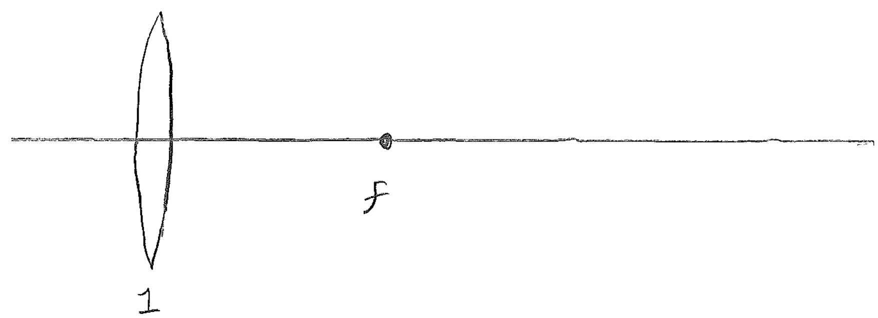


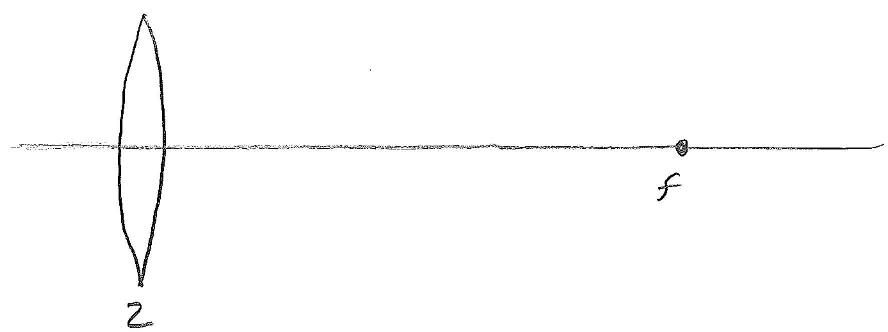
Multiple Lens System

What image does your eye see?



Which lens has more power? 1 2 Same

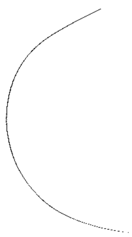




A 8.6 cm tall object is placed 37 cm from a convex lens with a focal length of 10 cm. Where will the image be located, how big will the image be and what will its orientation be?

A 3.5 cm tall object is placed 9.5 cm from a convex lens with focal length of 12 cm. Where will the image be located, how big will the image be and what will its orientation be?

A 5.7 cm tall object is placed 8.2 cm from a concave mirror with focal length of 6 cm. Where will the image be located, how big will the image be and what will its orientation be?



A 4.5 cm tall object is placed 4.0 cm from a concave mirror with focal length of 5.0 cm. Where will the image be located, how big will the image be and what will its orientation be?

A 9.5 cm tall object is placed 11 cm from a <u>convex</u> <u>mirror</u> with a focal length of 6 cm. Where will the image be located, how big will the image be?

A 8.5 cm tall object is placed 11 cm from a <u>concave</u> <u>lens</u> with a focal length of 6 cm. Where will the image be located, how big will the image be and what will its orientation be?

Convex Lens (Converging Lens)

d_o	d_i	orientation	size	type
> 2f	btwn 2f and f	inverted	diminished	real
at 2f	at 2f	inverted	equal	real
btwn 2f and f	> 2f	inverted	magnified	real
at f	no image	no image	no image	no image
< f	behind lens	erect	magnified	virtual

Concave Mirror (Converging Mirror)

d_o	d_i	orientation	size	type
> C	btwn C and f	inverted	diminished	real
at C	at C	inverted	equal	real
btwn C and f	> C	inverted	magnified	real
at f	no image	no image	no image	no image
< f	behind mirror	erect	magnified	virtual