Electromagnetic waves

Changing magnetic field makes changing electric field → this is why changing the flux through a loop induces a current.

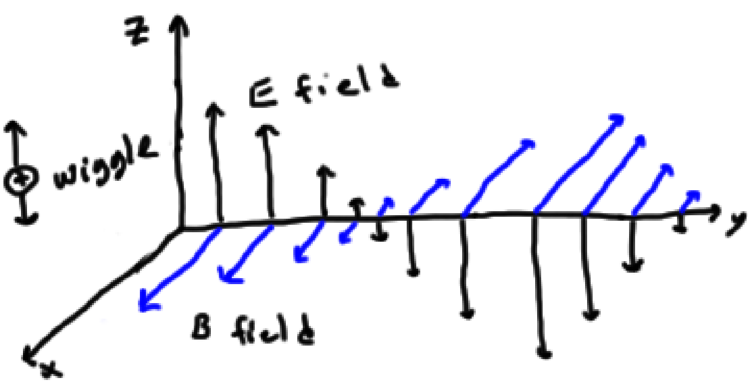
It is also true that changing electric field makes a changing magnetic field.

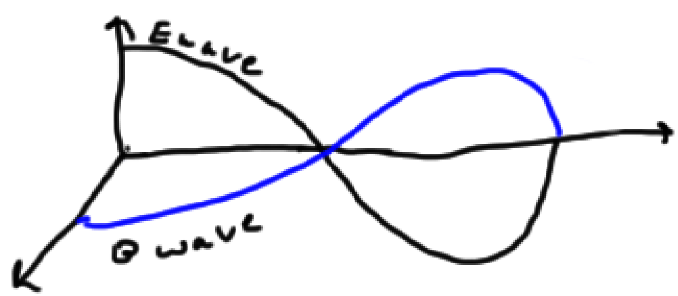
1) ΔE → induces B
2) induced B means a change in B
3) ΔB → induces E
4) induced E means a change in E
5) go back to step 1) → repeat

↑ This cycle propagates itself as an <u>electromagnetic wave</u>!

The light we see is just a particular range of EM waves.

Lets take one charge and wiggle it up and down.



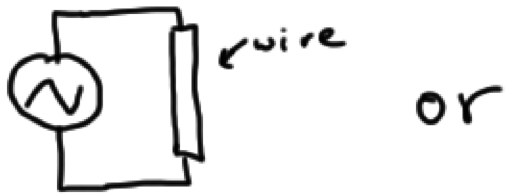


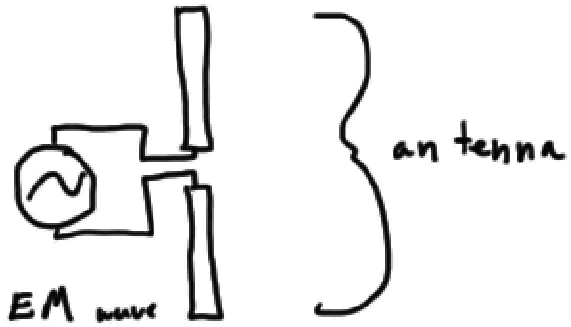
↑ This is a bit different than the field created right next to the charge

right next to charge → near field

far away → far field aka radiation field.

Bigger field with more charges moving.





By moving the charges → produce EM wave

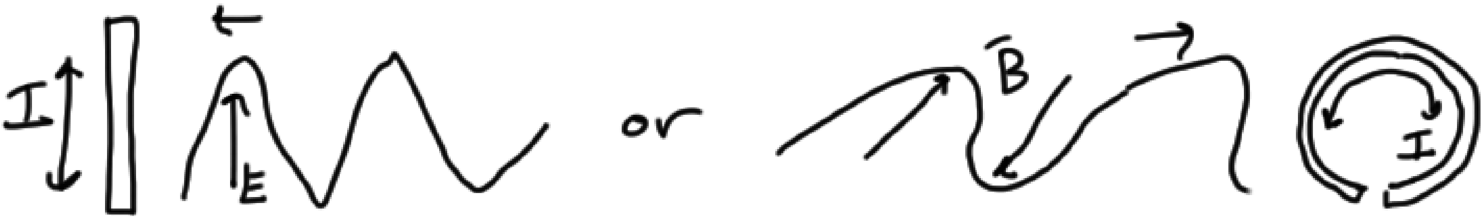
By detecting movement of charges

→ detect "see" EM waves

We can be more specific

"Movemet of charges"

↳ specifically the <u>acceleration</u> of charges



EM waves travel with a speed

$$c = 3.00 \times 10^{8}\ \frac{m}{s}$$

This is true for every frequency of light.

Remember $v = f\lambda$ SO $c = f\lambda$

velocity frequency lambda

Radio waves
Infrared
x-rays
light

all EM waves made by accelerating charges

red	Violet
4×10^{14} Hz	7.9×10^{14}
$\lambda = ?$	$\lambda = ?$

$$c = f\lambda \qquad \lambda_r = \frac{c}{f} = \frac{3.0 \times 10^{8}\ m/s}{4 \times 10^{14}\ Hz \to \frac{1}{s}}$$

$$\lambda = 7.5 \times 10^{-7} m$$

nanometer $\to 10^{-9} m$

$$7.5 \times 10^{-7} m \ \frac{1 nm}{10^{-9} m} = \boxed{750 nm = \lambda_{red}}$$

$$\lambda_b = \frac{3 \times 10^{8}}{7.9 \times 10^{14}} \Rightarrow \boxed{\lambda_b = 380 nm}$$

These are the upper and lower bounds of what the human eye can see.

This allso explains why we don't see any phenomena assosiated with waves in our visual daily lives.

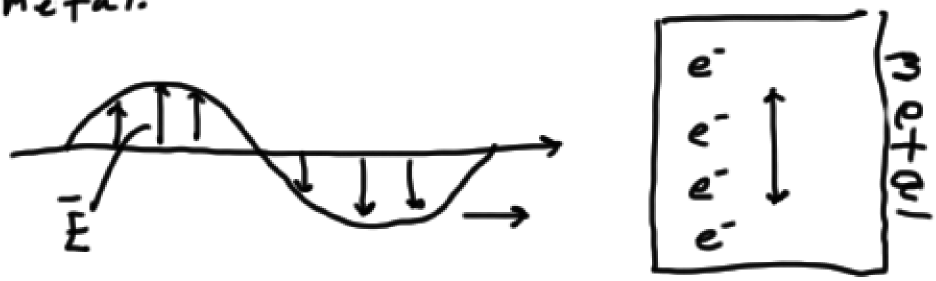
In order to see things like diffraction and interference the length scale has to be that of λ.

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}}$$

Polarization

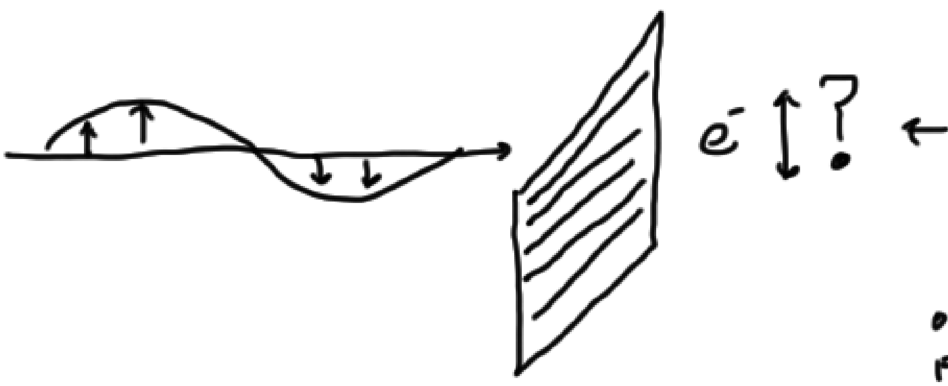
EM wave

Start by asking what happens when EMW hits a metal?



the free charges oskilate trying to follow the electric fild oscilations from the EMW. This causes the light to reflect off the surface but not travel through it.

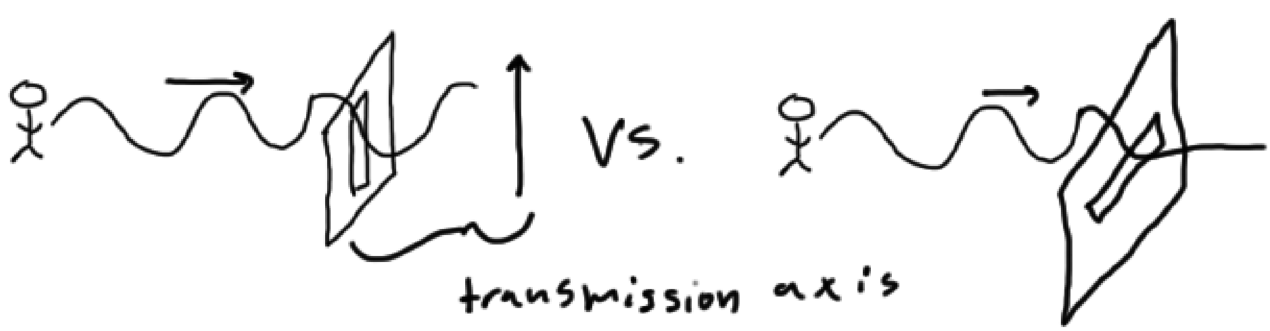
Now what happens if you cut some slits?



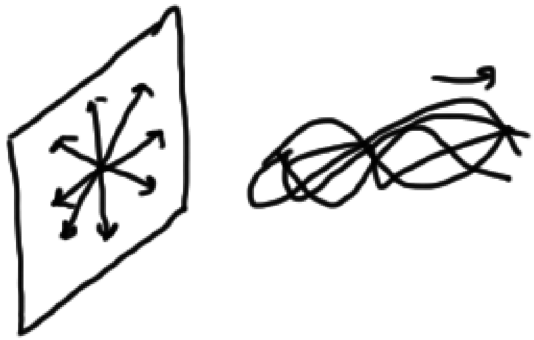
now the charges can not freely move up and down so the light is not reflected or absorbed but can pass through.

orient the slits verticaly though and the charges can follow the field → reflects/absorbs the light.

Similar to shaking a rope through a picket fence.

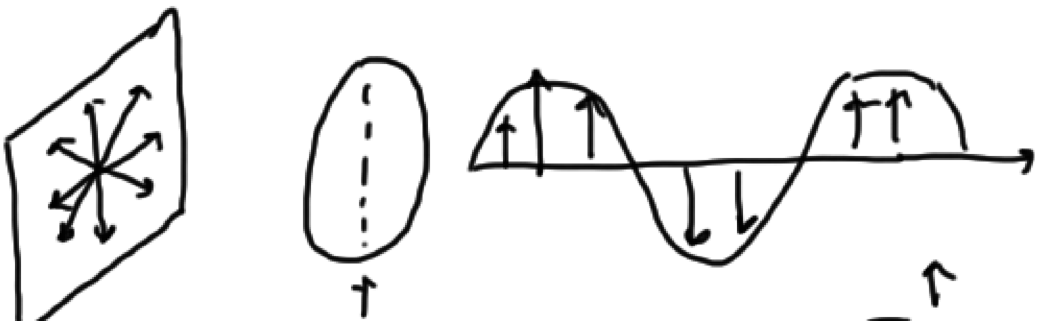


It is common to find light that is **unpolarized**. (could also say polarized in all directions)



light from light bulb
ambient light
(largly) light from sun
(atmosphere polarizes it a little)

Could polarize by sending throug a polarizer



transmission axis

The intensity of the light exiting the polarizer is $\frac{1}{2}$ the original intensity.

After one polarizer we can put another → called analyzer.

1) Intensity can be 0 but negative intensity does not make much sense.

2) larger intensity when 2 transmission axes are in line

→ Using 1) & 2) it is reasonable that that the intensity after the analyzer is:

$$\bar{S} = \bar{S}_0 \cos^2\theta$$

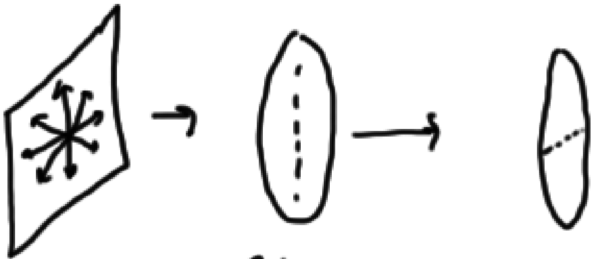
average → not vector

always ⊕

S_0 → incoming intensity

S → outgoing intensity

Some polarizer examples

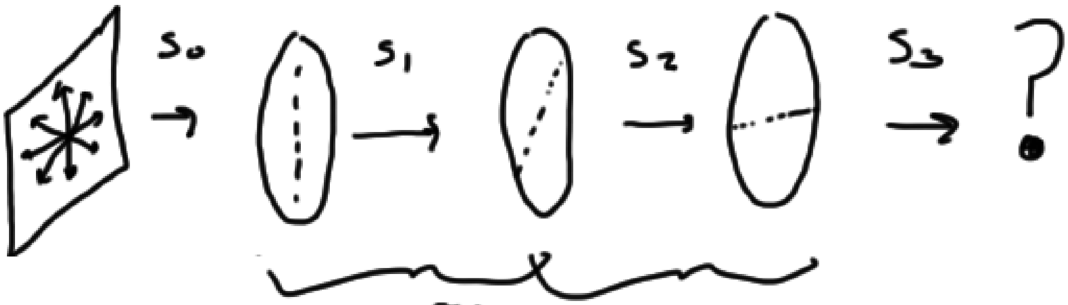


Polarizer analyzer

What happens when they are "crossed" aka perpendicular?

$$\bar{S} = \bar{S}_0 \underbrace{\cos^2 \pi/2}_{0} \qquad \bar{S} = 0$$

Interesting to include 1 more:



$\theta = \pi/4$ $\quad$ $\theta = \pi/4$

Given $\bar{S}_0 \rightarrow$ find S_3

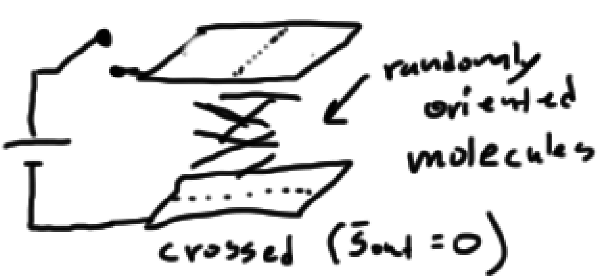
$$\bar{S}_1 = \bar{S}_0 / 2$$

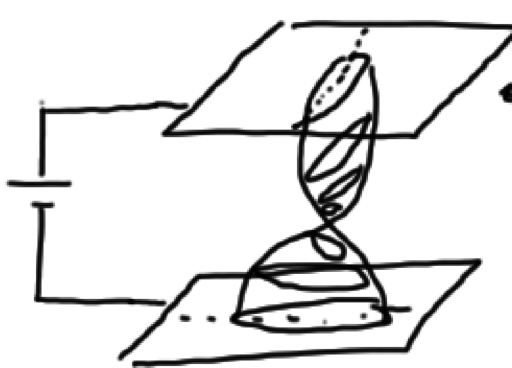
$$\bar{S}_2 = \bar{S}_1 \cos^2 \pi/4 = \frac{\bar{S}_0}{2}\left(\frac{\sqrt{2}}{2}\right)^2 = \frac{\bar{S}_0}{2}\,\frac{2}{4} = \boxed{\frac{\bar{S}_0}{4}}$$

$$\bar{S}_3 = \bar{S}_2 \cos^2 \pi/4 = \frac{\bar{S}_0}{4}\,\frac{2}{4} = \frac{\bar{S}_0}{8}$$

$$\boxed{S_3 = \frac{\bar{S}_0}{8}} \neq 0$$

LCDs

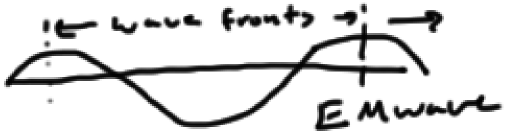


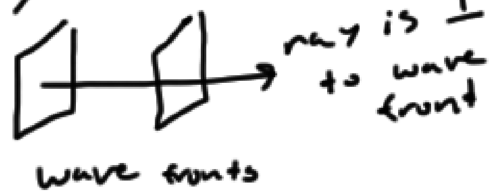


← like having many Polarizers to twist the light.

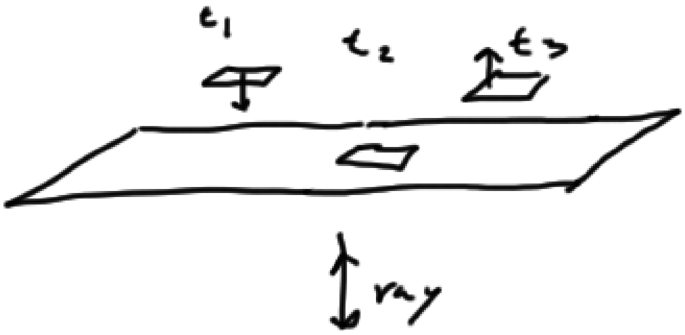
Reflection

Since λ is small for visible light we can imagine it as a ray

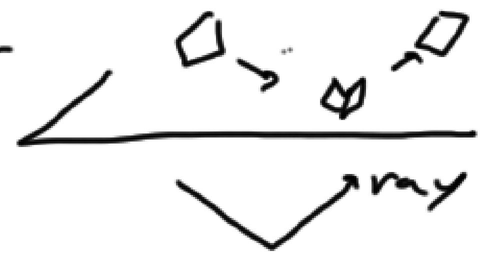




Imagine wave fronts incedent on a reflecting surface.



or



θ_i = incident

θ_r = reflected

dotted line is normal to surface

if $\theta_i = \theta_r \Rightarrow$ specular reflection

if $\theta_i \neq \theta_r \Rightarrow$ diffuse reflection

Plane mirror

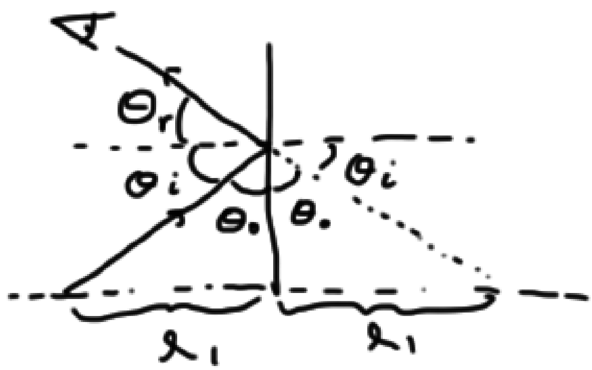
where the dashed lines converge is where the image is.

A single point will (usually) emit light in multiple directions.

1) draw to lines that enter the eye from the same point on the object.

2) See it you can continue those lines from the eye to some other point. (other than the actual source)
→ that point will be the place that you perceive the object to be.

If you can do step 2) → Virtual image



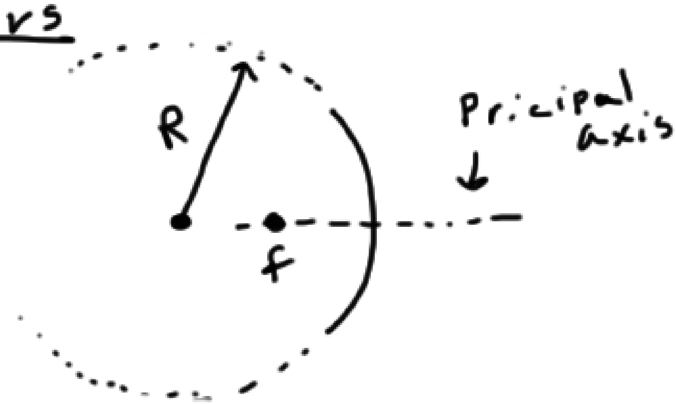
← Based off of this drawing a flat mirror does not distort the image

$\boxed{l_1 = l_2}$

Spherical Mirrors

concave

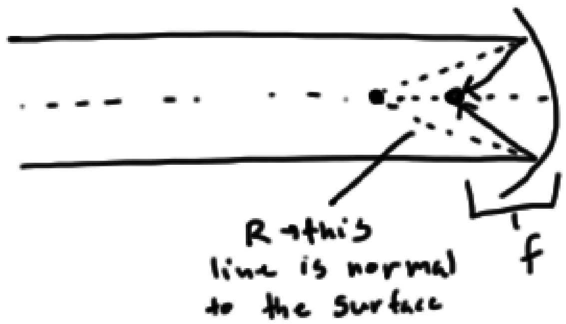
convex



f → focal point

Image point only equals f when the object is really (∞) far away.

In this case (object at ∞) light rays are parallel



$x = l$ for small θ

$\rightarrow f = \frac{1}{2}R$

rays close to pricipal axis are <u>paraxial rays</u>

→ not necessarily parallel to it.

Points far from principal axis won't converge right on focal point. → makes blurred image

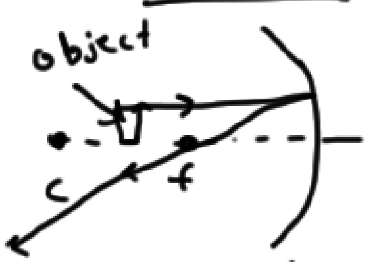
→ called spherical aberration.

└ want a mirror that is small compared to R.

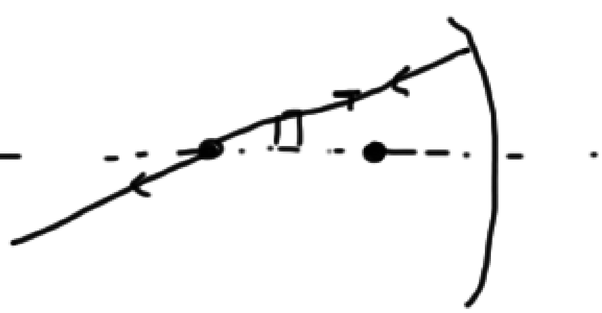
→ or parabolic mirror

<u>Images by spherical mirrors</u>

<u>ray trace</u>



from one point on object paralax rays appear to intersect at the point of the image

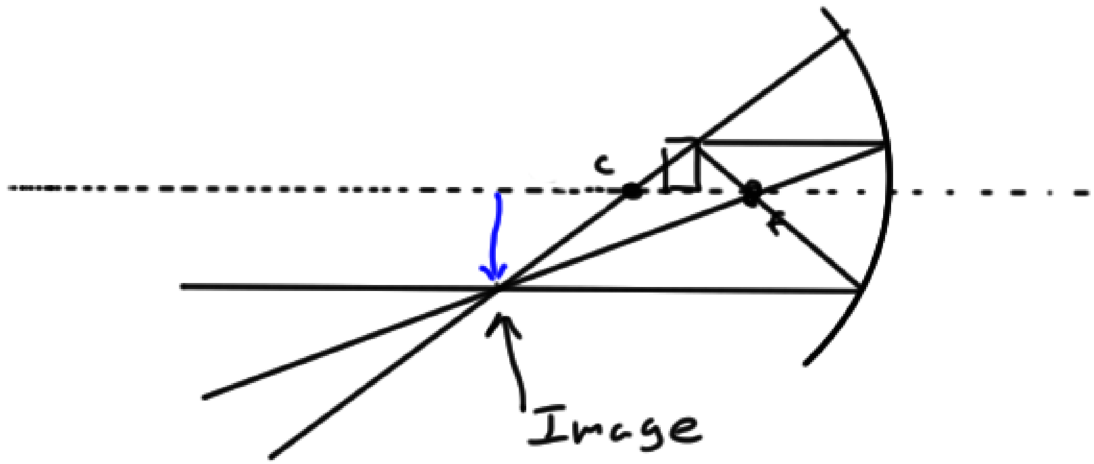


1) from obj. parallel to pric. axis
→ throug focal point

2) from obj. through focal point
→ parallel to pric axis

3) from obj $\perp$ to surface
→ goes through C

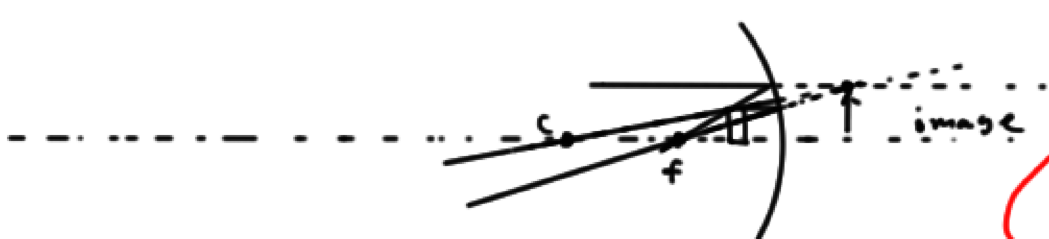
These give you the location of that point on obj. of image



A little redundent → only need 2
→ check with 3rd.

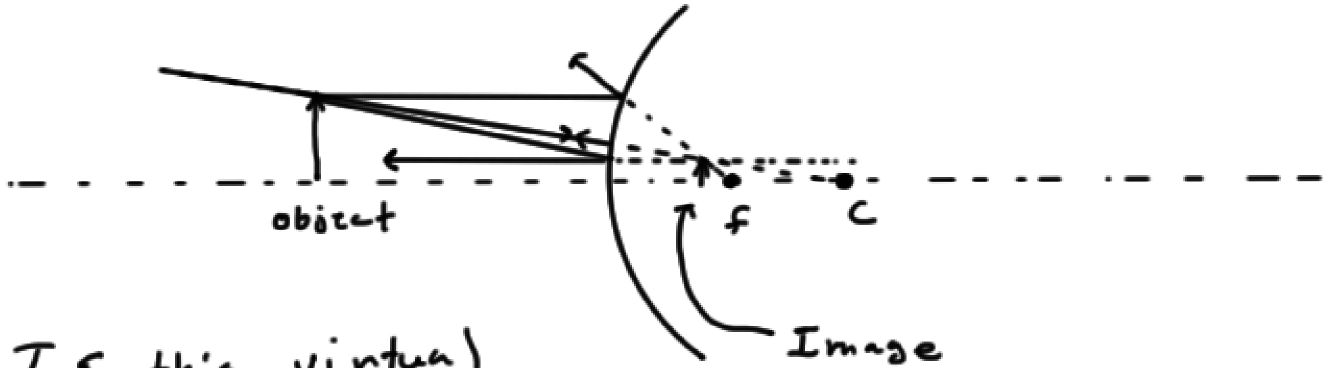
This is NOT A VIRTUAL image
A REAL image is one where swapping the image with the object gives you the exact same ray diagram but with the directions reversed.

Can we get a virtual image with a spherical concave mirror?



does not abide by swapping rule
→ Virtual Image

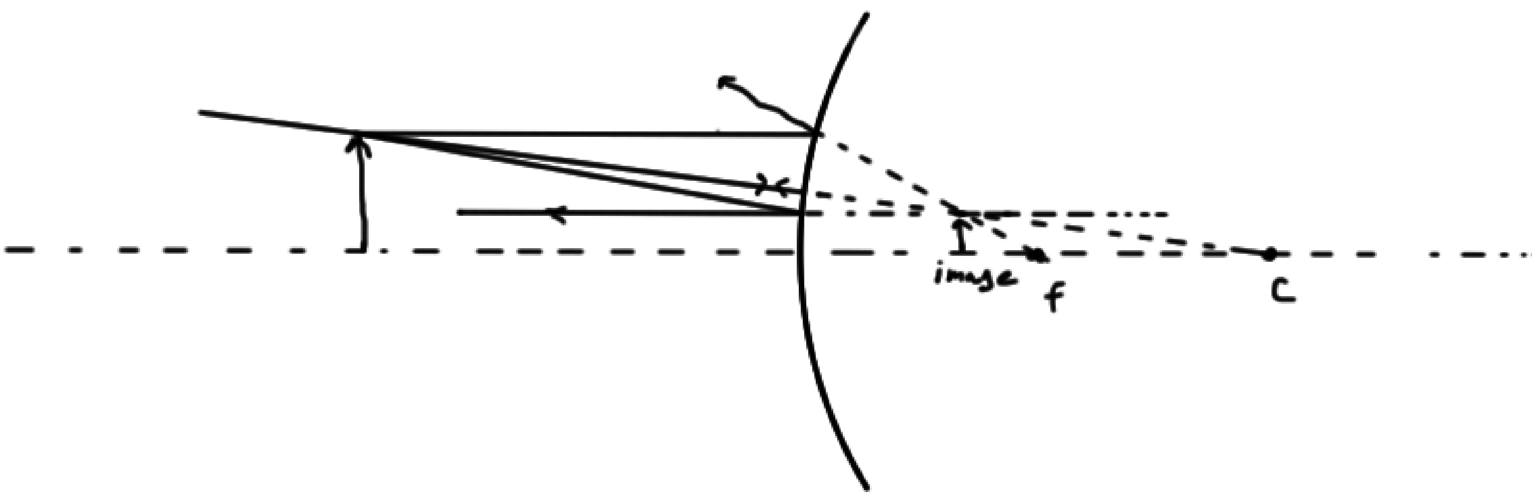
Convex mirrors



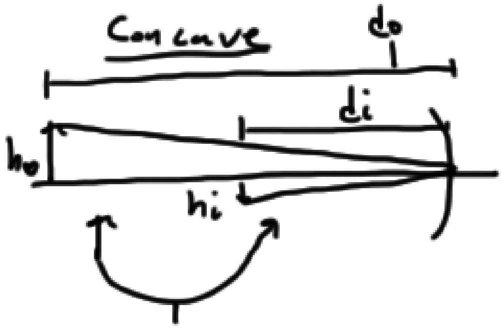
Is this virtual
or real?

Virtual since exchanging the image with the object does not give the same ray diagram just with reversed directions

For practice lets do the same thing as above but with a different curvature.



The mirror and magnification equations

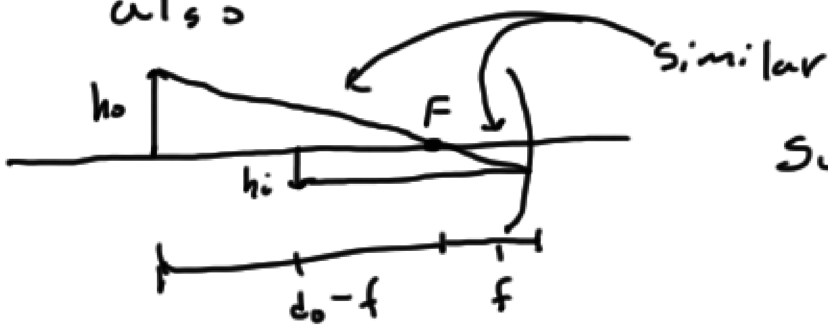


$h_o \rightarrow$ height object

$h_i \rightarrow$ height image

similar triangles so $\dfrac{h_o}{-h_i} = \dfrac{d_o}{d_i}$

also



so $\dfrac{h_o}{-h_i} = \dfrac{d_o - f}{f}$

Set eqns = to eachother

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

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

magnification defined as $\dfrac{h_i}{h_o}$

$\boxed{m = \dfrac{h_i}{h_o}}$ also equal to $\boxed{\dfrac{-d_i}{d_o}}$

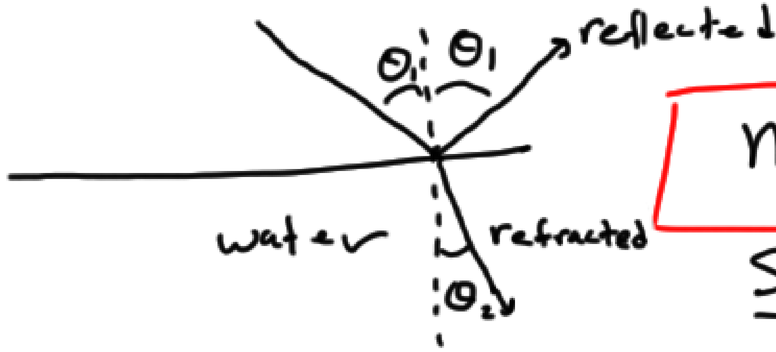
Index of refraction

$$n = \frac{c}{V}$$

c ← speed of light in vacume

V ← speed of light in other material

n ↑ index of refraction



$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

Snell's Law

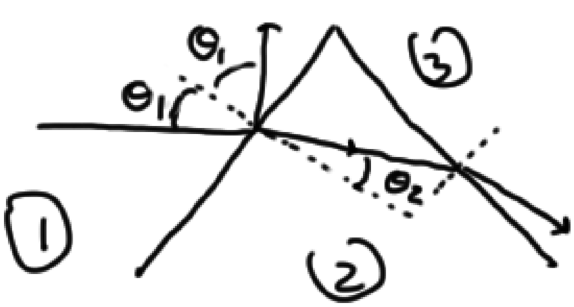
1) from small n to larger n
→ ray bends twords normal

2) from larger n to smaller n
→ ray bends away from normal.

Lenses

Start with a prism

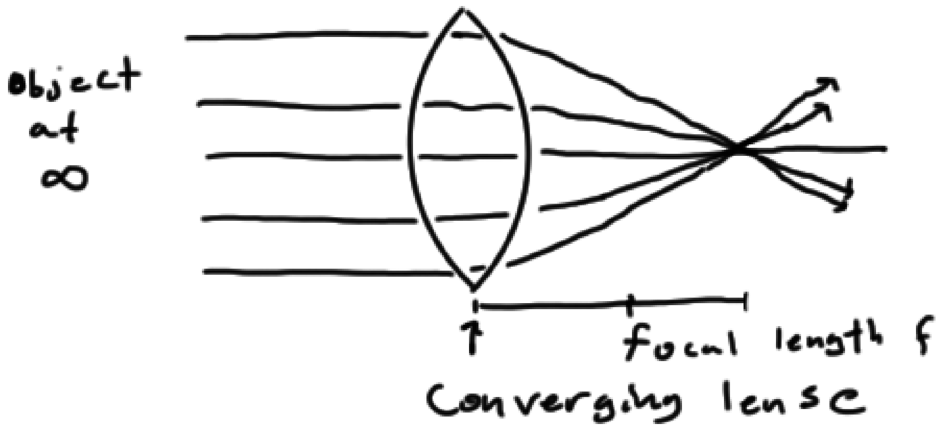
Zoom in



If $n_2 > n_1$ then light bends towards normal

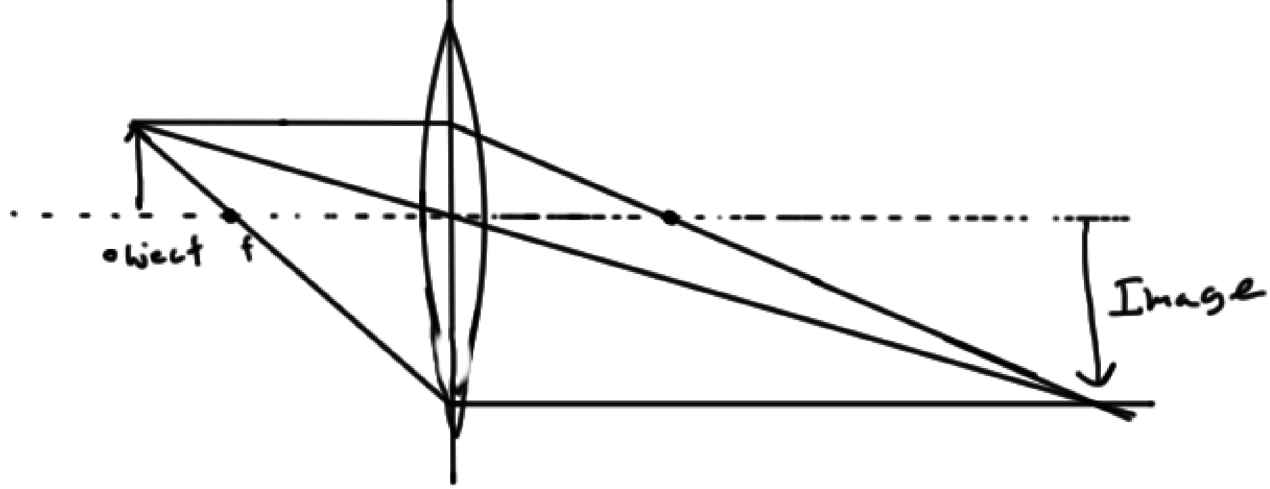
If $n_3 = n_2$ then $n_2 > n_3$
light bends away from norm.

If we use a special shape then parallel rays will converge on a single point



assume the lense is thin so that f is measured from its center.

What about objects closer than ∞?



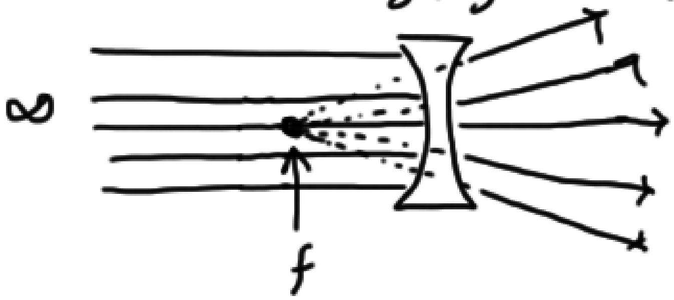
Almost the same as the rules for the mirror.

1) line from object through intersection of pricipal axis and the lense.

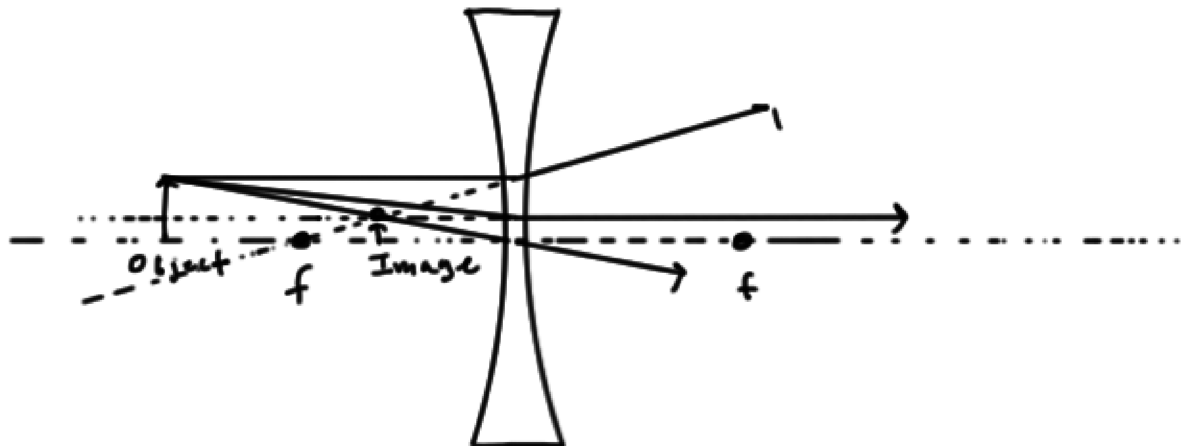
2) line from object parallel to pricipal axis to lense
→ then frome lense to (far) focal point

3) from object through (closest) focal point to lense.
→ then from lense parallel to to pricipal axis.

Diverging lenses

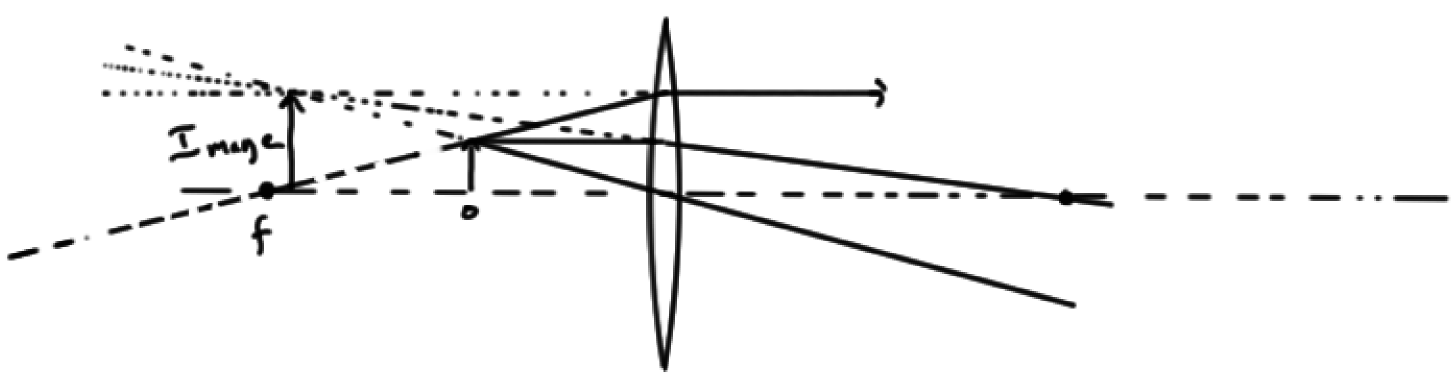


Object closer than ∞



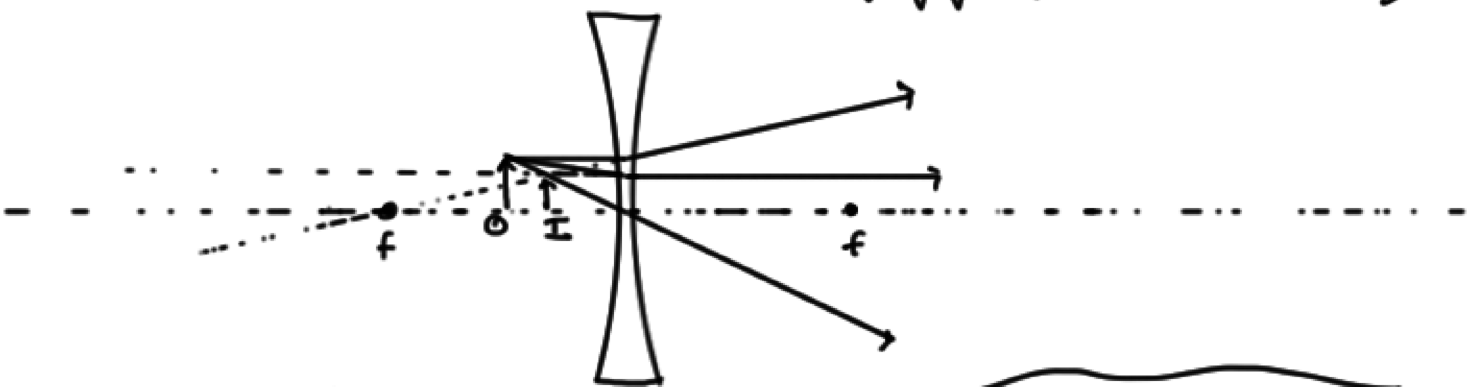
So far we have just done lense problems where the object is further from the lense than f. What happens when its closer?

First converging lense



Diverging lense (object closer than focal length)

Virtual image



The thin lense equation

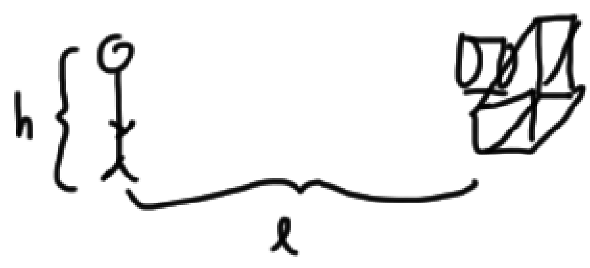
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$ just like mirror eqn.

magnification

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

ex (book)

camera (converging length → f known)



find image distance, Real or virtual?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$ ← solve for d_i $$\frac{1}{f} - \frac{1}{l} = \frac{1}{d_i}$$

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

If we put in #s and find d_i → positive then $\boxed{\text{real}}$

If d_i → negative → $\boxed{\text{virtual}}$

Knowing do & di from the last page
means we can find m

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

if its a real image so di is positive
than m is negative → inverted image

lense sign conventions

f + → converging lense
f − → diverging
d + → object left of lense
d − → object right " "

di + → object right $\boxed{\text{real}}$
di − → object left $\boxed{\text{Virtual}}$

m + → image has same orientation as object
m − → " " different " "