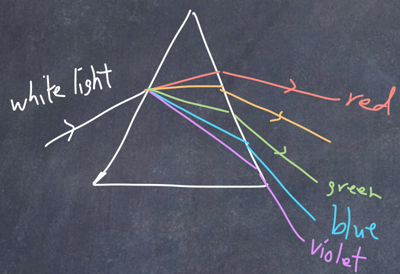
PHY117 HS2024

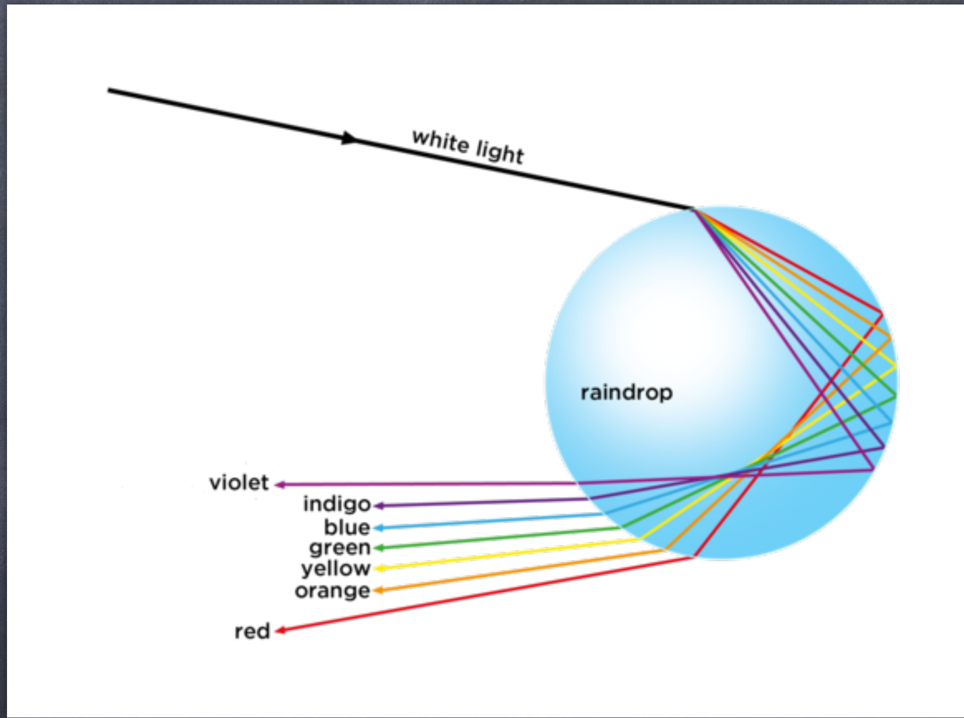
"I have set my rainbow in the clouds"
we add: "and it shall be at 42° with
respect to you and the sun due
to refraction and geometry..."

Also today : Creating light from darkness

Week 13, Lecture 2
Dec. 11th, 2024
Prof. Ben Kilminster

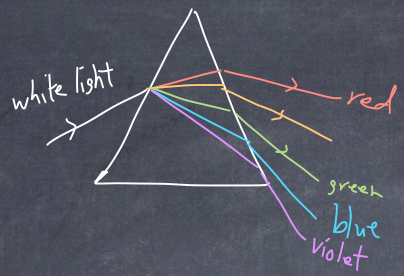
Light through a rain drop





Light is refracted at different angles depending on λ

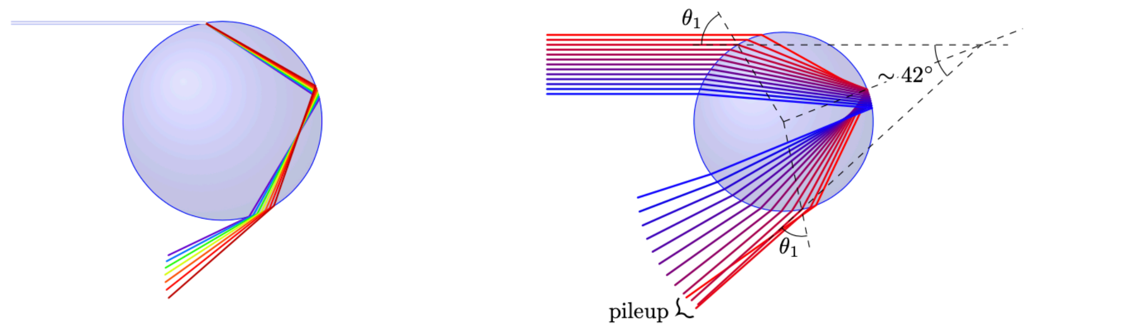
Pyramid:



water droplet sphere:

Different wavelengths:

Same wavelength Different paths

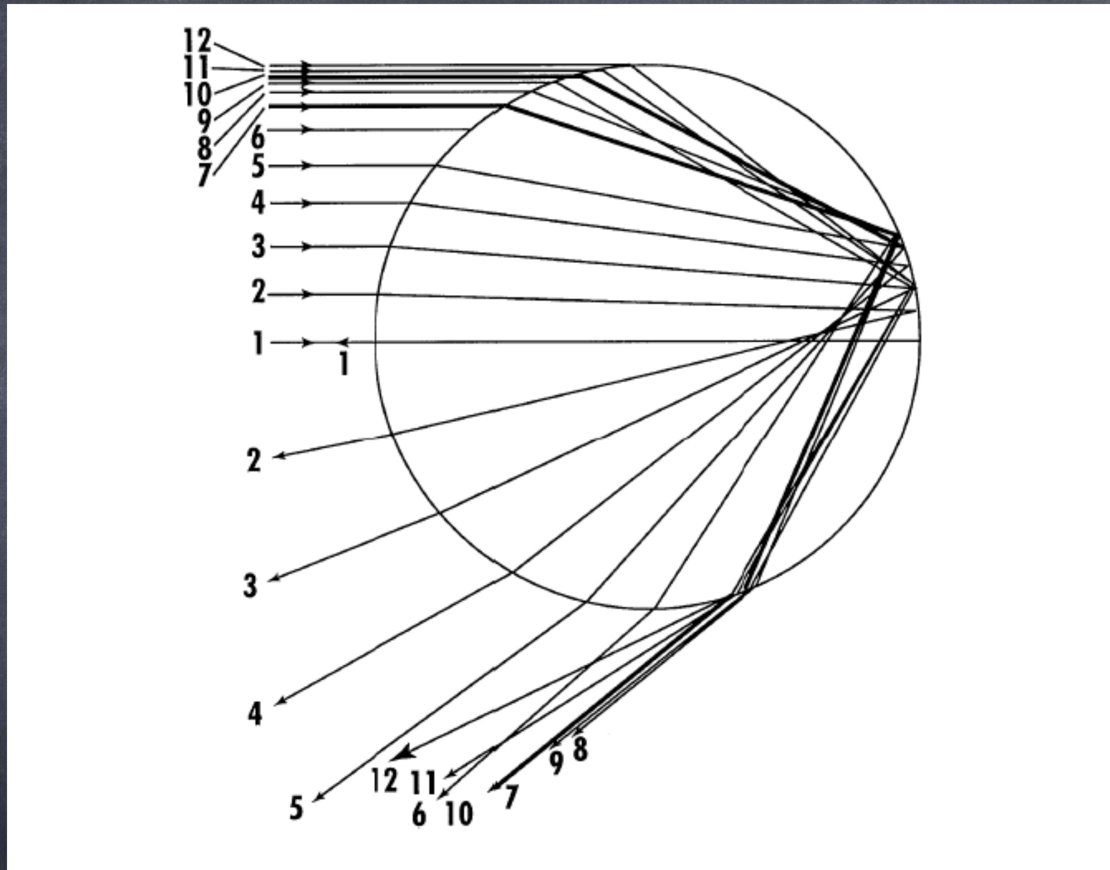


(a) A white light beam is spread in a rainbow due to dispersion (not to scale).

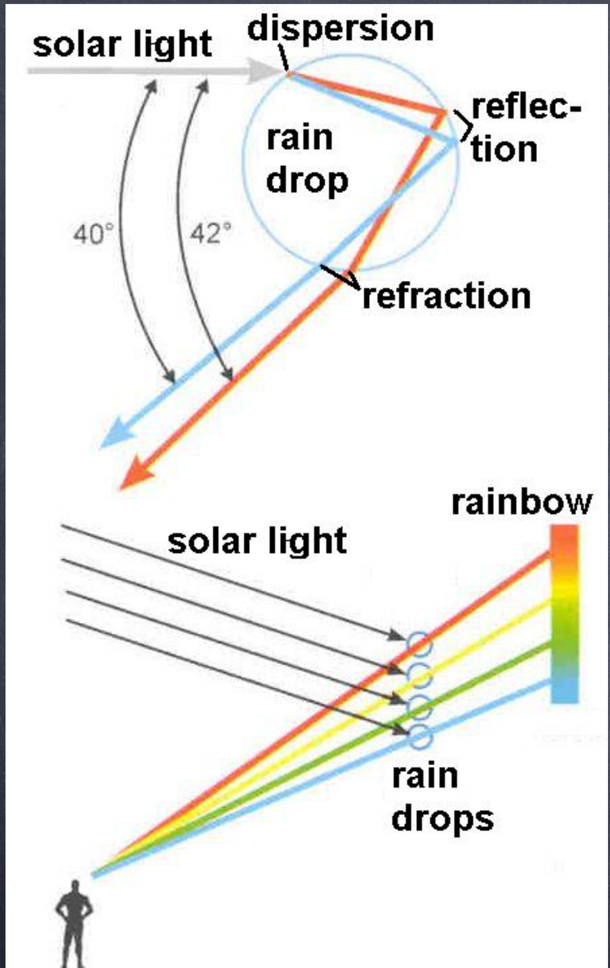
(b) At an effective reflection angle of about 42°, light is more concentrated (color unrelated to wavelength).

Figure 14.6: Explaining rainbows with dispersion and internal reflection in water droplets.

parallel light of same wavelength entering



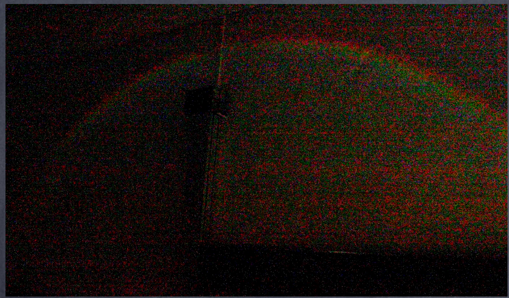
pileup of light at a certain angle.



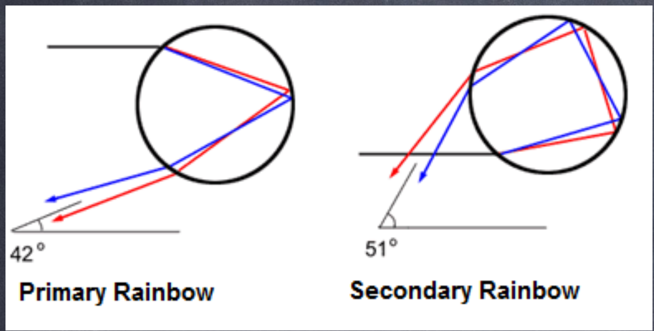
Blue light has an angle which piles up at 40°

and red light has an angle of 42°

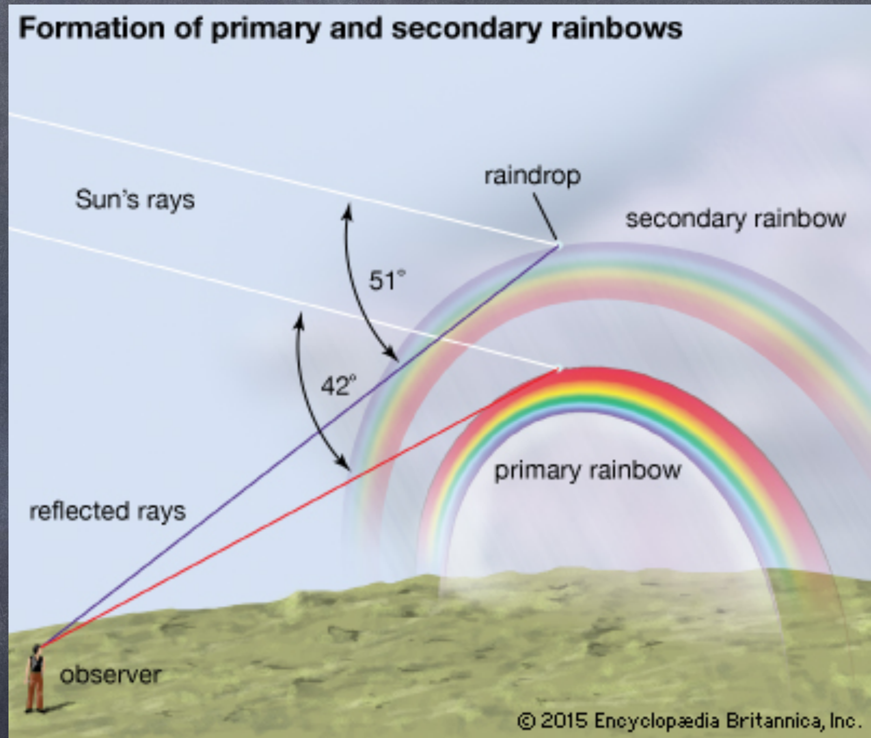
This is how a rainbow works



Sometimes, you even see a second, "inverted" rainbow.



~42°

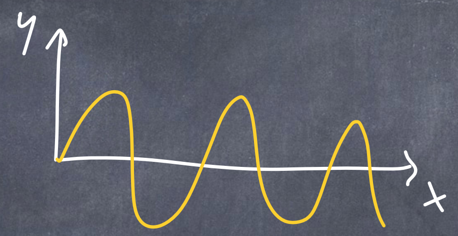


Look out for the second one!

Polarization – in any transverse wave

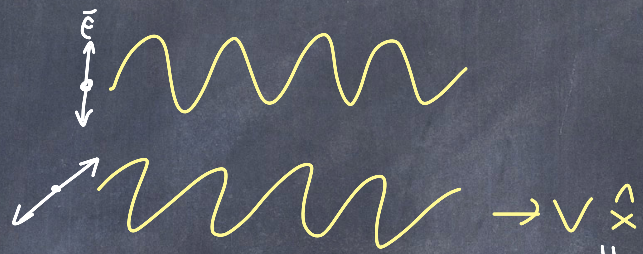
linear polarization

$\bar{E}$ ∥ to just one axis



unpolarized

many sources oscillating in random directions (all $\bar{E}$ ⊥ to $\bar{v}$)



combined

Electric field of light emitted in x direction is in random combinations of $\hat{y}$ and $\hat{z}$ directions

circular polarization – $\bar{E}$ rotates with time (* not in this class)

EM waves can be produced unpolarized in a substance since all atoms may act independently (random from heating)

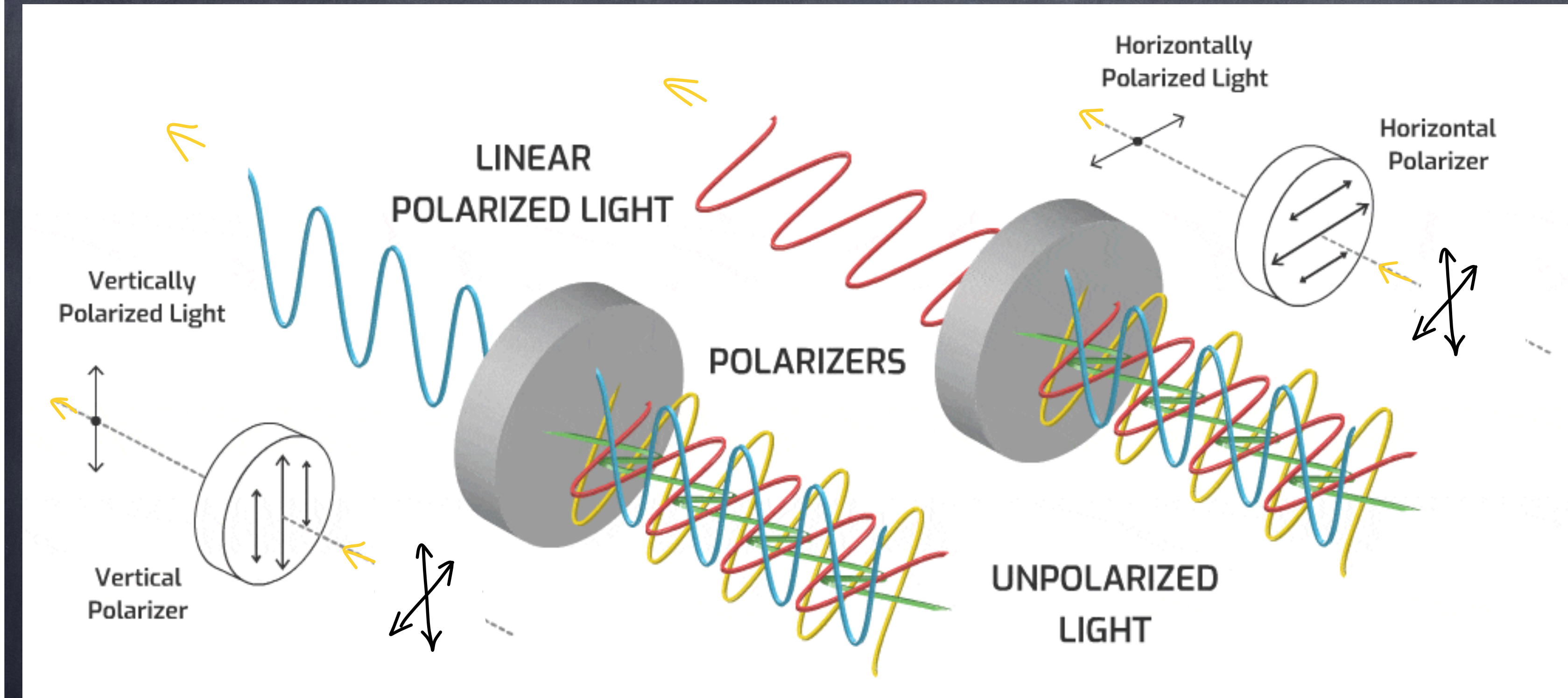
or polarized if coherent electric field

Polarized light can be produced from unpolarized light by:

1) absorption *
2) scattering
3) reflection *
4) birefringence

* In this class

absorption: To start,
Unpolarized light has E-field in two directions



Polarizer selects only light with $\vec{E}$ in one direction by absorbing second component: reduces intensity by $\frac{1}{2}$

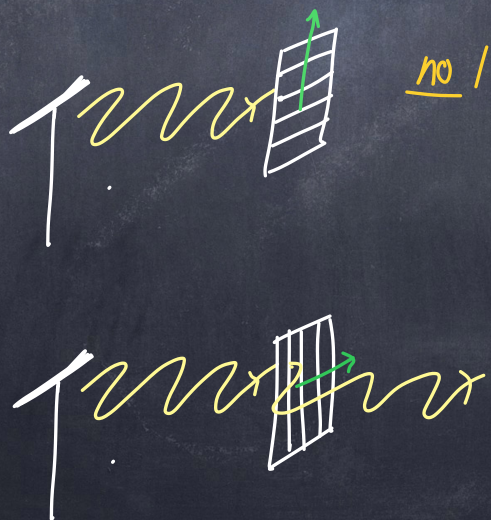
→ polarizers can produce & detect polarized light polarization by absorption: When E-field is absorbed in one direction, then only the E-field ⊥ to the absorption is transmitted.

polarizing film or natural crystals

↑ long chains of hydrocarbons aligned, conducting at optical wavelengths.

transmission axis in green

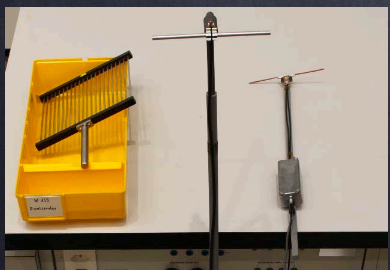
Example of microwaves



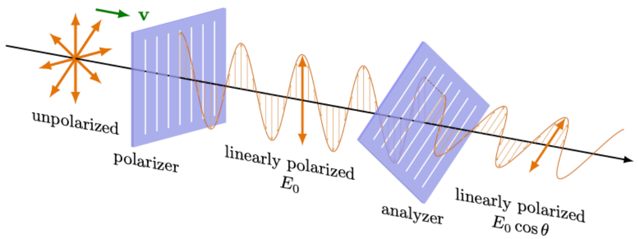
no light passes through

conductor parallel to E absorbs polarized light

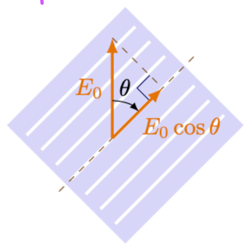
light passes through



$E_{transmitted} = E_0 \cos\theta$



(a) Initially unpolarized light beam gets linearly polarized. The transmitted electric field is reduced to $E_0 \cos\theta$.



(b) Polarizer only lets through the component parallel to its polarizing axis.

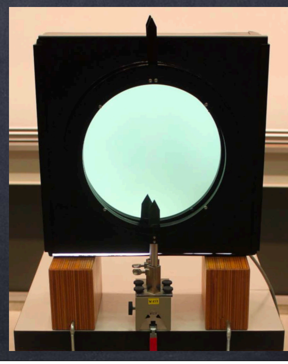
Two polarizing absorbers: polarizer, analyzer

The intensity of light goes like $|\vec{E}|^2$: $I \propto \mathcal{E}^2$ (electric field $= \mathcal{E}$)

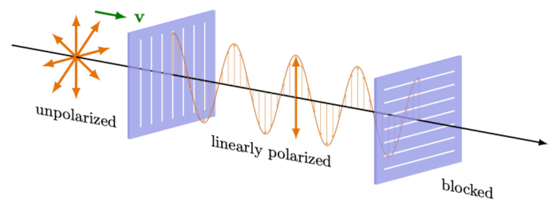
$$I = I_0 \cos^2\theta$$

Malus' Law

case: $\theta = 90^\circ \rightarrow I = 0$

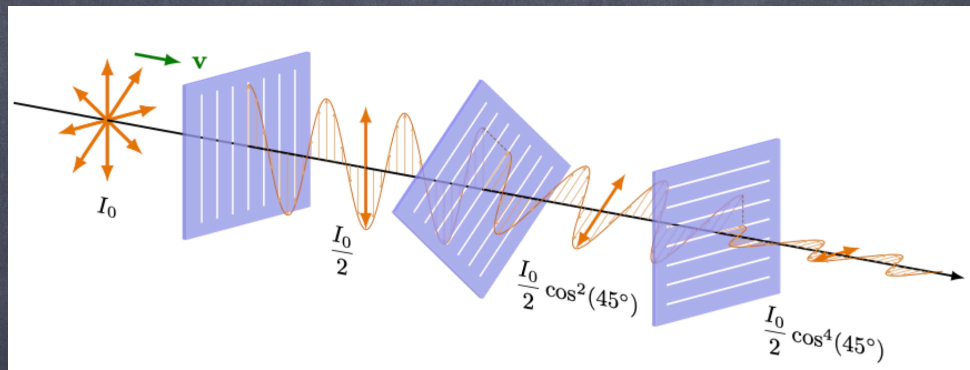


No light passes

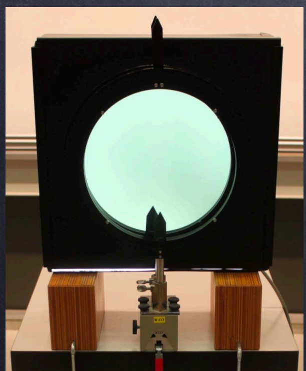


(c) If the axes of two subsequent polarizer differ by 90°, all light gets blocked.

Light passes



initial · intermediate · final

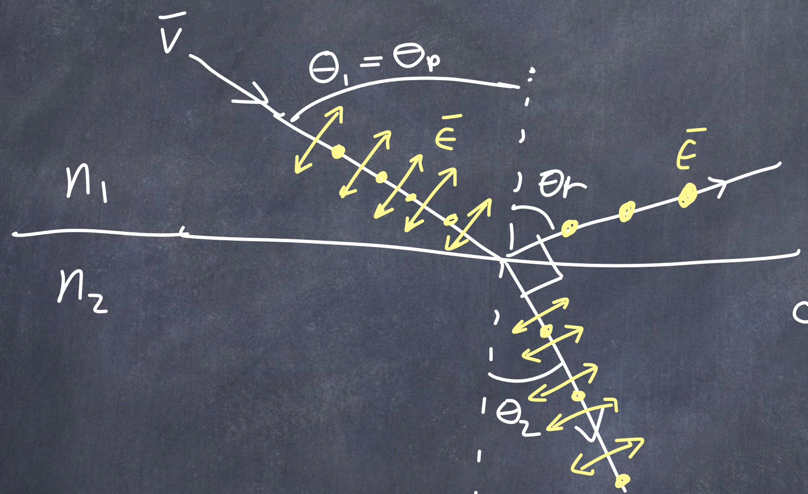


Another Example: If $\theta = 10°$, then $I_1 = I_0 \cos^2 10°$

If $\theta = 80°$, then $I_2 = I_0 (\cos^2 10°)(\cos^2 80°)$

Polarization by reflection:

There is a partial polarization on the reflecting light reflected between two transparent media, such as air + glass, or air + water, ...



Incoming light as $\bar{E}$-field with 2 components, perpendicular to velocity

check: $\theta_r = \theta_1$

$\theta_r + 90^\circ + \theta_2 = 180^\circ$

If the angle of incidence $\theta_1 = \theta_p$ (polarization angle), which is defined such that there is a 90° angle between the reflected and refracted light, then the reflected light will be 100% polarized perpendicular to the plane of incidence.

The refracted light is slightly polarized.

Condition of polarization by reflection:

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

$\updownarrow$

θ_p

The condition is that $\theta_2 = 90° - \theta_1$

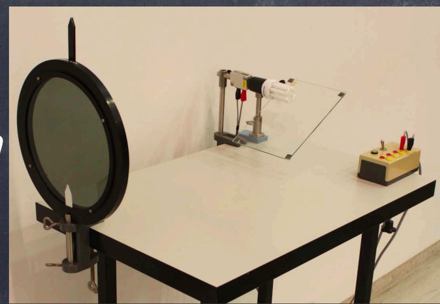
$$n_1 \sin\theta_p = n_2 \sin(90° - \theta_p)$$

$$n_1 \sin\theta_p = n_2 \cos\theta_p$$

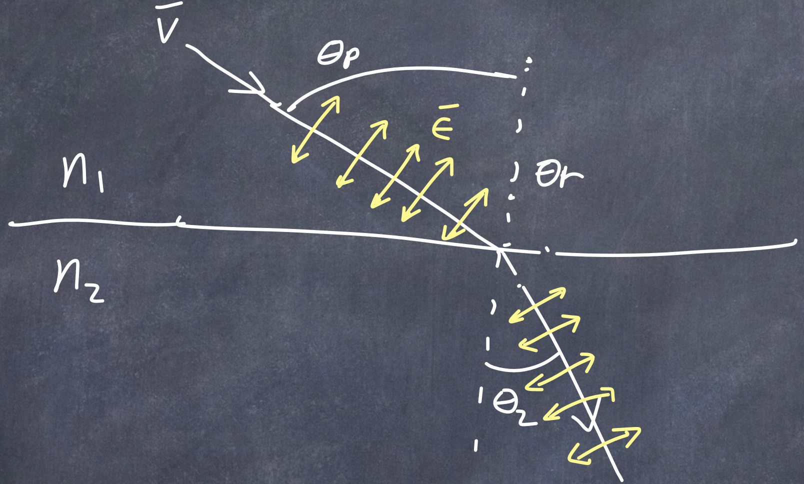
$$\tan\theta_p = \frac{n_2}{n_1}$$

Brewster's Law for the angle of complete polarizaton of reflected light

polarizer used as analyzer



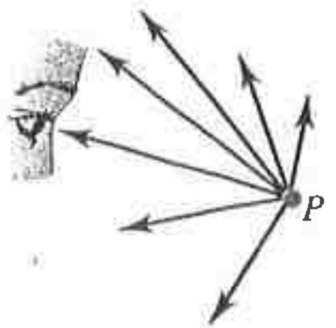
what if our initial light is polarized in a direction $\perp$ to surface & direction of motion?



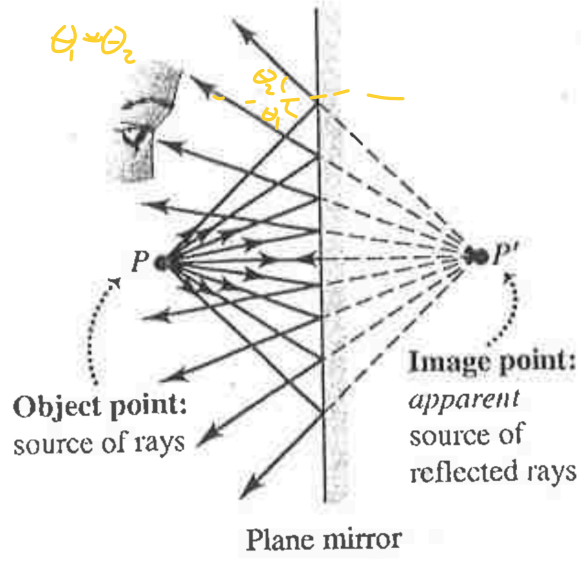
then at $\theta_1 = \theta_p$, no reflection occurs

Images produced by reflection:

34.1 Light rays radiate from a point object P in all directions. For an observer to see this object directly, there must be no obstruction between the object and the observer's eyes.



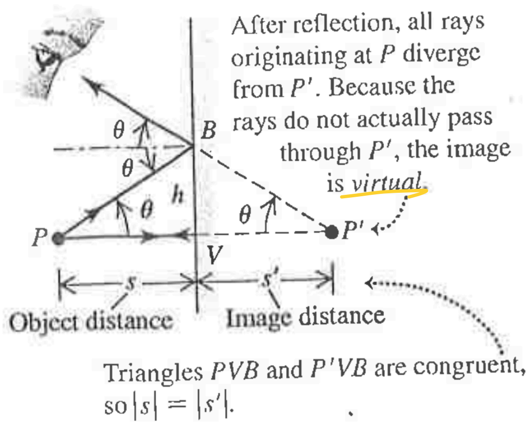
34.2 Light rays from the object at point P are reflected from a plane mirror. The reflected rays entering the eye look as though they had come from image point P'.

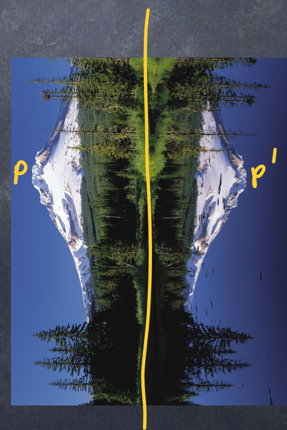


we can observe an object directly (P) or its image (P')

Reflection :

34.4 Construction for determining the location of the image formed by a plane mirror. The image point P' is as far behind the mirror as the object point P is in front of it.

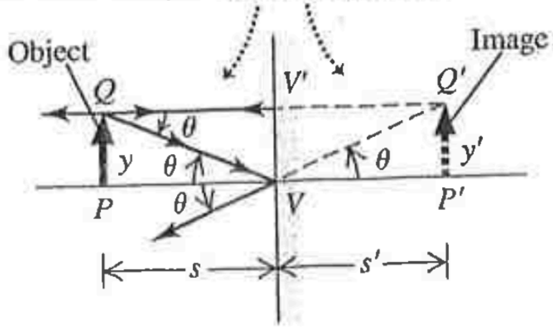


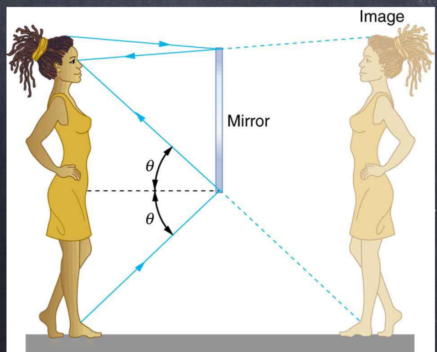


Reflection:

34.6 Construction for determining the height of an image formed by reflection at a plane reflecting surface.

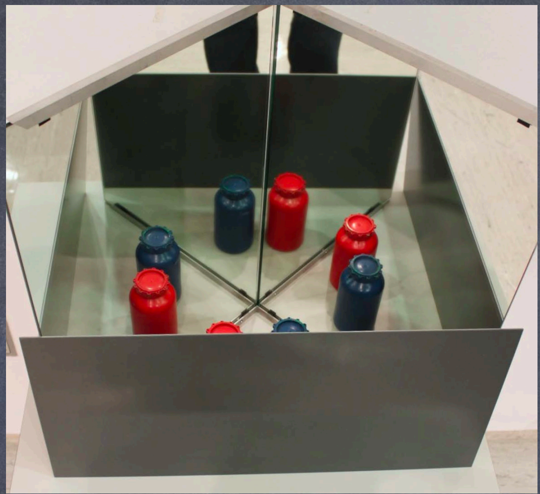
For a plane mirror, PQV and $P'Q'V$ are congruent, so $y = y'$ and the object and image are the same size (the lateral magnification is 1).





Mirror size to see full body

Reflection:



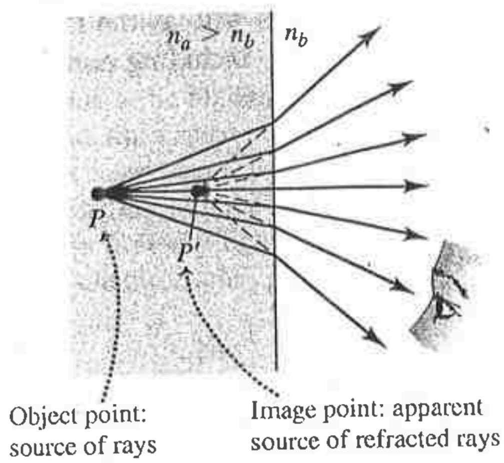
Mirror angle produces more images

90°: 3 images
60°: 5 images
30°: 11 images
⋮
(there is a formula,
but not in this class)

Image produced by refraction:

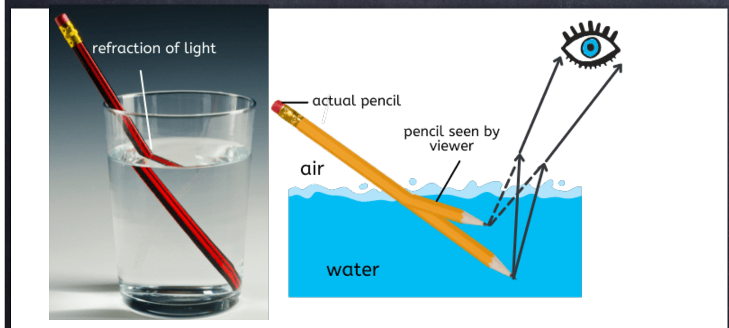
34.3 Light rays from the object at point P are refracted at the plane interface. The refracted rays entering the eye look as though they had come from image point P'.

When $n_a > n_b$, P' is closer to the surface than P; for $n_a < n_b$, the reverse is true.



If we look through a transparent medium (water, glass) at an object P.

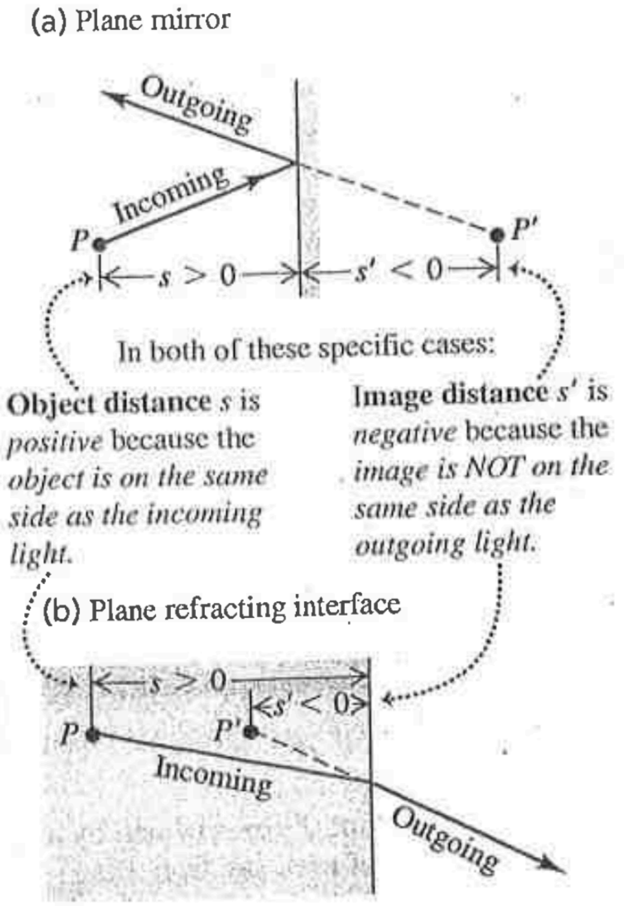
Refraction causes the distance to change, to a distance P'.



Figures 34.2 + 34.3 show "virtual images" because ontgoing light rays do not pass through p'

Where is the image?

34.5 For both of these situations, the object distance s is positive (rule 1) and the image distance s' is negative (rule 2).



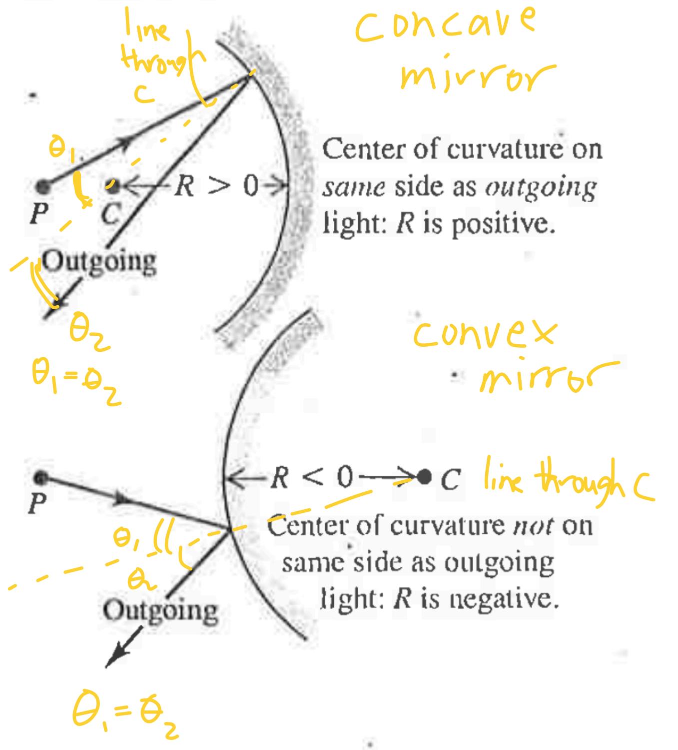
we refer to S as the distance from the object to the surface.

S': distance to the image.

objects: $S > 0$ if object is on the same side as the incoming light to the surface

images: $S' > 0$ if image is on the same side as the outgoing light from the surface.

34.11 The sign rule for the radius of a spherical mirror.



spherical mirrors cause light rays to

converge (concave mirrors)

or

diverge (convex mirrors)

Some terms:

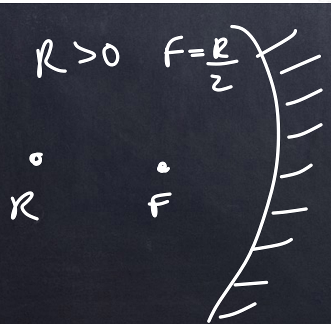
C: center of mirror if it was extended into a sphere.

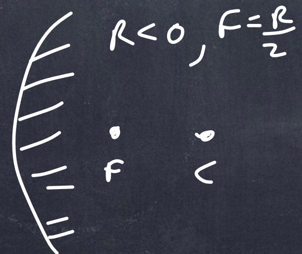
R: radius of the sphere

R can be + or −

F: focal point

$$F = \frac{R}{2}$$



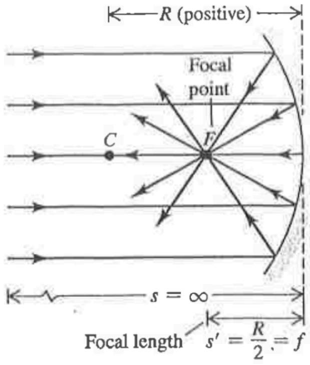


light rays through spherical mirrors

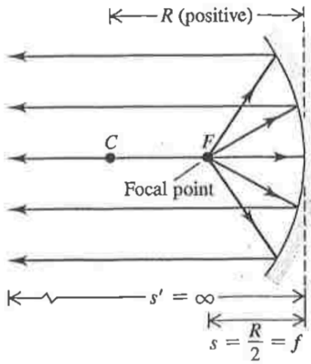
concave mirror

34.13 The focal point and focal length of a concave mirror.

(a) All parallel rays incident on a spherical mirror reflect through the focal point.



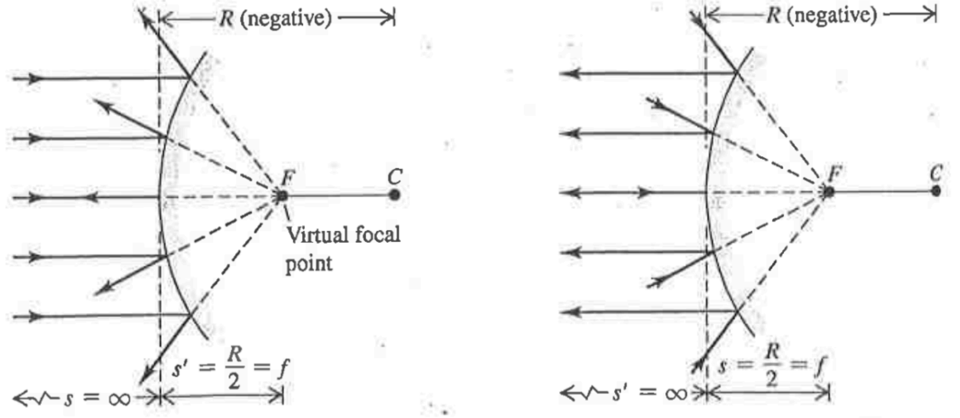
(b) Rays diverging from the focal point reflect to form parallel outgoing rays.



convex mirror

(a) Paraxial rays incident on a convex spherical mirror diverge from a virtual focal point.

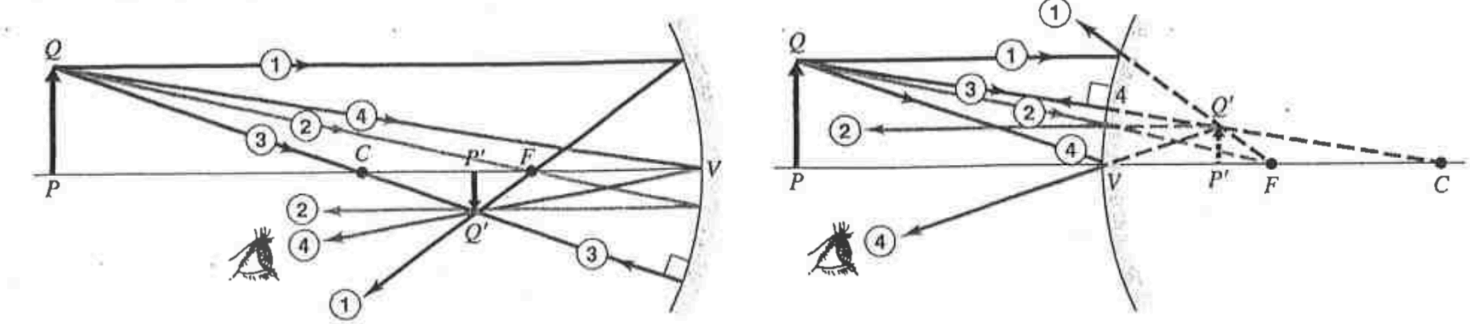
(b) Rays aimed at the virtual focal point are parallel to the axis after reflection.



Rules for finding images with spherical mirrors:

34.19 The graphical method of locating an image formed by a spherical mirror. The colors of the rays are for identification only; they do not refer to specific colors of light.

(a) Principal rays for concave mirror (b) Principal rays for convex mirror



(a)

1. Ray parallel to axis reflects through focal point.
2. Ray through focal point reflects parallel to axis.
3. Ray through center of curvature intersects the surface normally and reflects along its original path.
4. Ray to vertex reflects symmetrically around optic axis.

(b)

1. Reflected parallel ray appears to come from focal point.
2. Ray toward focal point reflects parallel to axis.
3. As with concave mirror: Ray radial to center of curvature intersects the surface normally and reflects along its original path.
4. As with concave mirror: Ray to vertex reflects symmetrically around optic axis.

Any 2 rays are enough to find the image, (position, & the height)

but more will check your answer.

Mirrors

An object has an image that is in general a different size + different distance from the center of the mirror surface

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

s: distance to object
s': distance to image

$$\text{magnification} = m = -\frac{s'}{s} = \frac{y'}{y}$$

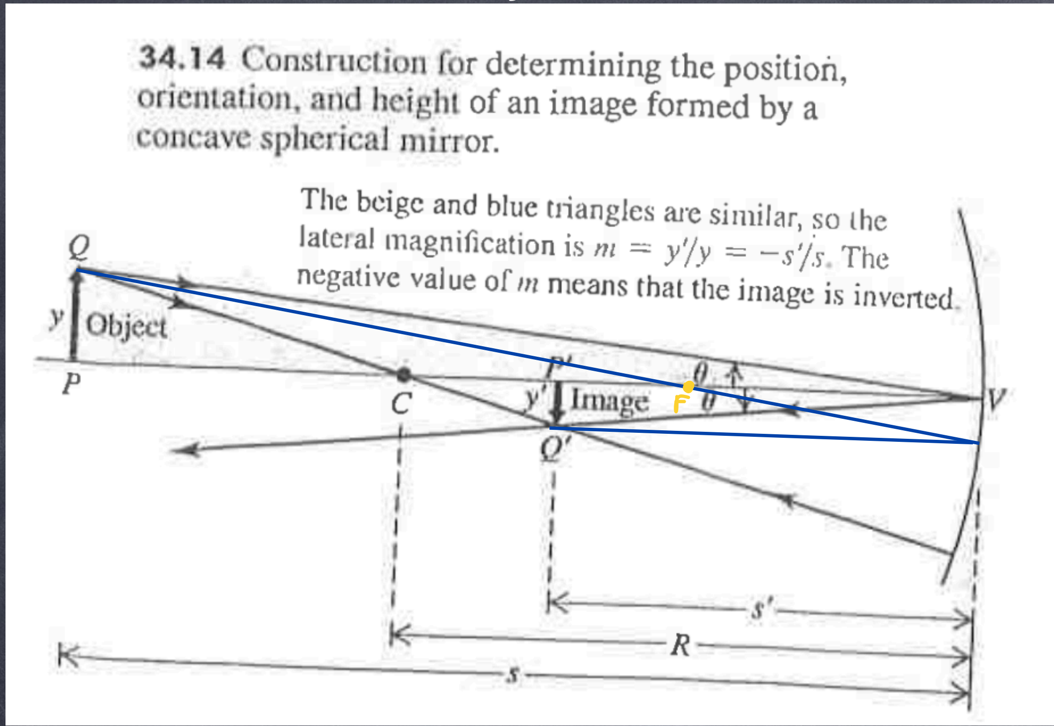
y': height of the image
y : height of the object

A negative m means the image is "inverted".

Signs of s, s', r, f

s	+ if the object is in front of the mirror (real object)
	− if the object is behind the mirror (virtual object)*
s'	+ if the image is in front of the mirror (real image)
	− if the image is behind the mirror (virtual image)
r,f	+ if the center of curvature is in front of the mirror (concave mirror)
	− if the center of curvature is behind the mirror (convex mirror)

Example where object has +s > R : Finding image



1: ray through the center reflected through the center

2: ray to vertex (v) reflected at same angle as incoming

3: ray through focal point is reflected parallel to CV

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

Example: An object 2 cm tall is 3 cm from a concave mirror with radius of curvature of 10 cm. Where is the image? What is the image height? Is it inverted? Is it real or virtual?

---

we know: $R = 10\,\text{cm} \Rightarrow f = \frac{1}{2}R = 5\,\text{cm}$

$s = 3\,\text{cm}$, $y = 2\,\text{cm}$

we need: s' + y'

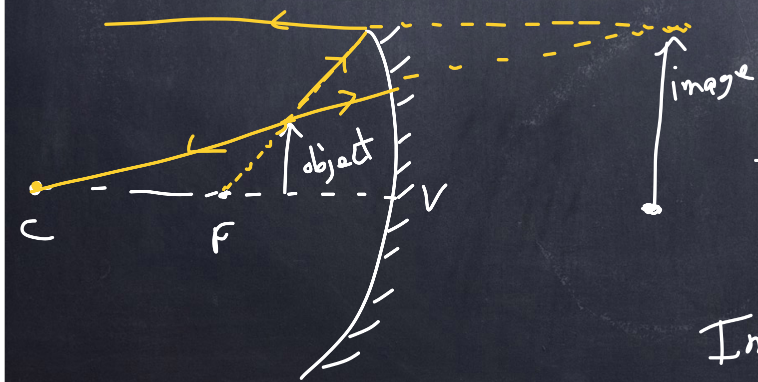
solve for s': $\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \Rightarrow \frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{5\,\text{cm}} - \frac{1}{3\,\text{cm}}$

$$\frac{1}{s'} = \frac{3-5}{15\,\text{cm}} = \frac{-2}{15\,\text{cm}}$$

$$s' = -7.5\,\text{cm}$$

(7.5 cm behind mirror.

check

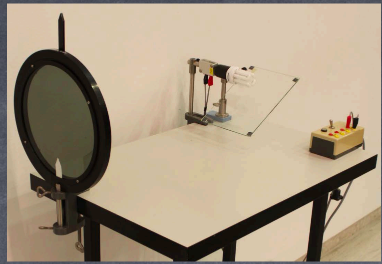


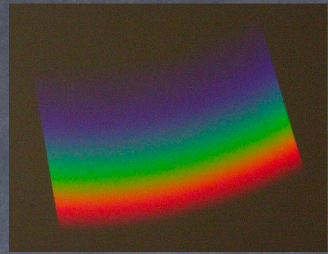
$$\frac{y'}{y} = m = \frac{-s'}{s} = -\left(\frac{-7.5\,\text{cm}}{3\,\text{cm}}\right) = +2.5$$

$$y' = my = (2.5)(2\,\text{cm}) = 5\,\text{cm}$$ new height

Image is not inverted. Image is virtual.


W51


W138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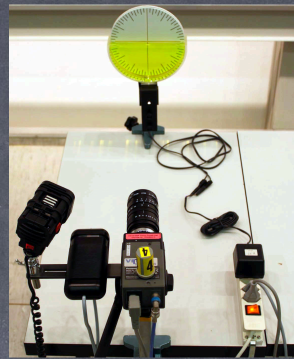
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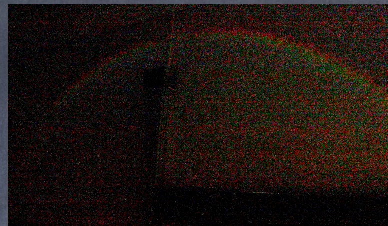
W77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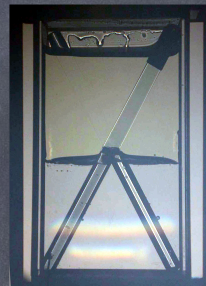
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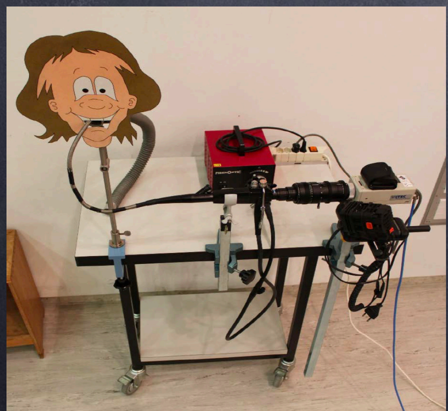
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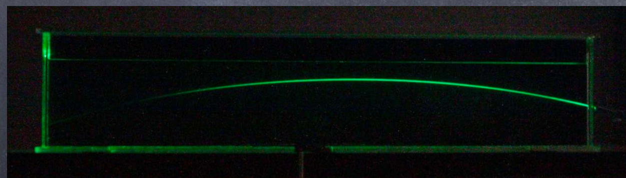
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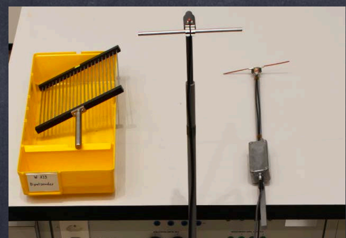
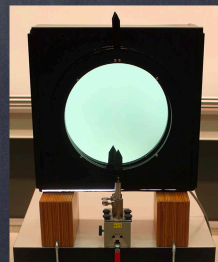

W139


W137