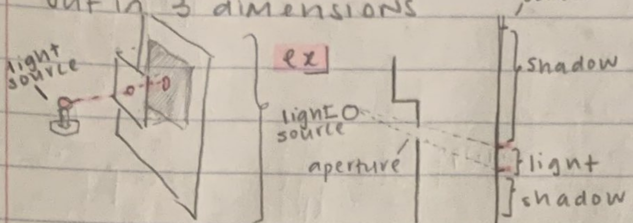
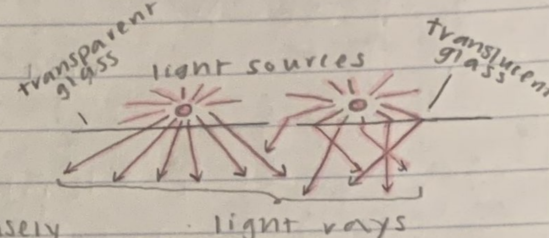
Chapter 33 Textbook Notes

33.1 - Rays

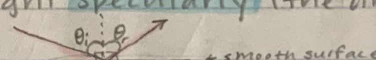
- Light sources can be thought of as many straight beams that spread out in 3 dimensions



33.2 - Absorption, Transmission, Reflection

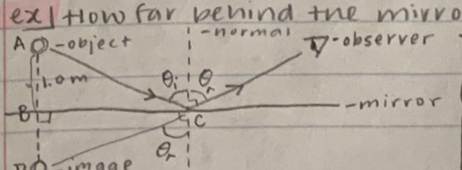


- Transmitted Light - Passes through a material
  - Transparent Materials transmit light
  - Translucent materials transmit light diffusely
- Absorbed Light - Enters a material but never exits (opaque)
  - Light is converted to some other form of energy (usually thermal)
- Reflected Light - Any light redirected away from the material
  - Smooth surfaces reflect light specularly (the angle between it and the normal does not change



$\theta_i = \theta_r$ } Law of reflection
  - Angle of incidence θ_i = angle between incoming ray and the normal to the surface
  - Angle of reflection θ_r - angle between outgoing ray and the normal
- Rays that come from an object and reflected from a smooth surface form an image (optical duplicate)
  - Point where rays converge = where image appears to be coming from
  - virtual image - formed when rays do not actually travel through the point which they appear to be coming from

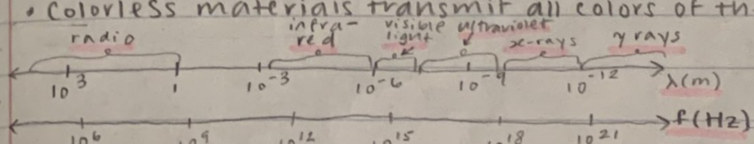
ex | How far behind the mirror is the image?



$\overline{BD}$ = image distance

$\angle DCB = 90° - \theta_r$
$\angle ACB = 90° - \theta_i$ } $\angle DCB = \angle ACB$, $\triangle ABC = \triangle DBC$ } $\overline{AB} = \overline{BD}$, $\overline{BD} = 1.0$ m

- Colorless materials transmit all colors of the visual spectrum



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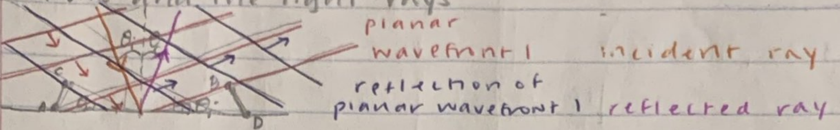
- A red apple absorbs all colors except red, which gets reflected → back to the observer

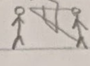
- **Wavefronts** are drawn perpendicular to the direction of propagation of the wave and the light rays



$\overline{CA} = \overline{BD}$, so $\theta_i = \theta_r$

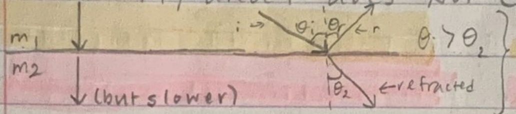
- Mirrors form **extended images**

This mirror does NOT need to be as tall as the man in order to see a complete image of himself, since the mirror only needs to extend to half his height in order for a ray to pass from his head to his feet.



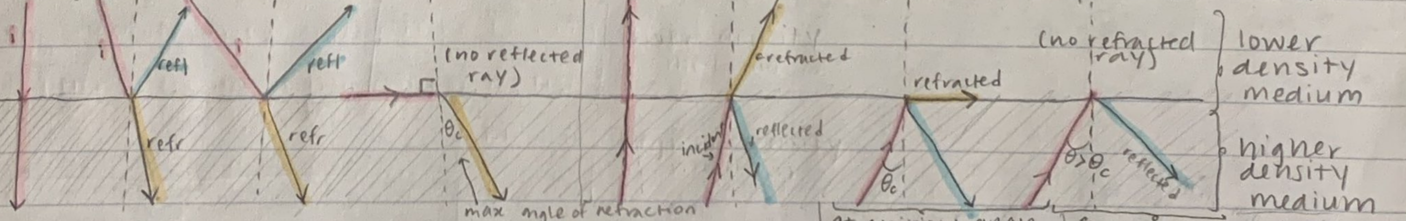
33.3 - Refraction and Dispersion

- Speed of light changes in different mediums
  - ↳ $c = \lambda f$, and f does not change in different mediums, so **λ must change**



$m_1 = c_1 > c_2$; $m_2 = c_2 < c_1$ — As the incident ray passes into a slower medium, the left & right sides of the wavefronts travel at different speeds, causing a bending of the incident ray (**refraction**) in addition to reflection.

- **Angle of refraction θ_2** = angle between refracted ray & normal
- When a light ray travels from one material to a second material where light travels more slowly, the ray bends toward the normal to the interface between the materials
- Speed of light decreases as the mass density of the material increases
- Angles do not depend on which ray is incident, refracted, or reflected



- **Total Internal Reflection** - when $\theta_i > \theta_c$, and therefore no light is refracted, and all light is reflected back into the higher density medium

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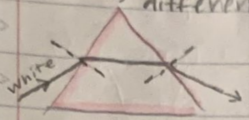
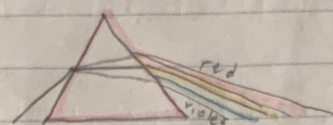
- **Dispersion** - when rays of different colors are seperated when refracted
  ↳ different frequencies of light → slightly different speeds in the same medium
  → different angles of refraction



prism refracts light of a single frequency

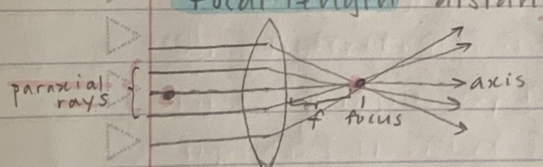


dispersion: different colors have diff. refraction angles

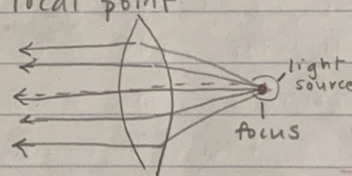
- Gems - cut w/ many internal surfaces from which total internal reflection takes place
- Rainbows - Total Internal Reflection & dispersion from water droplets
- As frequency of light increases, the critical angle for total internal reflection in a given medium decreases
- **Fermat's Principle** - The path taken by a light ray between two locations is the path for which the time interval needed to travel between those locations is a minimum

33.4 - Forming Images

- **Converging lens** - lens made of convex surfaces that redirects rays parallel to the lens axis to the **focus/focal point**
- **Focal length** - distance from center of lens to focal point

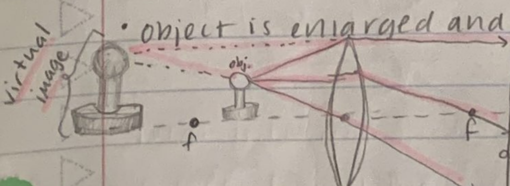


rays that enter lens parallel to lens axis converge at focus

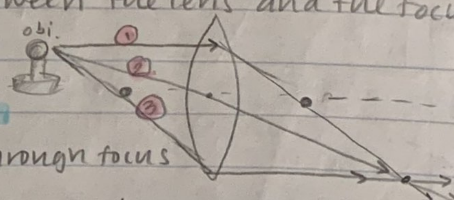


Rays that originate at focus emerge parallel to lens axis (no image)

- every lens has two foci, one on either side, with the same focal length
- **Focal plane** - Plane that is perpendicular to the axis a distance f from the lens (contains focal point) → If ray angle on lens changes, focus changes but plane doesn't.
- **Paraxial Rays** - rays that are close to and parallel (or almost parallel) to lens axis
- object is enlarged and virtual when placed between the lens and the focus



How to determine outgoing rays using principle rays:
1. Parallel to lens axis → through focus
2. Through lens center → undisturbed
3. Through left focus → parallel to lens axis



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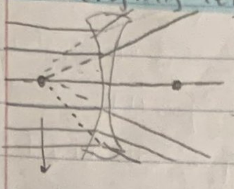
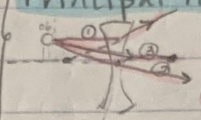
- Real images can be seen on a screen placed at that location, virtual images cannot
- Diverging lens - lens made of concave surfaces and create a virtual focus.



Foci are virtual because the rays do not actually converge at them

virtual image is formed

Principal rays for diverging lens:



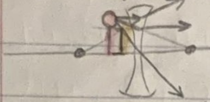
① Parallel → points from left focus

② center → undisturbed

③ Toward right focus → parallel

- All lenses have radii of curvature $f = \frac{R}{2}$ (f = focal length, R = radius of curvature)

Ex) object is placed between focus and diverging lens. Real, virtual, smaller, larger?



Object / Image — Therefore the image formed is virtual because the real rays do not converge, and the image is smaller.

33.5 - Snel's Law

- Speed of light in a medium is specified by the index of refraction $n = \frac{c_0}{c}$ (c_0 ← vaccuum, c ← medium)
- wavelength λ is greater in the medium in which wave speed is greater
- Snel's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$
  - ↳ where: n_1 = index of refraction for medium 1, n_2 for medium 2, θ_1 = angle of incidence, and θ_2 = angle of refraction
  - Critical angle of incidence θ_c (beyond which tot. int. reflection occurs) is given by: $\theta_c = \sin^{-1}\left(\frac{n_1}{n_2}\right)$

33.6 - Thin Lenses and Optical Instruments

- A thin lens allows for refractions but is not thick enough for dispersion
- Lens equation: $\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$, where:
  - f = focal length of lens
  - o = distance from lens to object
  - i = distance from lens to image

  This equation is true for real images, virtual images, converging lenses, or diverging lenses
- For a converging lens, f & o are positive if object is in front of lens
- If image is on same side as emerging light → image is real & i is positive
- If image is on opp side as emerging light → image is virtual & i is negative
- i is always negative for diverging lenses

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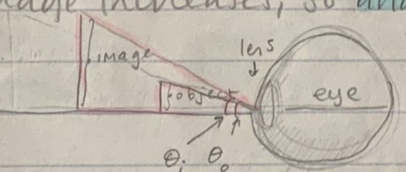
Sign conventions for f, i, and o (positive = real, negative = virtual)

sign	lens	mirror
f = +	converging lens	converging mirror
f = -	diverging lens	diverging mirror
o = +	object in front of lens	object in front of mirror
o = -	object behind lens	object behind mirror
i = +	image behind lens	object in front of mirror
i = -	image in front of lens	object behind mirror
h_i = +	image upright	image upright
h_i = -	image inverted	image inverted
$\|M\|>1$	image larger than object	image larger than object
$\|M\|<1$	image smaller than object	image smaller than object

* where "in front" means on the side where rays originate

- Magnification of image = ratio of image height to object height $\Rightarrow \frac{h_i}{h_o} = -\frac{i}{o}$
  - ↳ M is written this way so that magnification of upright images is positive and that of inverted images is negative
  - The angle created between the object and the observer increases as the image increases, so angular magnification is defined as $M = \left|\frac{\theta_i}{\theta_o}\right|$

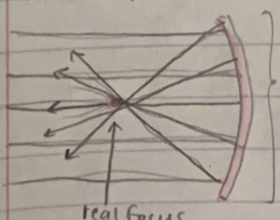


Small angle/paraxial approximation of θ_i (subtended angle): $\theta_i = \tan\theta = \frac{h_o}{f}$ (good to within 1% for angles ≤ 10°)

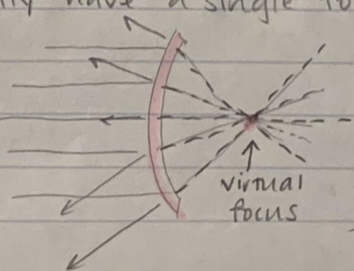
- Diopters: $d = \frac{1m}{f}$, where d is the lens strength measured in diopters and is positive for converging lenses and negative for diverging lenses

33.7 - Spherical Mirrors

- Concave mirror - focuses parallel rays to a real focus (converging)
- Convex mirror - focuses parallel rays to a virtual focus (diverging)
  - Spherical mirrors only have a single focus



concave mirror



convex mirror

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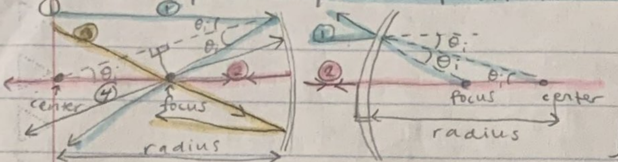
- **Principal Rays for Spherical Mirrors:**

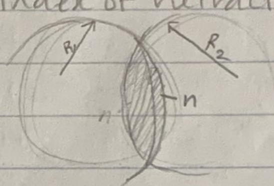


① Parallel to mirror axis → through focus
② Normal incidence → reflected back along axis
③ Passes through focus → parallel to axis
④ Perpendicular to mirror surface → reflects back on itself

- $f = \frac{R}{2}$ ⇒ where R = radius of curvature, f = focal length
- lens equation $\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$ still applies for spherical mirrors

33.8 Lensmakers Formula

- Focal length of lens depends on lens' index of refraction n and on radii of curvature R_1, R_2 of the lens faces



- Lensmakers Formula: $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$
  ↳ where n = index of refraction