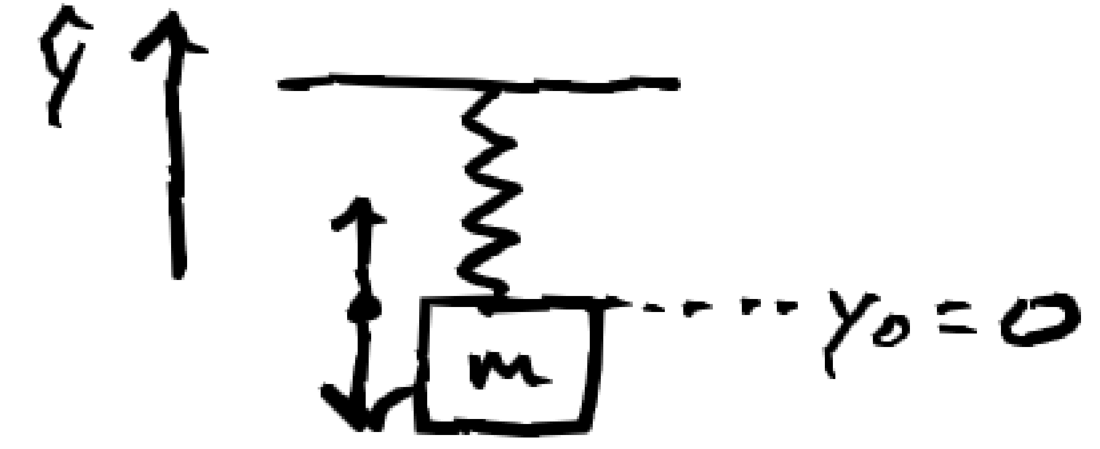
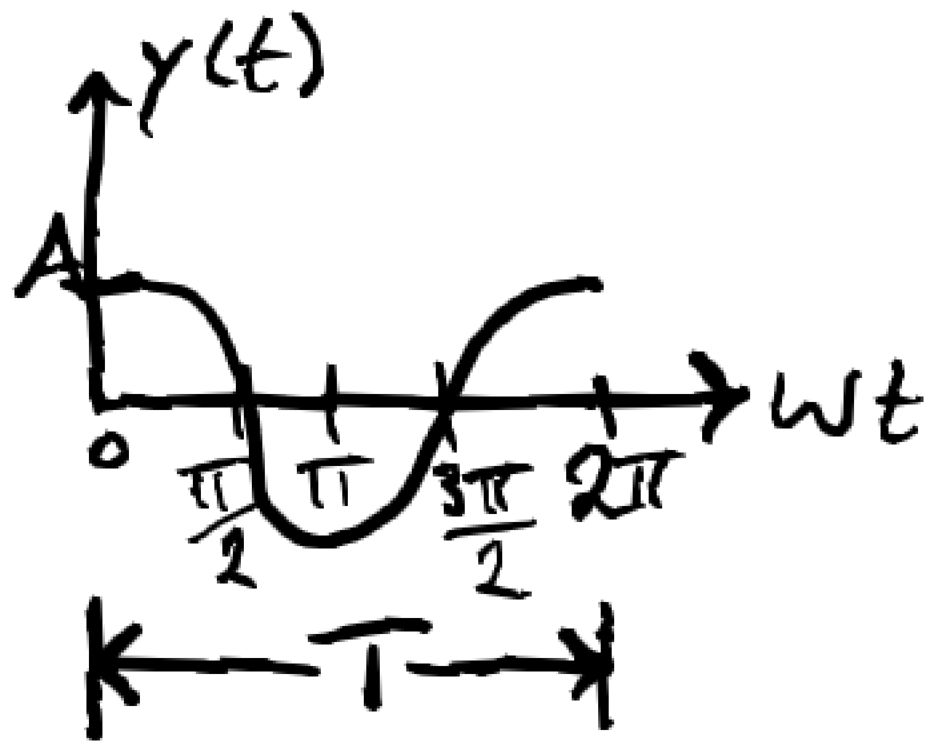
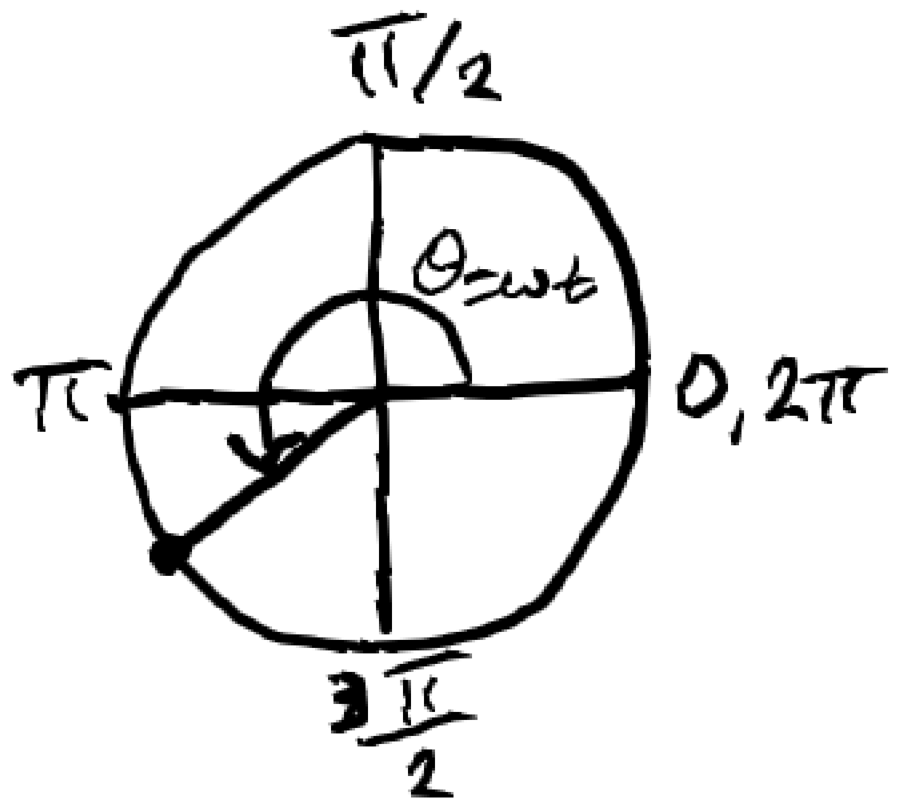
Lab 1: Simple Harmonic Motion

Part 1







Position

$y(t) = A\cos(\omega t)$

A = amplitude

$\omega = \frac{\Delta\theta}{\Delta t} = 2\pi f = \frac{2\pi}{T}$

T = Period of oscillation

Velocity

$$v(t) = -\underbrace{A\omega}\sin(\omega t)$$
$$= -v_{max}\sin(\omega t)$$

Acceleration

$$a(t) = -\underbrace{A\omega^2}\cos(\omega t)$$
$$= -a_{max}\cos(\omega t)$$

Newton's 2nd Law

$F = ma$

Hooke's Law

$F_s = -k\Delta y$

$\rightarrow -k\Delta y = ma$

$\rightarrow -k\Delta y = -mA\omega^2\cos(\omega t)$

Max acceleration $\Rightarrow$ Max Δy, $\cos(\omega t) = 1$

$\rightarrow k\Delta y = m\Delta y\omega^2$

$\rightarrow \omega = \sqrt{\frac{k}{m}}$; $\omega = \frac{2\pi}{T}$

$\Rightarrow T = 2\pi\sqrt{\frac{m}{k}}$

(Assuming Massless Spring)

Consider fractional mass of Spring

f_{ms}

$m \rightarrow m + f_{ms}$

So, $T = 2\pi\sqrt{\frac{m + f_{ms}}{k}}$

$T^2 = 4\pi^2\left(\frac{m + f_{ms}}{k}\right)$

$$\rightarrow T^2 = \underbrace{\left(\frac{4\pi^2}{k}\right)}_{\text{slope}} m + \underbrace{\left(\frac{4\pi^2 f_{ms}}{k}\right)}_{\text{y-intercept}}$$

$k = \frac{4\pi^2}{\text{slope}}$

Part 2

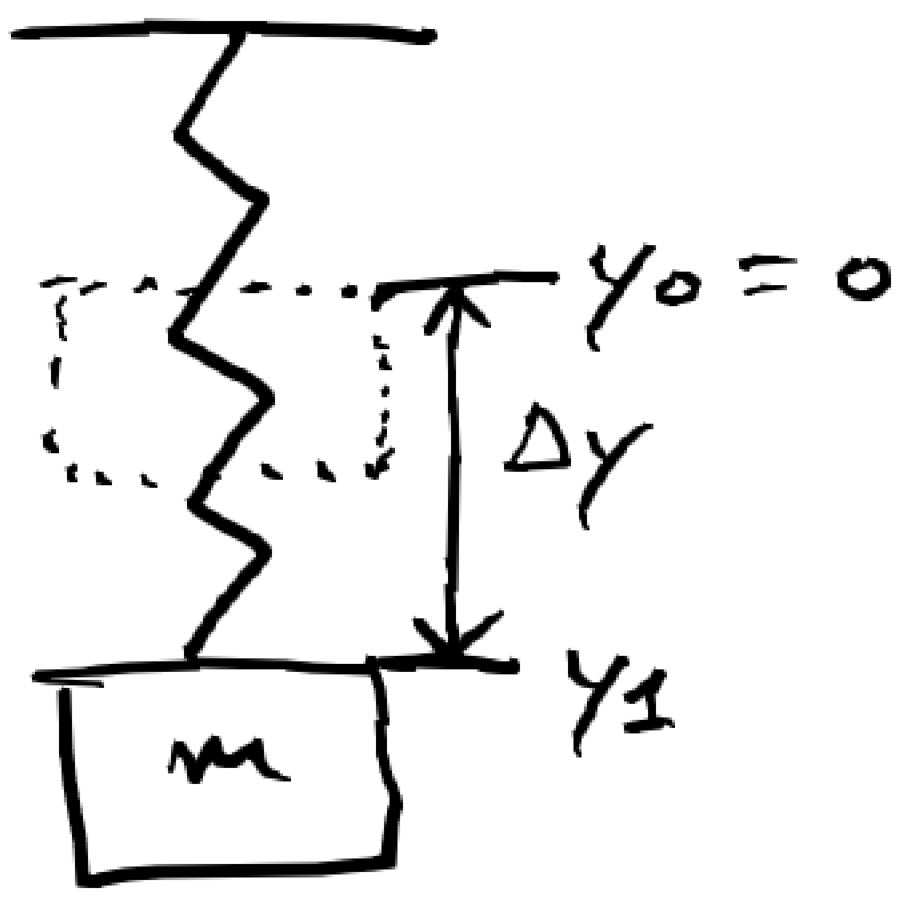
- $F = -k\Delta y$

At equilibrium,

$|F_{gravity}| = |F_{spring}|$

$\rightarrow mg = k\Delta y$

$\Rightarrow k = \dfrac{mg}{\Delta y}$

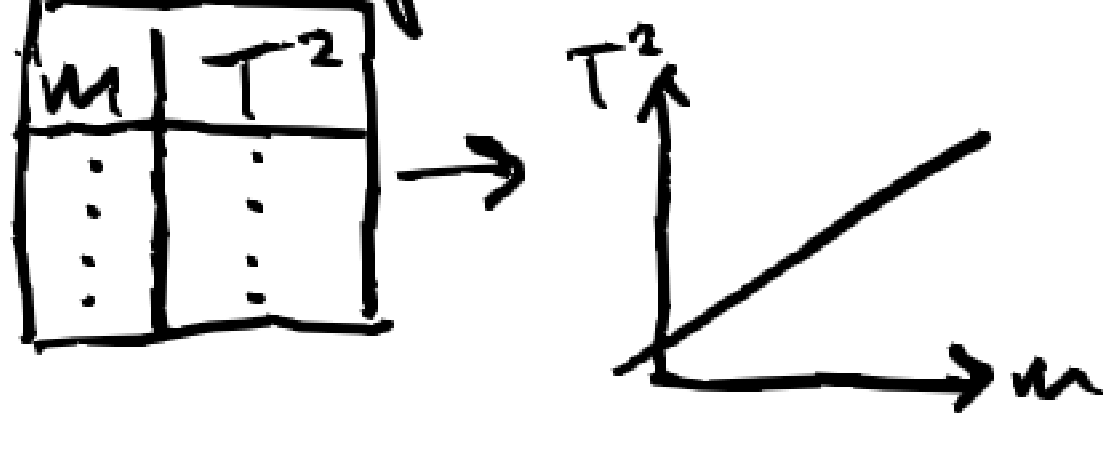


Part 1

1) Measure mass of spring

2) 6 different weights $\left(\overset{500g}{\text{large}} \rightarrow \overset{20g}{\text{small}}\right)$
to fill out table
- Measure time for 20 small oscillations
(lift weight up, don't pull down)
- Calculate Period $T = \frac{t}{20} \rightarrow$ # of osc.
- Square Period $\Rightarrow T^2$

3) Excel → Plot T^2 vs m
- find slope (use line of best fit)



4) Calculate Stiffness Constant K

5) Find expression for m_s from T^2 equation
- use K and y-int to calculate m_s.

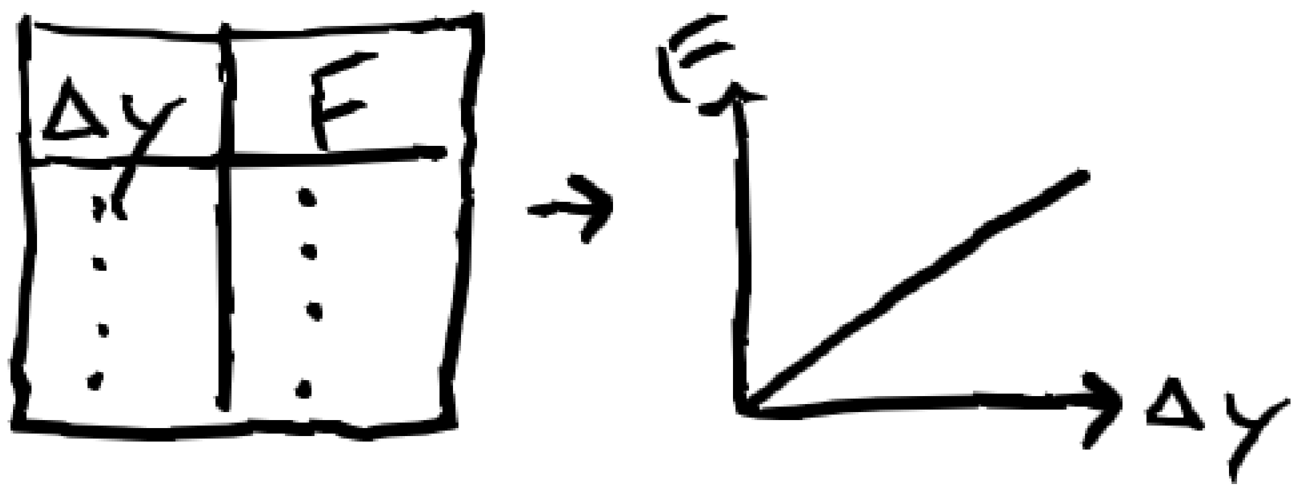
Part 2

1) Measure initial length of spring

2) Use same 6 weights
   - Measure length of spring after adding weight and it is at rest

3) Calculate $F = mg$ for each weight

4) Excel → Plot F vs Δy
   - find slope



Part 3 (PH 2233 Only)

- Procedure in manual is good.

Question 4: Information in the concept section will help to answer this.

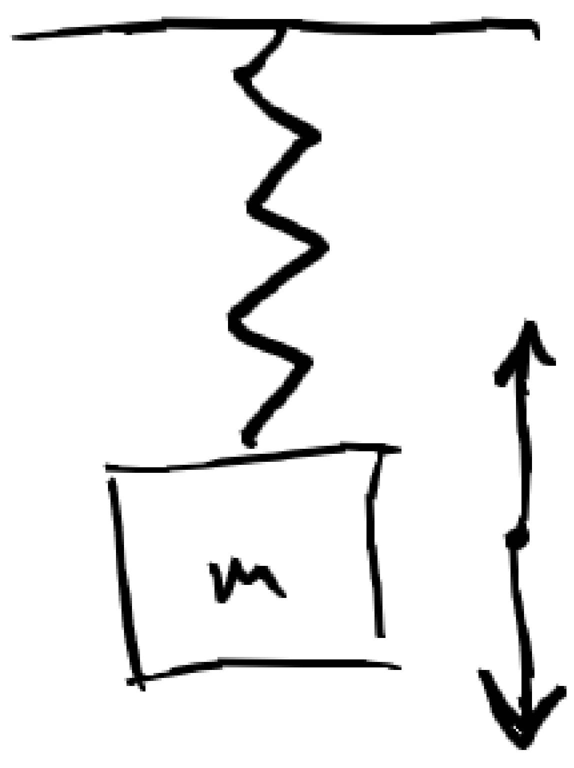
4d) If mass is pulled down: $y(t) = A\sin(\omega t - \frac{\pi}{2})$; $\phi = -\frac{\pi}{2}$
$y(t) = A\cos(\omega t + \pi)$; $\phi = +\pi$

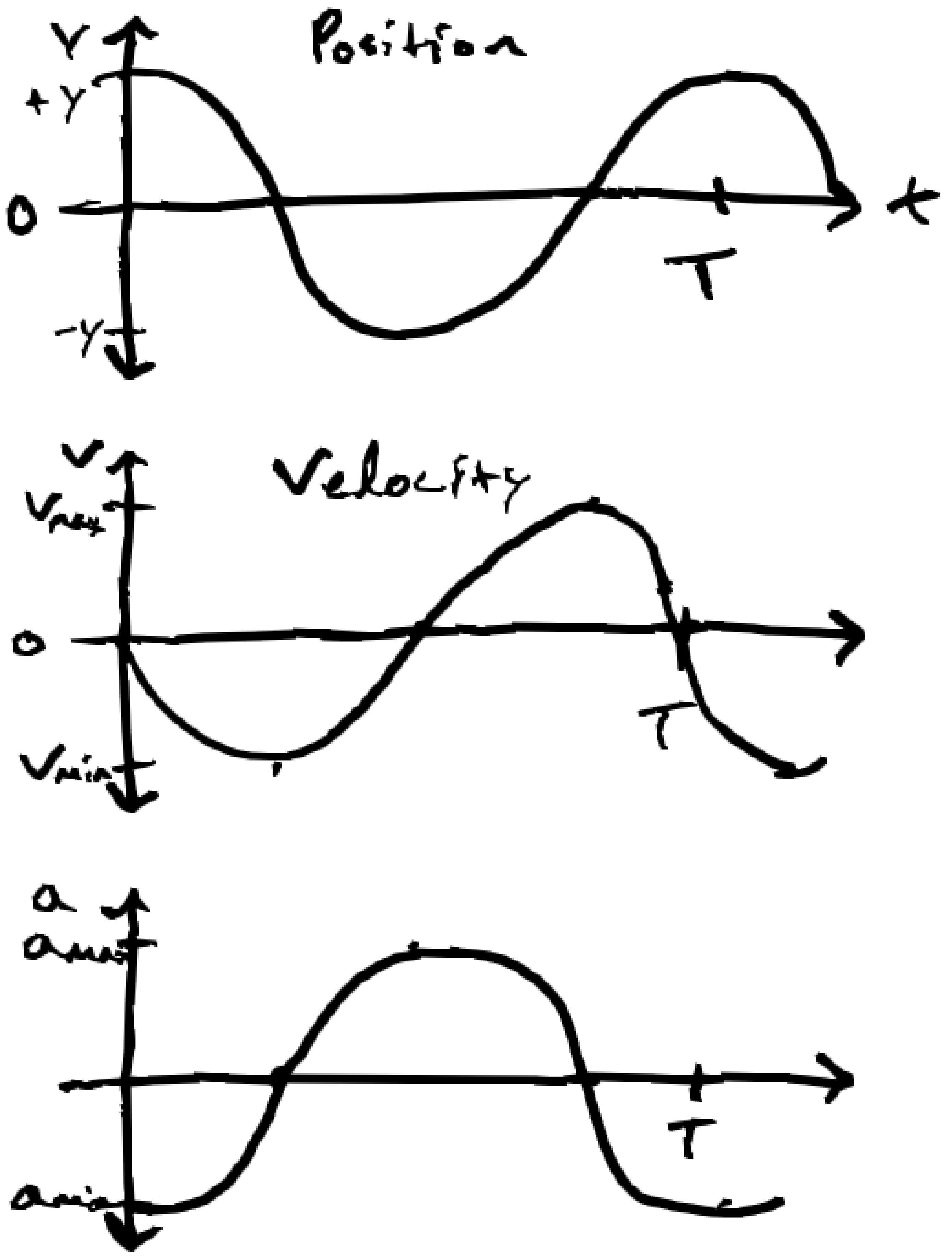
If mass is lifted up: $y(t) = A\sin(\omega t + \frac{\pi}{2})$; $\phi = +\frac{\pi}{2}$
$y(t) = A\cos(\omega t)$; $\phi = 0$

Question 5: Using $A = \frac{y_{max} - y_{min}}{2}$, $\omega = \frac{2\pi}{T}$

Calculate $y(t=1s)$ and $y(t=1.4s)$ then compare results with data from sensor. (Assuming the sensor started recording data exactly when the mass is at y_{min}.

Lab 2: Periodic Motion

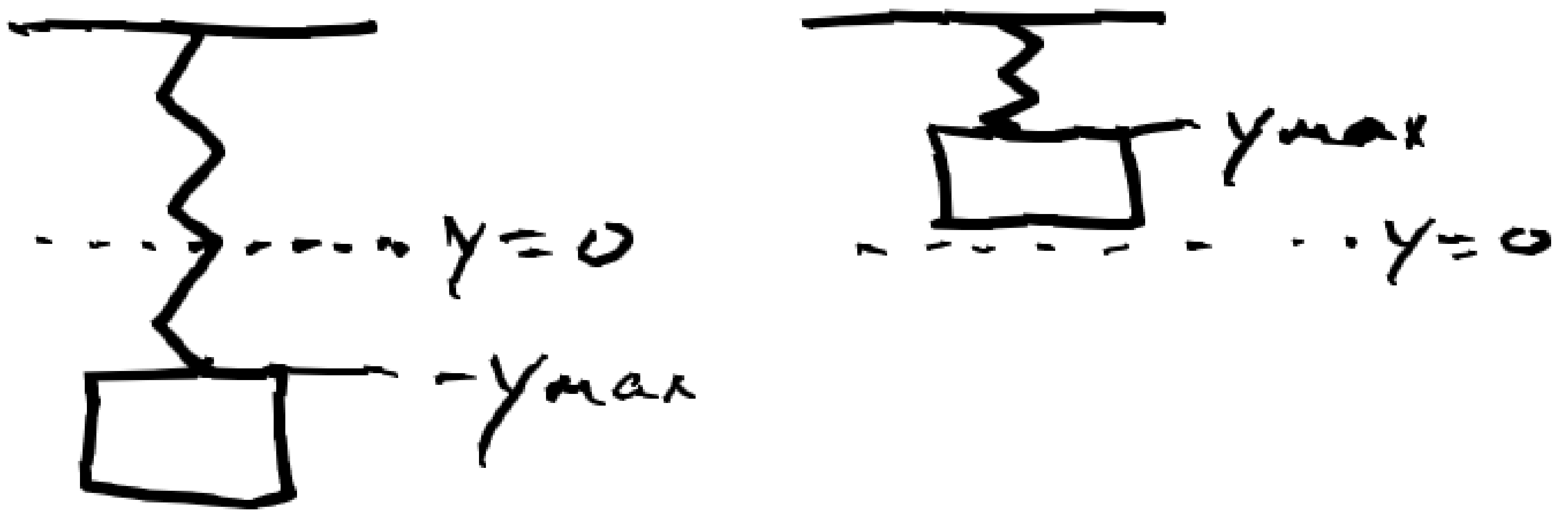




Oscillation driven by exchange of kinetic and potential energy.

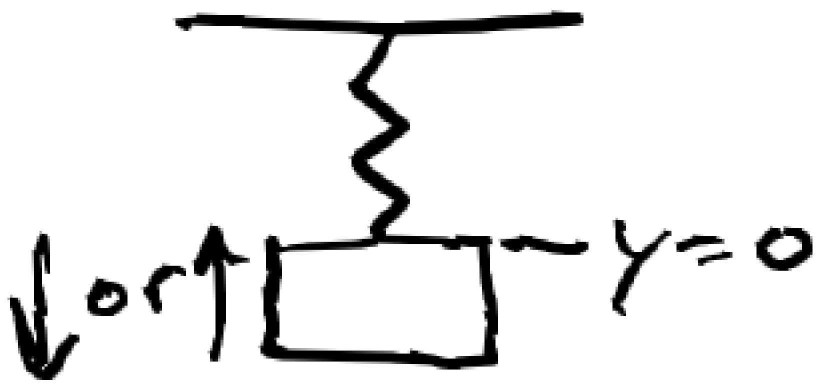
$$E = KE + PE$$

$KE = \frac{1}{2}mv^2$ $PE = \frac{1}{2}ky^2$; y= distance from equilibrium



Max Displacement: $v=0$, $y=\text{max}$, $a=\text{max}$

→ $KE=0$, $PE=\text{max}$



Zero Displacement: $y=0$, $a=0$, $v=\text{max}$

→ $KE=\text{max}$, $PE=0$

Procedure

- Connect Motion Sensor to Pasco Interface (Motion Sensor CH)
- Place sensor ~40cm below spring
  - Directly below weight
- Measure Height of weight from top of sensor.
- Double click "Graph" icon on right
- Click ⌞* icon on top to get 3 total graphs
  - Position, Velocity, Acceleration
- Table 1: 3 trials - Same mass, different displacements
  - Click -¦- icon to add Multicoordinate tool
    - Right click little box → Tool Settings
      → Numerical Format
      → Number of Decimal Places = 3
    - Repeat for each box.
  - Use Multicoordinate Tool to find min, max Position.
  - Amplitude = $\frac{\text{max} - \text{min}}{2}$
  - Equilibrium Point = $\frac{\text{max} + \text{min}}{2}$
  - T_1(s) and T_2(s) = times of two consecutive max positions.
  - Calculate Period and Spring Constant

- Table 2: 1 Trial - 3 points (Not max, min, equilibrium)
  - Random Points
  - For each point, find Acceleration and Displacement
  - Calculate $F = m\underset{\substack{\uparrow \\ \text{acceleration}}}{a}$ and $F_s = -k\underset{\substack{\uparrow \\ \text{displacement}}}{x}$

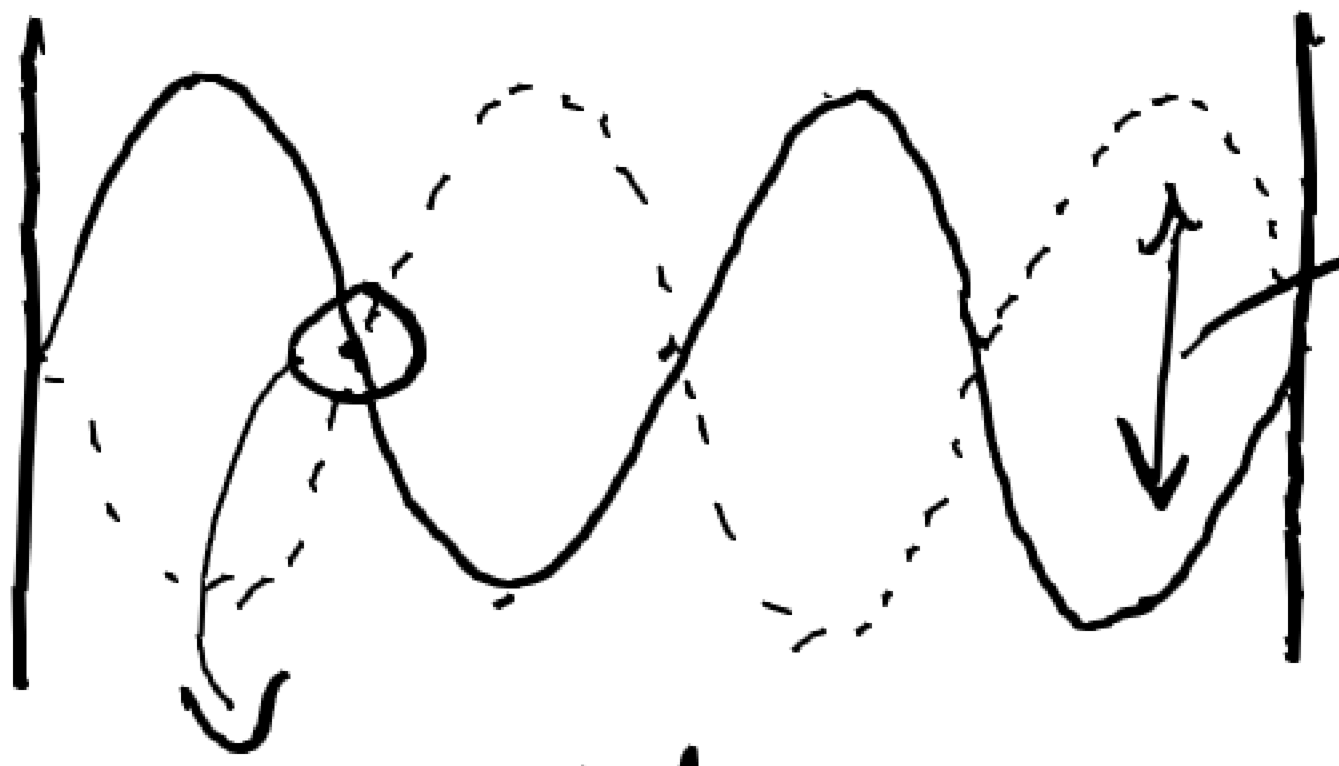
$T = 2\pi\sqrt{\frac{m}{K}}$ $K = m\left(\frac{2\pi}{T}\right)^2$

Lab 3: Standing Wave on a String

Transverse wave traveling along string

Reflected

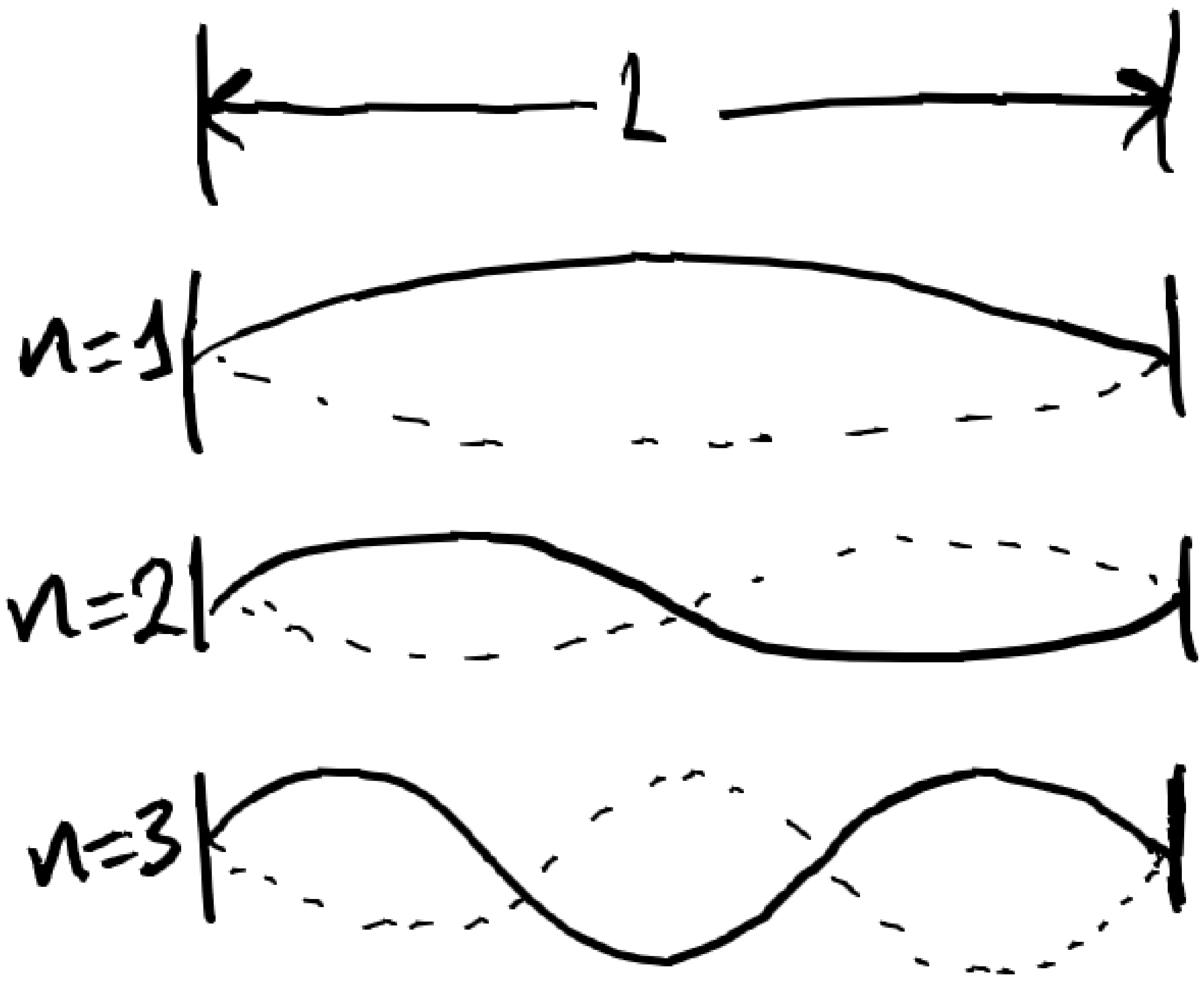
Interference - Energy of waves are either added together (constructive interference) or cancel each other (destructive interference).



Antinodes: Waves add together (2x Amplitude)

Nodes: Waves cancel

Harmonic: Natural frequency produced by two waves combining to form standing wave. (same Amp + f.)



$\frac{1}{2}\lambda_1 = L \rightarrow \lambda_1 = \frac{2}{1}L$

$\lambda_2 = L \rightarrow \lambda_2 = \frac{2}{2}L$

$\frac{3}{2}\lambda_3 = L \rightarrow \lambda_3 = \frac{2}{3}L$

Harmonics occur only when there is a node at each end.

Lowest frequency for this: fundimental frequency
(first Harmonic)

- $n=1$

There are $n+1$ nodes and n antinodes in every standing wave.

For n^{th} harmonic:

$$\lambda_n = \frac{2}{n}L$$

$$v = \frac{\lambda}{T} = \lambda f$$

For string under tension:

$$v = \sqrt{\frac{F_T}{\mu}}$$; μ = Mass per unit length for string.

$$\mu = 0.0002 \, \frac{kg}{m}$$

Equipment Setup

- Plug wires into frequency output 
- Hardware Setup → Output Frequency Sensor
- Signal Generator (4th icon under Hardware Setup)
  → 120 Hz, 3V
  → On

Lab Procedure

1) Measure length of string in meters
   - From where it is tied to device to where it touches pulley
2) Measure mass of weight hanger. ~10g
3) Use varying weights to find 6 diff. harmonics
   - Start with ~1000g to get n=1, then go down in weight
   - Count nodes (n+1)
4) Plot v vs λ on Excel
   - Find Slope using data points

Challenge: Draw transverse wave and longitudinal wave

PH 2233 Only

Guitar String Problem

$$v = \sqrt{\frac{F_T}{\mu}} = \lambda f = \frac{2L}{n} f \; ; \; n=1$$

$$\rightarrow F_T = v^2 \mu = 4L^2 f^2 \mu$$

$$D \rightarrow F_T = 4(1m)^2(293\,Hz)^2(.0072\,kg/m) = 2472.45N$$

$$G \rightarrow F_T = 4(1.1m)^2(192\,Hz)^2(.0062\,kg/m) = 1106.21\,N$$

$$B \rightarrow F_T = 4(1.1m)^2(246\,Hz)^2(.0068\,kg/m) = 1991.70\,N$$

$$E \rightarrow F_T = 4(1\,m)^2(329\,Hz)^2(.0075\,kg/m) = 3247.23N$$

Last Problem

$$y(x,t) = A\sin(\omega t)\sin(kx) \; , \; v = \frac{\lambda\omega}{2\pi} = \frac{\lambda}{2\pi}\sqrt{\frac{k}{m}}$$

$$\frac{\partial^2 y}{\partial x^2} = \frac{\mu}{F_T}\frac{\partial^2 y}{\partial t^2}$$

$$\frac{\partial^2 y}{\partial x^2} = -Ak^2\sin(\omega t)\sin(kx)$$

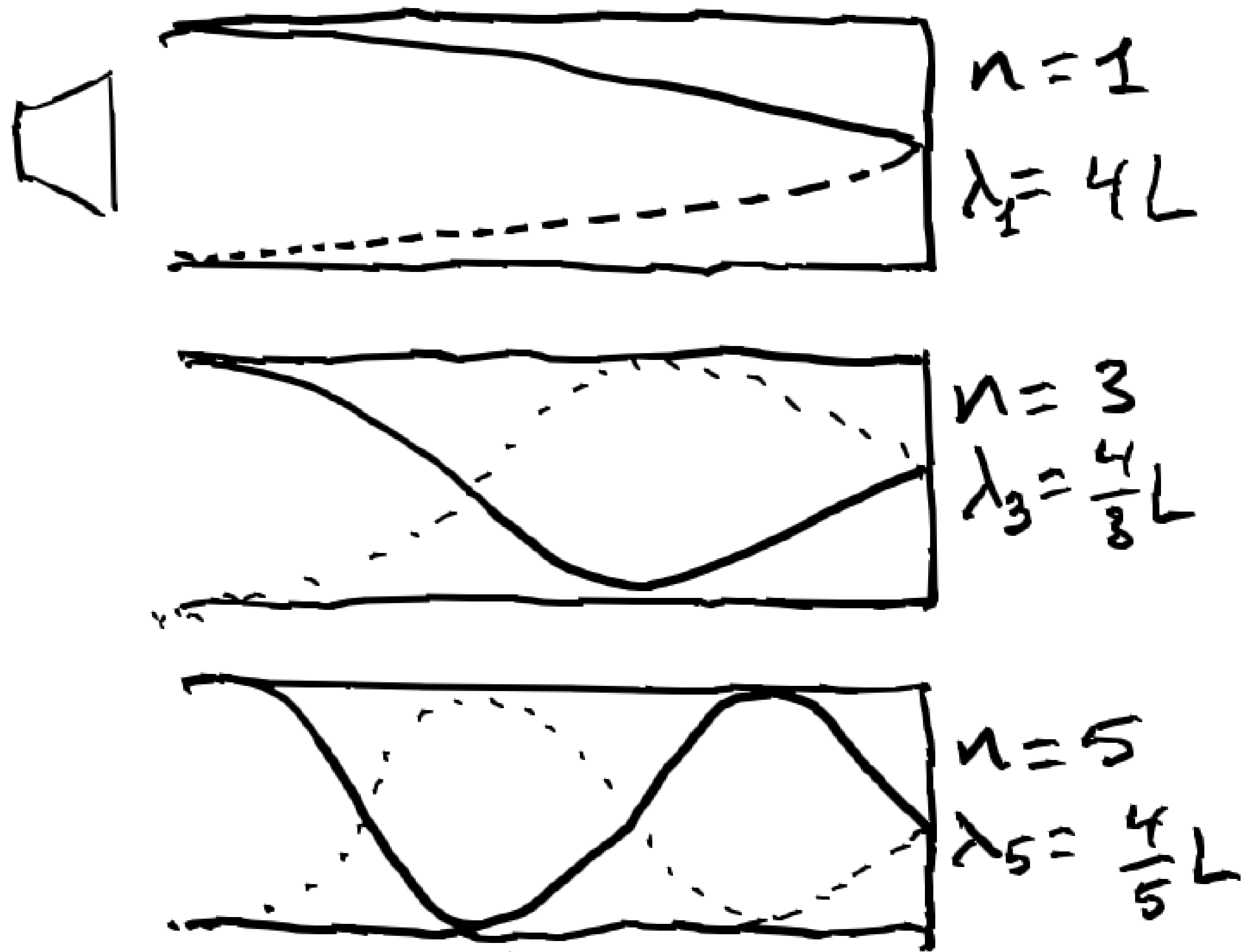
$$\frac{\partial^2 y}{\partial t^2} = -A\omega^2\sin(\omega t)\sin(kx)$$

$$\frac{\mu}{F_T} = \frac{1}{v^2} = \frac{4\pi^2}{\lambda^2\omega^2}$$

$$\rightarrow -Ak^2\sin(\omega t)\sin(kx) = -\frac{4\pi^2}{\lambda^2\omega^2}A\omega^2\sin(\omega t)\sin(kx)$$

$$\rightarrow \underset{\substack{\downarrow \\ \text{Angular Wave} \\ \text{Number } k = \frac{2\pi}{\lambda}}}{k^2} = \frac{4\pi^2}{\lambda^2} \Bigg\} \text{They need to show how this is true.}$$

Lab 4: Resonance Tube



Open end of tube is an antinode, and closed end is a node.

The reason is because sound is a longitudinal wave, so the air particles are moving back and forth. At the closed end, the movement is not possible.

This results in only odd harmonics

→ $n = 1, 3, 5, 7, \cdots$

$$V = \lambda f \rightarrow \lambda_n = \frac{4L}{n}, \; f_n = n\frac{V}{4L}$$

Speed of sound depends on air temp.

$V_s = (331.3 + 0.606\,T_c)\frac{m}{s}$; T_c = Temp of air in C.

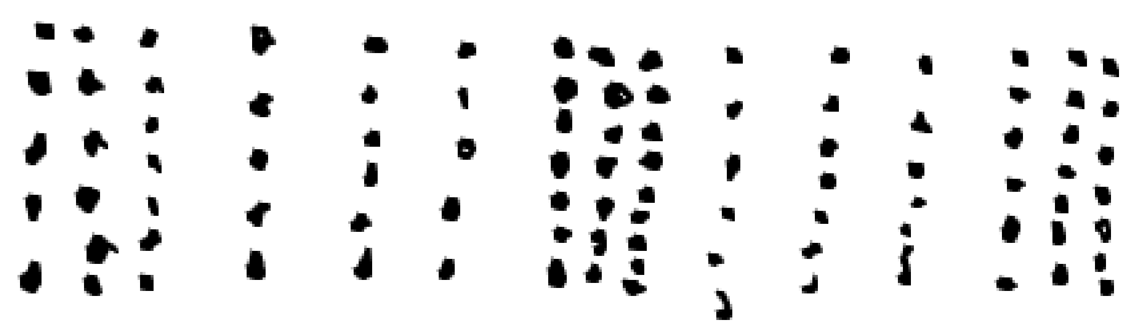
Procedure in manual is good to follow, except

→ Step 9: When the sound gets louder, move the piston back and forth slightly to find the best position which gives the loudest resonance, then mark the position.

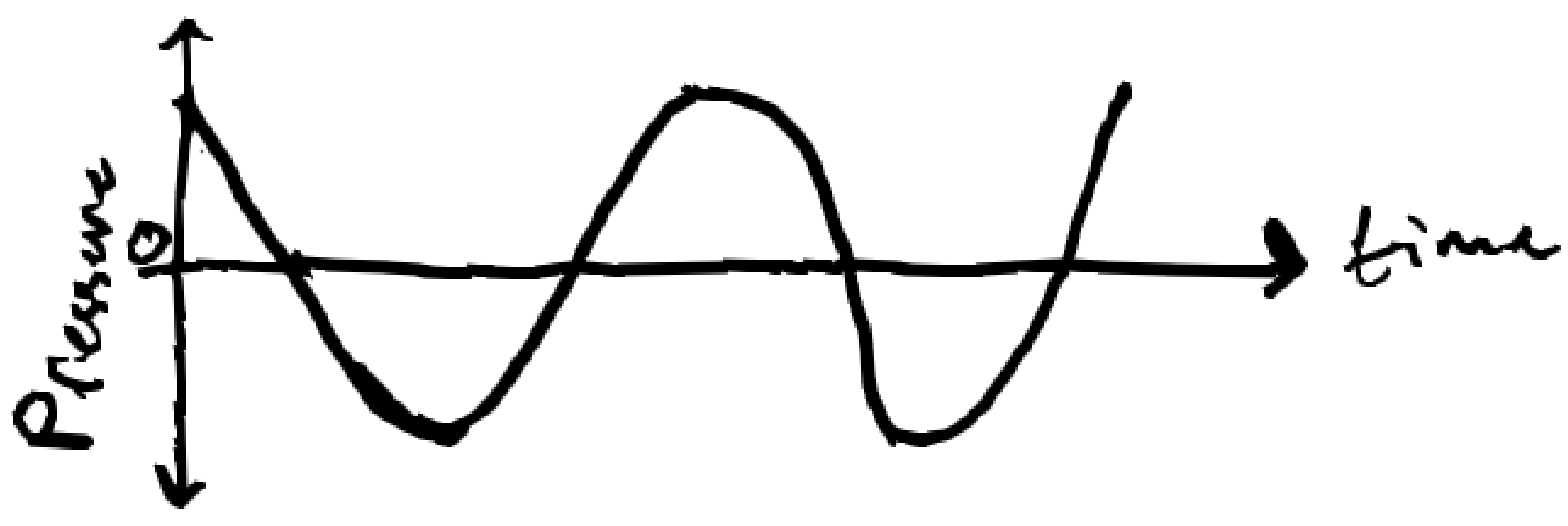
Step 10: Move the piston past that position until the next position where the sound gets louder and repeat step 9.

Sound

- Pressure wave created by vibrations.



Pressure wave through air particles



High pressure regions: Compressions } Density changes as particles compress
Low pressure regions: Rarefactions } and decompress

- Energy is transfered through this periodic vibration of particles
  - Sound is detected when this energy causes other things to vibrate (eg. ear drums, diaphragm of microphone)
    - This lab: Sound Sensor - Vibrations in air pressure cause vibrations in a diaphragm → Creates electric signal.

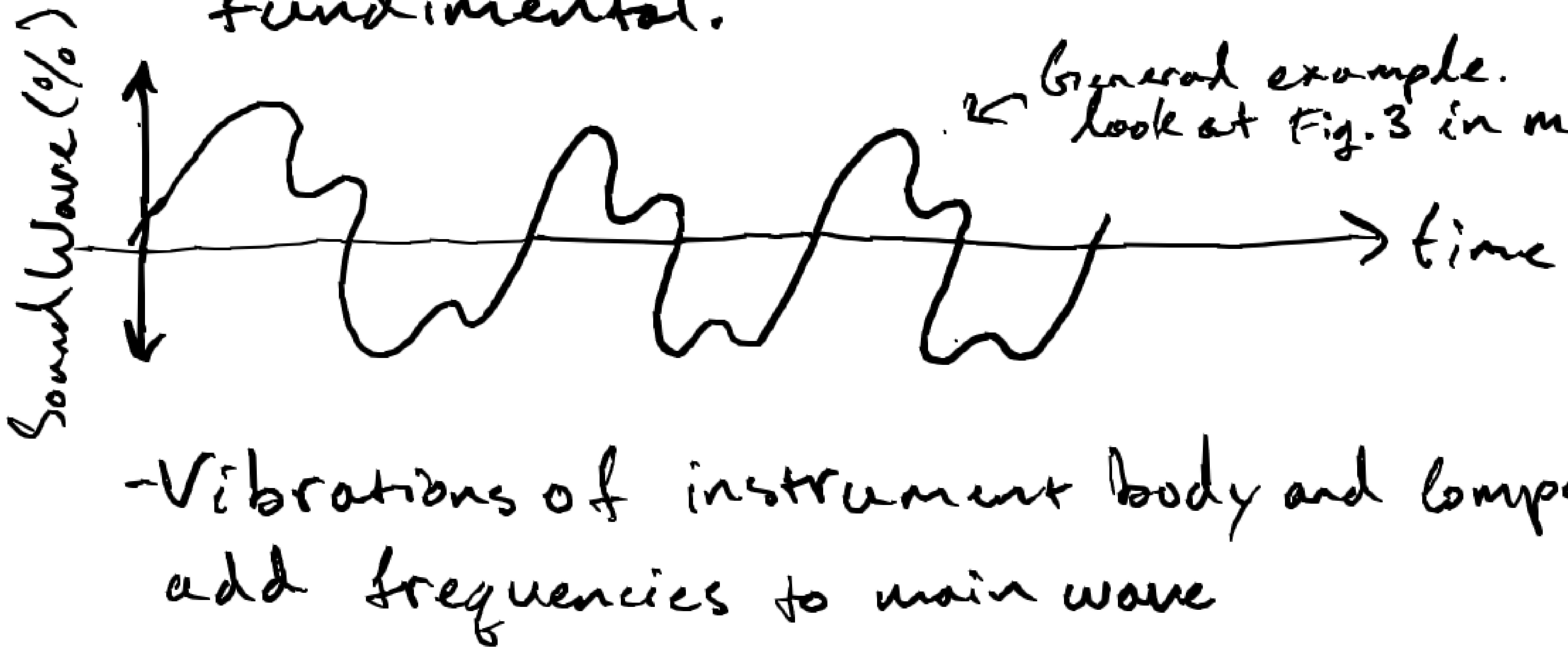
- Speed of sound depends on density and elasticity of the medium
  - Lower density = faster speed of sound
  - Stronger attraction between particles = faster sound.
  - Speed of sound is slow in air because air is easily compressible.
  - Air density depends on temperature

→ $V_s = (331.3 + 0.606 T_c)$ m/s ; T_c = temp of air in Celsius
(ignoring humidity effect)

- Music combines resonant sound wave frequencies, created by the vibration of various instruments and their parts, in complex scales (Patterns of particular sound waves) that are tied closely to Mathematics and are pleasing to listen to.

- Complexity in musical sounds is due to Overtones: any resonant frequency that is higher than the fundimental frequency.

  * Harmonic frequencies (Studied in last lab) are the overtones that are specifically integer multiples of the fundimental.



General example. look at Fig. 3 in manual

- Vibrations of instrument body and components add frequencies to main wave

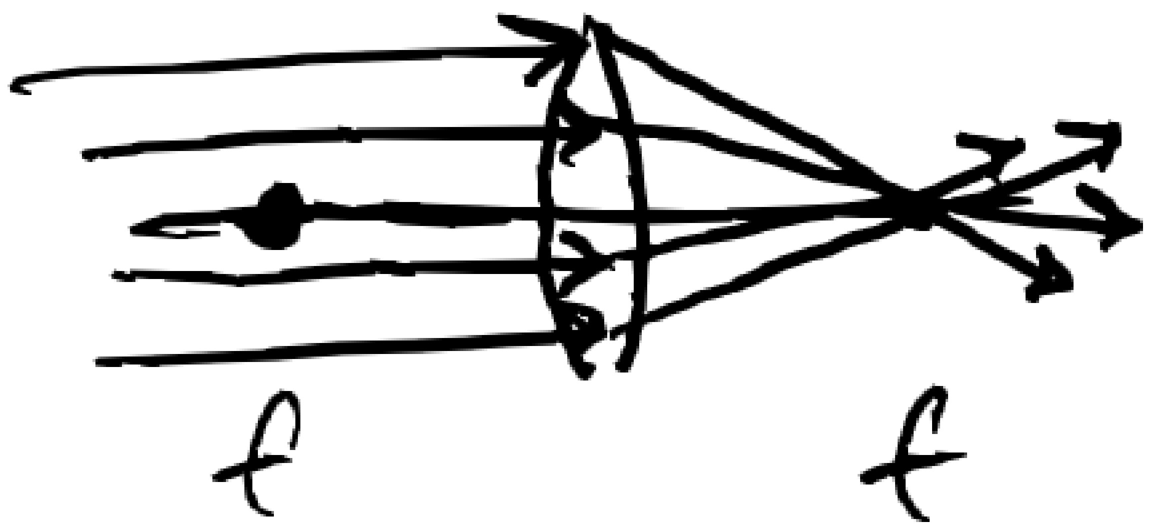
Lab 6 Thin Lenses

- Light is an Electromagnetic Wave
- Speed of light changes when it enters a new medium. This causes it to bend (Refraction)
- Lenses use their shape to bend light in a way that focuses it at a point.

Thin Lens Equation

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \Big| \quad \text{if } d_o = \infty \rightarrow \frac{1}{d_o} = 0 \rightarrow \frac{1}{f} = \frac{1}{d_i}$$

- Parallel rays are focused at focal point
- Rays from objects at infinity arrive parallel, because all other rays have diverged away



Magnification

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

h_i - image height

h_o - object height

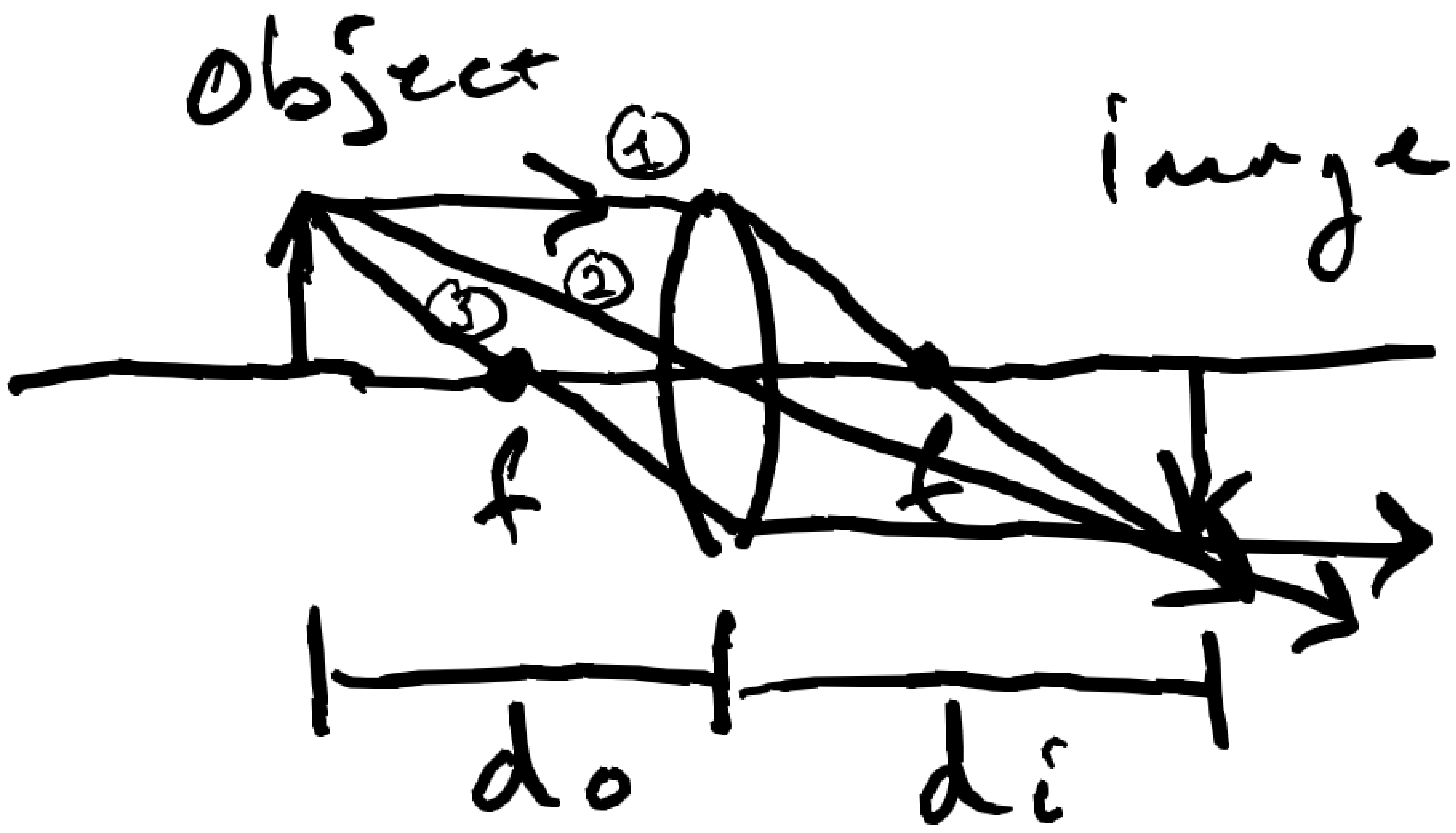
- $M < 0$ → Inverted image (Negative Magnification)
- $|M| < 1$ → Reduced image
- $|M| > 1$ → Enlarged image

Ray Diagrams

- Lens drawn with axis through center
- Distances <u>Must</u> be drawn to scale.
- Distances always measured from center line of lens
- Object Distance is positive if on opposite side of lens from eye, Negative if on same side as eye
- Image Distance is positive if on same side of lens as eye, Negative if on opposite side.

Convex Lens (Converging Lens)

- Positive f
- Light Rays Converge



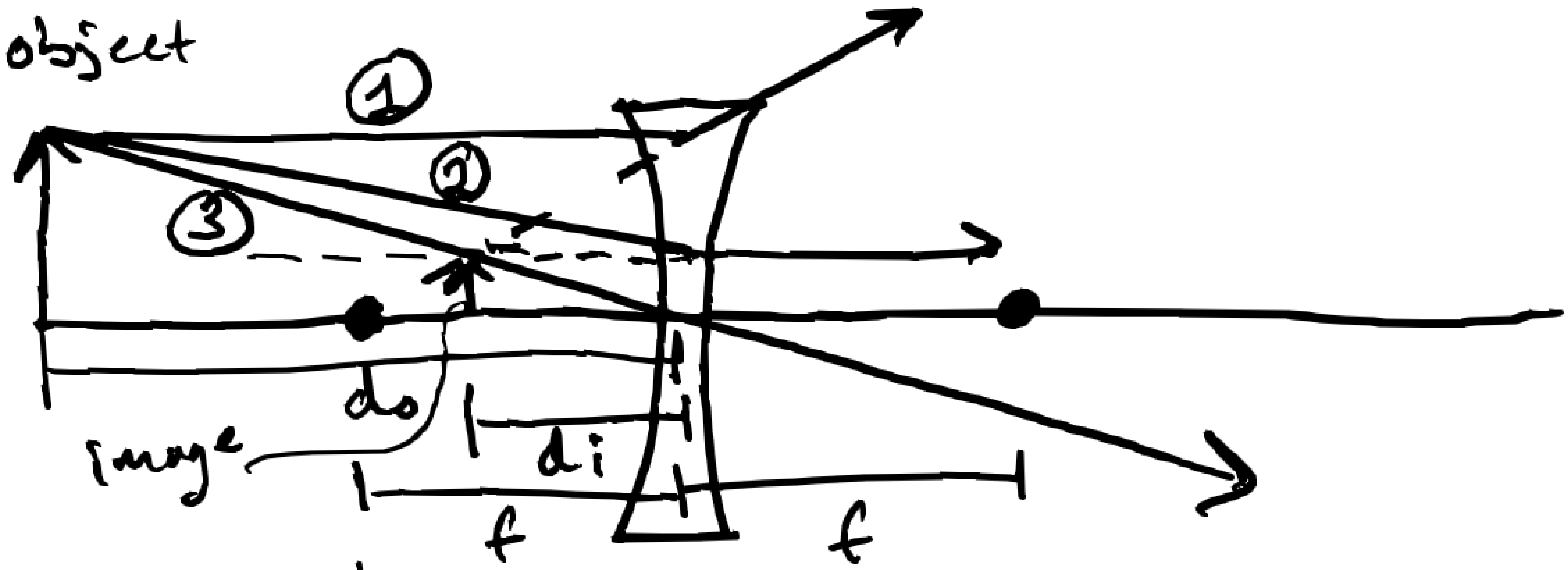
Rays to draw

1) from top of object, parallel to axis, to center of lens, then to focal point on opposite side.
2) from top of object, straight through middle of lens.
3) from top of object, through focal point, to center of lens, then parallel.

- Image forms where Rays intersect.

Concave Lens (Diverging Lens)

- Negative f
- Light Rays Diverge



Rays to draw

① From top of object, parallel to axis, to center line, then away in line with a dotted line from object side focal point.

② From top of object, in line with far side focal point, to center line, then parallel with dotted line going back.

③ From top of object straight through center of lens.

- Image forms where dotted lines and line ③ intersect.

Real Image

- Can be projected on screen
- Formed on same side as eye
- Positive di
- Convex lens always forms Real image

Virtual Image

- Cannot be projected on screen
- Formed on opposite side of lens from eye
  - Can only be seen by looking through lens
- Negative di
- Concave lens always forms Virtual image

Double lens System

- Draw Ray diagram for 1st lens as if 2nd lens is not there
- Image of 1st lens becomes Object for 2nd lens
- Draw Ray diagram for 2nd lens as if 1st lens is not there, using image from 1st lens as object.

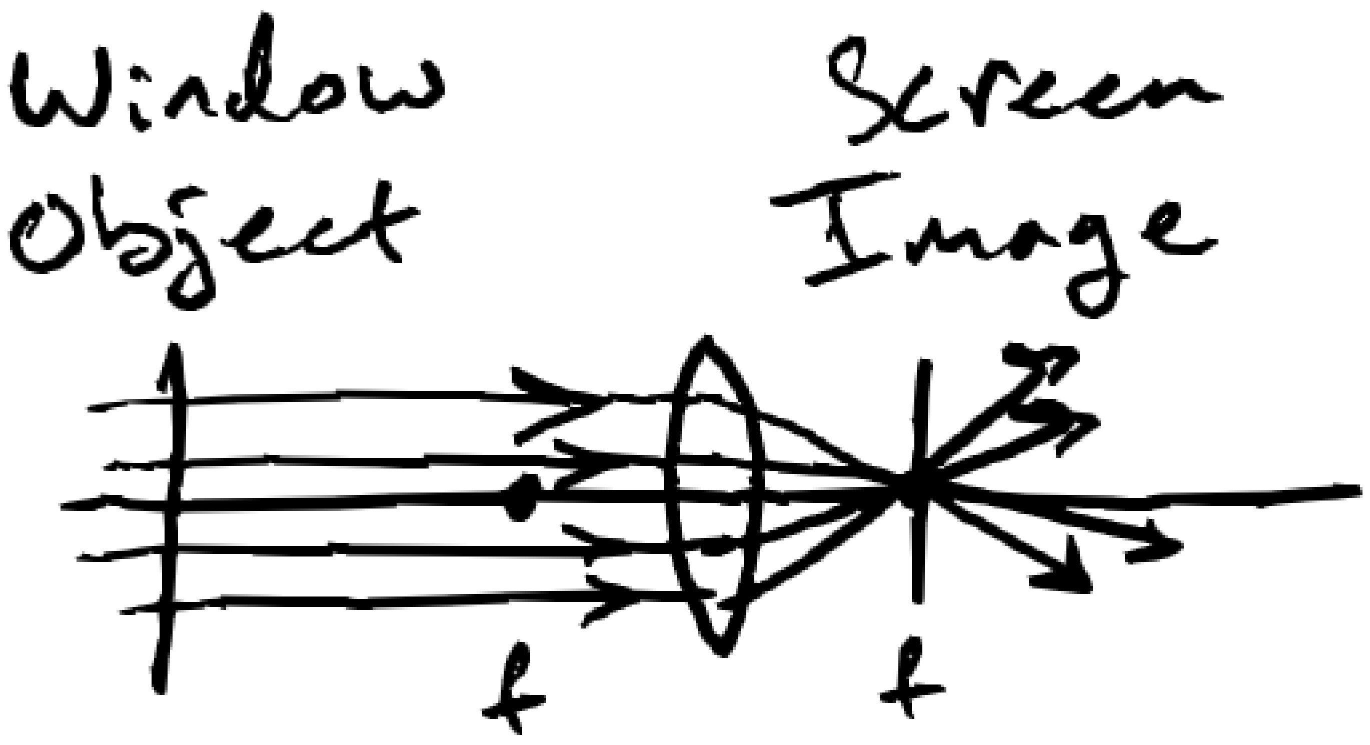
Procedure

Part 1

1) Use Sunlight to get focal length of Convex lens.

   - Open window shade
   - Place +100mm Convex lens and screen on Optical bench with the lens between the screen and window.
   - Move screen until image on screen is focused

2)



Real Object
Real Image

Part 2

1. Place light source at easy to measure spot on optical bench.
2. Place +100mm Convex lens on optical bench at least 11cm from light source.
3. Place screen after lens and adjust its position until image is well focused
4. Measure d_o, d_i, h_i, h_o ; $h_o = 4\text{cm}$ (will be Negative)
5. Calculate $f \rightarrow \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$, $M = \frac{h_i}{h_o}$, $M = \frac{-d_i}{d_o}$
6. Move lens to new position and repeat from 3.

3) Compare calculated f values to measured f value from part 1.

Possible errors:

- Poorly focused image
- Measurement error
- Math error

4) Compare $M = \frac{h_i}{h_o}$ to $M = \frac{-d_i}{d_o}$ in each trial.

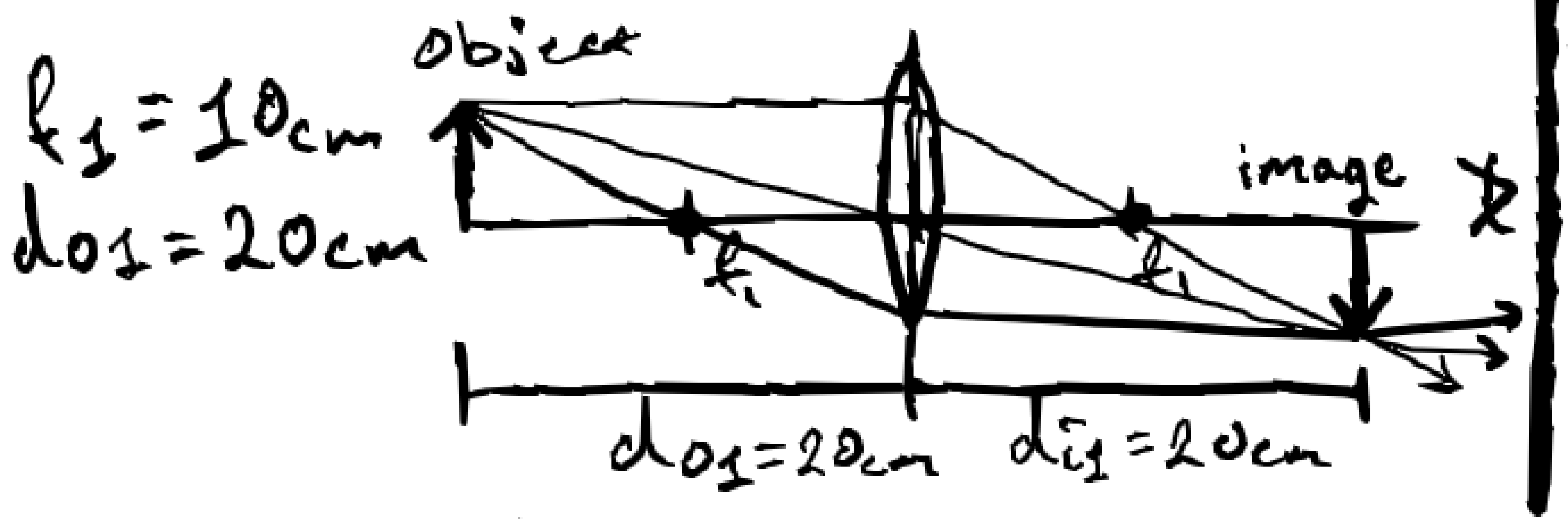
- $\frac{h_i}{h_o}$ is generally better since h_o is well known
- Possible errors are the same as above.

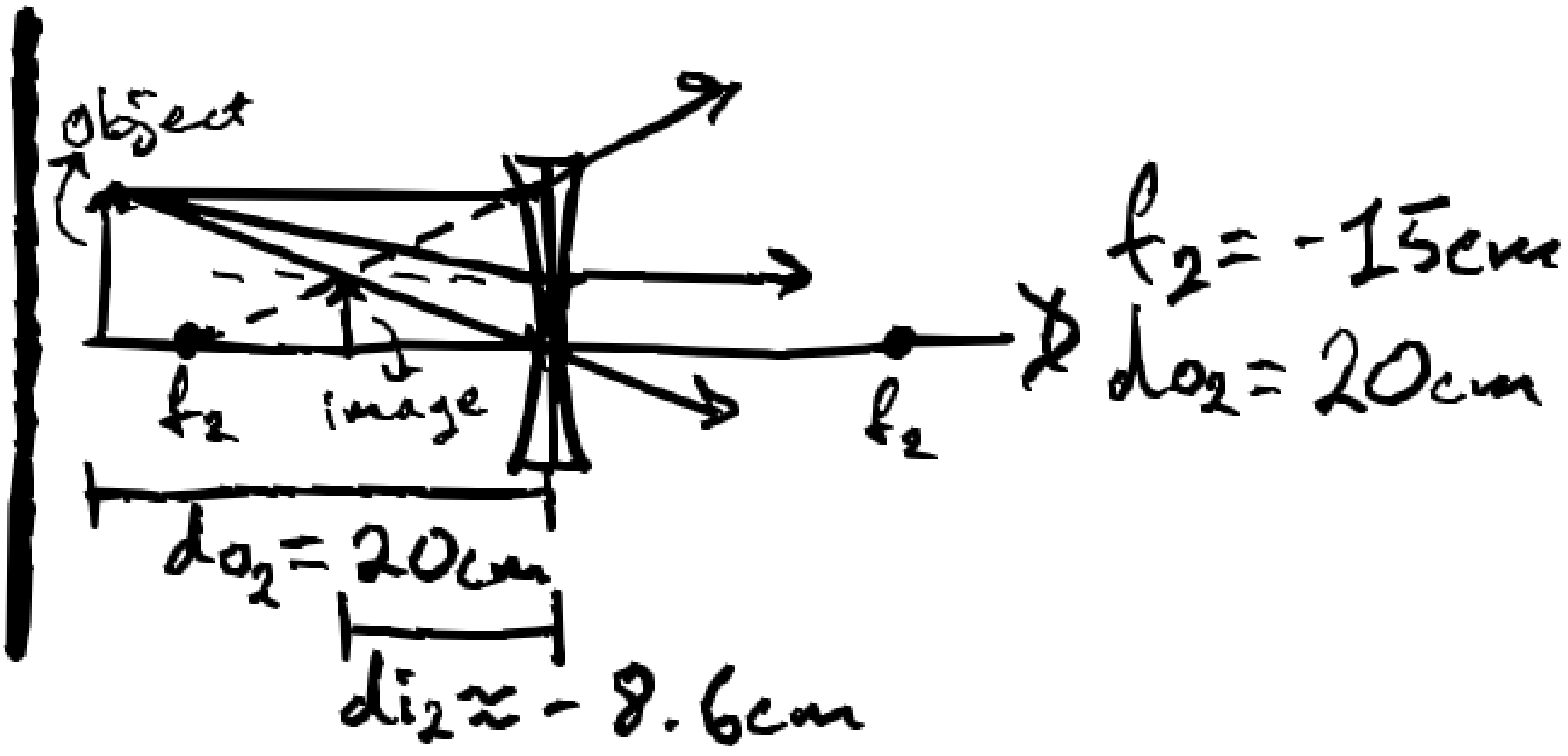
Part 3

1. Place +100mm Convex lens and find focused image on screen, just like part 2.
2. Measure d_{o1}, d_{i1}
3. Place -150mm Concave lens at around the middle point between Convex lens and screen without moving the screen.
4. Measure d_{o2}. d_{o2} is the distance between the -150mm Concave lens and the screen and is negative.
5. Move screen until image is focused
6. Measure d_{i2} (should be positive)
7. Calculate f_1 and f_2

5) Ray diagram for this double lens system is too complicated to expect students to understand and complete within the lab period, and it distracts from helping them with what will be on their exam.

Instead, I have them draw an accurate ray digram for a convex lens using f_1, d_{o1}, and d_{i1}, then separately draw an accurate ray diagram for a concave lens using f_2 and arbitrary but reasonable values for the object and image distances: (Good practice for lecture class)

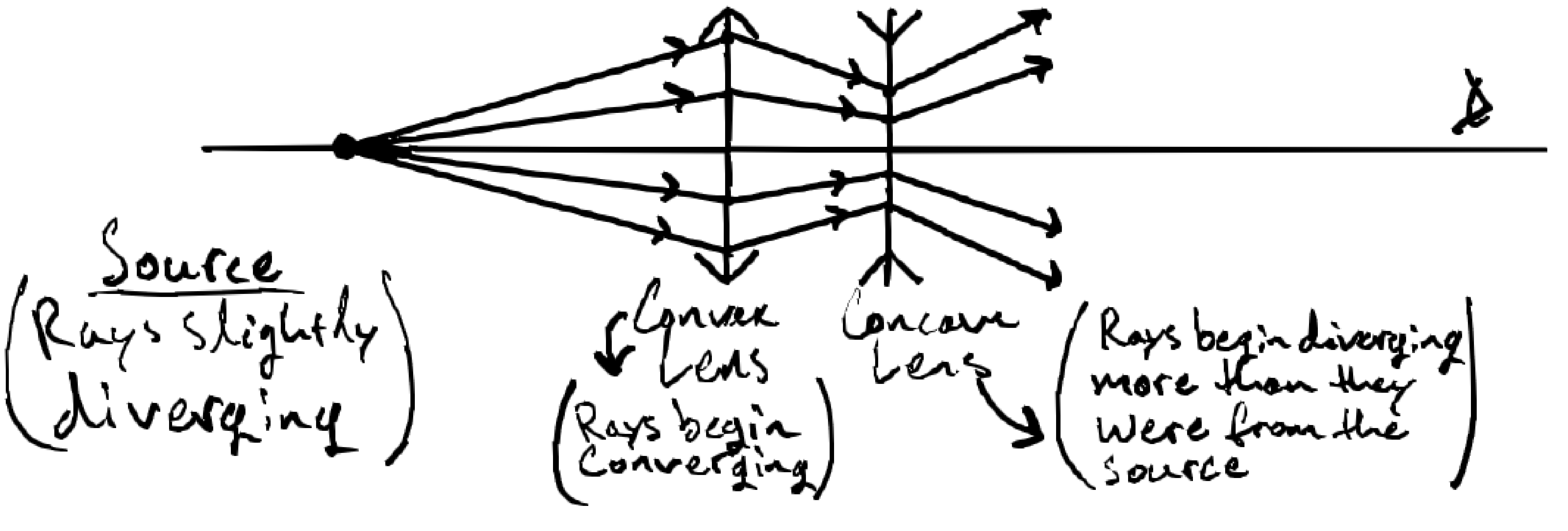




$$d_{i1} = \frac{1}{\left(\frac{1}{10cm} - \frac{1}{20cm}\right)} = 20cm$$

$$d_{i2} = \frac{1}{\left(\frac{-1}{15cm} - \frac{1}{20cm}\right)} \approx -8.6cm$$

Alternatively, they can draw a rough diagram showing what the light rays are doing as they pass through each lens: (Good for understanding physical concept)

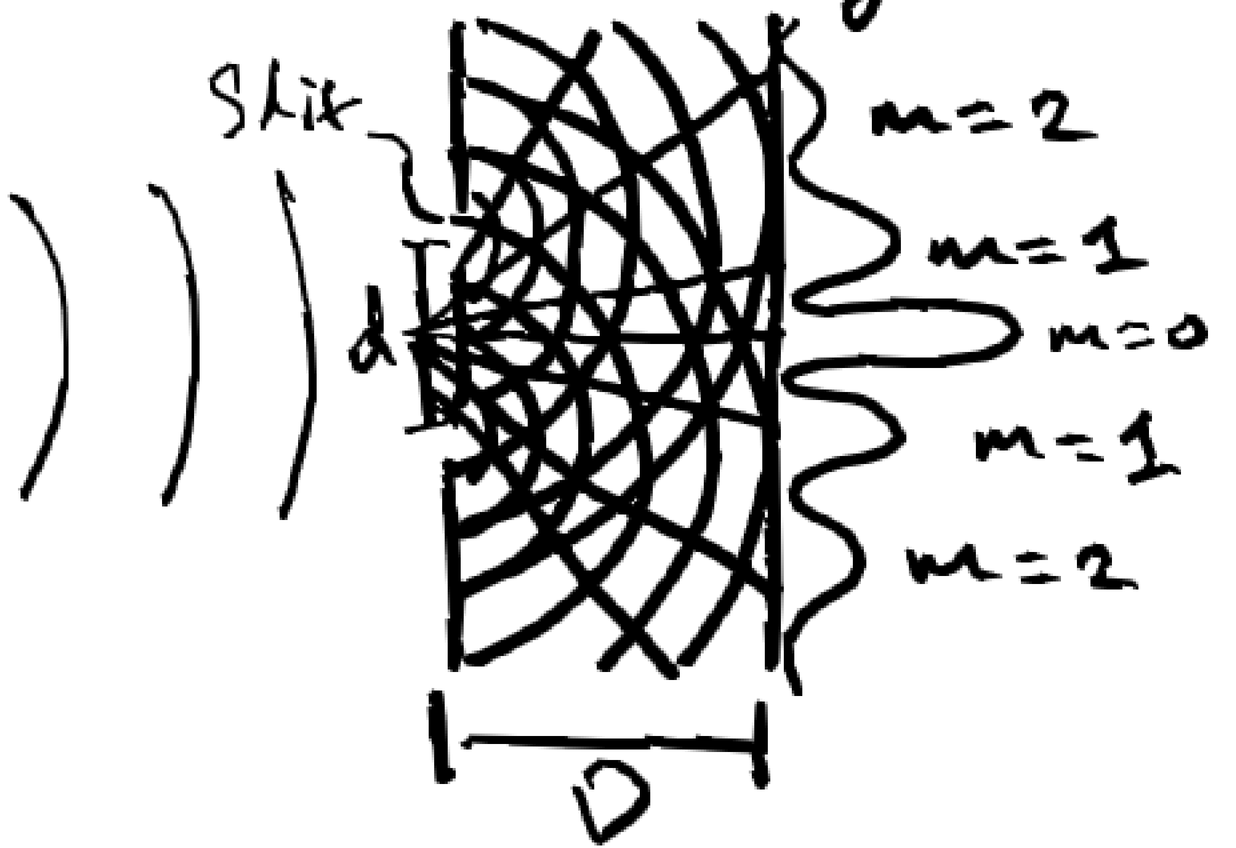


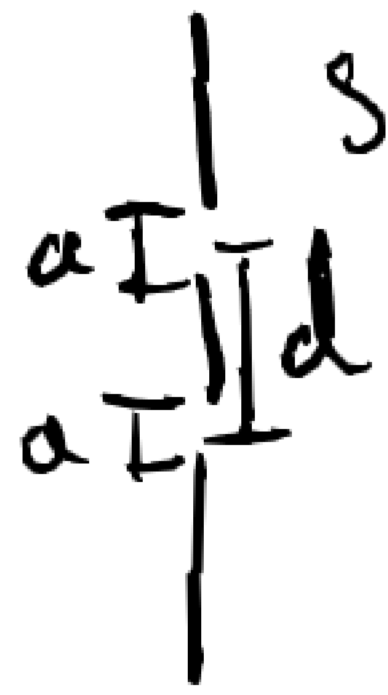
Lab 7: Interference and Diffraction

Interference: Wave phenomenon that occurs with all types of waves when two or more waves interact.

- Works by the principle of superposition:
  - When a physical system exists in multiple states simultaneously.
  - In the context of waves: Multiple waves can pass through each other, influencing the medium at the same time. (We saw this in Standing Waves)

peak + peak = Add together
peak + trough = Cancel each other





Slit width = a
Slit Separation = d

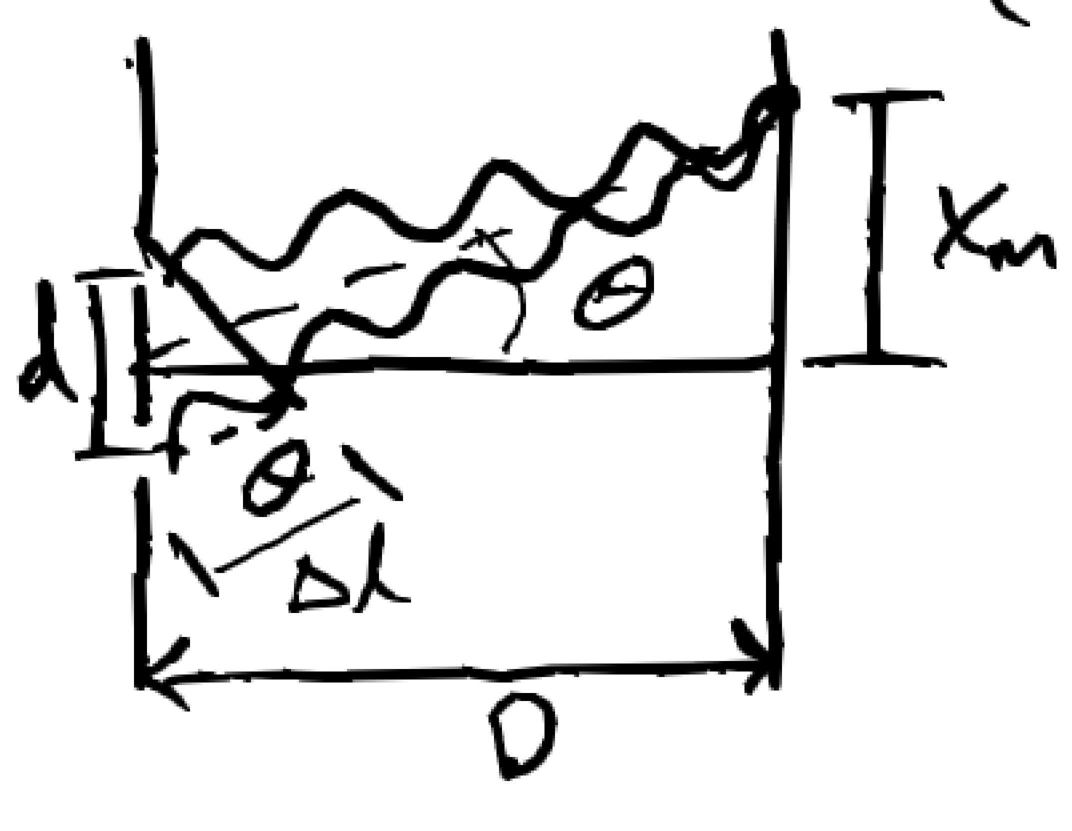
- Light hits two small slits, each acting as a source. Resulting Waves interact, creating interference pattern.

Interference pattern is due to phase offset

- Extra distance, Δl, traveled by one wave compared to another.

Coherent Waves: $\Delta l = m\lambda$ (constructive interference)

Incoherent Waves: $\Delta l = (m + \frac{1}{2})\lambda$ (destructive interference)

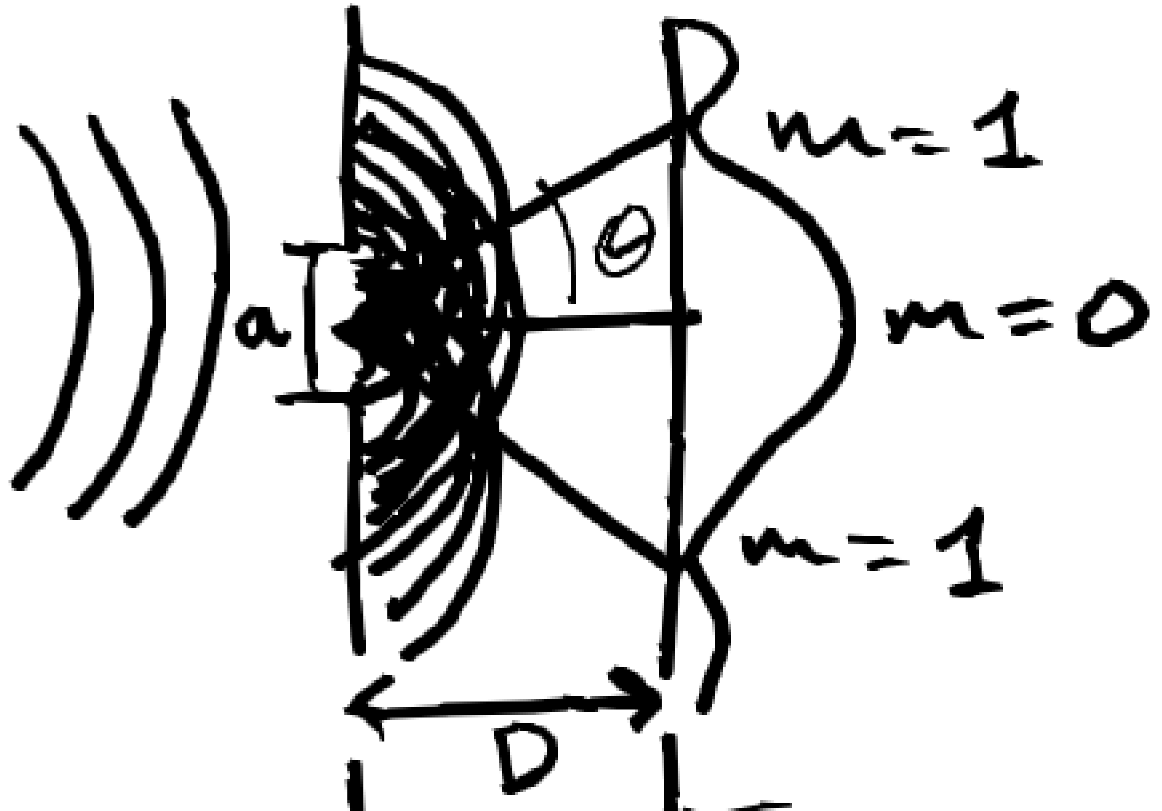


$\Delta l = d \sin\theta$

$\tan\theta = \frac{X_m}{D}$

Huygen's Principle: Each wave front is made up of small "wavelets" originating from an infinite number of points along wavefront.

- Basis of **Diffraction**: the spreading and interference of wavelets from wavefront.
- Can be ignored with double-slit interference
- Prominent in single-slit interference.



- Wavelets spread out from slit
- Interfere to create Diffraction pattern
- Equations for Constructive + Destructive interference swap in Single-Slit.
- $d \rightarrow a$

$\Delta l = a \sin\theta$

$\Delta l = m\lambda \rightarrow$ Destructive Int. (Dark Spot)

$\Delta l = (m+\frac{1}{2})\lambda \rightarrow$ Constructive Int. (Bright Spot)

$$\tan\theta = \frac{X_m}{D}$$

Procedure

Part 1 - Double Slit

1. Assemble laser and slits according to manual
2. Put Screen on optics track & measure its distance from slits: D
3. Clamp a worksheet to Screen so that interference pattern is aligned with measuring line.
4. Use measuring line to fill out table 1 on another worksheet for the diff. slit widths.
5. Calculate angle to first order bright spot: $\tan\theta = \frac{Y_1}{L}$ and wavelength: $\sin\theta = \frac{m\lambda}{d}$; $m=1$
6. Calculate Average wavelength and % difference.
7. Question 1: Number decreases, Size doesn't change

Part 2 - Single Slit

1. Clamp worksheet to screen as in Part 1 step 3, but with part 2 side.
2. Set Slits to Single-slit "$a = 0.02$mm"
3. Use measuring line to fill out table 2.
4. Calculate angle to first order dark spot: $\tan\theta = \frac{Y_1}{L}$ and wavelength: $\sin\theta = \frac{m\lambda}{D}$; $m=1$
5. Question 2: Wavelets interfere
6. Question 3: As slit width increases, the size of the Central bright spot decreases

Lab 8: Light Dispersion

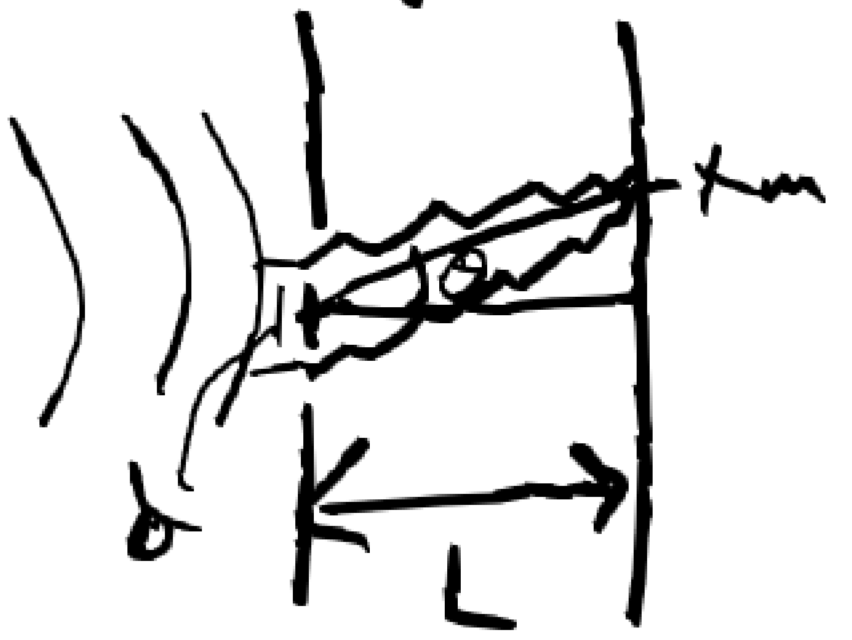
Polychromatic Dispersion: Light consisting of different Colors is split into its constituents.

Each wavelength of light disperses at its own angle.
- We saw this last lab for just one wavelength.
- In this lab, we will use more wavelengths

Double Slit

$d \sin\theta = m\lambda$, $\tan\theta = \frac{x_m}{L}$

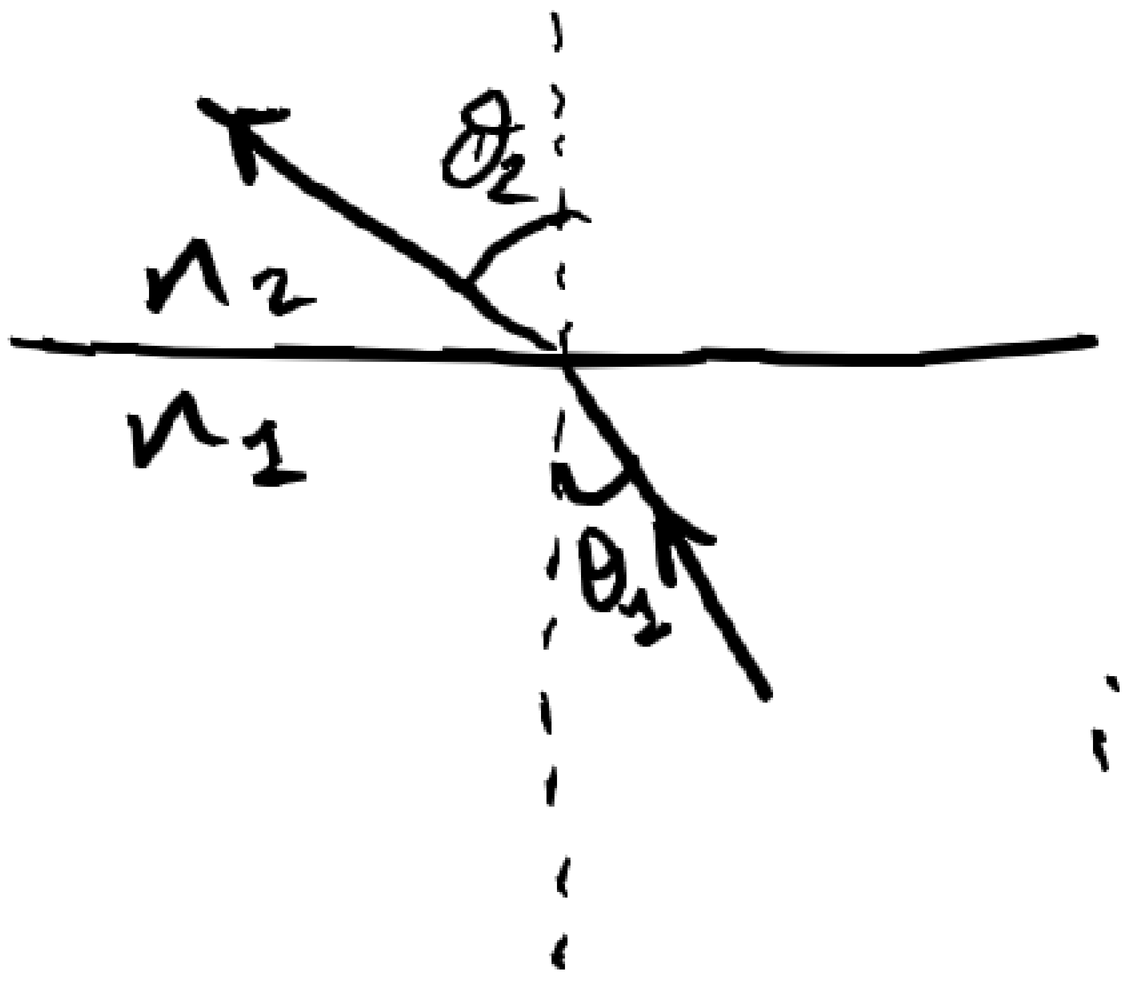
- Angle depends on slits and wavelength.



Refraction: Dispersion of light due to entering a different substance.

- Each wavelength of light has an index of refraction for each substance.

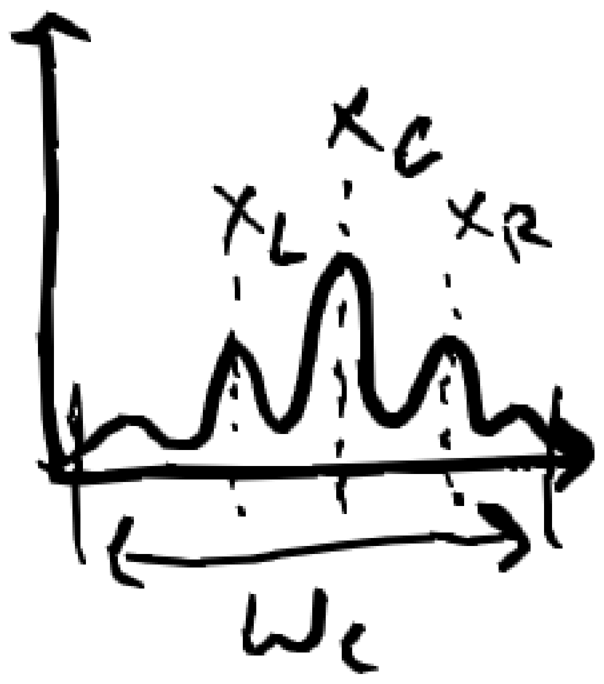
$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad \text{(Snell's law)}$$



Speed of light is different in different Substances.

if $n_1 > n_2$, then $v_1 < v_2$
and $\theta_2 > \theta_1$

Part 1



Xc = Center Peak Position

XL = First Fringe Left of Center Peak Position

XR = First Fringe Right of Center Peak Position

$$X_{1avg} = \frac{|X_c - X_L| + |X_R - X_c|}{2}$$

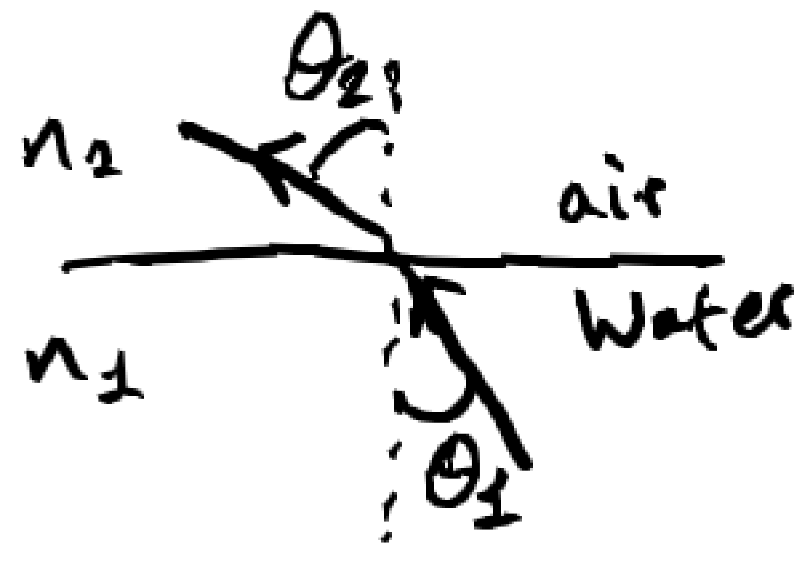
$$\tan\theta_{1avg} = \frac{X_{1avg}}{L}$$; L = Distance to slits from Screen.

Q1) Violet

Q2) Red

Q3) Violet has the smallest wavelength, and Red has the largest.

Part 2



$\theta_1 = 40°$, $n_2 = 1$

$n_1 \sin(40°) = \sin(\theta_2)$ (Solve for n_1)

- Repeat for Violet laser pen
  - Notice that n_1 is slightly different for violet.

Q4) Set red laser to $\theta_1 = 55°$

- All the light is reflected. $\theta_2 = 90°$
  - Total internal reflection
    - $\theta_1 = 55°$ is the critical angle.

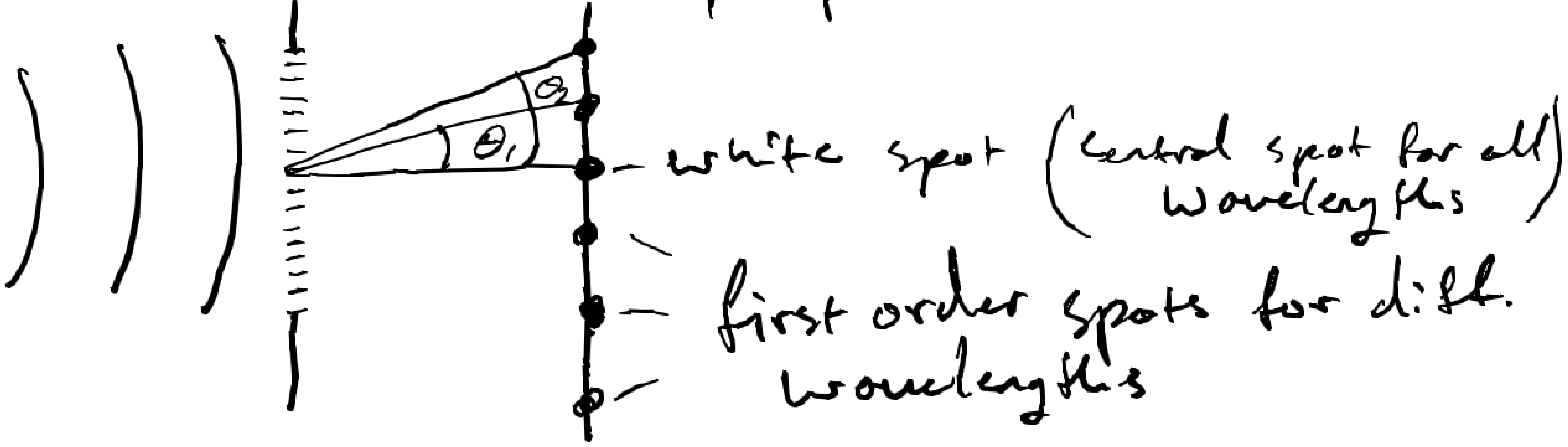
- I have been using the "Why?" part of Q4 as the interview question.

Lab 9: Grating Spectrometer.

In this lab, we use the diffraction pattern for polychromatic light from excited gas molecules to measure their spectra.

Every atom and molecule emits light at specific frequencies when excited due to its unique structure.

Diffraction Grating: Very many slits that are uniformly spaced.



Grating density: # of slits per mm

Slit separation: $\frac{1}{\text{density}} = d$

$$d \sin\theta = m\lambda$$

Procedure: Same as manual

Lab 10: Human Eye

The eye is a system of lenses.

- Light enters the eye through the cornea.
- Behind the cornea, is the iris, which surrounds the pupil and opens and closes to regulate how much light enters the eye.
- Between the iris and cornea is a fluid called the aqueous humor, which nourishes the eye and shapes cornea.
- Behind the iris is the crystalline lens, which is a convex lens that focuses light onto the retina.
- Between the lens and the retina is the vitreous humor, which is a clear fluid which supports the shape and size of the eye.
- At the back of the eye is the retina, which is the light sensitive part of the eye that contains the rods and cones.
  - Since the lens is a convex lens, the images that your eye sees are all inverted.
- Within the retina, there is the Optic nerve, which sends signals to the brain.
  - There are no rods or cones where the optic nerve is, so the light that falls on it is not seen.

- Muscles in the eye change the shape of the lens to focus objects at different distances.
  - If your eye is damaged (and naturally as you get older) these muscles do not focus the lens very well. The lens itself may also be damaged or removed altogether.
- Far Sightedness is when the image is focused at a point farther from the lens than your retina.
- Near Sightedness is when the image is focused at a point closer to the lens than your retina.
- An Astigmatism is when the shape of the eye is abnormal, causing one axis to be focused differently than the other.
  - A cyllindrical lens also does this.

- Everyone's eyesight is unique, including pariferal vision.
  - Unique angle where objects are noticed
  - Unique angle where color is recognized
  - Unique angle of optic nerve blind spot.
  - In general, parifearal vision is better at detecting movement, while direct vision is better at identifying details.

Procedure

- Fill eye model with water until almost full

Accomodation

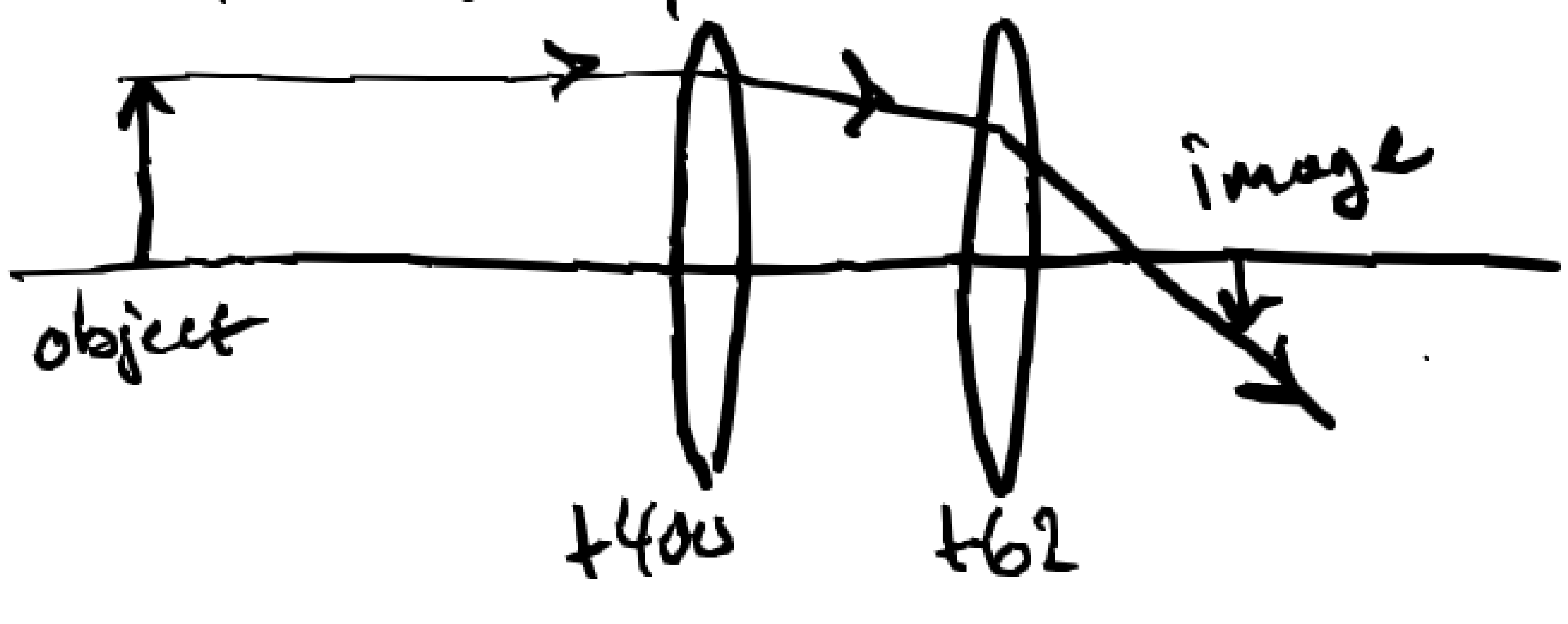
- Put +62mm lens in Septum spot
- Put light box 36 cm in front of eye model.
  - look at image formed on "Retina".
- Replace +62mm lens with +120mm lens

Magnifyer

- Put +62mm lens in Septum spot and light box 36cm away.
  - Measure ho and hi → Use Calipers for hi
- Put +120mm lens in front of eye model.
  - Adjust light box distance to focus image
  - Measure new hi

Far/Near Sightedness

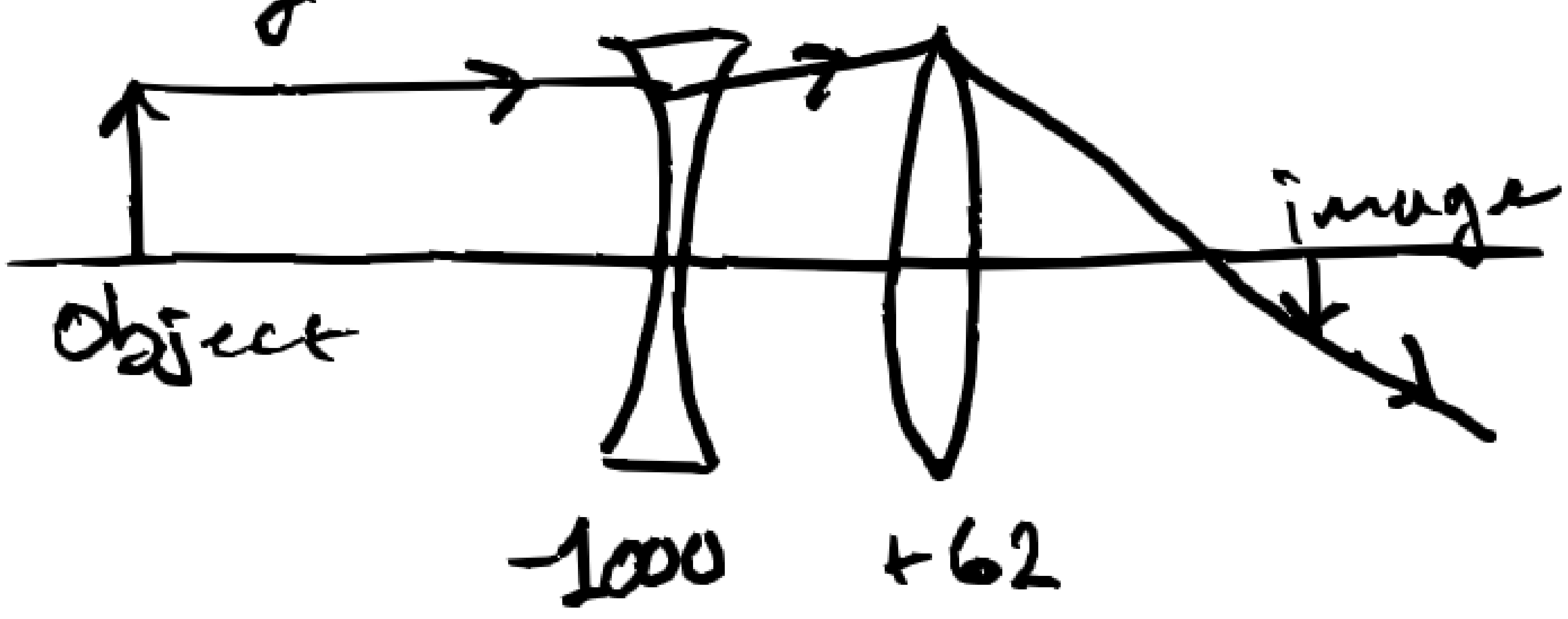
- Take +120mm lens away and put light box 36cm away.
  - Make sure +62mm lens is still in Septum spot.
- Move "Retina" to "Far" position to simulate far sightedness.
  - Place different lenses in front of eye model one at a time to find best image (+400mm, Convex)
  - Only top ray is needed for diagram:



+62 lens bends light more than +400 lens.

Image is inverted

- Place "Retina" to the "Near" Position to simulate Nearsightedness.
  - Place different lens in front to focus image. (-1000mm, Concave)
  - Diagram:



Concave lens makes light diverge.

Image is inverted

Astigmatism (Scratch out "and Nearsightedness")

- Put "Retina" back to "Normal" Position with +62mm lens in Septum. Remove any other lenses
  - Put -128mm lens in "A" spot between "Cornea" and "Septum" to simulate Astigmatism.
  - Find two lenses that correct image when placed outside of eye. Try rotating them. (+307mm, -1000mm) order doesn't matter

Absence of Crystalline Lens

- Remove all lenses from eye model.
  - Try different combinations of lenses in front to correct image. (different Combinations work for different distances)
    - image will not be completely clear because there is no lens inside the different medium within eye.

-1000, +120	-1000, +62
(~18cm do)	(~8.5cm do)

Pupil

- Put +62mm lens back in "Septum" spot and light box back at 36cm.
- Put black piece in spot A with circle side down.
  - Notice change in image.
- Flip black piece over so that circle is up.
  - Notice change in image.
- Remove black piece and move light box until image is slightly blurry, then put black piece back and notice what happens to image with both sides of black piece.

Color Vision and Blind Spot

Follow Lab Manual

Lab 11: Optical Instruments

Last lab we saw how the human eye is a multi-lens system.

This lab demonstrates three more useful multi-lens systems:

- Microscope
- Kepler Telescope
- Galileo Telescope

All of these take advantage of the image from one lens being the object for the second lens. The position of the first lens' image relative to the focal point of the second lens gives various magnifications for viewing details in objects at different distances depending on the lenses used.

Microscope uses small focal length lens as the first lens (objective lens) to view small objects that are close to the lens.

$$M = M_1 M_2 \cdots$$

$$M_1 = M_{\text{objective lens}}$$

$$M_2 = M_{\text{eyepiece}} = \frac{25\,\text{cm}}{f_e} \leftarrow \text{focal length of eyepiece}$$

Telescopes use a large focal length lens as the objective lens to view detail in objects far away.

Magnification Approximation: $M_T \approx -\frac{f_o}{f_e}$

Kepler Telescope

Uses two convex lenses

Galileo Telescope

Uses a convex lens and a concave lens

Procedure Modifications

Microscope

1. "..... recreate Figure (1b) and (1f) ..."

Kepler Telescope

13. Hold the ruler against the eye piece and approximate the width of the object you are viewing. Then, bring the ruler and your eye above the lens, keeping the ruler the same distance from your eye, and approximate the width of the same object.