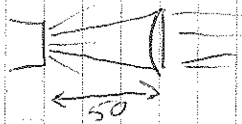
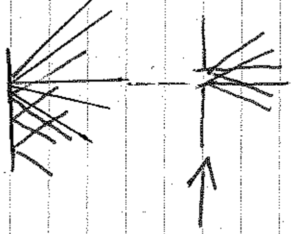
~~Lens~~ Lab (9/16/15)

gratings: reflective 1200 $\frac{lines}{mm}$ 600 $\frac{lines}{mm}$
500 nm blaze wavelength $\gamma = 17° 27'$

collimating white light source: ~~50 mm PLCX lens~~

~~50 mm~~ PLCX → 200 mm

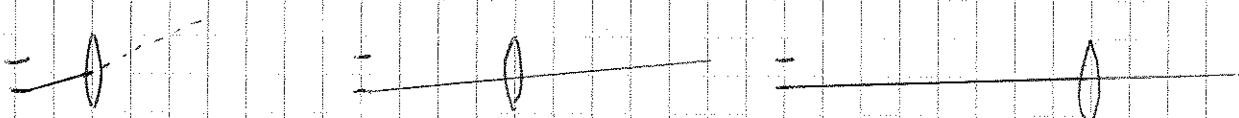




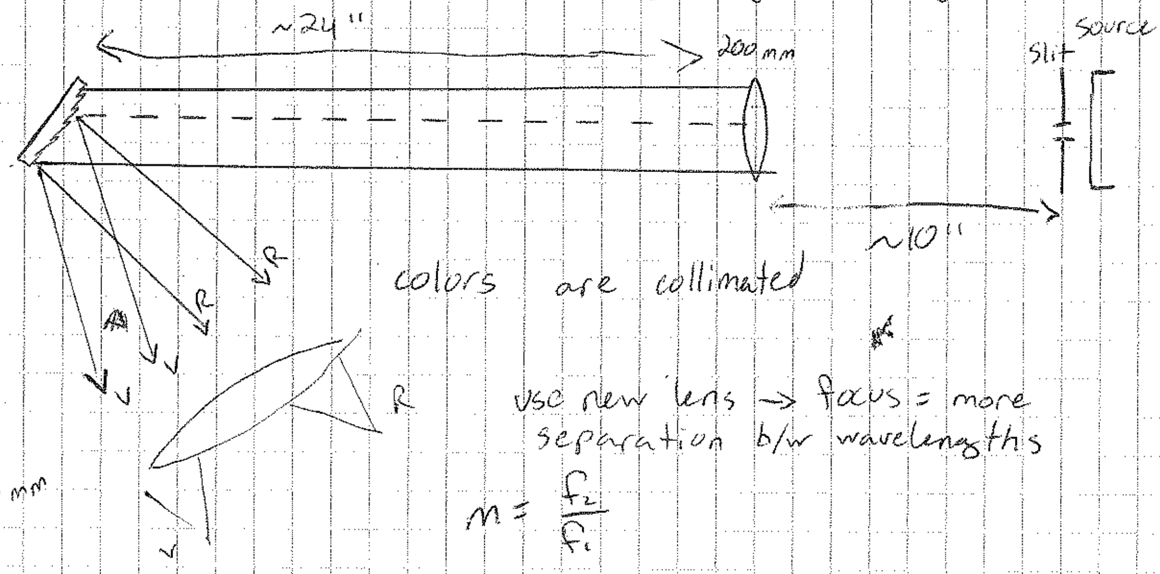
entrance slit or aperture → turn extended source into point using slit in paper

choosing lens:

50 mm 100 mm 200 mm



longer efL → small chief ray angle / divergence



colors are collimated

use new lens → focus = more separation b/w wavelengths

$m = \frac{f_2}{f_1}$

bandwidth

wavelength

tector

Via

ar

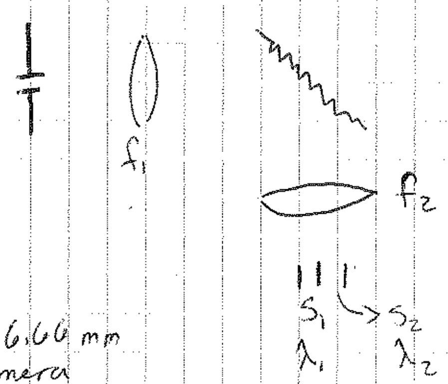
spectral resolution
spectral range
slit width
pixel width
detector pixels

parts list
- grating GR25-1205
- 200 mm PLCX lens
- 100 mm PLCX
- white light source

~~pictures~~

from grating equation: $d \sin\theta = m\lambda$
and desiring resolution $\Delta\lambda$

differentiating grating equation gives
$\Delta\theta$ dependence



$$\tan\theta_{\lambda_{min}} = \frac{C/2}{f_2}$$

$$f_2 = \frac{3.33\text{ mm}}{\tan(}$$

C = 6.66 mm
camera area

$d \sin\theta = m\lambda$
$\theta = \arcsin\left(\frac{700\text{nm}}{} \cdot \frac{1200 \text{ lines}}{1}\right.$

3 options:
- rotate grating → slit/detector
- translate slite & detector
- image spectrum onto whole detector surface

2 detectors:
- cmos camera DCC1545M
- Si ~~vol~~ power → voltage converter

- first attempt:
  - use slit + Si detector & scan through spectrum
  - translation stage didn't have enough travel so other option would be to translate by <u>hand</u>
  - required continuously recording voltage reading from DMM
  - ultimately, made more sense conceptually but difficult to implement

- second attempt:
  - take entire spectrum onto camera detector
  - line profile of image gives amount of light as function of position, which is function of λ

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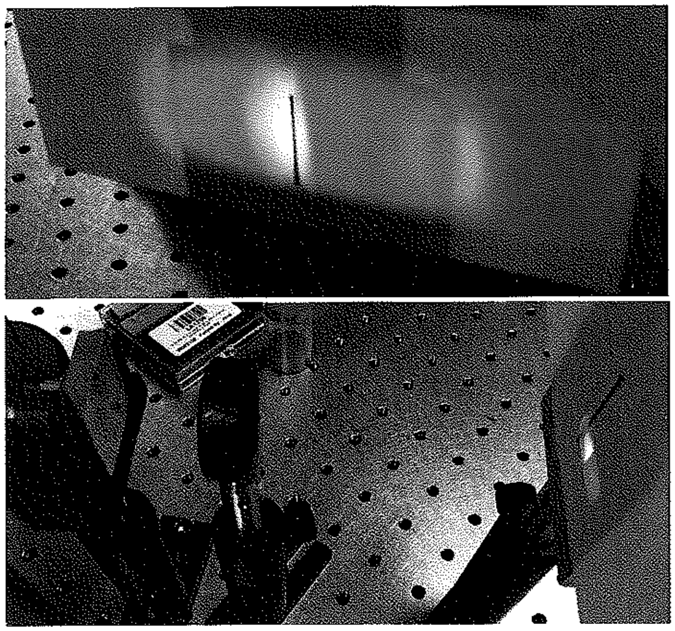


spectrum after diffraction: unfocused (top) and focused through an f = 100mm lens (bottom)

DCC 1545 m specs:

detector area

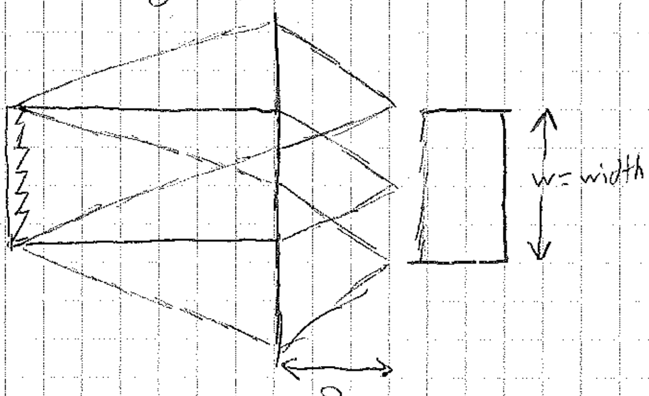
5.32 × 6.66 mm

~~1205~~ 1280 x 1024 pixels

6.66 x 5.32 mm

5.2 μm square pixel

~~imag~~ focusing spectrum onto camera face:

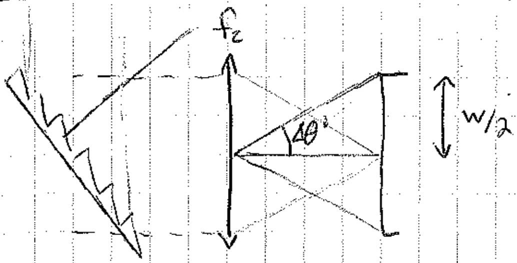


$\Delta\theta'$ = angle b/w λ_{mid} & λ_{max} (600 800)

$\Delta\theta = \frac{s}{f_1}$ resolution criteria

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

$\Delta\lambda = d \cdot \Delta\theta$



$\Delta\theta' = \theta_{max} - \theta_{mid}$

$\tan\Delta\theta' \approx \Delta\theta' = \frac{w/2}{f_2}$

$m\lambda = d\,\theta = d\,\Delta\theta'$

$\theta_{600} = (600\,nm)(1200\ \frac{lines}{mm}) = 0.72$
$\theta_{800} = (800\,nm)(1200) = 0.96$

$\Delta\theta' = 0.24\ rad$

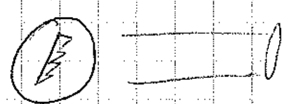
$2\Delta\theta' = \frac{6.66\,mm}{f_2}$

$f_2 = \frac{6.66\,mm}{0.48\,rad} = 13.9\ mm$

too small for practicality

other possibility:

and



grating on rotation stage
0° = grating normal // beam
$\Delta\theta_{stage} = \theta_i$

implementing this (8:44 am)

(picture)

$\lambda_{mid} + \lambda_{max}$
600 800)
n criteria

from rotation stage -> know θincident
but not using this to translate

translation stage: travel through spectrum

- want to find known λ points (using filter) to calibrate + then use that ~~to~~ + travelled distance to calculate an angle + the λ

~~550 nm = 0.264 in = 5.4 mV~~

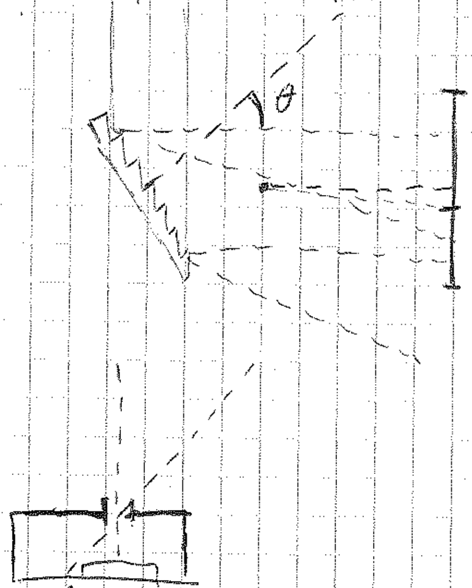
49°

550 nm ~~5.4 mV~~ ~~6.1 mV~~ 7.5 mV ~~0.468~~ 0.671

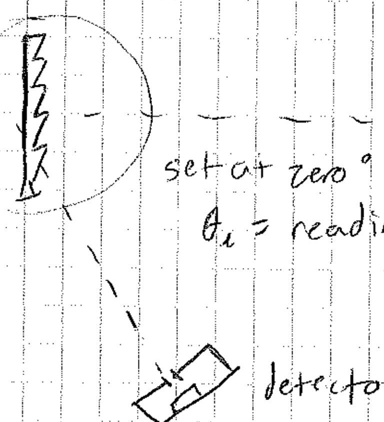
520 nm 2.9 mV 0.524

$m\lambda = d\sin\theta$

$= d\sin\theta_i - d\sin\theta_r$



at ends of spectrum, light doesn't hit detector → would be easier to use rotation stage than translation such that light is always normal to detector



source

set at zero° initially

θ_i = reading of rotation stage

detector at set angle (measured)

for Monday:
- set rotating stage to zero
- measure angle of detector (ensure ⊥)
- take reference point(s)
- scan through source
- scan through absorption

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zeroing rotation stage: set to zero, back reflection returns to source

reference w/ filters:

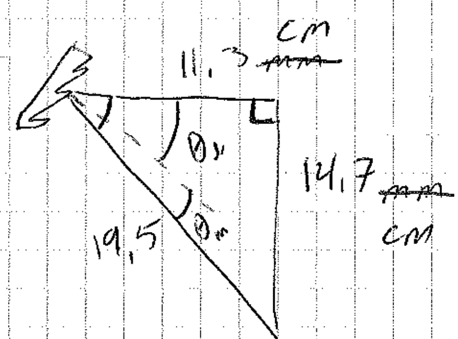
~~5.5~~	550 nm	~~9.3~~ 8.9 mV	43.6° or 43.7°
	600 nm	13.8 mV	46.6°

positioned such that beginning of red end is on detector at given angle

Started at 50° went by 0.5° to 38°

minimum ~~current~~ voltage reading ~2.4 mV

θ_i = rotation stage



~~$\tan\theta =$~~

$\sin\theta = \frac{14.7}{19.5}$

$\theta = 48.92 = \alpha$

$$d\left[\sin\theta_m + \sin\theta_i\right] = \lambda = 550\text{ nm} \times 10^{-9}$$

$$\frac{1}{1200}10^{-3}\left[\sin\theta_m + \sin(43.6)\right] = 550\times10^{-9}$$

data was collected & processed in ~~an~~ excel

α = angle between incident light and grating-detector line

Calculations

$\theta_m = \theta_i - \alpha$

at $50° = \theta_i$: $\theta_m = 50° - 48.92° = 1.08°$

$\lambda = d\left[\sin\theta_m + \sin\theta_i\right]$

$= \left(\frac{10^{-3}}{1200}\text{m}\right)\left[\sin 1.08° + \sin 50°\right] 10^{9}\frac{\text{nm}}{\text{m}} = 654.1\text{ nm}$

$$\% \text{ Transmission} = \frac{\text{light transmitted}}{\text{transmit} + \text{absorb}} = \frac{V_{dye}}{V_{no\,dye}} \times 100\%$$

$$\% T_{50°} = \frac{25.5\text{ mV}}{28.5\text{ mV}} \times 100\% = 89.5\%$$

$$\% \text{ Absorption} = \frac{(\text{total} - \text{transmitted})}{\text{total}} \times 100\%$$

$$\% A = \frac{(28.5 - 25.5)\text{ mV}}{28.5\text{ mV}} \times 100\% = 10.5\%$$

Resolution

$$\Delta\theta = \frac{s}{f_1} = \frac{\text{aperture size}}{\text{focal length}} = \frac{1\text{ mm}}{200\text{ mm}}$$

$$\Delta\lambda = d\,\Delta\theta = \left(\frac{1}{1200}\text{ mm}\right)\left(\frac{1}{200}\right)\left(10^{6}\text{ nm/mm}\right) = 4.17\text{ nm}$$

<u>Error Propogation</u>

~~$\sigma_\alpha = \left[\left(\frac{\partial\alpha}{\partial\theta_i} \cdot S_{\theta_i}\right)^2 + \left(\frac{\partial\alpha}{\partial\theta}\right.\right.$~~

$$\sigma_\alpha = \left[\left(\frac{\partial\alpha}{\partial opp} \cdot S_{opp}\right)^2 + \left(\frac{\partial\alpha}{\partial h} \cdot S_h\right)^2\right]^{1/2}$$

error comes from measurement limitations of the triangle on the previous page
lengths were measured with a ruler, but due to the difficulty of precise location, measurement error is estimated at ± 2 mm

$$\sigma_\alpha = 0.0098\text{ rad}$$

$$\sigma_{\theta m} = \left[S_\alpha^2 + S_{\theta_i}^2\right]^{1/2}$$

error in θ_i ~~will~~ depends only on measurement uncertainty of the rotation stage, which measures to minute

$$\pm\frac{1}{60} = \pm 0.017° = \pm 0.00029\text{ rad}$$

$$\sigma_{\theta m} = 0.0098\text{ rad}$$

)%

17 nm

of the

due to
ment

t uncertainty
o minute

$$\sigma_T = \left[\left(\frac{\partial T}{\partial V_n} \cdot S_{V_n}\right)^2 + \left(\frac{\partial T}{\partial V_d} \cdot S_{V_d}\right)^2\right]^{1/2}$$

error in voltage measurements are fundamental to the detector ± 0.05 mV

$$\sigma_T = \left[\left(\frac{1}{V_n} \cdot 0.05\right)^2 + \left(\frac{V_d}{V_n^2} \cdot 0.05\right)^2\right]^{1/2}$$

$= 0.00235$ at $50°$

$$T := \frac{Vd}{Vn}$$

$$\frac{Vd}{Vn}$$

$$dn := \frac{d}{d\,Vn} T$$

$$-\frac{Vd}{Vn^2}$$

$$dd := \frac{d}{d\,Vd} T$$

$$\frac{1}{Vn}$$

$Vn := 28.5$

28.5

$Vd := 25.5$

25.5

$St := \text{sqrt}\left((dd \cdot 0.05)^2 + (dn \cdot 0.05)^2\right)$

0.002354117966

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$$a := \arcsin\left(\frac{opp}{h}\right)$$

$$\arcsin\left(\frac{opp}{h}\right)$$

$$dopp := \frac{d}{d\,opp}\, a$$

$$\frac{1}{h\sqrt{1-\frac{opp^2}{h^2}}}$$

$$dh := \frac{d}{d\,h}\, a$$

$$-\frac{opp}{h^2\sqrt{1-\frac{opp^2}{h^2}}}$$

$opp := 147 : h := 195. :$

$S\_a := \mathrm{sqrt}\left((dopp)^2 + (dh)^2\right)$

0.009774142973

$Sm := \mathrm{sqrt}\left(\left(\mathrm{sqrt}\left((dopp)^2 + (dh)^2\right)\right)^2 + 0.00029^2\right)$

0.009778444194

$y := d\cdot(\sin(m) + \sin(i))$

$d\,(\sin(m) + \sin(i))$

$$dy := \frac{d}{d\,m}y$$

$d\cos(m)$

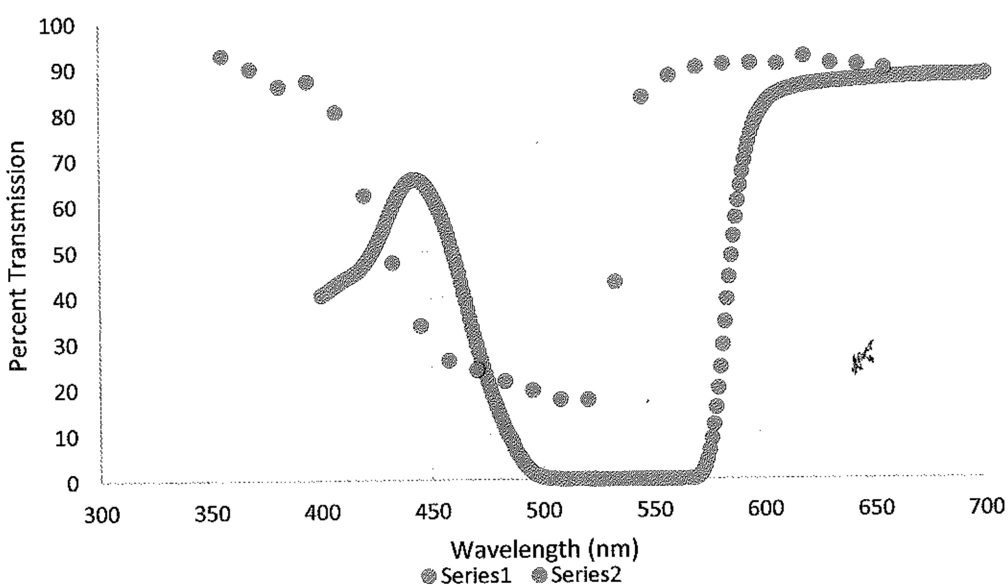
$$di := \frac{d}{d\,i}y$$

$d\cos(i)$

Table 1: data points and calculations

d	833.33											
theta m	theta i	V base (mV)	V dye	dTheta	dLambda	theta m rad	theta i rad	lambda	%T	dT	%A	dA
1.08	50	28.5	25.5	0.0026	4.17	0.019	0.8727	654.1	89.5	0.0024	10.5	0.0024
0.08	49	28.9	26.2	0.0026	4.17	0.001	0.8552	630.1	90.7	0.0023	9.3	0.0023
-0.92	48	27.4	24.8	0.0026	4.17	-0.016	0.8378	605.9	90.5	0.0025	9.5	0.0025
-1.92	47	24.4	22.1	0.0026	4.17	-0.034	0.8203	581.5	90.6	0.0028	9.4	0.0028
-2.92	46	20.9	18.4	0.0026	4.17	-0.051	0.8029	557.0	88.0	0.0032	12.0	0.0032
-3.92	45	17.9	7.7	0.0026	4.17	-0.068	0.7854	532.3	43.0	0.0030	57.0	0.0030
-4.92	44	14.9	2.6	0.0026	4.17	-0.086	0.7679	507.4	17.4	0.0034	82.6	0.0034
-5.92	43	11.6	2.5	0.0026	4.17	-0.103	0.7505	482.4	21.6	0.0044	78.4	0.0044
-6.92	42	8.8	2.3	0.0026	4.17	-0.121	0.7330	457.2	26.1	0.0059	73.9	0.0059
-7.92	41	6.1	2.9	0.0026	4.17	-0.138	0.7156	431.9	47.5	0.0091	52.5	0.0091
-8.92	40	4.6	3.7	0.0026	4.17	-0.156	0.6981	406.4	80.4	0.0139	19.6	0.0139
-9.92	39	3.6	3.1	0.0026	4.17	-0.173	0.6807	380.9	86.1	0.0183	13.9	0.0183
-10.92	38	2.8	2.6	0.0026	4.17	-0.191	0.6632	355.2	92.9	0.0244	7.1	0.0244
0.58	49.5	29.1	26.3	0.0026	4.17	0.010	0.8639	642.1	90.4	0.0023	9.6	0.0023
-0.42	48.5	28	25.8	0.0026	4.17	-0.007	0.8465	618.0	92.1	0.0024	7.9	0.0024
-1.42	47.5	25.8	23.4	0.0026	4.17	-0.025	0.8290	593.7	90.7	0.0026	9.3	0.0026
-2.42	46.5	22.6	20.3	0.0026	4.17	-0.042	0.8116	569.3	89.8	0.0030	10.2	0.0030
-3.42	45.5	18.7	15.6	0.0026	4.17	-0.060	0.7941	544.7	83.4	0.0035	16.6	0.0035
-4.42	44.5	16.05	2.8	0.0026	4.17	-0.077	0.7767	519.9	17.4	0.0032	82.6	0.0032
-5.42	43.5	12.8	2.5	0.0026	4.17	-0.095	0.7592	494.9	19.5	0.0040	80.5	0.0040
-6.42	42.5	10	2.4	0.0026	4.17	-0.112	0.7418	469.8	24.0	0.0051	76.0	0.0051
-7.42	41.5	7.4	2.5	0.0026	4.17	-0.130	0.7243	444.6	33.8	0.0071	66.2	0.0071
-8.42	40.5	5.3	3.3	0.0026	4.17	-0.147	0.7069	419.2	62.3	0.0111	37.7	0.0111
-9.42	39.5	3.9	3.4	0.0026	4.17	-0.164	0.6894	393.7	87.2	0.0170	12.8	0.0170
-10.42	38.5	3	2.7	0.0026	4.17	-0.182	0.6720	368.0	90.0	0.0224	10.0	0.0224

Transmission of Dye via Commercial and Custom Spectrometer



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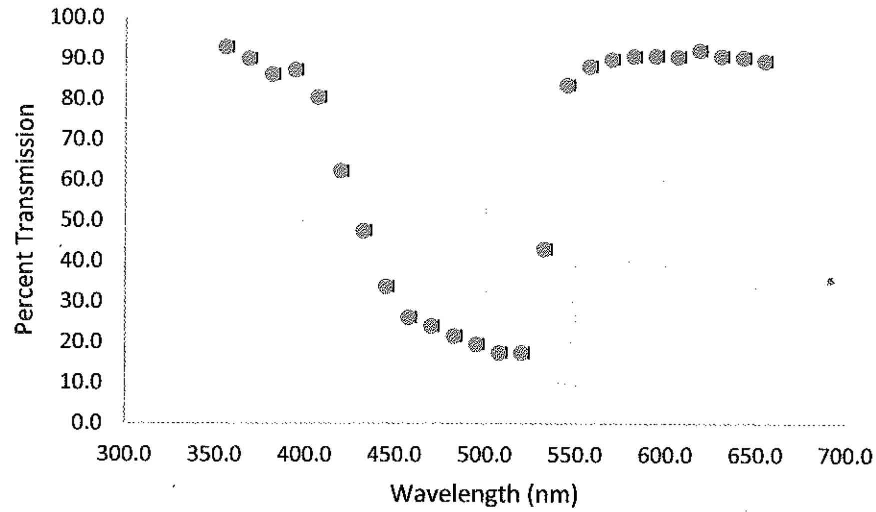
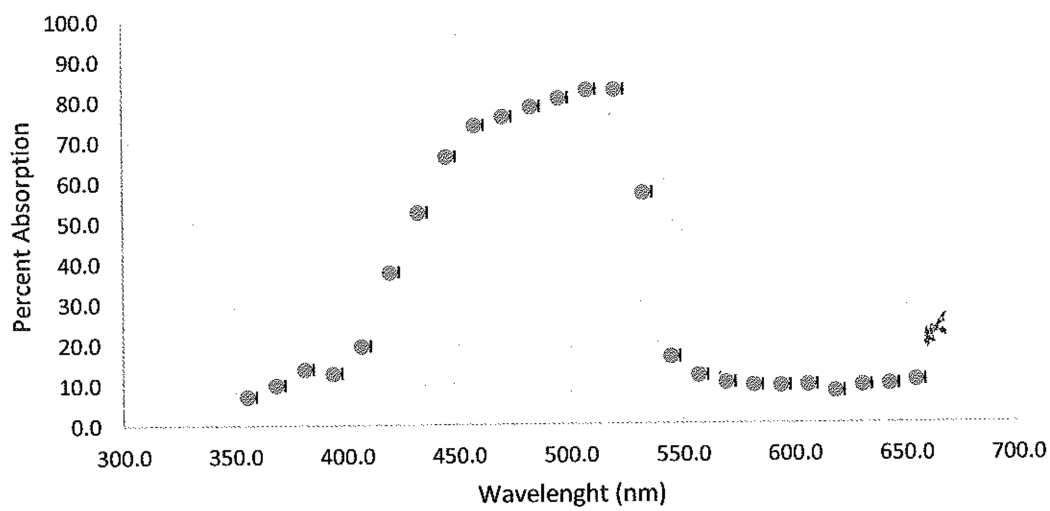
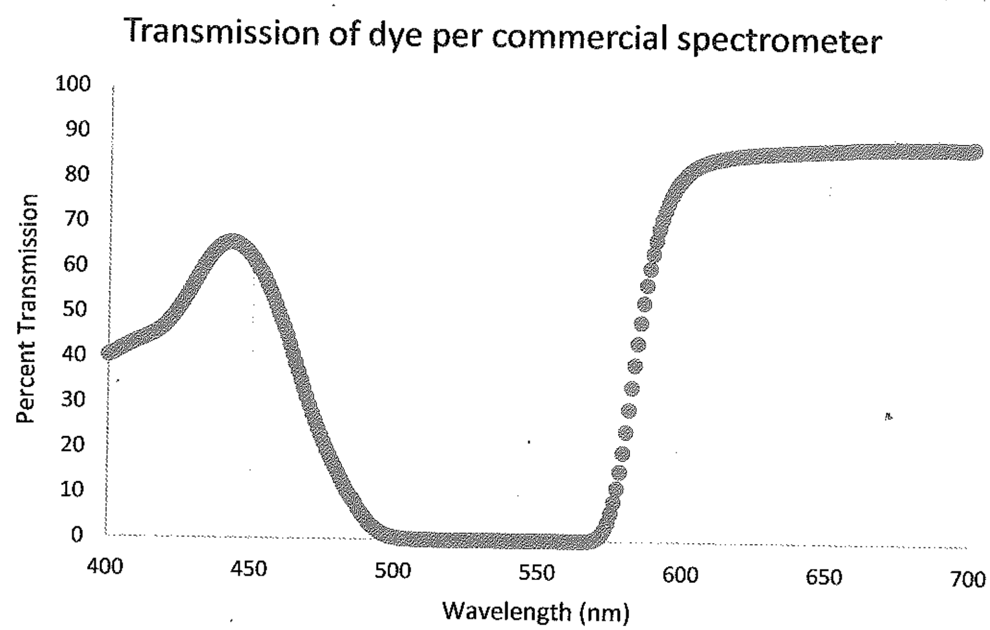
Transmission via Voltage With and Without Rhodamine 6 Dye



Absorption via Voltage With and Without Rhodamine 6 Dye





materials
- plano convex f = +200 mm lens
- plano convex f = +100 mm lens
- 1200 lines/mm reflective, ruled grating
- PDA 36A Si detector
- white light source
- 3 half-inch irises

Conclusion

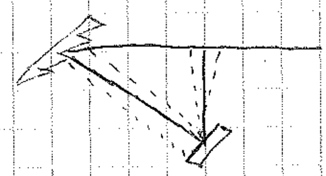
While the custom spectrometer shows diminished transmission (and increased absorption) in the approximate range expected - green and yellow are absorbed, leaving red and blue to create the pink-appearing dye - the absorption band is slightly left shifted compared to the commercial spectrum.

700.0

The sources of this error in the procedure include the resolution factor, measuring the spread of the wavelengths, so that at a given angle there will be ~~multiple~~ a spread of wavelengths entering the iris and detector.

More significantly, there is the accuracy of measurement in the angle between the detector

normal and the incident light. The ruler for distance measurements was imprecise, but the location in space of the detecter ~~twi~~ surface (within the device), the point of incidence on the grating, and the intersecton of these lines were considerably imprecise



9/30/15

Lab 3 - Refractive Index of Air

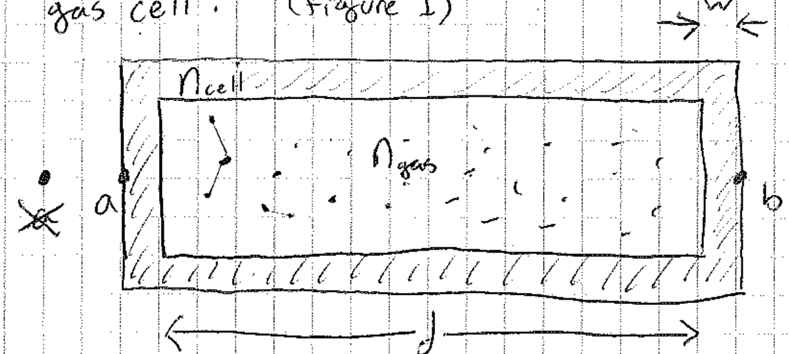
Kelly Farner
(+ Serena Park)

objective:

determine the refractive index of air via interferometry. A michelson interferometer in which one arm contains a vacuum cell will creat fringes as a function of path difference, which in turn depends on index.

introduction

1) gas cell: (figure 1)



optical path length, a to b $\quad OPL = (2 n_{cell} W) + n_g \cdot d \quad$ (1)

optical path <u>difference</u> $\quad OPD = 2n_c W + n_g d - (2w + d)$

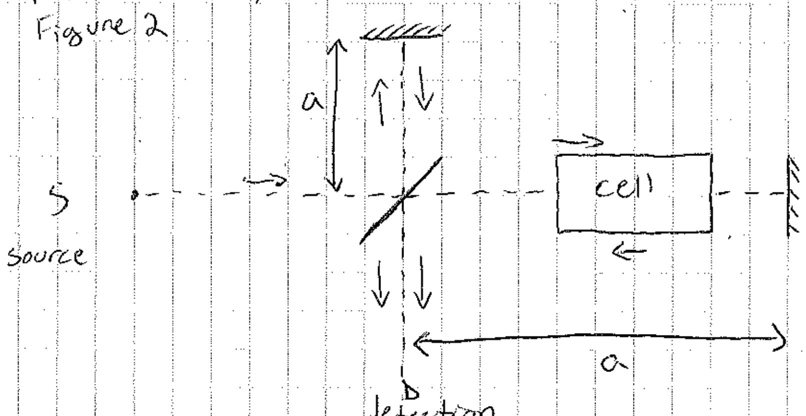
$$= 2w(n_c - 1) + d(n_g - 1) \quad (2)$$

for path a to b to a (as in arm of interferometer):

$$OPD = 4w(n_c - 1) + 2d(n_g - 1) \quad (3)$$

2) interferometer

Figure 2



$$m\lambda = OPD$$

$$m = \frac{4w(n_c - 1) + 2d(n_g - 1)}{\lambda}$$

constructive interference rules have $OPD = m\lambda$, the path difference being an integer factor of the wavelength. When the <u>physical</u> length of the arms are the same, the OPD is that given by Eqn 3 for a gas cell.

To measure this, the number of fringes which ~~change~~, ~~m~~, pass, the dimensions of the cell, and the source wavelength must be measured when the gas changes.

- So a red HeNe laser is the source $\lambda \sim 632$ nm
- BS103 50:50 beamsplitter evenly splits beam
- 2 flat silver mirrors
- gas cell
- detector capable of recording or counting fringes

The interferometer ~~would~~ will be assembled, alligned, and set with distances. The cell with air ~~is~~ will be included.

The fringes which pass the detector as the cell is evacuated must be recorded.

The change in fringes is due to change in path length due to the change of index from

$$n_{air} \text{ to } n_{vac} = 1$$

Then the equation

$$m = \frac{4w(n_c - 1) + 2d(n_g - 1)}{\lambda}$$

relates one unknown (n_g) ~~to~~ ~~in an eq~~ to known or measured characteristics

m = counted fringes
λ = source wavelength

w, n_c, d = qualities of gas cell