

# Monochromator/Photomultiplier Lab

## i. Establish Linearity of the PMT

1:15p.

↳ We'll chop a white light source and vary the intensity using a ND filter  $\rightarrow$  start at lowest intensity

↳ See p2 of lab manual for expt. diagram.

↳ Set scope to auto-trigger for now: 2mV (most sensitive.)

↳ We'll trigger on pulses later...

↳ Can see noise in ambient (desk lamp) light.

↳ noise is smaller when I use my hand to block entrance slit.

↳ PMT: 1200 V supply.

↳ Position lamp 2ft away  $\rightarrow$  Maybe use a field lens?

↳ Nah. As long as we're careful with the normal lamp and position it s.t. it impacts the slit homogeneously.

↳ started the fan motor as a chopper. The output on the scope is now square pulses.

↳ It's really noisy! First few values will be very inaccurate.

- We will record the voltage produced at the PMT as a function of transmission. 1:50pm

Step #	$V_{pp}$ (mV)	$V_{rms}$ (mV)	Attenuation	$V_{peak}$ (mV)
22	<del>86.0</del>	<del>3.84</del>	<del><math>2.3 \pm 0.02</math></del>	<del><math>6.40 \pm 0.4</math></del>
21	<del>34.2</del>	<del><math>9.26 \mu V</math></del>	<del>2.3</del>	<del><math>7.40 \pm 0.4</math></del>
20	<del><math>35.0 \pm 1</math></del>	<del>6 mV</del>	<del>2.3</del>	<del><math>11.0 \pm 0.4</math></del>
19	<del><math>39 \pm 1</math></del>	<del>9</del>	<del>2.91</del>	<del><math>17.6 \pm 0.6</math></del>
18	<del><math>65 \pm 5</math></del>	<del><math>55 \pm 4</math></del>	<del>2.75</del>	<del><math>29.2 \pm 0.8</math></del> 22.8
17	<del><math>64 \pm 4</math></del>	<del><math>63 \pm 6</math></del>	<del>2.58</del>	<del><math>27.2 \pm 0.8</math></del> 28.4
16	<del><math>70 \pm 5</math></del>	<del><math>82 \pm 5</math></del>	<del>2.45</del>	<del><math>36.0 \pm 0.8</math></del> 41.6
15	<del><math>122 \pm 6</math></del>	<del><math>130 \pm 10</math></del>	<del>2.30</del>	<del><math>76.0 \pm 2</math></del> 54.4 68
14	<del><math>168 \pm 3</math></del>	<del><math>85 \pm 1</math></del>	<del>2.16</del>	<del><math>106 \pm 7</math></del> 66.4 $\pm 4$
13	<del><math>238 \pm 4</math></del>	<del><math>84 \pm 1</math></del>	<del>2.00</del>	<del><math>164 \pm 4</math></del>
** 12	<del><math>384 \pm 8</math></del>	<del><math>135 \pm 3</math></del>	<del>1.85</del>	<del><math>264 \pm 10</math></del>
11	<del><math>630 \pm 10</math></del>	<del><math>254 \pm 2</math></del>	<del>1.69</del>	<del><math>484 \pm 10</math></del>
10	<del><math>880 \pm 10</math></del>	<del><math>357 \pm 1</math></del>	<del>1.58</del>	<del><math>712 \pm 12</math></del>
9	<del><math>1.35 \pm 0.02 V</math></del>	<del><math>581 \pm 1</math></del>	<del>1.40</del>	<del><math>1.14 \pm 0.04 V</math></del>
8	<del><math>2.16 \pm 0.02</math></del>	<del><math>945 \pm 3</math></del>	<del>1.23</del>	<del><math>1.88 \pm 0.06 V</math></del>
7	<del><math>3.58 \pm 0.02</math></del>	<del><math>1.57 \pm 0.1</math></del>	<del>1.07</del>	<del><math>2.96 \pm 0.1 V</math></del>
6	<del><math>5.60 \pm 0.08</math></del>	<del><math>2.54 \pm 0.2</math></del>	<del>0.95</del>	<del><math>4.88 \pm 0.1</math></del>
5	<del><math>6.46 \pm 0.02</math></del>	<del><math>2.93 \pm 0.01</math></del>	<del>0.79</del>	<del><math>6.04 \pm 0.10</math></del> 5.72 $\pm 0.2 V$
4	<del><math>12.9 \pm 0.5</math></del>	<del><math>5.80 \pm 0.05</math></del>	<del>0.64</del>	<del><math>11.1 \pm 0.5 V</math></del>
3	<del><math>21 \pm 1</math></del>	<del><math>10.4 \pm 0.1</math></del>	<del>0.50</del>	<del><math>19.6 \pm 0.8 V</math></del> ✓
2			0.35	
1	STOP		0.19	STOP
0			0.05	

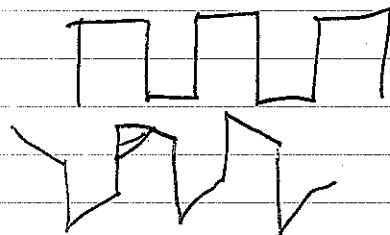
\* When I tried to reproduce these results, it didn't work. But subsequent repetitions produced the values that are not crossed out are consistent.

\*\* And here the intensity dropped, then rose again ( $T \approx 2s$ )

As the intensity rises, the square wave

goes

distorted shape



trigger problems

## Part 2: Monochromator $\lambda$ -calibration

As per lab manual, aligning He lamp w.r.t. monochromator with setting at 800nm.

↳ Helium tube is used for a light source.

↳ w/o chopper. The signal is periodic (120 Hz)

↳ Suspect that it's line hum. Thankfully the peak intensity attains a steady-state for a little while between cycles.

At max PMT gain we see  $\sim 1V$  (880mV). So can proceed to calibrate wavelengths.

Helium:  $\gamma$  From supplementary material

Expected line (nm)	Measured line (nm)	Intensity
388.9	393nm $\pm 0.5$	<p>→ wildly varying intensity due to AC noise made this value useless. We simply varied the mono back/forth until we saw a maximum on the scope ✓</p>
447.1	451.5 $\pm 0.5$ nm	
402.6	406.5 $\pm 0.5$	
438.8	442.5 $\pm 0.5$ nm	
471.3	476.0	
492.1	497.0	
501.65 ???	505.0	
	509.0	
587.6	593.0	
667.8	674.0	
706.5	713.0	
318.8	322.5	
We scanned thru 361.4	365	
370.5	375	
382.0	385	
396.5	400	
412.0	417.	

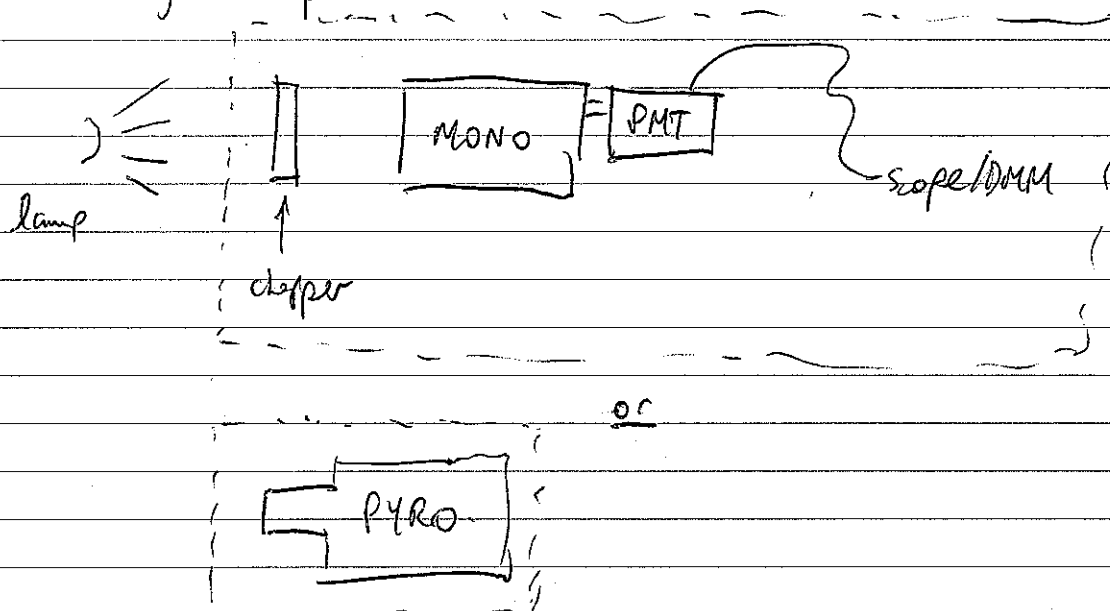
✱ We scanned through the entire mono range and recorded peak locations first, to address consistency etc. → Then we matched these locations to the known lines.

↳ sometimes were really dim.

4:00pm

## Part 3: Response of the Monochromator/PMT system

Setup: First we want to use the pyrometer to measure the brightness temp. of our tungsten lamp.



After our location on the  $T/\lambda/I$  contour is determined, we replace the pyro with our chopper/MONO/PMT setup. By measuring the peak intensities we obtain a spectrum that we can normalize to w.r.t. the glow curve in Figure 1.4 of the Lab Manual, which yields the response of the system.

Notes: - Need to convert Pyro reading (in  $^{\circ}\text{C}$ ) to K ( $K = C + 273.15$ )

At full brightness (max V on lamp source):  $T = 22.4 \pm 0.5 \times 100^{\circ}\text{C}$

Half turn on voltage adjustment:  $T = 19.0 \pm 0.4 \times 100^{\circ}\text{C}$

↳ We'll convert these later to put them in Kelvin and also correct measurements for emissivity, etc.

Now we put on the MONO/PMT setup and align the mono as outlined in the lab manual. Chopping the light, we will again measure the voltage, this time as a function of mono position (of course, we need to correct for mono nonlinearity but we'll calculate that later).

Table 1: Brightest temperature

$\lambda_{\text{mono}} (\text{nm})$	$\lambda_{\text{actual}}$	$V_{p-p} (\text{mV})$	$V_{\text{rms}} (\text{mV})$
300 *		N/A	N/A
325 *		N/A $21 \pm 1$	N/A
350		<del><math>120 \pm 4</math></del> $82 \pm 2$	<del><math>34 \pm 1</math></del>
375		<del><math>245 \pm 5</math></del> $188 \pm 2$	$90 \pm 1$
400		<del><math>440 \pm 10</math></del> $360 \pm 4$	$179 \pm 1$
425		<del><math>620 \pm 20</math></del> $512 \pm 12$	$263 \pm 1$
450		<del><math>672</math></del> $650 \pm 10$	$320 \pm 1$
475		<del><math>784 \pm 18</math></del> $832 \pm 8$	$412 \pm 1$
500		$944 \pm 14$	$466 \pm 1$
525		$896 \pm 8$	$444 \pm 1$
550		$784 \pm 12$	$380 \pm 1$
575		$656 \pm 8$	$317 \pm 2$
600		$488 \pm 4$	$233 \pm 1$
625		$176 \pm 4$	$78 \pm 1$
650		$60 \pm 10$	$22 \pm 1$
675		$24 \pm 2$	$8 \pm 1$
700		N/A	N/A

Table 2: Brightest - 300°K

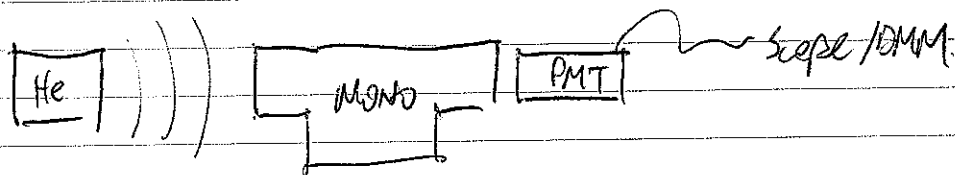
350	$11 \pm 1$	4
375	$34 \pm 2$	$11 \pm 1$
400	<del><math>61</math></del> $61 \pm 4$	$24 \pm 1$
425	$95 \pm 5$	$41 \pm 1$
450	$134 \pm 5$	$59 \pm 1$
475	$176 \pm 4$	$80 \pm 1$
500	$206 \pm 4$	$96 \pm 1$
525	$210 \pm 4$	$96 \pm 1$
550	$196 \pm 4$	$88 \pm 1$
575	$174 \pm 6$	$79 \pm 1$
600	$136 \pm 8$	$61 \pm 1$
625	$52 \pm 5$	$21 \pm 1$
650	$21 \pm 2$	$6 \pm 1$
675	$13 \pm 2$	2

Table 3: Obsd spectrum (4 Averages)

$\lambda_{\text{mono}}(\text{nm})$	$\lambda_{\text{actual}}$	$V_{\text{peak}}(\text{mV})$	$V_{\text{rms}}(\text{mV})$ ? All $\emptyset$ ?
300			
325		$7.2 \pm 1.2$	0
350		$7.8 \pm 2.0$	0
375		$17.8 \pm 5$	0
400		$16 \pm 3$	0
425		$15 \pm 2$	0
450		$16 \pm 2$	0
475		$17 \pm 3$	0
500		$15 \pm 3$	0
525		$15 \pm 3$	0
550		$16 \pm 3$	0
575		$16 \pm 2$	0
600		$18 \pm 5$	0
625		$17 \pm 2$	0
650		$15 \pm 4$	0
675		$17 \pm 2$	0
700		$16 \pm 2$	0

## Part 4: Spectral lines of Helium:

We set up the apparatus as shown below, and measure the relative intensities of the lines of helium:



Set the scope to trigger off of AC line since the power supply stabilizes off of the line (60 Hz)  $\rightarrow$  makes triggering super easy!

We can use the data from last day to measure the expected wavelengths on the monochromator.

MONO/PMT

Not the real value! Need to normalize

19 Sept 107.

$\lambda_{\text{mono}} (\text{nm})$ (expected from last day)	$V_{\text{peak}} (\text{mV})$	$V_{\text{rms}} (\text{mV})$
322.5 $\rightarrow$ 322.5 $\pm$ 0.5	31 $\pm$ 5	4.0
365 $\rightarrow$ 365 $\downarrow$	33 $\pm$ 5	4.0
375 $\rightarrow$ 375	33 $\pm$ 8	4.0
385 $\rightarrow$ 385	79 $\pm$ 3	15 $\pm$ 1
393 $\rightarrow$ 393	3.48 $\pm$ 0.04 V	1.04 $\pm$ 0.02 V
400 $\rightarrow$ 400	148 $\pm$ 8	31 $\pm$ 1
<del>417</del> 406 $\rightarrow$ 406.5 $\pm$ 0.5	292 $\pm$ 14	72 $\pm$ 1
417 $\rightarrow$ 416	82 $\pm$ 4	16 $\pm$ 1
442 $\rightarrow$ 443	110 $\pm$ 4	22 $\pm$ 1
476 $\rightarrow$ 476	476 $\pm$ 10	127 $\pm$ 2
497 $\rightarrow$ 497	540 $\pm$ 12	153 $\pm$ 1
505 $\rightarrow$ 506	1.74 $\pm$ 0.02 V	490 $\pm$ 2
509 $\rightarrow$ 509	188 $\pm$ 8	44 $\pm$ 1
593 $\rightarrow$ 593	5.60 $\pm$ 0.04 V	1.83 $\pm$ 0.01 V
674 $\rightarrow$ 674	276 $\pm$ 8	68 $\pm$ 1
713 $\rightarrow$ 713	138 $\pm$ 6	30 $\pm$ 1
$\rightarrow$ 451.5 $\rightarrow$ 451.5	1.56 $\pm$ 0.02 V	0.461

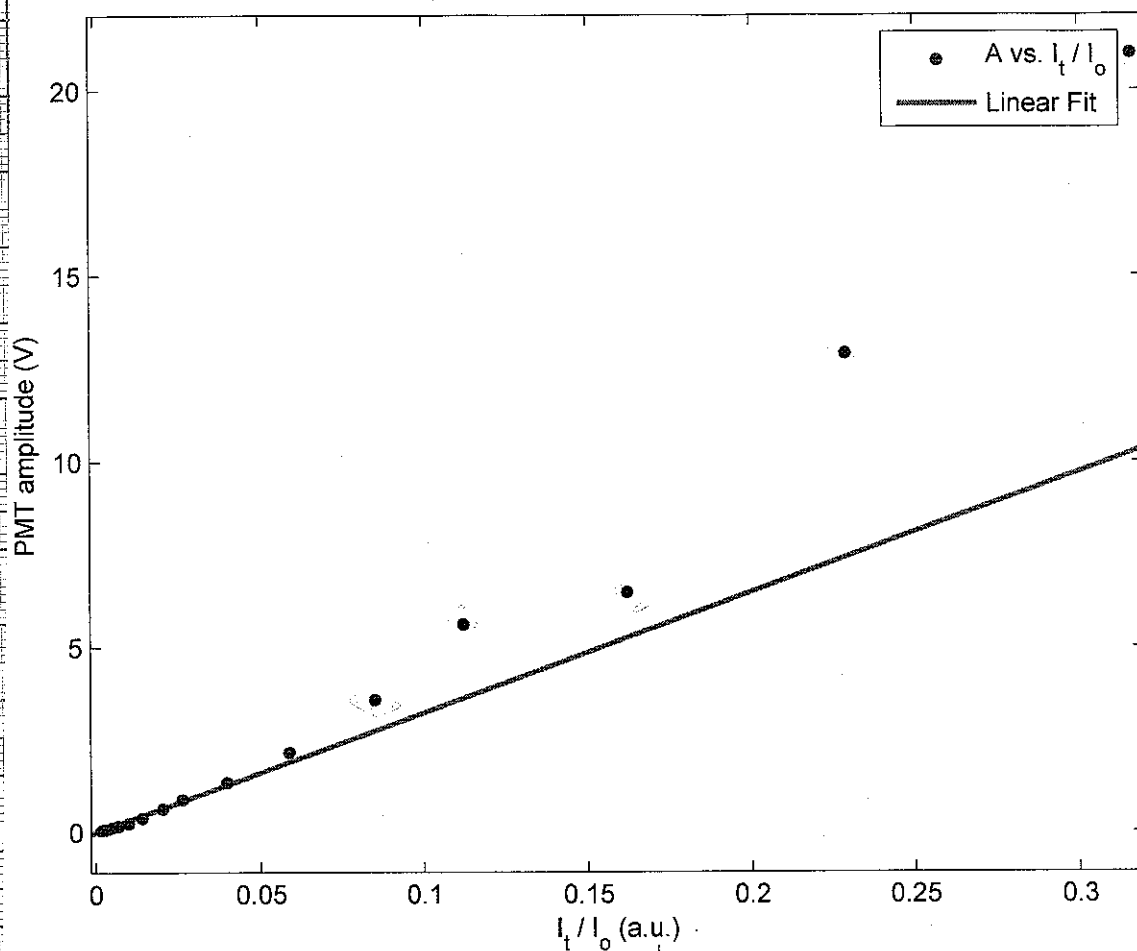
As before, the highest-wavelength line was not observed due to the response of the PMT/mono.

We can normalize this later, both w.r.t. the brightest line, and to correct the wavelength offset/nonlinearity on the mono step drive.

- As last time, the location of the maxima was determined by adjusting the mono until a line is visible, then fine adjustment until maximum voltage was observed on the scope. The wavelength was then read out.
- Placement of the Geiger tube was such that a high voltage without saturation ( $\sim 5V$  for the biggest peak) was seen on the oscilloscope. This corresponded to placement  $\sim 10\text{cm}$  away from the entrance slit of the mono.

JO

PMT amplitude vs. transmitted intensity



It's a ratio. No  
ratios have units?



PMT linearity: Analysis and plot.

- To the left, I've plotted the PMT amplitude (ie voltage) against the transmitted intensity  $I_t$  of the light.  $I_t$  was calculated by

$$D_N = -\log \frac{I_t}{I_0}$$

$$\Rightarrow \frac{I_t}{I_0} = 10^{-D_N}$$

$D_N$  is the step wedge density, given in the lab.

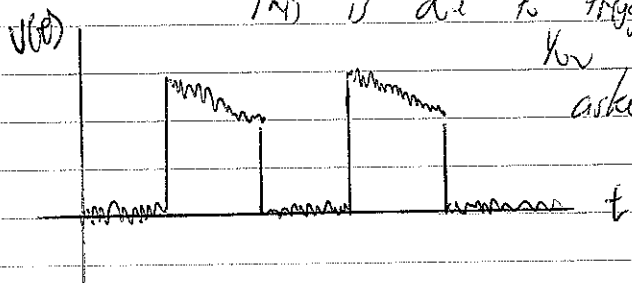
We don't really have to bother to find  $I_0$  because at this step we only care to see how linear the PMT is. So I've plotted the x-axis as  $\frac{I_t}{I_0}$  or simply  $10^{-D_N}$ . Since we expect the high power to be nonlinear I've excluded the highlighted parts from the fit.

As stated in the lab manual, we expect this to be about linear, except for higher powers. This is indeed the case: beyond about 5V, the error in the plot between the measured and predicted plots is on the order of the signal level itself.

From this we can conclude that up until ~~4.1866V~~, around 5V, we can reasonably expect the PMT's response to be linear.

A rigorous error analysis was not done here because we only wanted to see qualitatively how linear the PMT is. Or

At higher powers, the trace on the scope distorts from a square wave to something like this:

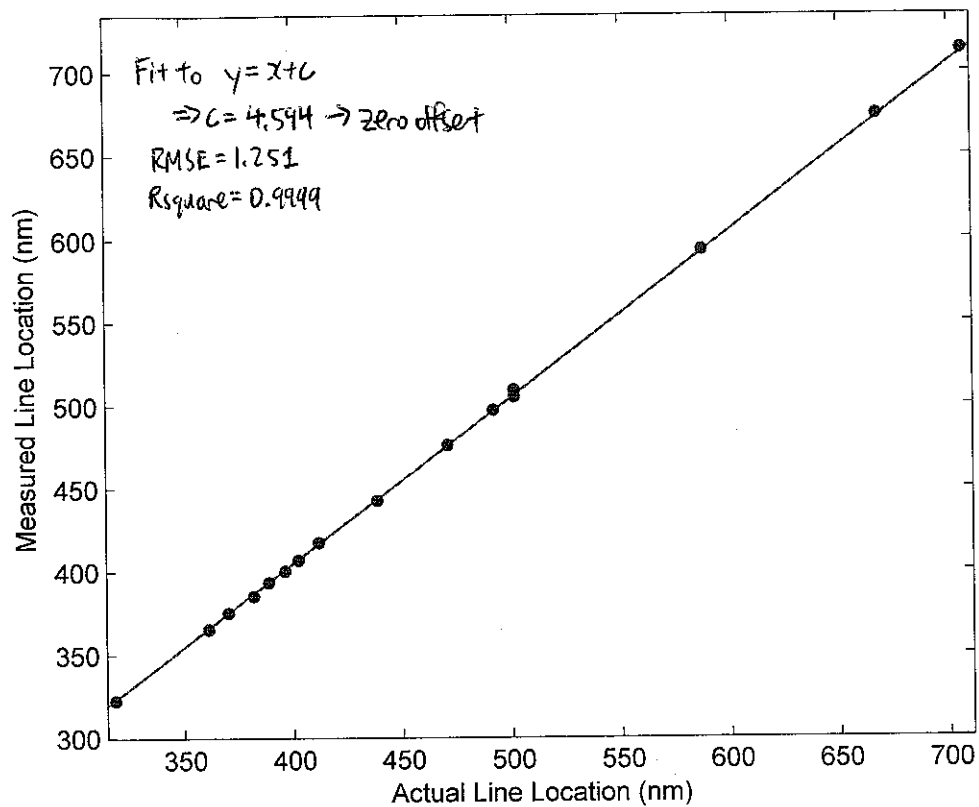


This is due to trigger issues. You should have asked for help.

0.25

The distortion is one possible source of error when measuring p-p voltage. It would make the value bigger than it actually is, which is borne out by the plots. ✓

Measured vs. Actual Line Locations of Helium



Monochromator wavelength calibration.

To find the zero offset of the mono, we take down the locations (according to the mono's step drive dial) of some lines of helium, and plot them against the known (given) locations.

Fitting to a linear function (1:1) with a zero offset, i.e. the functional form

$$y = mx + c.$$

$m = ?$

but  $\Delta h = ?$

12.25

yields a zero-offset of  $4.594 \text{ nm} \pm 0.5 \text{ nm} \rightarrow \boxed{4.6 \pm 0.5 \text{ nm}}$

The RMSE error of the fit is 1.251, on the order of the precision of the step drive (1 nm). Error estimate is given by the 95% confidence band of the fit.

We'll need to apply this correction whenever we deal with wavelengths later on.

Temperature of Tungsten Filament.

At full brightness we measured  $T = 22.4 \pm 0.5 \times 100^\circ \text{C}$ .

At full  $\sim 300^\circ \text{C}$ , we measured  $T = 19.0 \pm 0.5 \times 100^\circ \text{C}$ .

} again down did you get this error? -0.25

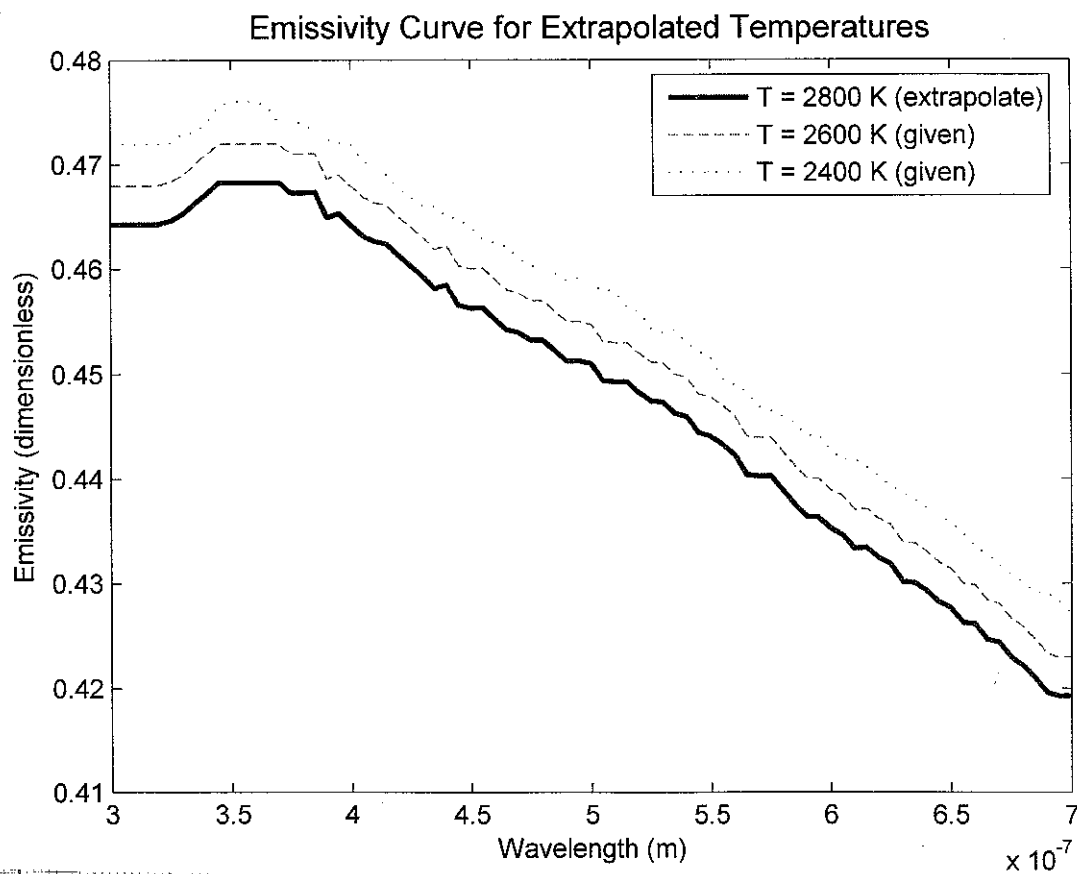
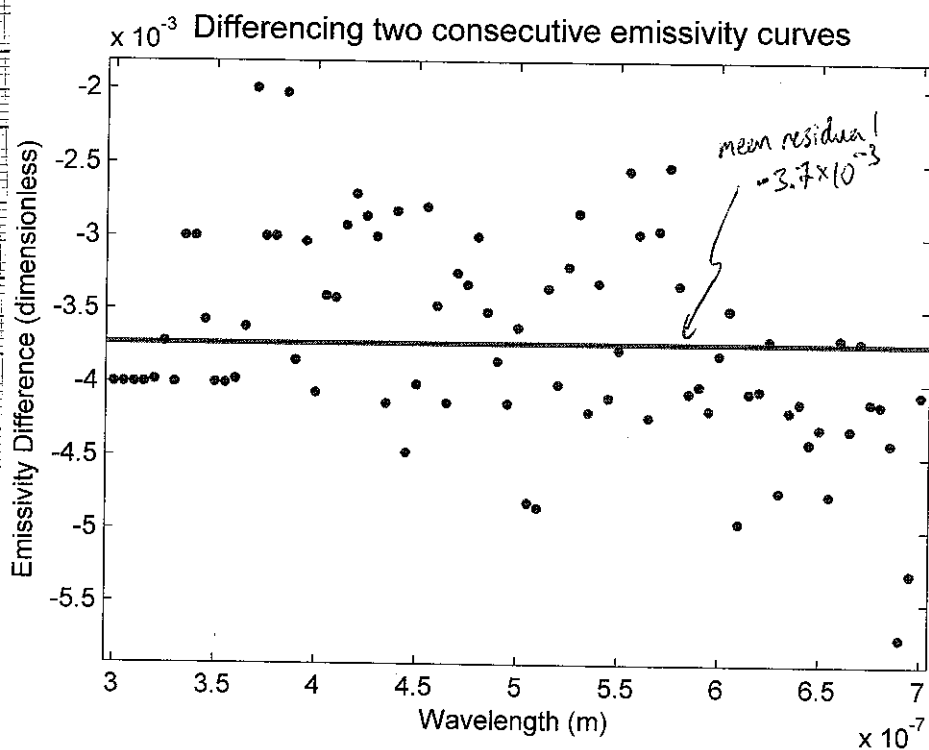
Apply a correction temperature: Reading off the provided graph gives us more measurements!

$T_{\text{cor}} = 280$  and  $200^\circ \text{C}$  respectively for the full- and mid-brightness.

$$\text{So } T_0 = \begin{cases} 2520^\circ \text{C} & \text{full brightness} \\ 2100^\circ \text{C} & \text{mid brightness} \end{cases} + 273.15 = \begin{cases} 2793 \text{ K} \\ 2373 \text{ K} \end{cases}$$

When picking brightness we forget to add the temp. correction.

↳ We will have to extrapolate the temp/brightness emitting curves for 2800K.



To obtain a reasonable extrapolation for an emissivity curve at  $T=2800\text{K}$ , I am going to do a linear extrapolation: that is, I am taking the two curves at 2600 and 2400, and take their difference. I will then take the mean of the variation and subtract it pointwise from the 2600K curve.

↳ The emissivity curves are recorded at different  $\lambda$ -steps so I'll have to interpolate  $\rightarrow$  use cubic splines.

- ↳ Procedure:
- 1) Import E-data for  $T=2400+2600\text{K}$
  - 2) Truncate data to  $\lambda \in (300, 700\text{nm})$ .
  - 3) Cubic-spline interpolate to equal time steps.
  - 4) Take difference of interpolated E-curves
  - 5) Find mean of the difference.

↳ by inspection, the curves just look offset by some constant.

↳ Furthermore a plot of the residuals is distributed about a mean pseudo-randomly.

- 6) Subtract mean from  $T=2600$  E-curve.

- 7) Voilà! some sort of emissivity curve.

nice

For the high temperature, I will use this curve for the analysis.

Response Function: example calculations:

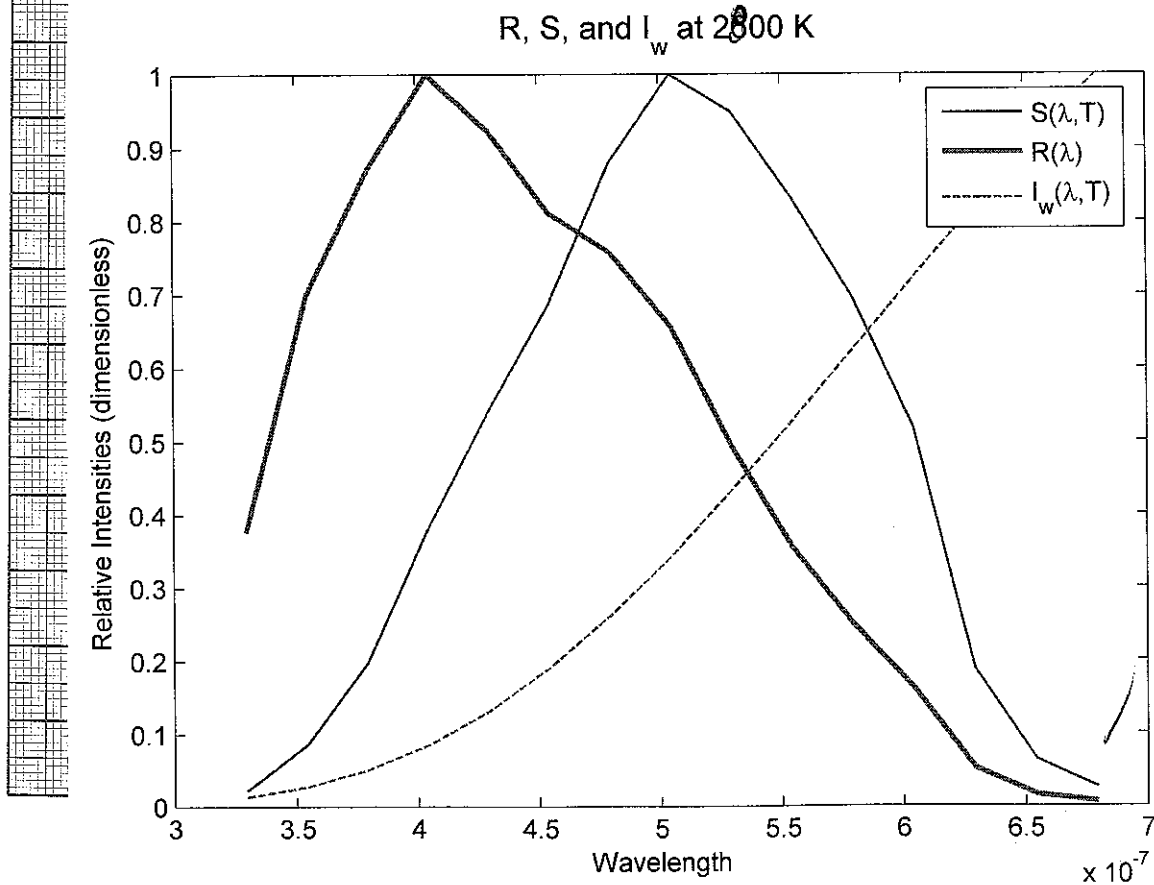
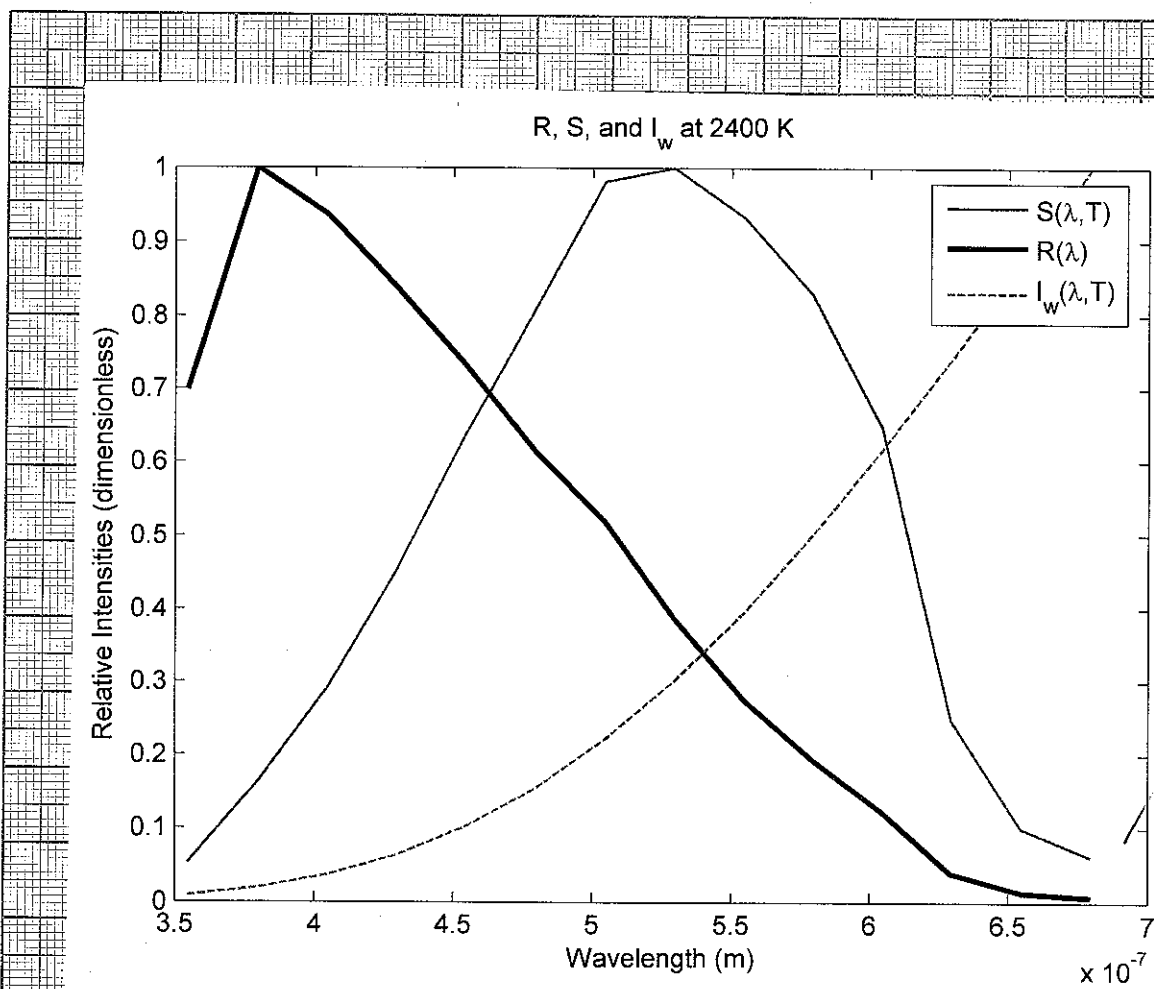
$I_w(\lambda, T) = \epsilon_w(\lambda, T) I(\lambda, T)$  for each value of  $\lambda$ , and each value of  $T$ , take  $\epsilon_w$  from the emissivity curve and multiply by  $I = \frac{A \lambda^{-5}}{e^{\frac{hc}{\lambda T}} - 1}$  with  $A = 2c^2 h = 1.19 \times 10^{-16} \text{ W m}^2 \text{ K}^{-5}$  and  $B = 1.44 \times 10^{-2} \text{ m K}$ .

Then take voltage  $S$  and divide by  $I_w$  to obtain  $R(\lambda)$  ✓

eg. @  $\lambda_{\text{max}} = 325\text{nm}$ ,  $T = 2800\text{K}$ . Then  $\epsilon_w = 0.464$  (table lookup)

$$I = \frac{(1.19 \times 10^{-16})(325 \times 10^{-9})^{-5}}{e^{\frac{1.44 \times 10^{-2}}{(2800)(325 \times 10^{-9})}} - 1} = 4.40 \times 10^{-20} \Rightarrow I_w = \epsilon I = \frac{2.41 \times 10^{-20}}{2.2 \times 10^{-9}}$$

$$\text{Then } R = \frac{S}{I_w} = \frac{2.1 \times 10^{-3}}{\frac{2.41 \times 10^{-20}}{2.2 \times 10^{-9}}} = 8.71 \times 10^{27} \text{ V m}^2 = 9.55 \times 10^{-12}$$



eg. 2 Take  $T=2400\text{K}$ ,  $\lambda=600\text{nm}$ . Here  $\epsilon=0.44277$  and  $S_{\text{measured}}$  is  $0.136\text{V}$ .

$$\begin{aligned}\text{Then } I_w = \epsilon I &= \epsilon A \lambda^5 \left( \exp\left(\frac{B}{\lambda T}\right) - 1 \right)^{-1} \\ &= \frac{(0.44277)(1.19 \times 10^{-16})(600 \times 10^{-9})^{-5}}{\exp\left(\frac{1.44 \times 10^2}{(600 \times 10^{-9})(2400)}\right) - 1} = 3.19 \times 10^{-10}\end{aligned}$$

$$R(\lambda) = \frac{S}{I_w} = \frac{0.136}{3.19 \times 10^{-10}} = 4.2653 \times 10^{-12} \quad \checkmark$$

For my results I will not subtract the background spectrum. It (the bgd signal) is clearly below the noise floor, since we had all lights off during measurement. Also, the one clear spurious point (cosmic?) would ruin the entire analysis.  
OK / guess.

### Error Analysis

Want to find  $\partial R$ , error in  $R(\lambda)$ . Sources of error:  $\lambda, T, S$ .

$$\partial R^2 = \left(\frac{\partial R}{\partial \lambda}\right)^2 \partial \lambda^2 + \left(\frac{\partial R}{\partial T}\right)^2 \partial T^2 + \left(\frac{\partial R}{\partial S}\right)^2 \partial S^2.$$

$$\text{Can show } \frac{\partial R}{\partial \lambda} = \frac{5(e^{B/\lambda T} - 1) S \lambda^4}{A \epsilon} - \frac{B e^{B/\lambda T} S \lambda^3}{A T \epsilon} = \frac{S \lambda^3 (-5T\lambda - e^{B/\lambda T} (B - 5T\lambda))}{A T \epsilon}.$$

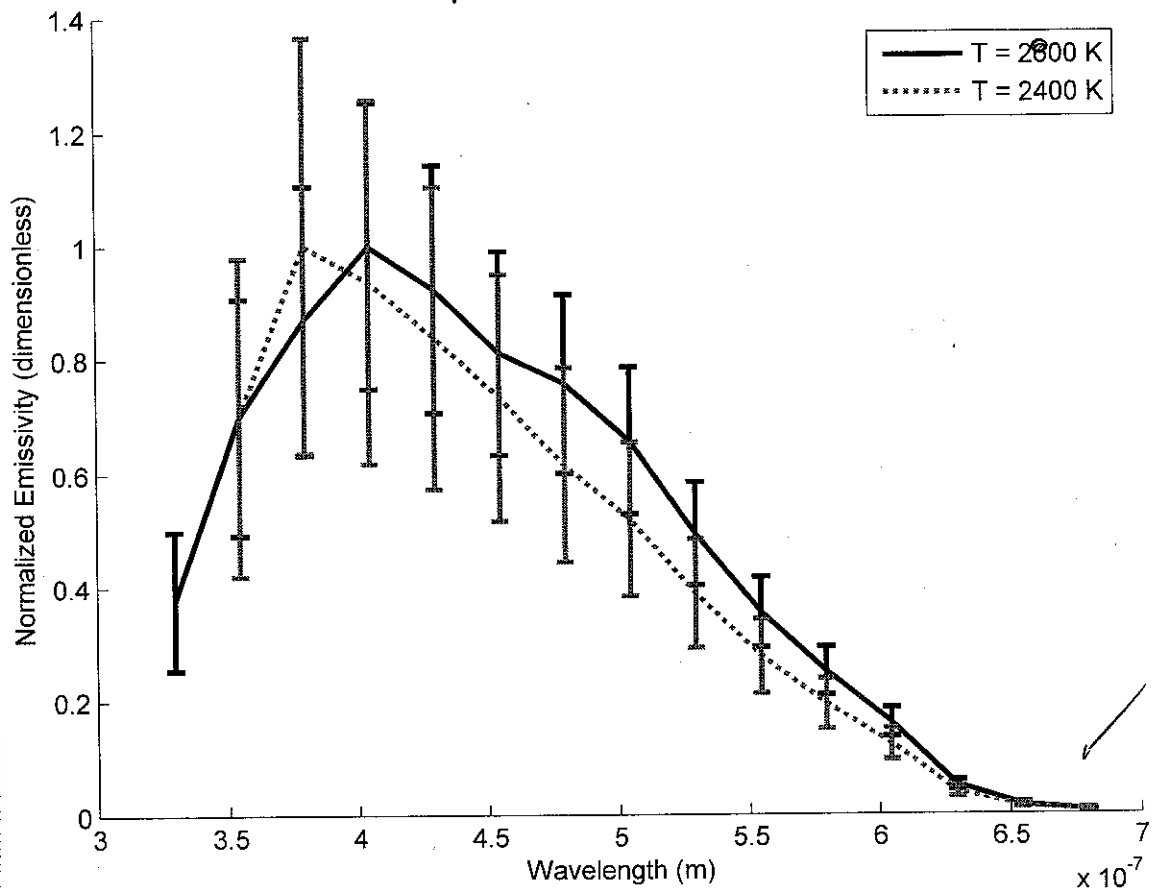
$$\frac{\partial R}{\partial T} = \frac{-B e^{B/\lambda T} S \lambda^3}{A T^2 \epsilon} = -\frac{B e^{B/\lambda T} S \lambda^3}{A T^2 \epsilon}$$

$$\frac{\partial R}{\partial S} = \frac{e^{B/\lambda T} - 1}{A \epsilon} \quad \text{OK}$$

I performed the rest of these calculations on Mathworks MATLAB R14. Plots to the left illustrate  $R, S$ , and  $I_w$  (normalized) for both temperatures.

Results next page.

Normalized Response of Monochromator/PMT System





A plot of the results is shown below. Note that the two curves, one on 2600K and the other at 2400K, are within error. This suggests that indeed,  $R$  is a function of  $\lambda$  only.

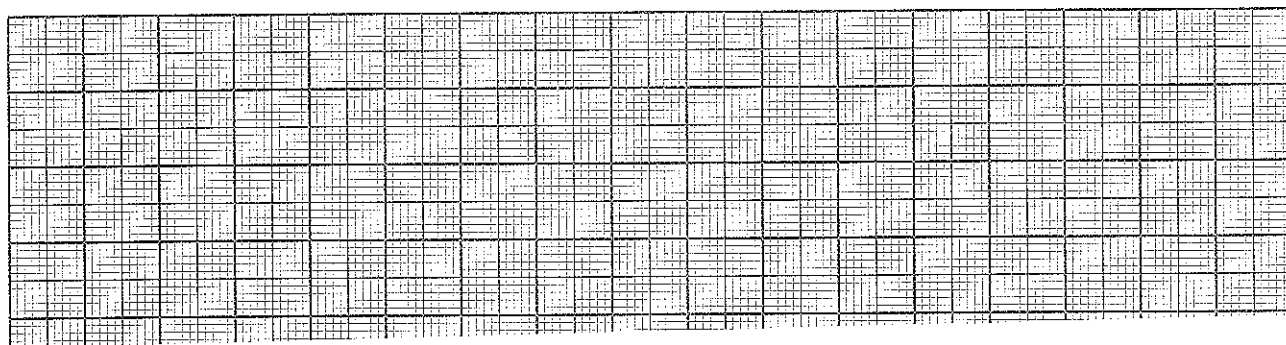
The actual numerical data is rather tedious to include in the report, I will make the raw files available online at <http://www.phas.ubc.ca/~lamm>. Here are the results summarized in the plot:

## 2400K

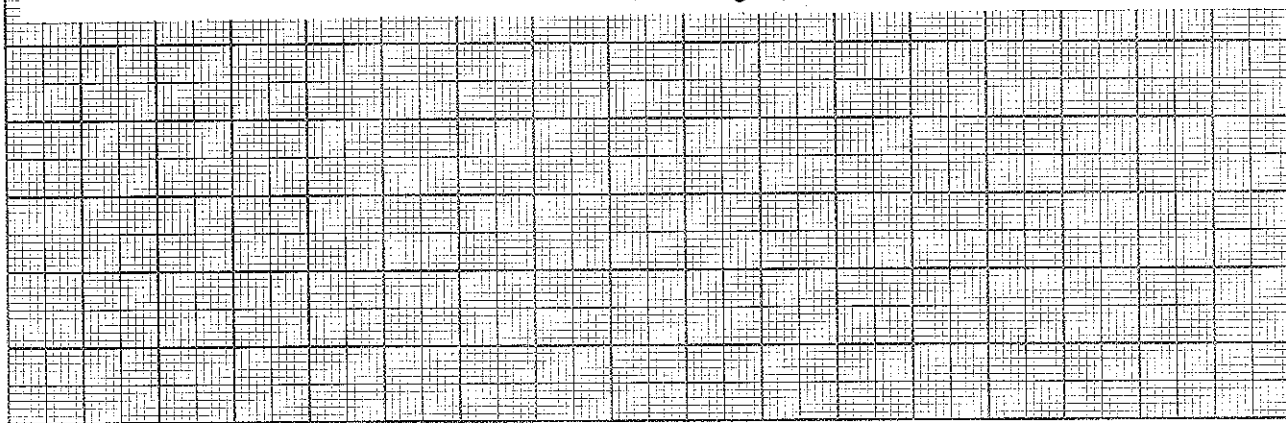
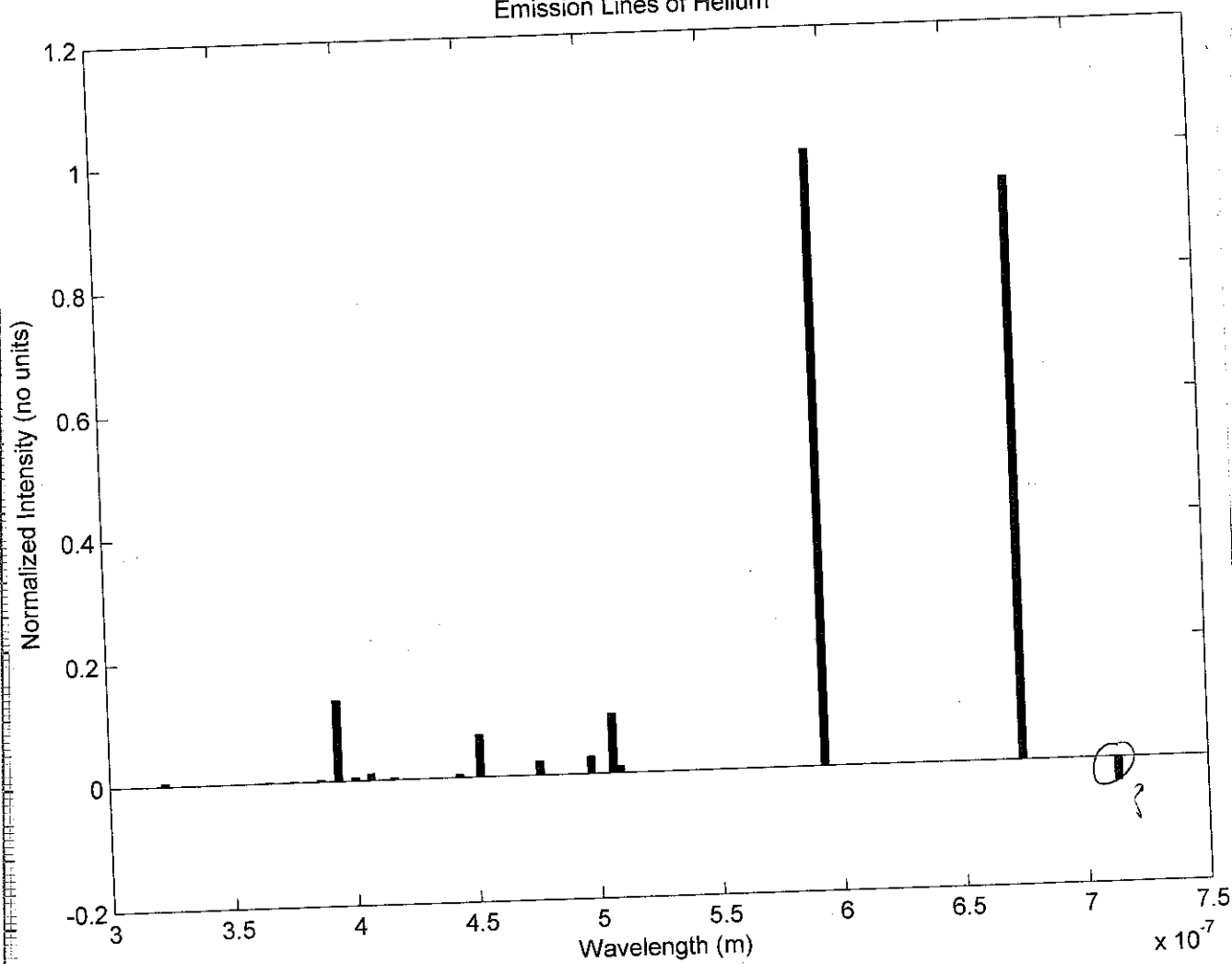
$\lambda(m)$	$R_{norm}(counts)$	$R_{norm}$
3.546e-007	0.6984	0.27934
3.796e-007	1	0.36441
4.046e-007	0.93671	0.31896
4.296e-007	0.83827	0.26532
4.546e-007	0.73277	0.21634
4.796e-007	0.61441	0.17014
5.046e-007	0.51877	0.13571
5.296e-007	0.3876	0.096193
5.546e-007	0.27605	0.065213
5.796e-007	0.19312	0.043846
6.046e-007	0.12265	0.027276
6.296e-007	0.039006	0.008846
6.546e-007	0.013417	0.0029368
6.796e-007	0.0072294	0.0017642

## 2600K

$\lambda(m)$	$R_{norm}(counts)$	$R_{norm}$
3.296e-007	0.37573	0.12286
3.546e-007	0.69934	0.20727
3.796e-007	0.86911	0.23642
4.046e-007	1	0.25208
4.296e-007	0.92378	0.21784
4.546e-007	0.8108	0.17859
4.796e-007	0.75715	0.15662
5.046e-007	0.65668	0.12846
5.296e-007	0.49286	0.091156
5.546e-007	0.35379	0.062323
5.796e-007	0.24982	0.041869
6.046e-007	0.16061	0.025666
6.296e-007	0.05112	0.0078924
6.546e-007	0.015639	0.0034701
6.796e-007	0.0057058	0.00093282



Emission Lines of Helium



For the emission lines of helium, we'll interpolate  $R(\lambda)$  using a cubic spline.

Once we do that, we simply compute  $I_w = \frac{S}{R}$  ✓ to find

the intensity, normalized to the system. A spectrum is plotted below.

Comparing with literature values is not helpful. Find large discrepancies!

eg. Their strongest line is at  $5875 \text{ \AA}$  ( $587.5 \text{ nm}$ ) by Fe: the  
second largest at  $706.5 \text{ nm}$  is over a factor of 2 smaller.

The line at  $667.8 \text{ nm}$  in our spectrum is way brighter than  $706.5$ . Not helpful.

Qualitatively, comparing the spectrum with the emission lines given  
in the lab booklet yield brightnesses that seem at least some  
what in accordance with our numbers.

did you normalize

$\lambda (\text{nm})$	$V_{pp} (\text{V})$	$I_w (\text{W/m}^2 \text{ nm})$	cf. Lit values	(Normalize $I_w$ to max=500) properly?	
$3.23 \times 10^{-7}$	0.031	0.13725	20	<del>0.005</del> 2.50	
$3.65 \times 10^{-7}$	0.033	0.042509	2	<del>0.0016</del> 0.78	might
$3.75 \times 10^{-7}$	0.033	0.039303	3	<del>0.0014</del> 0.71	account
$3.86 \times 10^{-7}$	0.079	0.086604	10	<u>0.0032</u> 1.58	for the
$3.93 \times 10^{-7}$	3.48	3.6391	500	66.43	differences.
$4 \times 10^{-7}$	0.148	0.14966	20	2.73	
$4.065 \times 10^{-7}$	0.292	0.29155	50	5.32	
$4.16 \times 10^{-7}$	0.082	0.083157	12	1.51	
$4.43 \times 10^{-7}$	0.11	0.12845	10	2.34	
$4.515 \times 10^{-7}$	1.56	1.8998	200	34.68	
$4.76 \times 10^{-7}$	0.476	0.62207	30	11.35	
$4.97 \times 10^{-7}$	0.54	0.77586	20	14.16	
$5.06 \times 10^{-7}$	1.74	2.6829	100	48.98	
$5.09 \times 10^{-7}$	0.188	0.29826	10	5.44	
$5.93 \times 10^{-7}$	5.6	27.387	500	500.00	
$6.74 \times 10^{-7}$	0.276	25.884	100	472.57	
$7.13 \times 10^{-7}$	0.138	+1.0243	200	18.70	

Sources of error include uncertainty in  $\lambda$  (not featured in here), and  
uncertainty in  $R$ . Nonlinearity at high power is also a problem. OK

Conclusions.

Several tasks were performed on the PMT/Monochromator system. The linearity of the PMT was established. The zero offset of the mono was found to be +4.6nm. The response curve was found for the PMT/Mono system and is included opposite page 13. It was confirmed that  $R$  is independent of  $\lambda$ , within error. Lastly, the emission lines of helium were examined. Comparison with literature values is not favorable, but several sources of error were discussed to justify this inaccuracy.

very good

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