Characterizing Wave Plates by White Light Spectroscopy

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What is a wave plate?

Optical element made of birefringent materials.

Adds a phase shift between the two polarization basis vectors

These basis vectors are determined by the orientation of the fast and slow axis of the material

Phase shift, δ, depends on birefringence (Δn): difference in index of refraction of the fast and slow axis

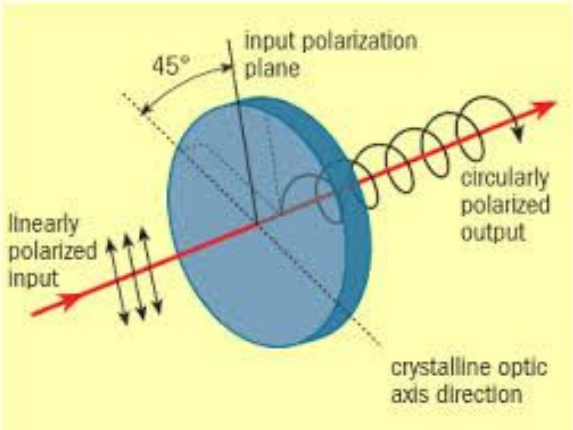
$$\delta = 2\pi\Delta nd/\lambda$$

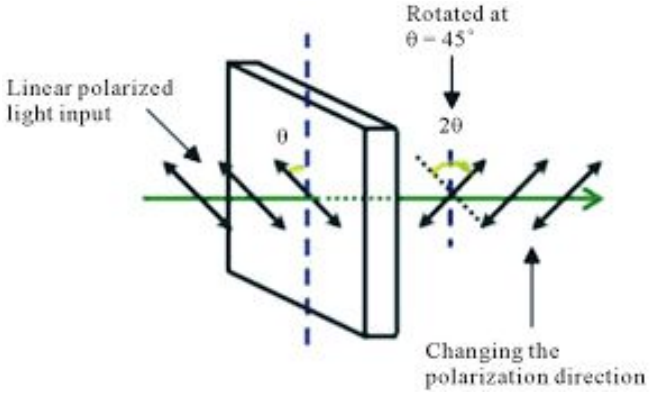
How to find the axes of a Wave Plate?

What you will need: two linear polarizers and a birefringent material

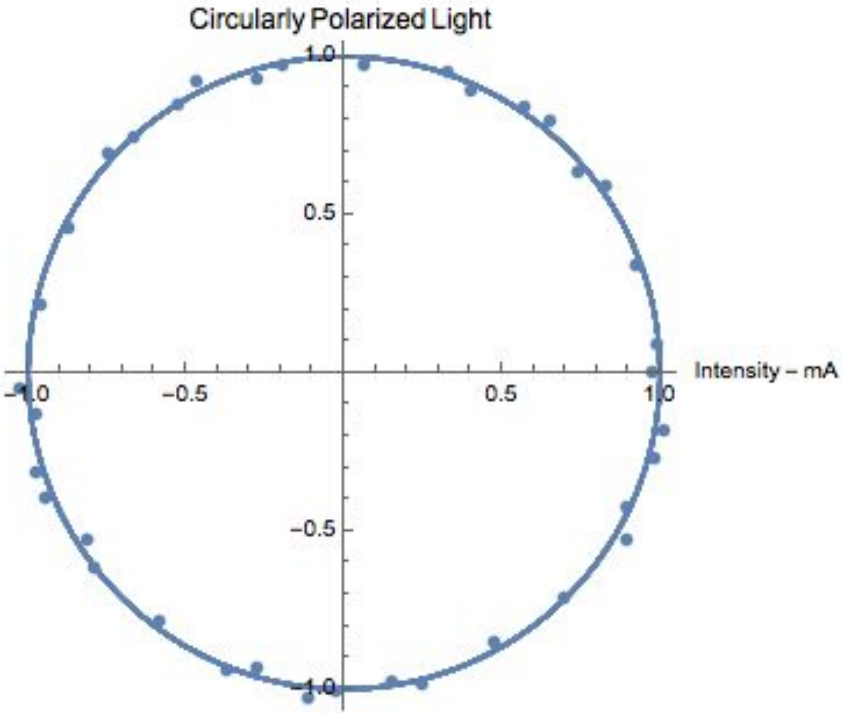
Set polarizers to extinction

Rotate birefringent material between polarizers and observe results





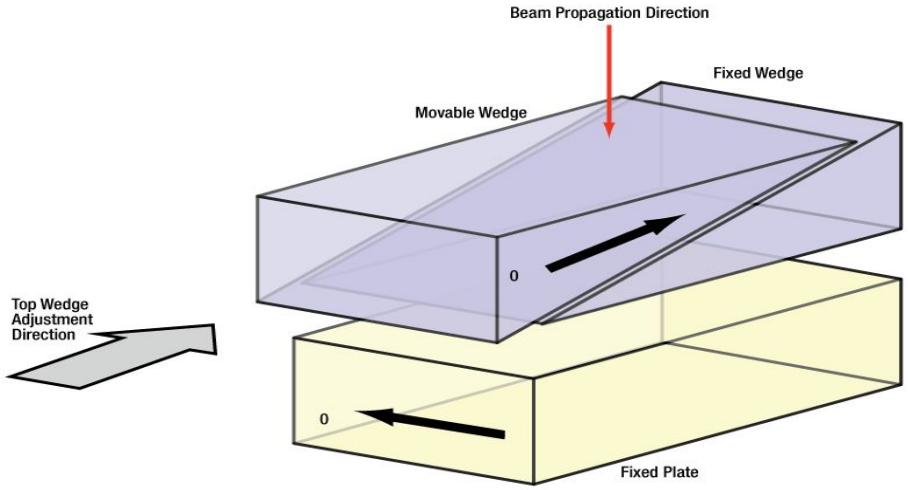
Observing Circularly Polarized Light



Babinet Compensator

Pros: acts as a variable wave-plate to give any desired phase shift (retardance), works over large wavelength range

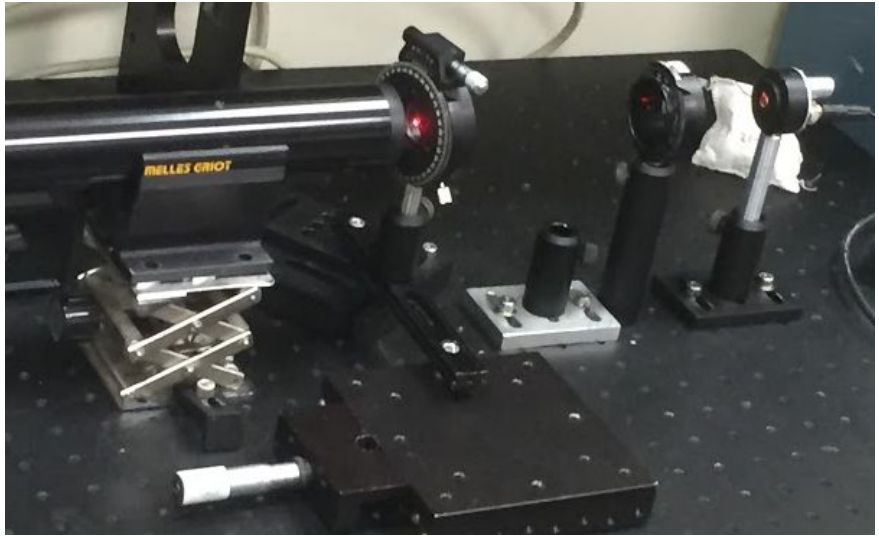
Cons: quartz prisms are expensive, can be made but needs to be very precisely aligned, needs time to be made and then shipped



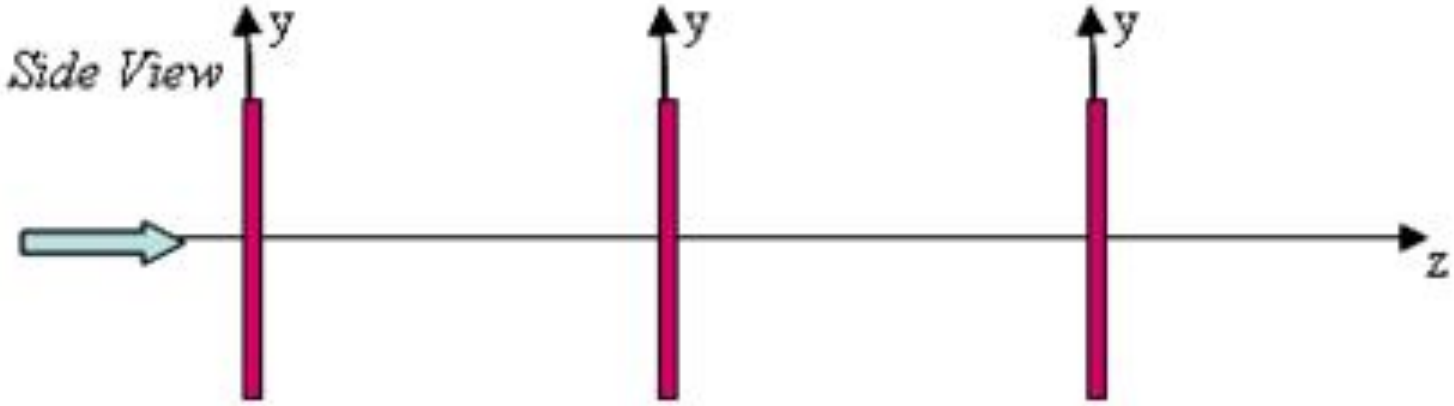
Ehringhaus (Tilting) Compensator

Pros: easily created (only need a waveplate and rotational mount) and inexpensive

Cons: reflectivity changes with respect to incidence angle, high order plate will have large phase shift with small change in incidence angle, *very* sensitive to small changes in optical axis orientation, allows us to determine phase retardance of an unknown element for a single wavelength at a time



Approach for Seeing Phase Shift



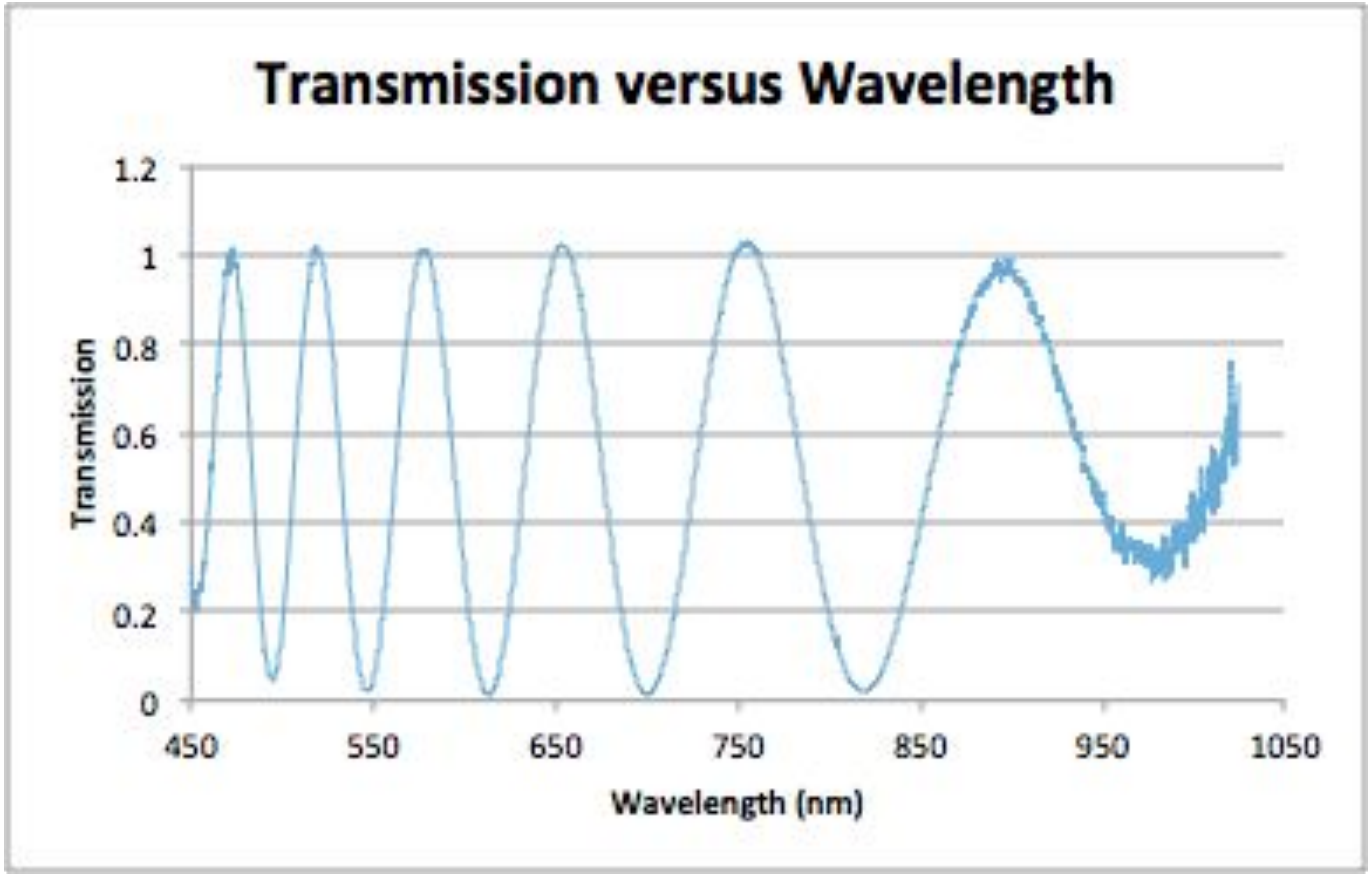
Polarizer

0 deg

Unknown

Polarizer

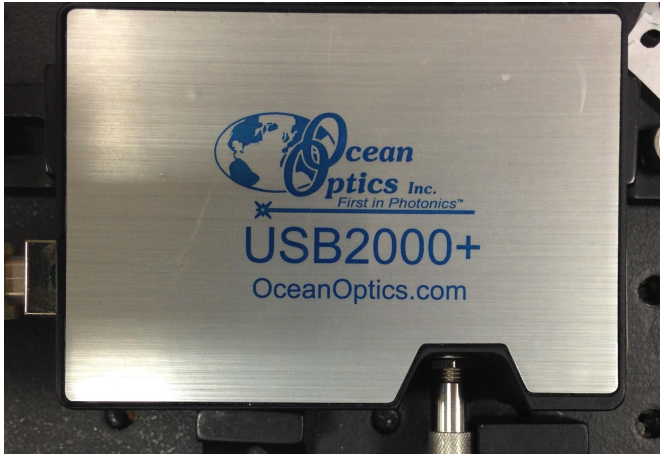
0 deg


Transmission versus Wavelength
1.2
1
0.8
0.6
0.4
0.2
0
Transmission
450
550
650
750
850
950
1050
Wavelength (nm)

Spectrometer

Allows us to observe how wave plate affects light at many wavelengths using a broadband source

Using an OceanOptics USB2000+ spectrometer, can collect data for wavelengths from 339nm to 1024nm, with a resolution of 0.282nm, Signal/Noise = 250/1



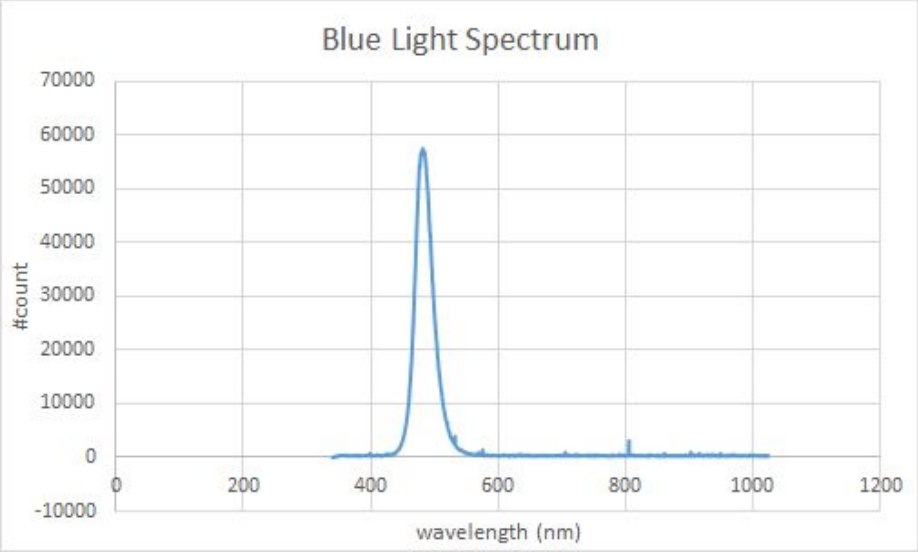
Light Sources

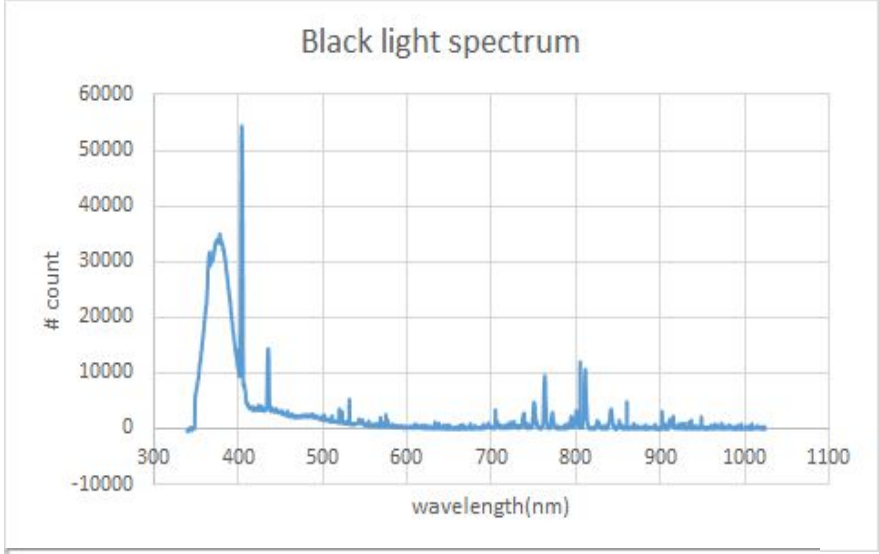
There are three different light sources in our experiment: white light source, blue light source and black light source.

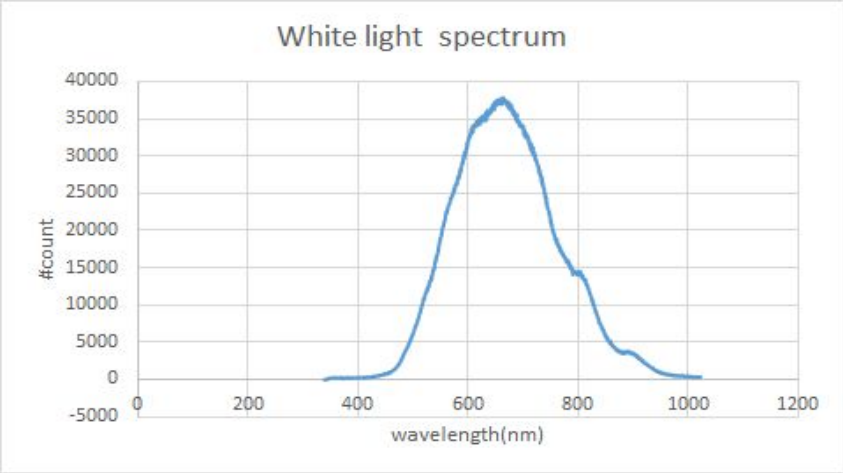
White light is provided by The OSL1 High Intensity Fiber Light Source. This source has tunable intensity.

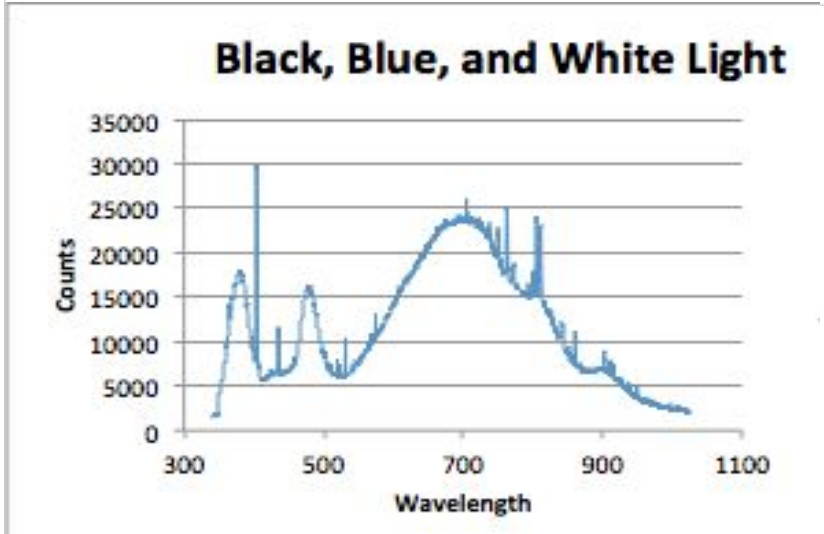
Blue light is provided by a blue LED.

Black light is provided by a black light flashlight.

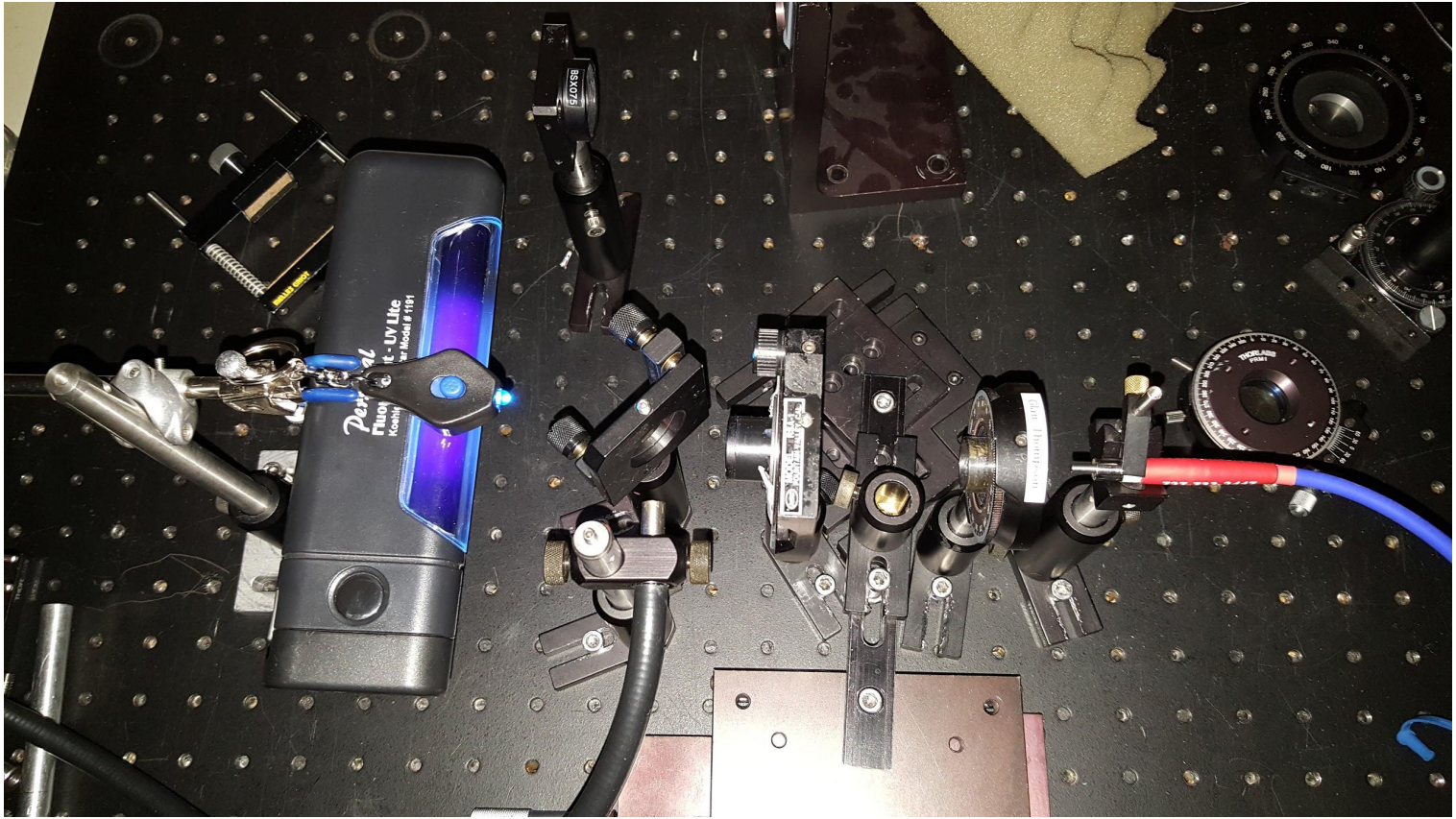

Blue Light Spectrum
#count
70000
60000
50000
40000
30000
20000
10000
0
-10000
0
200
400
600
800
1000
1200
wavelength (nm)


Black light spectrum
count
60000
50000
40000
30000
20000
10000
0
-10000
300
400
500
600
700
800
900
1000
1100
wavelength(nm)

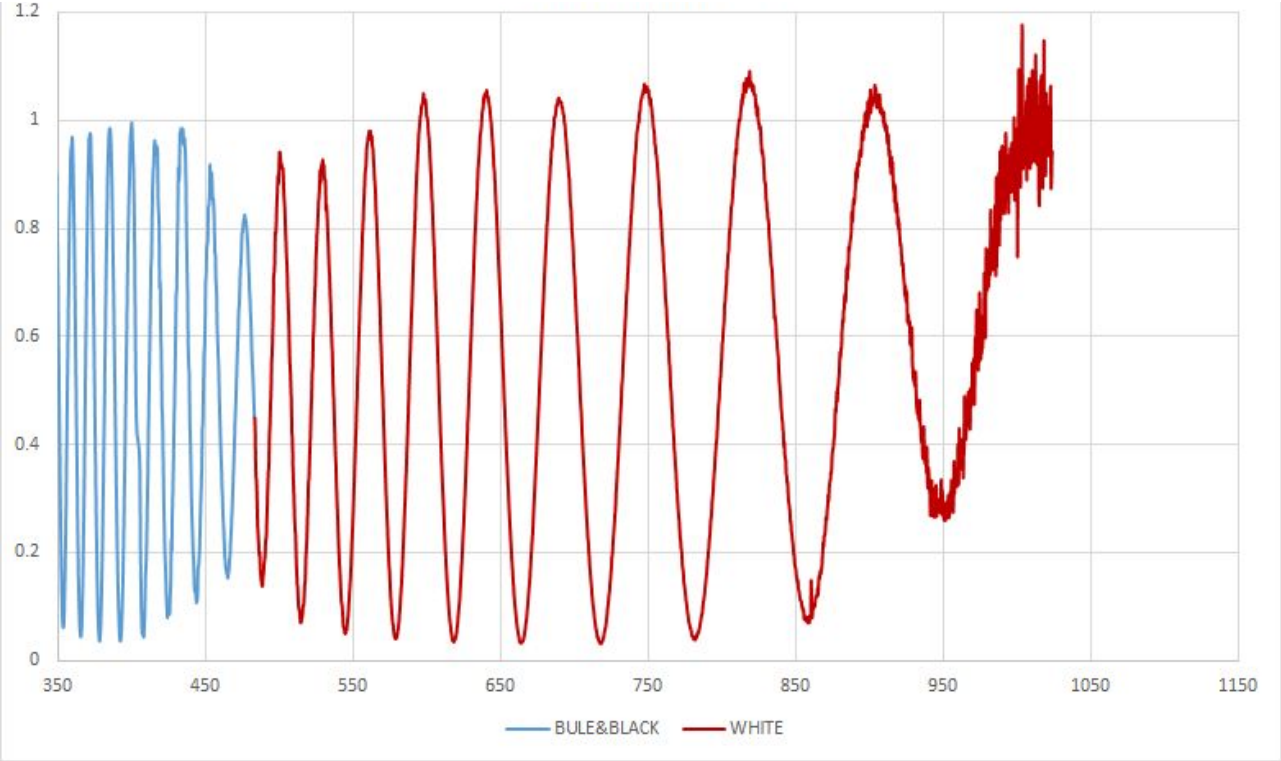

White light spectrum
#count
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
0
200
400
600
800
1000
1200
wavelength(nm)


Black, Blue, and White Light
Counts
35000
30000
25000
20000
15000
10000
5000
0
300
500
700
900
1100
Wavelength

Setup


BS007S
Pen
Photon
Konica
t - UV Lite
Model # 1191
THORLABS
FW102C

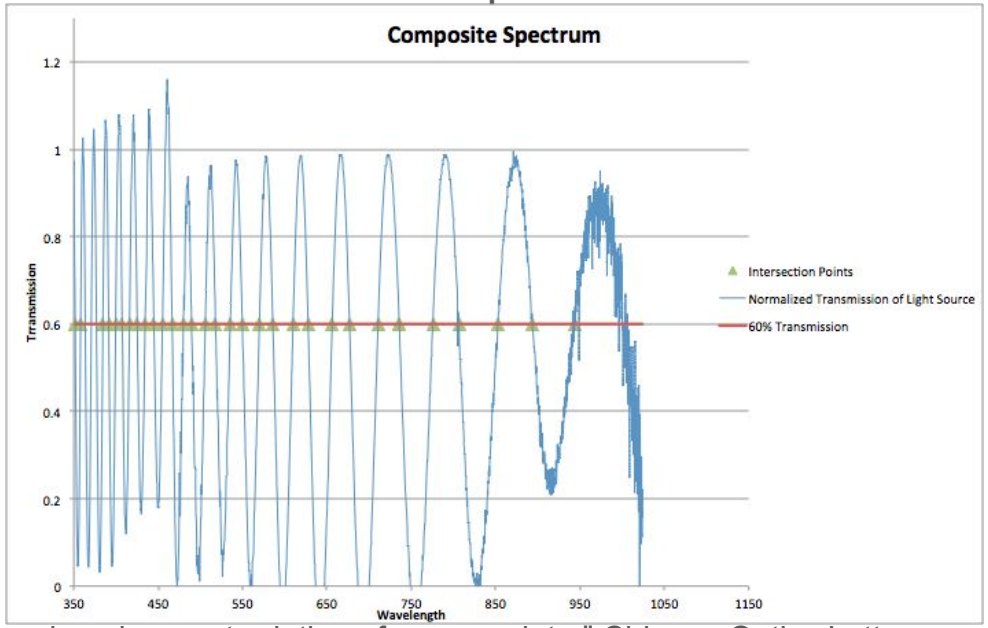
Composite Transmission Spectrum



Spectral technique for determining wave-plate characteristics**

Find the intersection points of the normalized transmission spectrum at an arbitrary transmission percentage

Label the location of these points: λ_i



**W. Wang, J. Chen, Z. Liu. “Spectral technique for measuring phase retardation of a wave plate.” Chinese Optics Letters. 10 Jan 2015.

Putting technique to the test

$$d = \frac{\lambda_i \lambda_{i+2}}{\Delta n(\lambda_i)\lambda_{i+2} - \Delta n(\lambda_{i+2})\lambda_i}$$

First tested with a known wave-plate (½-wave at 830nm) but it did not yield expected results of a ½-wave plate

Thicknesses also varied when using different sets of intersection points' wavelengths. We tried to average the thicknesses but it still did not yield the results we would expect

Tried minimization method to get better estimate of thickness of the element

Minimization Technique

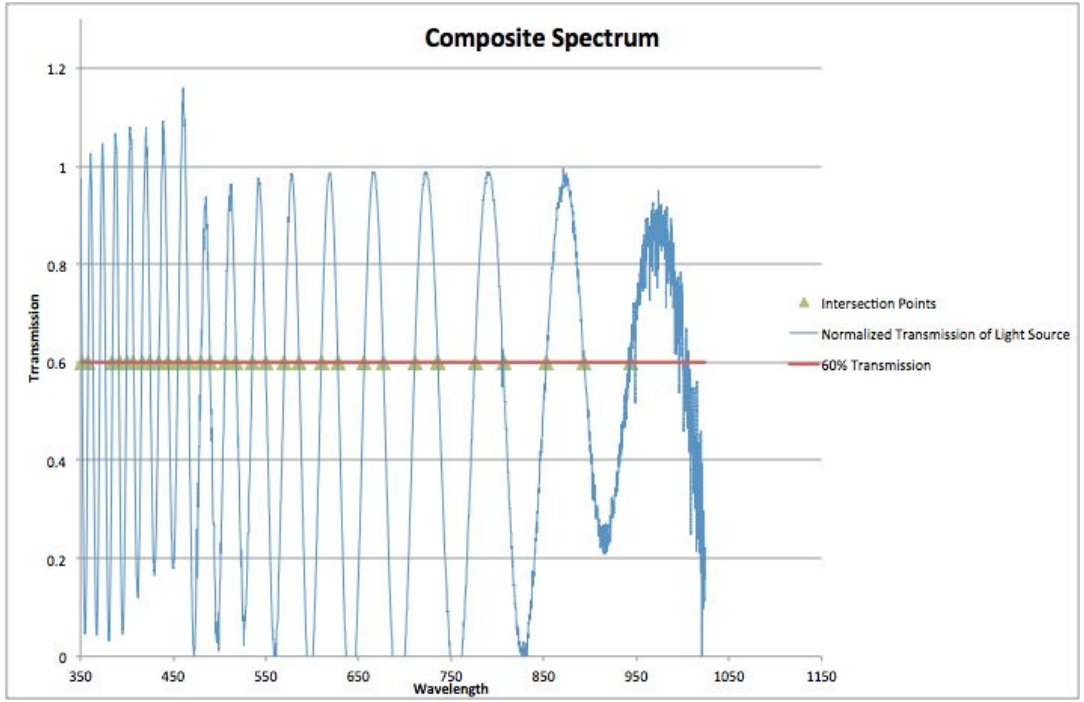
Phase shift: $\delta = 2\pi\Delta nd/\lambda$

Find the thickness for λ=830nm:

$$d = \lambda(2\pi \times \text{order} + \pi)/2\pi\Delta n$$

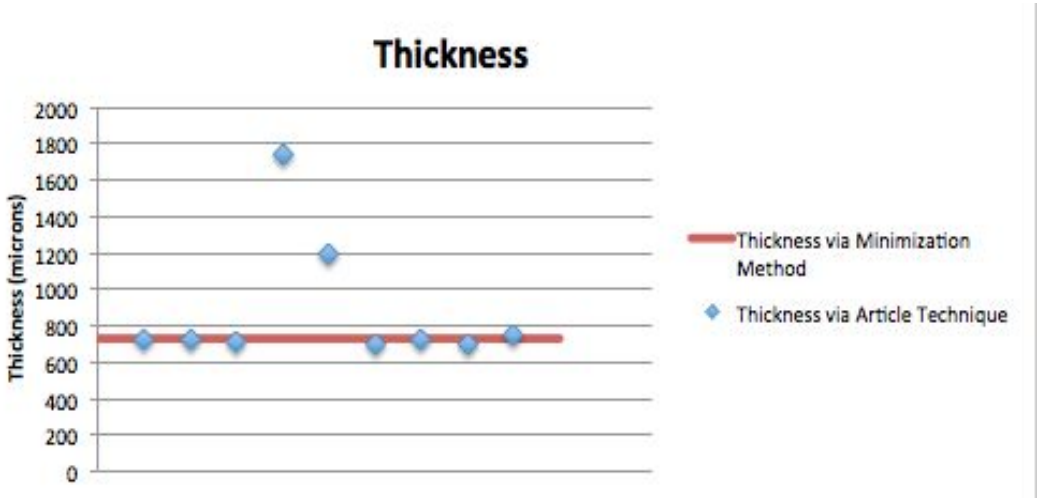
Minimize the integer N for peak wavelengths:

$$\Delta nd/\lambda = N$$



Comparing the two methods

We then compared the two methods and plotted them against each other



What if we don’t know the material of the element?

Assume birefringence variation across the range of wavelengths is small

$$\Delta n(\lambda_0) = \Delta n(\lambda_i) = \Delta n(\lambda_{i+2})$$

$$\Delta n * d = \frac{\lambda_i \lambda_{i+2}}{\lambda_{i+2} - \lambda_i}$$

Determining other Characteristics

Rest of the characteristics are determined with thickness calculations

Absolute Phase:

$$\delta(\lambda_0) = \frac{2\pi}{\lambda_0}\Delta n(\lambda_0) * d$$

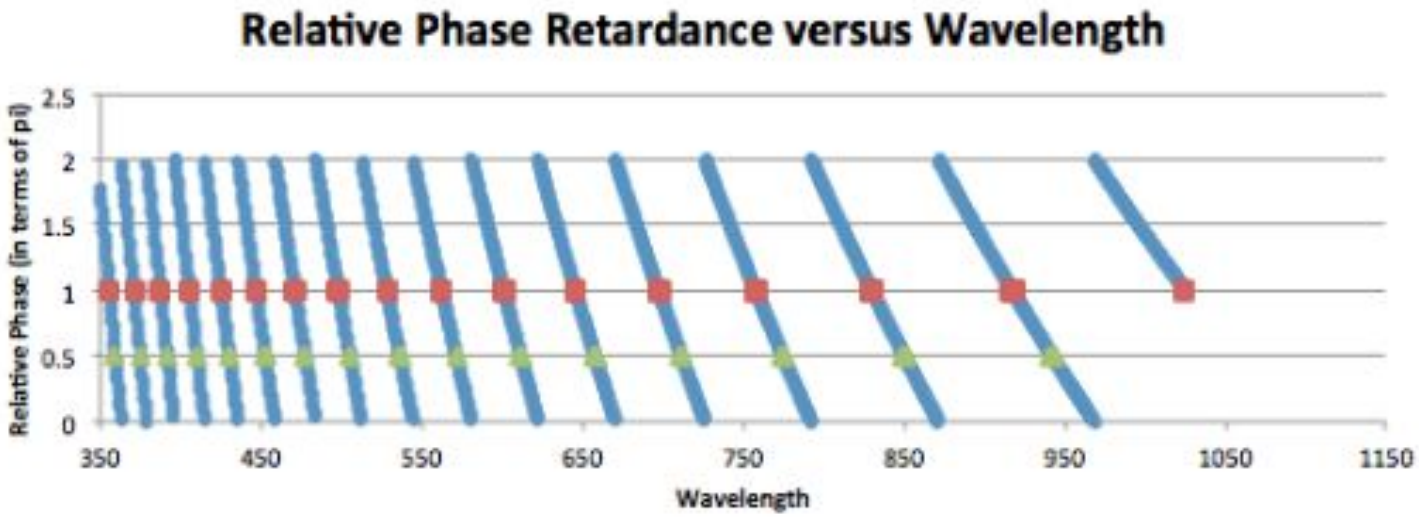
Relative Phase:

$$\delta(\lambda_0)_{eff} = MOD(\delta(\lambda_0), 2\pi)$$

Order:

$$N = INT\left(\frac{\delta(\lambda_0)}{2\pi}\right)$$

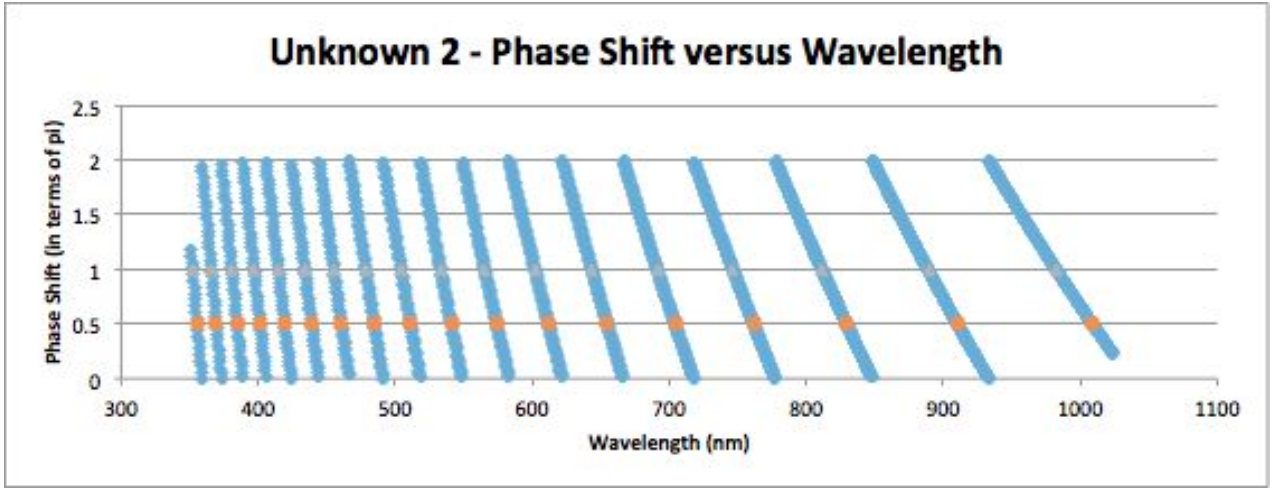
Retardance Characteristics for 830nm HWP



Half Wave	Quarter Wave
342	345
356	359
371	375
387	392
405	410
425	430
447	453
471	477
498	505
528	536
562	572
601	612
646	658
697	711
758	775
830	850
917	942

Unknown 2

This was an element we had previously tested to be a high-order ½-wave plate at 460nm



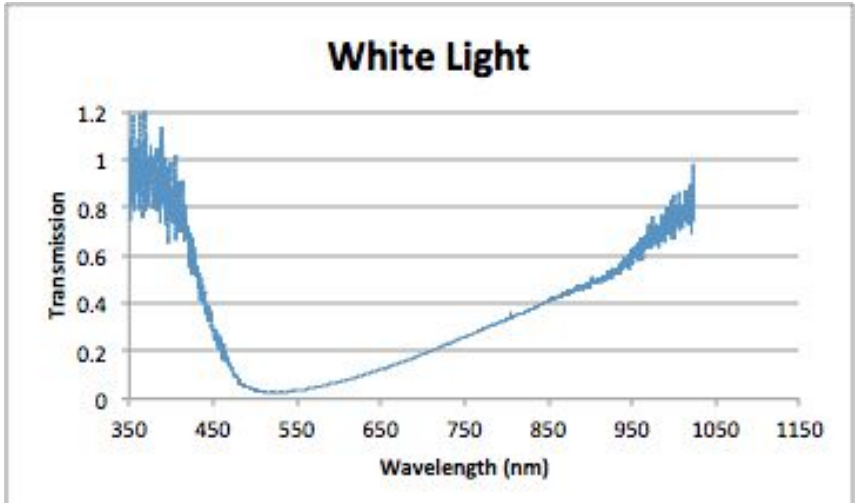
QWP	HWP
355	352
369	366
385	381
401	397
419	415
439	434
461	455
485	479
511	504
541	533
574	565
612	603
655	643
704	691
762	747
829	811
910	889
1009	982

Unknown 3

This element we had previously determined to be a zero/low order ¼-wave for 460 nm. Since this is low/zero order, our intersection points technique does not apply. We analyzed the data to determine this is a ½-wave for 520 nm and a ¼-wave for 433nm and 900nm

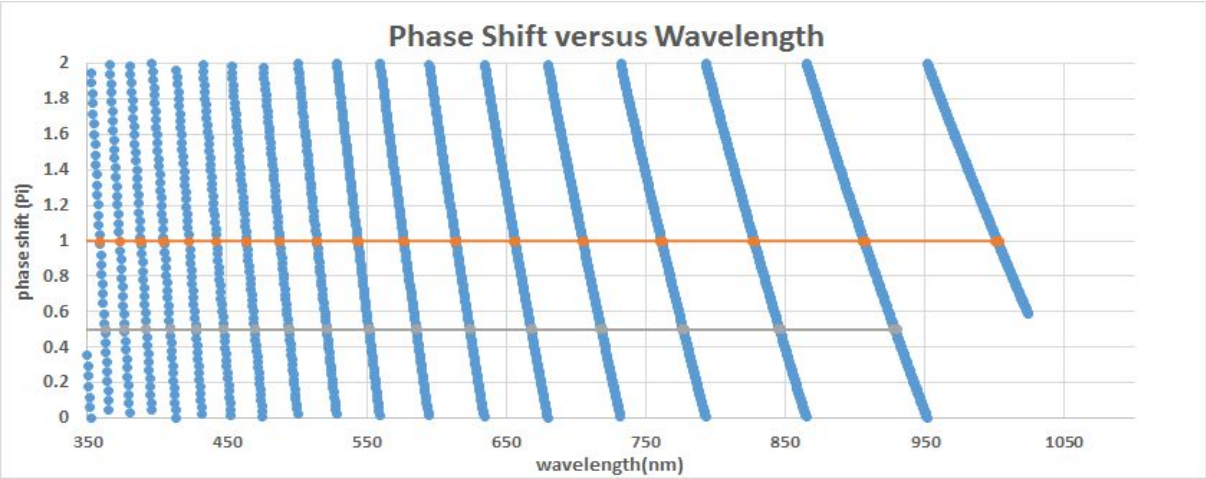
Upon rotating the analyzer transmission remained constant at 433nm and 900nm

At 520nm the transmission went from 0 to 1 changing the polarizers from pass to cross polarizations



Unknown 4

This was an element we had previously tested to be a high-order quarter wave plate at 633 nm



QWP	HWP
349	346
363	359
377	373
392	389
409	405
427	464
448	488
470	514
494	544
522	577
552	614
586	656
625	705
668	761
718	827
777	906
846	1002
929	

In the Future

Bring back the Ehringhaus compensator and apply the spectral technique to it across a range of angular tilt.

Perhaps create a simple manual for people to quickly use this setup to determine the intended wavelengths of an unknown waveplate.

Design a simple experiment that could be performed in an introductory optics course so students can explore the concepts of phase retardation, birefringence, and chromatic dispersion. All while learning practical lab techniques such as using a spectrum analyzer and polarizers for more than just sunglasses.

Acknowledgments

We would like to thank Dr. Bentley, Dr. Noe, Dr. Cohen and Dr. Metcalf for mentoring us and our work is supported by LTC

How we normalize

With the low intensities of our blue and black light spectrums, we normalize in such a way to reduce the effect of noise

A= GTs at full pass with the WP

B= GTs at full pass

C= 1st GT

D= WP only

E= GTs crossed (background signal)

*All values are in counts of the spectrum analyzer

$$\frac{A-E}{B-E} \Big/ \frac{C-E}{D-E}$$