RUBY

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Nothing is here

INTRODUCTION

In the first phase of this experiment, we will analyze the room lighting, background lighting, and calibrate the spcectrometer. The calibration will be done by comparing the measured wavelength of a green laser diode to its expected wavelength of 532 nm. We will then block out the background light with a black cloth, and measure the transmission and absorption spectrum of our ruby crystal sample by measuring the intensity of a wide spectrum white light and dividing by the intensity of the white light after it passes through the ruby.

In the next phase we will investigate ruby fluorescence. Ruby fluorescence is key in its ability to function as a laser, where, after being excited by an incident light source, the electrons will quickly enter a meta-stable state from which they will more slowly exit, emitting a photon. In this lab we will be observing the wavelength of this emittance, which corresponds to the difference in energy levels, and the lifetime of this meta-stable state. The latter will be measured by exciting the ruby with the same laser, but powered by a function generator in a square wave pattern. The output of the ruby will then be collected with a photodiode and measured on an oscilloscope.

APPARATUS

The apparatus consisted of the following.

- Aluminum optical breadboard with 1/4-20 tapped holes
- Green laser diode
- Spectrometer, Ocean Optics USB4000FL, OceanView software, USB cable
- Lens, 200mm focal length
- Lens, 25mm focal length
- Mirror in adjustable x-y mount with rotational micrometer
- Photodiode (PD) detector
- Neutral-Density (ND) optical filter
- Long-Pass optical filter
- Optical Fibers, 50 and 600 micron core
- Black cloth
- White light illuminator
- Ruby Crystal, Al_2O_3:Cr, approximately 0.05% Cr
- Oscilloscope, Tektronix TDS1052B
- Signal Generator, GW Instek GFG-8216A
- BNC Cables and T adapter

ROOM LIGHT SPECTRUM AND CALIBRATION

Procedure

First, a baseline for background noise in measurements made pointed at the breadboard was established. The OceanView software was used to tune the Scans to Average setting, which controls the amount of time the spectrometer collects incoming photons, to maximize the usage of the input bits of that device. This step would be performed for each spectrometer measurement.

Next, the spectrometer was calibrated using the 532 nm green laser, because the basic function of the laser will remain unchanged from its factory settings due to the nature of how laser light is produced, while a spectrometer as a measurement device relies on mirrors which can likely change their adjustment over time. The laser was connected directly to the fiber-optic cable, and then to the spectrometer, which removed any effect of the background noise.

Finally, the fiber-optic cable was pointed directly at the lab lights to analyze the spectral signature of the fluorescent lighting and other lightsources.

Results

The background measurements shown in fig. 1 were found not to be useful, as the two other measurements made without the black cloth covering would be substantially brighter than the background noise, and the

black cloth would be used for all future, more carefully controlled tests. This measurement may still be relevant if any of the peaks sneak into any of the the other data they shouldn't be in.

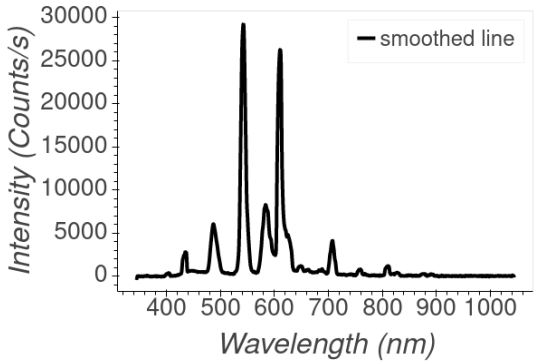

FIG. 1.

The spectrometer measurement of the green laser was indeed found to be just over 533 nm, meaning that all wavelength measurements using the spectrometer must be adjusted by 1 nm. This was done proactively when loading the data from .txt file for the rest of the lab involving the spectrometer, so all reported graphs and numbers have been corrected by this constant amount of 1.094 nm.

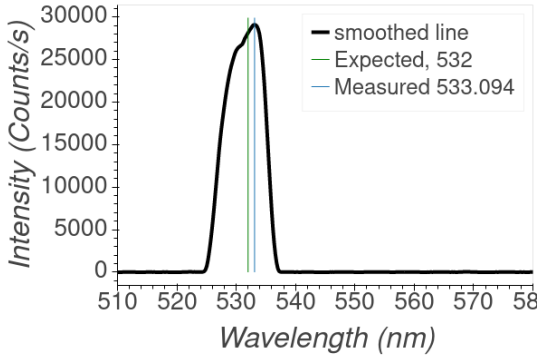

FIG. 2.

Finally the lab light spectrum was analyzed, and is given in fig.3. The 6 largest peaks were found, and their characteristic linewidth calculated. The narrowest one was at 435.3 nm, which corresponds to a violet color, with a linewidth of 1.9 nm.

It is interesting to briefly explore why there are separate peaks. Flourescent lights are percieved as white, but the white light source used later in the lab will have a significantly different spectral signature in spite of being percieved in much the same way. This is due to the nature of the photo-receptors in our eyes. The three color-receptors in fact overlap in the wavelengths they percieve, and the brain compensates for these overlaps by just adding them together. This adding together of percieved light is why, as we see in the table , orange + green + yellow + violet + red light = white light to our eyes. Flourescent bulbs create the illusion of white light by producing just a few different color lights, with a few different materials.

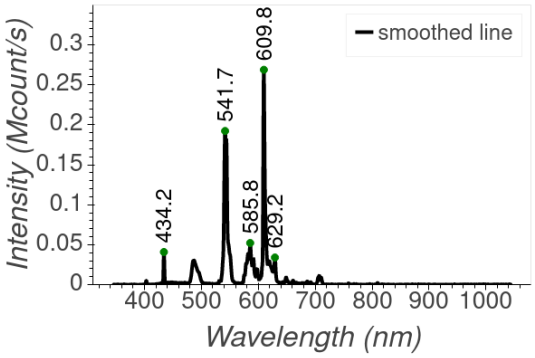

FIG. 3.

Wavelength (nm)	Intensity (cps)	Linewidth (nm)	Color
609.8	268854	3.3	Orange
541.7	192323	6.7	Green
585.8	52107	8.3	Yellow
434.2	40834	1.9	Violet
629.2	33929	2.2	Red

ABSORPTION SPECTRUM

Procedure

In this phase of the lab the absorption spectrum of the ruby sample is measured. Here we will use a white light source with a smooth output spectrum, and compare the spectral signature of white light that does not pass through the ruby and white light that does. The white light source was placed about 10 cm away from the FO cable connected to the spectrometer, and the ruby was mounted between them on a swivel to easily move in and out of the way of the beam. After everything was secured and aligned, the black cloth was placed over the measurement setup to block out background noise. A measurement was made with and without the ruby crystal in the beam's path. Measurements on the spectrogram were calibrated to optimize the use of its measurement range, and the wavelengths measured were corrected by the above specified amount.

Results

The background noise was subtracted from each spectrum, and both are plotted in fig. 4.

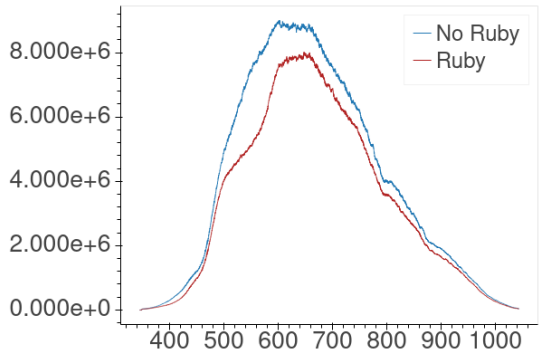

FIG. 4.

Eq. 1 was used to calculate various facets of the expected and measured spectral signature of the ruby. First, we examine the expected transmission at wavelength 700 nm, assuing that $\alpha = 0$ and using the accepted value for n, 1.7. The exponent evaluates to 1, and thus we get $(1-R)^2 = 0.870$. This value corresponds to the baseline (or maybe ceiling line) for how high transmission can be at any wavelength regardless of absorption at that wavelength, due to the portion of the signal that will be reflected due to the mismatch in n.

$$I = I_0(1-R)^2 e^{-\alpha L} \tag{1}$$

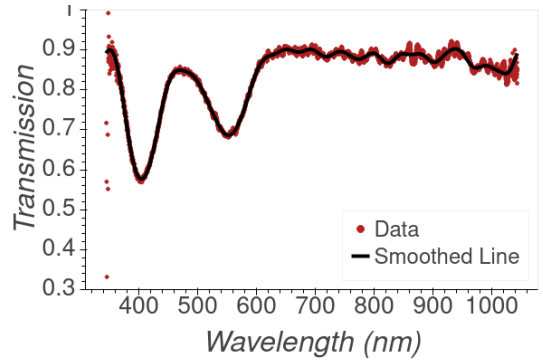

FIG. 5.

The transmission spectrum, given by eq. 2, was computed and plotted in 5.

$$T(\lambda) = I(\lambda)/I_0(\lambda) \tag{2}$$

The spectrum of the absorption coefficient as a function of wavelength, $\alpha(\lambda)$ was computed via eq. **??**, which was derived from eq. 1, and plotted in fig. 6.

$$\alpha = \frac{-1}{L} \cdot ln\left(\frac{T}{(1-R)^2}\right) \tag{3}$$

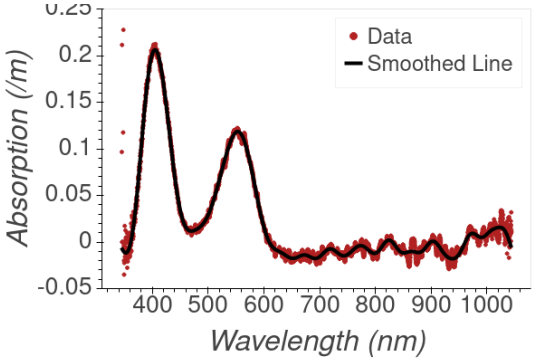

FIG. 6.

The absorption peaks are centered at 400 and 550 nm, which correspond to the wavelengths of light that the ruby absorbs. These correspond to, essentially, the other colors that aren't red, showing that the ruby appears red due to the red light passing through it. The wavelength, widths and absorption lengths are given in table I. The uncertainty displayed in the table was found by averaging the difference between the raw, noisy data, and the smoothed line (smoothed using a simple lowpass filter in the frequency domain).

Peak	Wavelength (nm)	Width (nm)	alpha (m^{-1})	1/alpha (m)
1	404	56.0	0.206+/-0.005	4.9 +/- 0.1
2	552	66.5	0.118+/-0.005	8.4 +/- 0.4

TABLE I.

Conclusions

SUMMARY

TABLE II. Measured and accepted values of the speed of light and refractive index of various materials.

Apparatus	η (%)	Accepted η value	Refs.	Deviation
Photovoltaic Cell	15 ± 2	17 ± 2.5	[2]	0σ
Elecrolyzer	87 ± 6	80	[3]	2σ
Hydrogen Fuel Cell	49 ± 5	60	[4]	-3σ

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[1] Wikipedia, Heat of Combustion: https://www.wikepedia.com
[2] Energysage, Most Efficient Solar Panels https://www.energysage.com/
[3] Carbon Commentary, Hydrogen made by Electolysis https://www.carboncommentary.com
[4] Energy.gov, Fuel Cell Fact Sheet https://www.energy.gov