Measuring GreNe and HeNe Wavlengths Via The Michelson Interferometer

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(Dated: 1 April 2020)

Abstract

By using a Michelson Interferometer, we were able to find the unknown value for the GreNe wavelength to a high degree of precision. We found that $\lambda_{GreNe} = 543.37 \pm 0.004$ nm which is in agreement with the accepted value of $\lambda_{GreNe} = 543.36513$ nm. We also found that different applications of the Michelson Interferometer can lead to differences in the accuracy within our measurements. If we find the wavelength of an unknown light laser without using a reference laser with a known wavelength, our accuracy will be limited to at least two decimal points. However, if we use a reference laser with a counter that allows us to change the delay time, our measurements will only be limited by the delay time as well as the longest possible displacement for the translation stage in a Michelson Interferometer.

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I. INTRODUCTION

Making precise measurements is an important thing to do within any physics experiment, and achieving those precise measurements can be extremely easy or extremely difficult. An example of a pretty difficult measurement would be to measure the wavelength of a laser. A great remedy that can make the measurement somewhat simple would be the Michelson Interferometer, which uses the wave-like nature of light, to make measurements of the unknown wavelength. The Michelson Interferometer allows us to not only measure displacements smaller than the wavelength of visible light, but it also allows us to have a high degree of accuracy within those measurements.

In order to fully appreciate the accuracy behind the Michelson Interferometer, we must first explore the wave-like nature of light. Like any wave, light undergoes interference when it interacts with another light source that is out of phase. The resulting interference pattern for light has two distinct bands called dark and bright fringes.

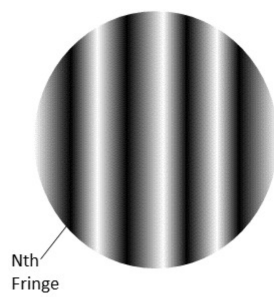

FIG. 1. Light interference pattern

Depending on the wavelength, λ_{air}, of the light used and the distance, d, that one of the mirrors travels in our Michelson Interferometer, we can get different amount of fringes, ΔN, in the interference pattern like the one shown in figure 1. We can also use the following equations to get an expression of λ_{air} with respect to the displacement and fringe counts.

$$\lambda_{air} = \frac{2d}{\Delta N} \tag{1}$$

Equation 1 is a useful equation for finding out the wavelength of an unknown light source when the only thing that we can measure is the number of fringes the light's intereference pattern has, and the displacement of a translation stage mirror. Although equation 1 is useful, we are very limited in terms of accuracy due to the measurement of the displacement of the translation stage(centimeters instead of nanometers). The way around this issue is to use a reference laser within our interferometer. Consider a light with an unknown wavelength λ_u and a reference light with a known wavelength λ_r. By equation 1, we can get the following expressions for both wavelengths:

$$\lambda_u = \frac{2d}{\Delta N_u} \tag{2}$$

$$\lambda_r = \frac{2d}{\Delta N_r} \tag{3}$$

Assuming we keep our displacement the same, we can rearrange equation 2 to look like the following:

$$2d = \lambda_u \cdot \Delta N_u$$

We can now put our expression for $2d$ into equation 3 and get the following relation:

$$\lambda_u = \frac{\Delta N_r}{\Delta N_u} \lambda_r \tag{4}$$

We can use equation 4 to gain accurate measurements of the unknown wavelength since we are now only limited by the accuracy of our reference laser as well as the amount of significant figures that we have from the $\frac{\Delta N_r}{\Delta N_u}$ ratios. Equation 4 is also going to be the backbone for the second part of the experiment which involves making a wavemeter and finding an accurate measurement for λ_u.

II. EXPERIMENT

Throughout our experiments we used the Michelson Interferometer, which consists of five mirrors, a beamsplitter and two photodiodes as shown on figure 2. For this set up, we used the GreNe laser as our laser with unknown wavelength, and used the HeNe laser as our reference laser. The only moving part in this set up is $M1$, which we had go through a displacement of 2 cm. The way this set up works is that we have the GreNe laser set up so that it has an interference pattern that is reflected from $M4$ to $PD1$, and the HeNe laser has an interference pattern that is reflected from $M5$ to $PD2$.

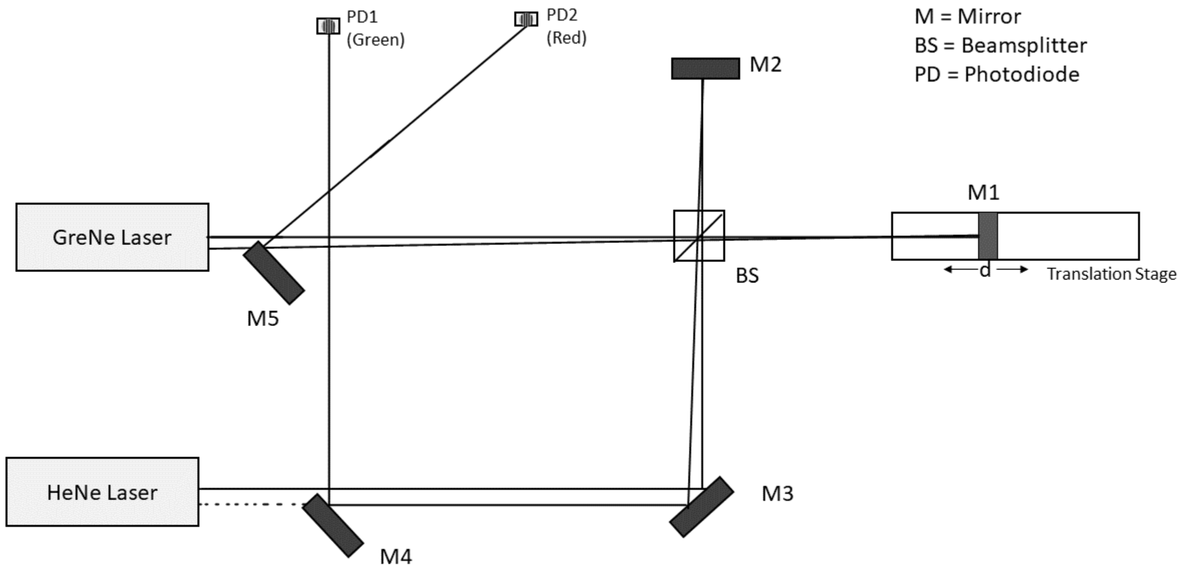

FIG. 2. Michelson Interferometer set up

The second part of this set up involves the electronics used. First with the translation stage, which uses a program that moves the mirror at different speed. With the slowest setting, “CycleSlow”, the mirror moves at 0.5 μm/s, and you can actually see interference effects on the photodiodes. Secondly we have the oscilloscope and a counter. We only used the oscilloscope to verify that the photodiodes were getting the interference patterns but the counter was actually the most important one.

The counter we used was an HP Universal Counter which took two channels and was used heavily for the two main experiments. The counter can count the amount of times a signal passes through a threshold voltage of about 2.5 volts, and we can also use it to make a ratio between the counts of two signals; for this specific counter, the ratio is $A : B$ as shown on figure 3.

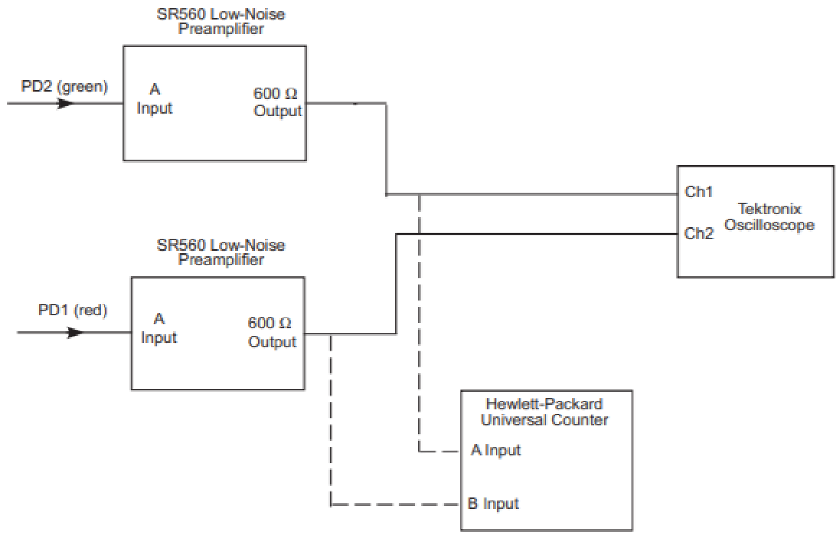

FIG. 3. The Electronics we used for this set up

A. Translation Stage Driver

For this part of the experiment we used the translation stage driver's second fastest setting. This makes mirror one move a distance of 40cm with a speed of about 1.0 mm/s. During the translation stage we ran the counter until the mirror had a displacement of 2cm, and then reset the counter after we took down data. We repeated the same process 4 more times for the GreNe laser, and then did the same 5 more times for the HeNe laser.

B. Wavemeter

In this experiment, we ran the stage driver's fastest setting, which travels a distance of 40 cm with a speed of about 12.5 mm/s. In this experiment, we looked at the ratio between the counts from the GreNe laser and the HeNe laser and increase our precision by changing the delay for the HP Counter. We started with a delay of 25ms, then went to 0.250 s, then finally to 2.500 s. We had a limit at 2.500 s since the stage driver could only travel 40 cm, we would need a longer stage driver in order to set the delay to 25 seconds. We took 10 measurements for each delay time which is what we are going to analyze in the Results section.

III. RESULTS

GreNe		HeNe	
Counts	**λ (nm)**	**Counts**	**λ(nm)**
72080	554.9390	63261	632.3011
75163	532.1767	63566	629.2672
73949	540.9133	63639	628.5454
73583	543.6038	62803	636.9122
74435	537.3816	63401	630.9049

TABLE I. Table containing the Counts and calculated wavelengths for both the GreNe and HeNe laser with a mirror translation of 2.0 cm

0.025 Seconds		0.250 Seconds		2.500 Seconds	
$\frac{\mathbf{C_g}}{\mathbf{C_r}}$	λ_{GreNe}	$\frac{\mathbf{C_g}}{\mathbf{C_r}}$	λ_{GreNe}	$\frac{\mathbf{C_g}}{\mathbf{C_r}}$	λ_{GreNe}
1.165	543	1.1647	543.3	1.16463	543.36
1.164	544	1.1645	543.4	1.16461	543.37
1.163	544	1.1646	543.4	1.16462	543.37
1.163	544	1.1645	543.4	1.16462	543.37
1.165	543	1.1647	543.3	1.16462	543.37

TABLE II. Measurements for the 25ms, 0.250s, and 2.500s delay times. λ_{GreNe} is calculated with $\lambda_{HeNe} = 632.81646$ nm

For the measurements in Table I, we had the translation stage of the Michelson Interferometer move 2.0 cm. For the GreNe laser, we calculated an average of 541.8029 nm and for the HeNe laser, we calculated an average of 631.5862 nm.

For the measurements in Table II, we used the HeNe laser as a reference, and had the translation stage move 40 cm. For the 0.025 second delay, we calculated an average of 544 nm, for the 0.250 second delay, we calculated an average of 543.3 nm, and for the 2.500 seconds delay, we calculated an average of 543.37 nm.

IV. DISCUSSION

For the first experiment we measured the wavelength of the GreNe laser to be $\lambda_{GreNe} = 541 \pm 8$ nm and we measured the wavelength of the HeNe laser to be $\lambda_{HeNe} = 632 \pm 3$ nm. comparing these to the given values of $\lambda_{HeNe} = 632.816416$ nm and $\lambda_{GreNe} \approx 543$ nm, we can conclude that the given values fall within the uncertainties of our measurements and therefore we can conclude that our measured values agree with the accepted values for each laser.

Since the measurements for our first experiment agree with the accepted values, we can conclude that Equation 1 holds and therefore, we can confirm that the number of interference fringes and the displacement of a light source give us the wavelength of the same light source. This also means that we can indeed use the Michelson Interferometer to make a quick measurement of a laser with unknown wavelength.

For the second experiment we measured the wavelength for the GreNe laser to be $\lambda_{GreNe} = 543.37 \pm 0.004$ nm. Comparing our measurement to the accepted value of $\lambda_{GreNe} = 543.36513$ nm [1], we can also conclude that the measurement of the GreNe laser from the wavemeter is in agreement with the accepted value.

Since our measurement for the GreNe wavelength in the second experiment agreed with the accepted value, we can conclude that Equation 4 gives us an accurate value for an unknown wavelength, and we can use the Michelson Interferometer to make accurate measurements of a laser with an unknown wavelength if we use a second laser with a known wavelength.

A noteworthy thing to include from the second experiment is the data gathering process. If you look at Table II, you can see that there are a lot of repeated values for our measurements. This results in the uncertainty in our experiments to get very close to 0. This does not mean that our measurements were exact, since there is still uncertainty in the curvature of the mirrors, and other measurements which can be compounded. Finally, it is important to recall that the accuracy of our measurements from the second experiment depends on the delay time for the gate in the HP counter. In this case, since our translation stage only has 40.0 cm of space, our delay time was limited to 2.500 seconds, if we wanted to improve our accuracy, we would need a longer translation stage.

V. CONCLUSION

As a whole the data and accepted values show that we can use equations (1) and (4) to accurately determine the wavelength of an unknown light source and thus we can use the Michelson Interferometer as a tool to make really precise measurements. We can improve the accuracy of the interferometer by using a drive with a longer displacement so that the delay gate can be increased.

[1] A. Kramida, Y. Ralchenko, J. Reader, and NIST ASD Team, *NIST Atomic Spectra Database (version 5.7.1)* (National Institute of Standards and Technology, Gaithersburg, MD, 2019).