LAB REPORT OF LAB103

Measuring the speed of light

May 8, 2022

Yubo Cai, Durmus Mehmet Emre

ÉCOLE POLYTECHNIQUE

IP PARIS

CONTENTS

1
OBJECTIVE OF THE EXPERIMENT

The main purpose of the experiment is to measure the speed of light by a simple but imprecise method, the time of flight method. For this method, the time it takes for light to travel a predetermined path back and forth is measured to determine its speed.

2
DESCRIPTION OF THE EXPERIMENT

The following is the setup for the experiment using two mirrors. We use mirrors to increase the distance of the light traveling to reduce the error of our measurement. The light is emitted and split inside of the light emitter. The sensor in the Light emitter receives two signals. The first signal is the split light is detected and it will be shown on the oscilloscope as the first pulse. The light first travels through the lens and is reflected by the two mirrors until it passes through a Fresnel lens that concentrates the light. The light then reaches the retro-reflector and is reflected back with minimal scattering and travels back in the same path but in the opposite direction.

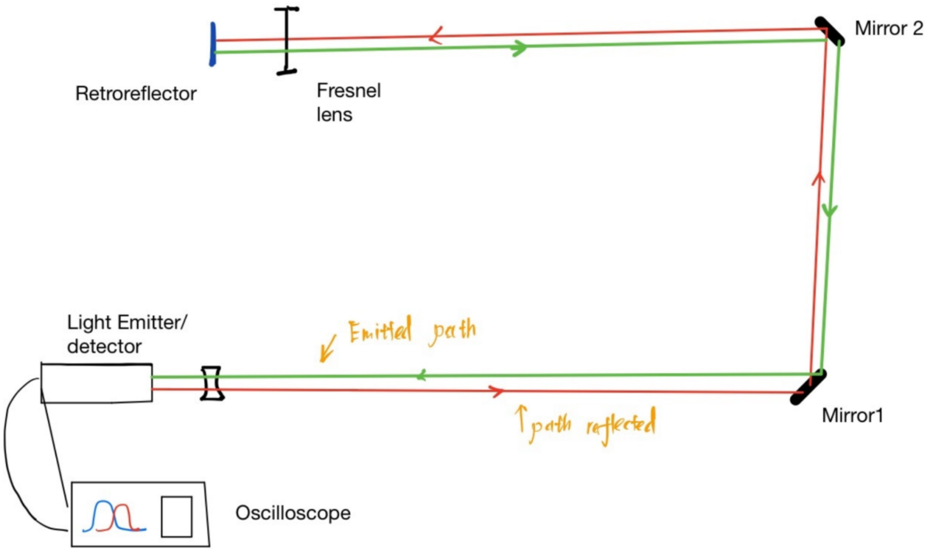

Figure 1: Instruction Graph of the equipment setup

The above is the setup for the experiment using two mirrors. We use mirrors to increase the distance of the light traveling to reduce the error of our measurement. The light is emitted and split inside of the light emitter. The sensor in the Light emitter receives two signals. The first signal is the split light is detected and it will be shown on the oscilloscope as the first pulse. The light first travels through the lens and is reflected by the two mirrors until it passes through a Fresnel lens that concentrates the light. The light then reaches the retro-reflector and is reflected back with minimal scattering and travels back in the same path but in the opposite direction.

Therefore the sensor will receive the second signal which is the reflected light by the retroreflector and the signal shown in the oscilloscope as the second pulse. So the graph on the oscilloscope will be the picture we put below.

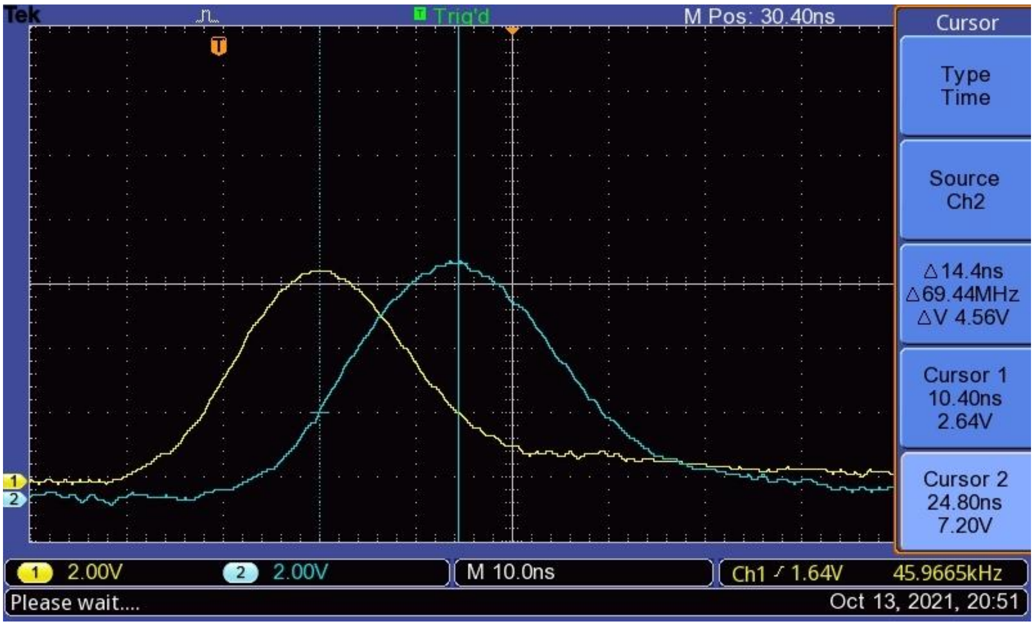

Figure 2: Instruction Graph of the equipment setup

From the graph on the oscilloscope, we can measure the period of the light traveled by computing the time difference between the peak of the first and second pulse. Also, we can use the tape measure to measure the distance of the light traveling. Then use the formula of $\frac{Distance}{Period} = Speed$ of light we can find the speed of light.

3 ANALYSIS

When we first started the experiment we wanted to see the path the light beam followed without the lens for collimation. Turning on the light emitter and varying the distance of a white sheet of paper that was held in front of it it was observed that that the beam was diverging, that is the beam of light's image was becoming bigger and dimmer circle as the length from the source increased.

Using the lens for collimation, we observed that now the image on the sheet of paper was constantly a circle of a certain size and hence the beam was collimated. This was clearly to be expected since the lens was used for this purpose.

Since the image produced was circular in both cases it was deduced that the shape of the emitter was also circular.

The same steps were followed for the Fresnel lens and it was observed that the beam was focused in front of the lens when the screen was in the right position that is at the lens' focal plane.

Before changing the screen to a retro-reflector we had a second signal on the oscilloscope, ie. there was some returning light and hence the noise. This was to be expected since there were other light sources around the setup at the time and the apparatus used had some internal reflection in it which caused errors in the measurement (as will be seen in the quantitative analysis).

After changing the screen to a retro-reflector we did get a clear second signal (the noise measured before was relatively minuscule and almost negligible compared to the signal measured now).

Upon rotating the retro-reflector, it was observed that the intensity of the light that was received by the light emitter got lower. This was an unexpected result since all the light should have been reflected back in the same direction it had come from with a small but negligible displacement. Nevertheless, after turning the retro-reflector only slightly, ie. in small increments the intensity was similar and almost the same. From these observations, it was deduced that the retro-reflector stopped working in an intended way when it was rotated too much. This was to be expected as the retro-reflector was planar. Using a retro-reflector that was curved/spherical this problem would have not existed. However, a planar one was enough for this experiment.

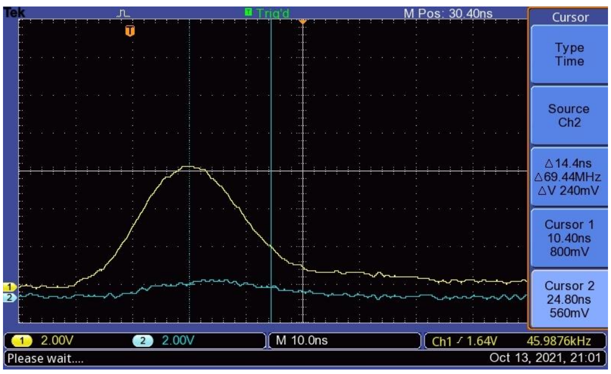

Figure 3: The signals received before respectively

Figure 4: The signals received after respectively

For the measurement of the time delay between the two signals, the following steps were followed: first the trigger signal on the oscilloscope was turned on. Then, the time base and the voltage range on the were adjusted to 10.0 ns and 2.00 V respectively, in order to clearly see the peaks of the signals. These peaks indicated the time when most of the beam of light left and returned to the light emitter and hence were important in the analysis. Then, the X-cursor was used on both signals to find their peaks (approximately) and the time for each peak was recorded down. However, since the peaks were spread out differently for each trial with different values of the distance this did introduce some uncertainty of these values the magnitude of which was respective to the signal produced in each trial.

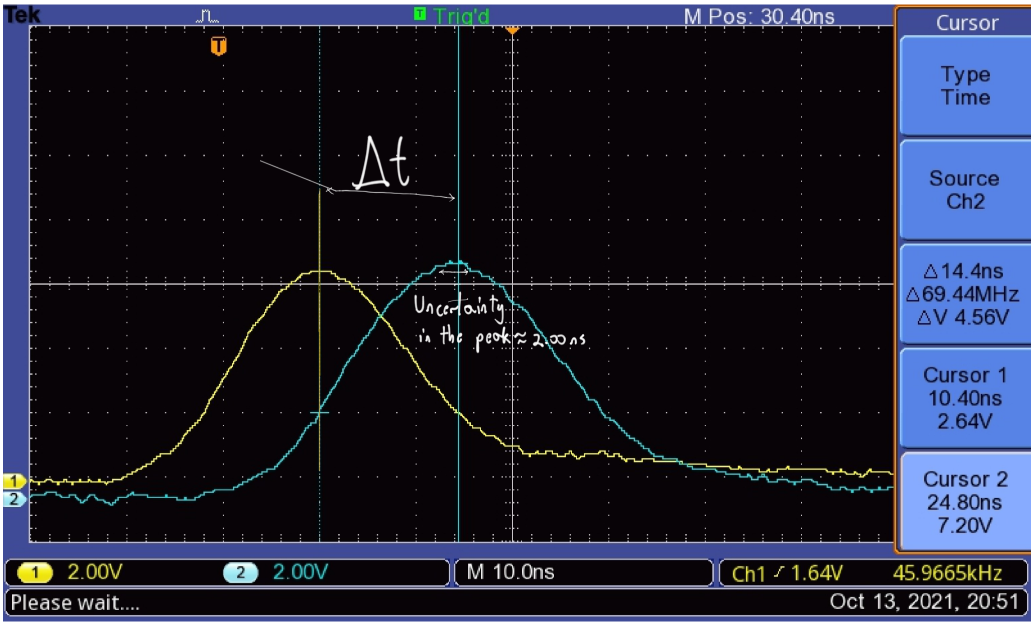

Figure 5: The time delay (Δt) and uncertainty of the peak on the signals

Since this was our first time using an oscilloscope and the settings of the oscilloscope were changed by the students who did the experiment before us, we did have some difficulties adjusting the settings at first. Nonetheless, our professor helped us understand and implement the steps. We also had some difficulties adjusting the Fresnel lens to get its focal plane on the screen at first because we had to determine it by adjusting its position slightly and observing the change in the image.

After the first measurement, using a flexible ruler and some mirrors, the retro-reflector was placed at varying distances from the light emitter. The uncertainty of the distance measured using the flexible ruler was $+/-0.1cm$ since the smallest increment on the ruler was $0.2cm$. This uncertainty was introduced due to the fact that the two ends of the ruler were held in place by two people and the distance was measured with a physical ruler.

Using these two values for the time of each signal's peak the time taken for the light to travel to the retro-reflector and back (Δt) was calculated. Combining these values with the distance between the light emitter and retro-reflector (ΔL) gives the following table where distance is actually $2\Delta L$ since the light travels to the retro-reflector and back and the speed of light c is the distance traveled over the time taken, which is: $2\frac{\Delta L}{\Delta t}$

Time of travel (ns) (Δt)	Uncertainty of the Time (ns)	Distance (m) ($2\Delta L$)	Uncertainty of distance (m)	Speed of light (m/s) (c)
7.20	2.00	2.00	0.60	277777777.80
14.40	2.00	4.00	0.60	277777777.80
20.00	2.00	6.00	0.30	300000000.00
23.20	1.00	7.00	0.30	301724137.90
28.80	1.00	8.50	0.30	295138888.90

As mentioned before the uncertainty of time was introduced due to the peaks of the signals being spread out. These uncertainties were determined by how spread out their peaks were, which was mainly 2.00 ns or 1.00 ns in the signals produced. Then, the uncertainty of time was used to determine the uncertainty of the distance by multiplying the time and the literature value of the speed of light, since in that amount of time the light would have travelled that much distance.Since the uncertainties in the distance obtained from this method were higher than the uncertainties determined before they were used as the uncertainty of the distance. It is also worth mentioning that the position of the lens for collimation and hence its effect on the measurements was negligible in this experiment due to the relatively higher value in the uncertainty of the distance.

Plotting these values on a graph and getting the best fit line give the following:

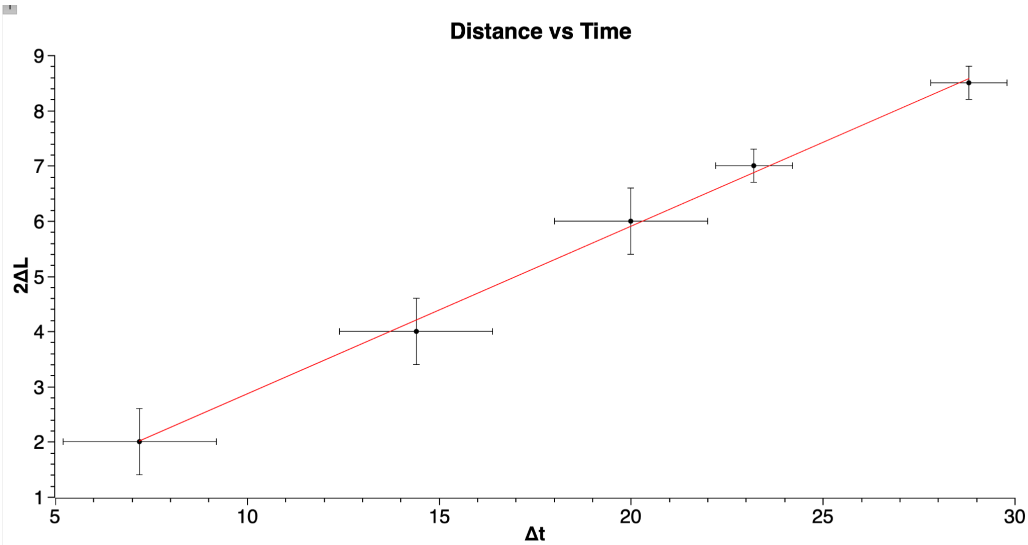

Figure 6: The graph of the distance travelled by light ($2\Delta L$) vs the time taken (Δt) with error bars indicating the uncertainties of each value for each trial.

The slope of the best fit line $2\frac{\Delta L}{\Delta t}$ is approximately $0.30 + / - 0.03$. This is the final value of the speed of light obtained from this experiment.

A major issue which is seen in this graph is, however, that the line doesn't go through the origin.

4 CONCLUSION

The final value obtained for the speed of light is approximately $0.30 + / - 0.03 m/ns$. When compared to the literature value (which is 299,792,458 m/s) the percentage error in the value obtained is calculated to be approximately 1.35%, which is surprisingly low considering the limitations and errors in the experiment. Moreover, the literature value is within the range of the value obtained. Nonetheless, extrapolating from the graph shows us that the line doesn't pass through the origin and in fact the y-intercept is a negative value. This indicates an error in the experiment since the aforementioned data would suggest that light would take a non-zero value of time to travel 0 meters. This error can be explained by the fact that the light emitter might have had some internaş reflection in it that caused the returning signal to be measured to be faster than light. Furthermore, many more errors such as the positioning of the retro-reflector, Fresnel lens, and the mirrors or some of the light being reflected away or being absorbed by the mirror or background noise such as background radiation and the other light sources in the room, and so on might and probably has caused the inaccuracy in the value of the speed of light obtained. In fact, during the experiment it was observed that as the distance increased the intensity of the signals received went down and hence the effect of the noise increased, which clearly demonstrates the limitations of the experiment with the setting, apparatus used, and method used.

Having heard about the theory developed by James Clerk Maxwell on the propagation of electric and magnetic fields, Yubo and I decided to write a short letter to Maxwell to tell him about our experimental measurement of the speed of light.