The Speed of Light

Bryan Yamashiro,[1] Christina Nelson,[1] Corey Mutnik,[1] and Daichi Hiramatsu[1]

[1] *Department of Physics & Astronomy,*
University of Hawaii at Manoa,
2505 Correa Rd, Honolulu, HI, 96822, USA

This study measured the speed of light in an experiment apparatus. Instruments used to measure the speed of light included a light emitting dioide (LED), a photomultiplier tube (PMT), and fast pulse circuitry. Measured speeds of light were $(3.06\pm0.16)\times10^8$ m/s and $(3.13\pm0.50)\times10^8$ m/s for the pulse widths of 2 ns and 40 ns.

Background

The method of measuring the speed of light used in this study is modeled after the Focault method, which used an apparatus containing sets of mirrors to project and measure light. The projected light reflects off a rotating mirror, to a fixed mirror, back to the rotating mirror, finally to a detector. The apparatus was optimized by Albert Michelson in the 1920s and experimentally measured the speed of light to an error of ±4 km/s [1]. Apparatuses such as the Focault apparatus allow for measuring the speed of light in a laboratory.

Apparatus

The apparatus replicates the Focault instrument, but without the rotating reflector. Values of the speed of light were measured with different pulse widths. New components include the time-to-amplitude converter (TAC), Multi-Channel Analyzer (MCA), and the computer program (MAESTRO) [2]. As the name suggests, the TAC converts the pulse time into decipherable amplitudes. The MCA takes the amplitude signal and distinguishes the counts across 2048 channels. MAESTRO compiles all amplitudes with corresponding channels and generates histograms and provides ASCII data. Components of the instrument are specified in figure 1.

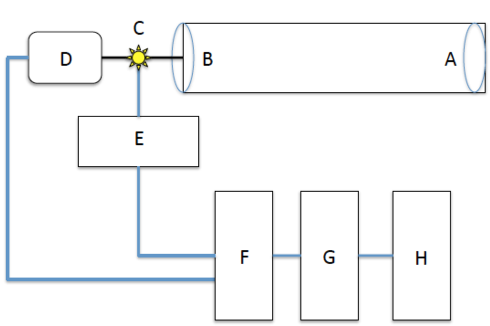

Figure 1. *A) Mirror, B) Fresnel Lens, C) LED Source, D) PMT, E) Pulser, F) TAC, G) MCA, H) MAESTRO. [3].*

Procedure

Table I. *Initial Apparatus Parameters*

Pulse Width (ns)	Tube Length (in.)	MCA Channels (sec.)
4	445.6±0.05	2048
20	445.6±0.05	2048

The experiment initiated with a LED emitting photons into the black enclosed tube [3]. Photons initially traveled through a Fresnel lens, which in turn caused some backscatter of photons. These photons were detected first by the PMT at the early time, t_1. Photons that weren't backscattered pass through the Fresnel lens and were reflected off a mirror on the back of the enclosed tube. The reflected photons were then detected at a delayed time of t_2. The detected photons were then converted into electrons via photoelectric effect. Ultimately the pulses and the electrons were then converted into amplitude using the TAC and then split over multiple channels in a histogram compiled with MAESTRO.

A calibration curve was compiled to represent the time interval (Δt) versus the MCA channel number for six unique time intervals for a linear fit. A linear fit was used to convert the channel numbers for the difference in time between the two-histogram peaks generated by MAESTRO. Resulting time for the peak difference was utilized along with the measured enclosed tube length to determine an experimental estimate of the speed of light.

Two trials of different pulse widths were conducted, including 2 ns and 40 ns. Nothing except the pulse widths were manipulated during this study to represent a fixed system with one changing parameter.

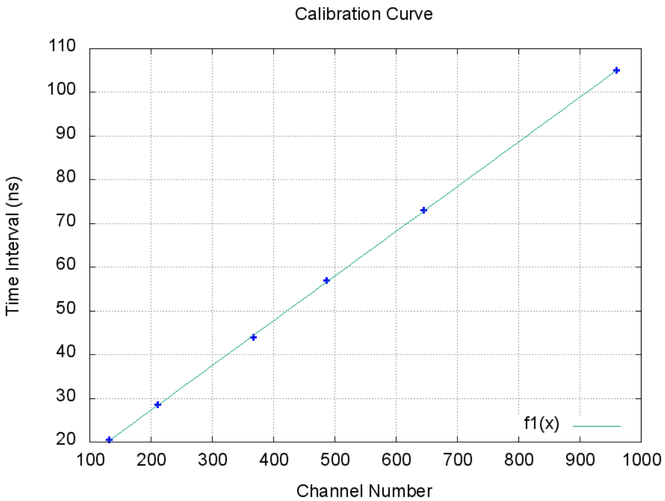

Figure 2. *Calibration curve of unique time intervals. The linear fit represents a correlation calibration between channel number and time.*

Calculation of Results and Errors

$$c = \frac{2L}{\Delta t} \tag{1}$$

The measured speed of light, c, was calculated using equation 1. Input parameters are shown in table 1. MAESTRO provided an ASCII data file that was then plotted, portrayed in figure 3 and 4. Both figures show two peaks for both the 2 ns and 40 ns.

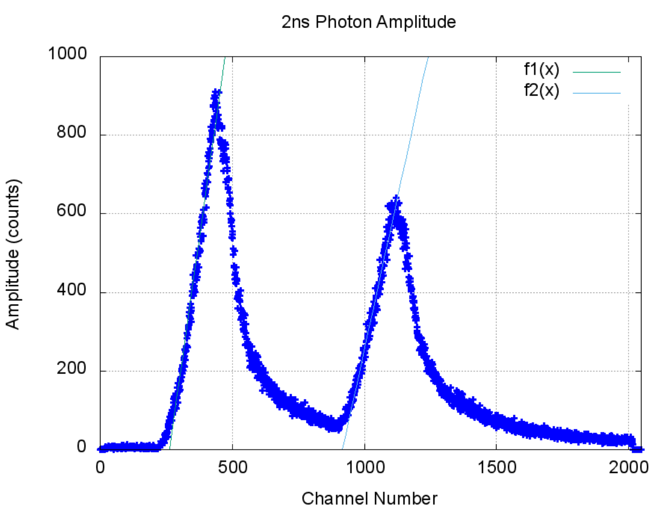

Figure 3. *2 ns pulse width photon amplitude.*

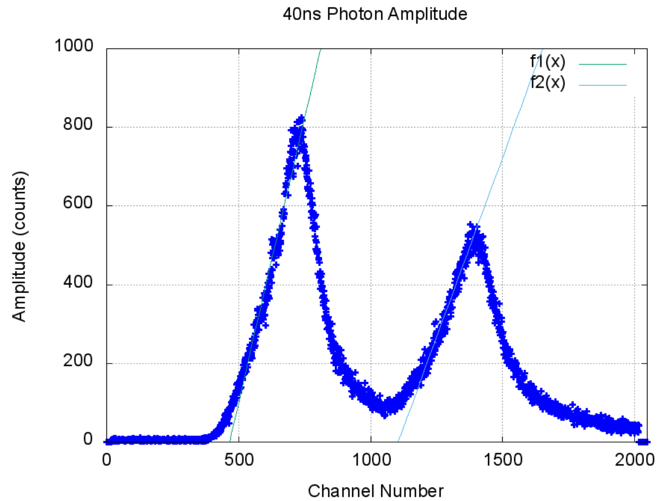

Figure 4. *40 ns pulse width photon amplitude.*

The two peaks correlate to the time of initial detection of reflected photons off the Fresnel lens, and the final detection of photons from the mirror at the back of the tube. Linear regressions were fit to the ascending slopes of the two peaks. Differences are taken from the x-intercepts of the fits for the difference in channel numbers. The channel difference is calibrated with the calibration curve to output a time difference. Initial length of the tube and time differences resulted in a measured speed of light.

The two speed of light experimental measurements are $(3.06\pm0.16)\times10^8$ m/s and $(3.13\pm0.50)\times10^8$ m/s for the 2 ns and 40 ns respectively. Compared to the true speed of light, 299,792,458 m/s, the two experimental speeds are within the statistical error.

Discussion

Measured speeds of light were determined to be similar to the theoretical speed of light. The double linear fits provided channel differences leading to a stable estimate of the time difference. Length of the tube was affected by extra slack in the measuring tape. Both measurements of speed of light were larger than the theoretical value and the slack could have factored into the calculation of equation 1.

[1] McFarland, Kevin. "Speed of Light Demonstration by the Foucault Method." University of Rochester. Web. 5 Nov. 2015.

[2] "Multichannel Analyzer (MCA) Application Software." Nuclear Applications Software—ORTEC Scientific Equipment. ORTEC. Web. 5 Nov. 2015.

[3] THE SPEED OF LIGHT. (n.d.). Retrieved November 4, 2015, from http://www.phys.hawaii.edu/~teb/phys480l/SpeedOfLight.txt