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PHYS480L

Measurement of the Speed of Light

Abstract

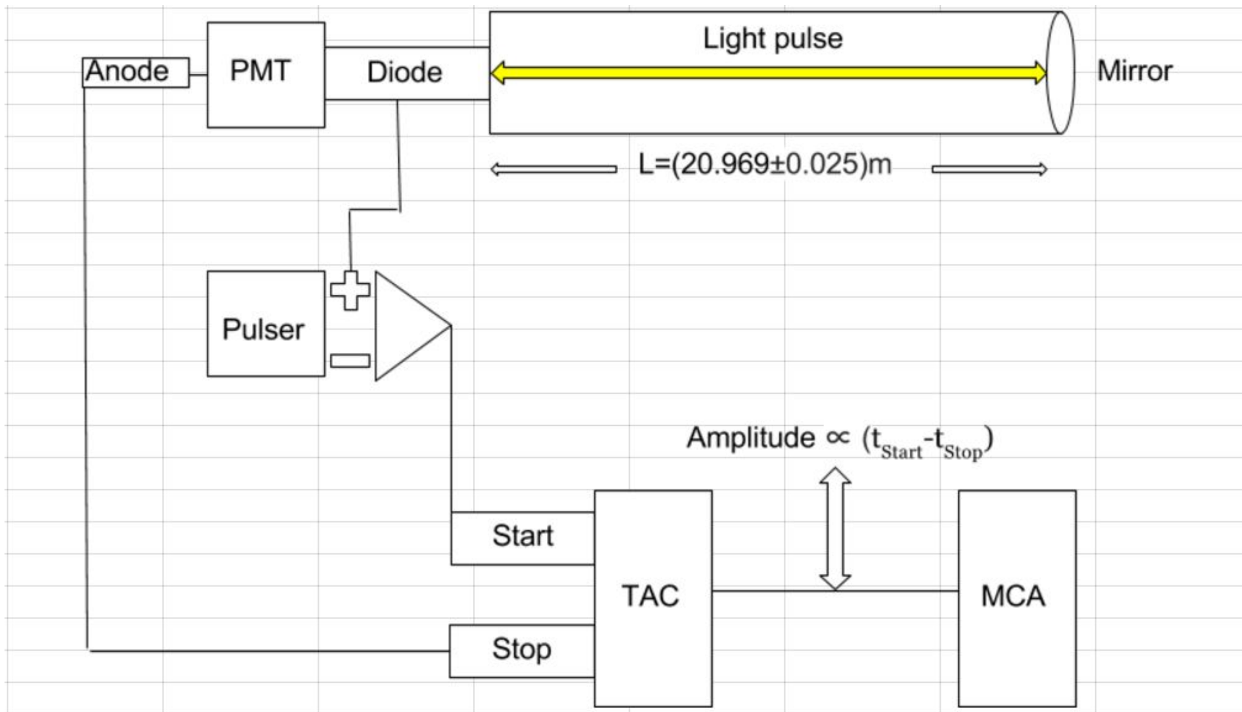
The speed of light was calculated by determining the time taken for a light pulse to traverse a known distance. Fast electronics were employed to control the pulse and measure its arrival and departure times. The value obtained [$(2.86 \pm 0.10) \cdot 10^8 m/s$] was determined to lie within -1.41 standard deviations from the accepted value.

Background

The speed of light is a fundamental constant of nature given by $c = [\mu\varepsilon]^{-1/2}$ where $\mu\varepsilon$ is the product of the magnetic susceptibility and electric permittivity of the medium. In a vacuum this speed is exactly $299792458\ m/s$.[1] In this experiment the speed of light was calculated by measuring the time taken for a controlled light pulse to traverse a known distance.

Apparatus

Figure 1: Block diagram of experimental apparatus/circuit used to determine the speed of light.



The experiment begins when the pulser causes the diode (connected to a high voltage source, not shown) to emit a controlled beam of light. A start signal is simultaneously sent to the TAC (time amplitude converter) indicating a light pulse has been emitted by the diode. This pulse then travels down an enclosed tube of known length (given above). Upon reaching the end of the tube the pulse is reflected by a stationary mirror, at which point it travels back down the tube where it is subsequently amplified into a measurable voltage signal by the photomultiplier tube (PMT). This signal travels from the anode to the stop register in the TAC. A pulse with a positive amplitude (proportional to the difference in time between the start and stop signals) is then registered by the MCA (multi-channel analyzer), which constructs a histogram of all registered pulses by placing each pulse into a bin determined by its amplitude.

Procedure

The TAC was calibrated by using the pulse generator to generate pulses, which were then discriminated and copied twice. Each copy was sent through the delay box, at which point one of the two pulses was delayed by a fixed amount as registered by an oscilloscope. Both copies were then sent through the TAC, which generated a voltage proportional to the time delay that was subsequently itemized by the MCA. This was repeated for a number of delays, and the resulting dependency of bin number on delayed time was determined using linear regression, resulting in a so called calibration curve.

Following calibration the experiment was conducted as described in the previous section, resulting in a histogram of registered pulses with two distinct spikes in the distribution representing the points at which the light was emitted by the diode and subsequently reabsorbed by the PMT.

Calculations

The slope of each of the two spikes in the histogram were fit to linear regressions of the form $y_i = a_i x + b_i$ and interpolated to find the roots $x_{0i} = (-b_i)/a_i$ of each line. The difference between these points $\Delta x_0 = x_{02} - x_{01}$ was then converted to a difference in time $\Delta t_0 = \Delta x_0/\alpha$ using the slope α of the calibration curve $y(\Delta t) = \alpha\Delta t + \beta$. The speed of light was then calculated as $c = 2L/\Delta t_0$ where L is the measure length of the tube.

The error δc in the measurement was found using the orthogonal uncertainty relation $\delta f(\{x_i\}_{i=1}^{i=N}) = [\sum_{i=1}^{N}(\partial_{x_i}[f] \cdot \delta x_i)^2]^{1/2}$ where $f(\{x_i\}_{i=1}^{i=N}) = c(L, \Delta t_0)$ with functional dependencies as given above. Error in the slope of the calibration curve $\delta\alpha$ was assumed to be negligible since $\frac{\chi^2}{ndf} = 1$ in the fit.

Data

Figure 2: Calibration curve used to relate bin numbers and time.

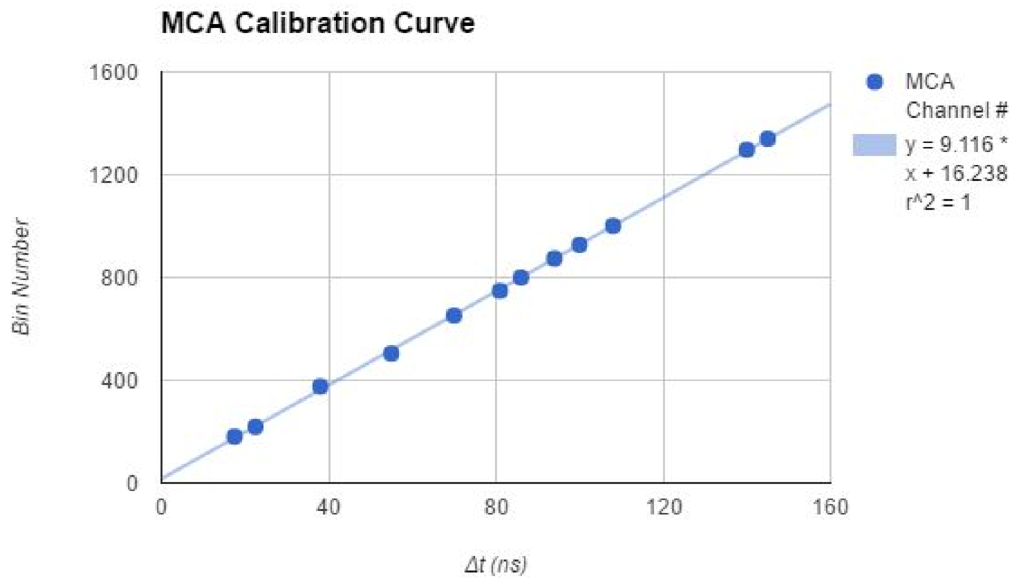


Figure 3: Histogram of counts corresponding to each bin. Note the two distinct peaks indicating the emission and absorption of the light pulse.

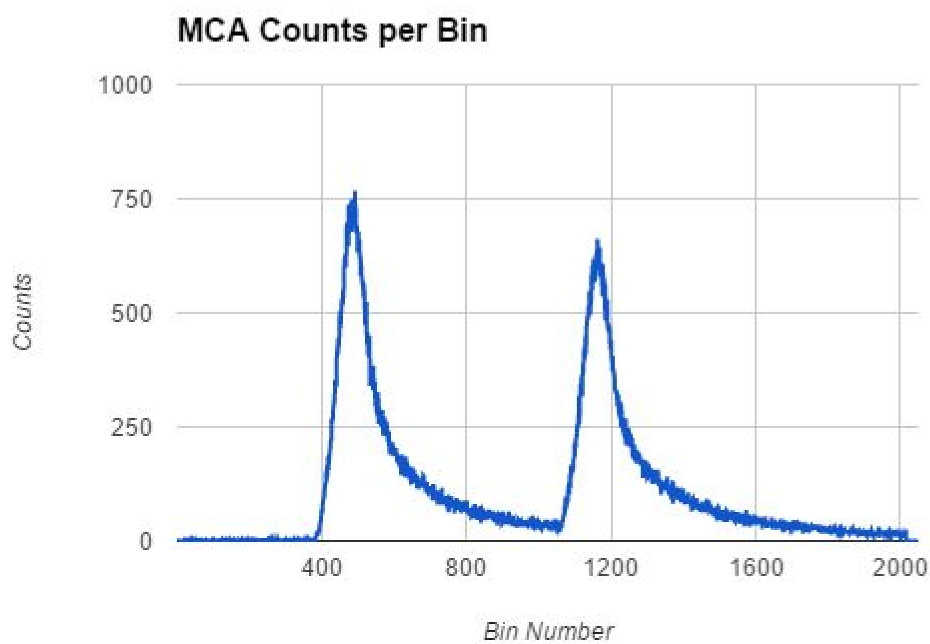


Figure 4: Linear regression of the first (leftmost) slope in the Figure 3, having parameter values $a_1 = (8.332 \pm 0.119)$ *counts/bin and* $b_1 = (3284.269 \pm 53.334)$ *counts.*

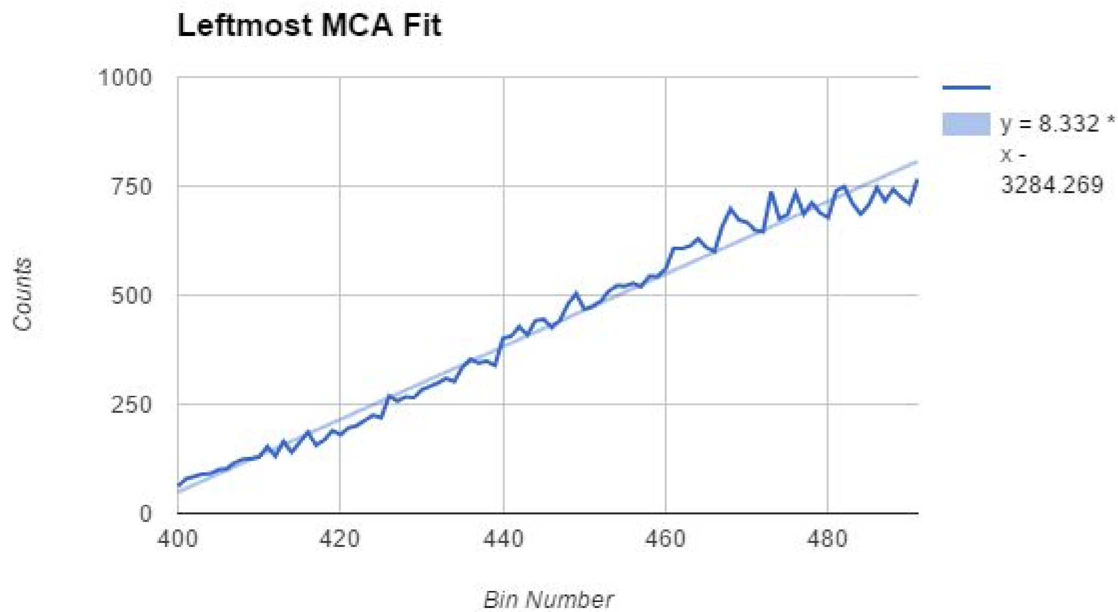
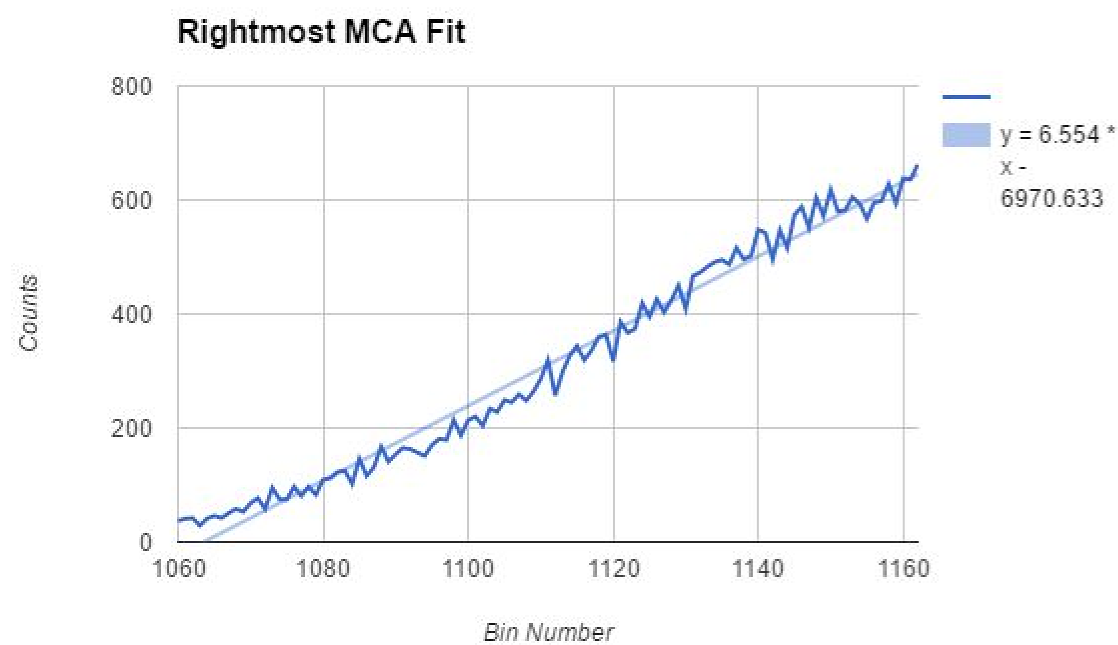


Figure 5: Linear regression of the second (rightmost) slope in Figure 3, having parameter values $a_2 = (6.554 \pm 0.091)$ *counts/bin and* $b_2 = (6970.632 \pm 107.077)$ *counts.*



Discussion

The speed of light was calculated to be $c_{exp} = (285561495 \pm 10116687) m/s$, or in terms of the known speed $c_{exp} = (0.9525 \pm 0.0337)c$ corresponding to $\frac{0.9525-1}{0.0337} = (-1.41)$ standard deviations from the true value. This is within a statistically acceptable 95% tolerance range.

The measurement which contributed most to this error was that of the length of the tube. Additional sources of error include the uncertainty associated with the fit of both linear regressions and the interpolation function.

This error could be reduced by further restricting the domain over which the two linear regressions were performed, in order to eliminate fluctuations present in the upper range of Figure 4 and the lower range of Figure 5. This would serve to improve the accuracy of the interpolation and therefore the calculated value of c.

Conclusion

The time taken for a light pulse to traverse a tube of known length was measured and used to determine the speed of light. The value of was c was experimentally determined to be $(2.86 \pm 0.10) \cdot 10^8 m/s$, representing (-1.41) standard deviations from the true value. More accurate fits to the data obtained would serve to improve this value further.

References

1. Nave, Carl R. "Fundamental Physical Constants." Hyperphysics. Georgia State University, n.d. Web. 18 Oct. 2016.

Collaborators

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2. Carly Hall
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