Remote Lab - Speed of Light Part 2

In this lab module, you will work with the data you took earlier in the Speed of Light lab, further understanding the uncertainties associated with the experiment.

In addition to answering all the questions, take notes throughout this activity. Your notes should be a record of the analysis, calculations, and other activities you did in class, including software used, websites visited, readings that you looked at, etc. The purpose is to help us follow along with the work that you did in class, and to make it possible for someone to be able to re-create this later.

Checkpoints where you should discuss your work with the instructors are in bold.

Section 1 – Further Analysis of Initial Dataset

Q1. In this experiment, we measured the speed of light by measuring the delay in laser pulses between two legs of an interferometer. We measured distance with a ruler, and we measured the time delay using an oscilloscope. Explain why we only need to measure *relative* distance and *relative* time in this experiment, instead of the total path length, or the total time it takes for the pulse to travel through the interferometer.

Q2. What is the magnitude of the estimated uncertainty in the distance measurement, and where does this uncertainty come from?

Q3. Uncertainty is sometimes described in terms of a "confidence interval," for example, "The estimated value is 17 +/- 0.3, within a 95% confidence interval" means that there is a 95% chance that the true value lies within the range given. How large would the uncertainty on the distance measurement need to be in order for you to have **100%** confidence that the true value lies within range of uncertainty? We'll call this *the maximum uncertainty*. For example, if you can estimate someone's height accurately to within 1 foot, you would be 100% sure that their height is 6 ft +/- 1 ft.

Q4. What is the estimated uncertainty in the time delay measurement, and where does this uncertainty come from?

Q5. Similar to Q3, how large would you need to increase this uncertainty to be 100% sure that the true value lies within the uncertainty range? Sketch what you saw and measured on the oscilloscope, and label this maximum uncertainty on the sketch. (Ok to sketch on a piece of paper and take a picture).

Checkpoint 1: Send your values for typical and maximum uncertainty to the instructors on Teams with your justification, before proceeding**.**

Q6. Calculate the *fractional* uncertainties for the furthest data point (longest distance and time delay), for your typical and maximum uncertainties for both distance and time. Fractional uncertainty is the uncertainty divided by the measured value, usually expressed as a percentage.

How do the fractional uncertainties compare between the two measurements? Why is this important?

Q7. Given your estimated typical and maximum uncertainties, use propagation of errors to determine a range of estimated fractional uncertainty for the measurement of the speed of light. This tells you how well you expect to be able to measure the speed of light, *without using any of your data*. (Hint: See Taylor, page 53).

Q8. The plot below shows the data points for distance vs delay time, you probably created something similar for the original lab.

a) Why is distance plotted along the x-axis?

b) Fill in the blanks for the simple physical meaning of the slope of the line, 3.4789 (including the value of the slope and units): It takes __________ for light to travel ____________.

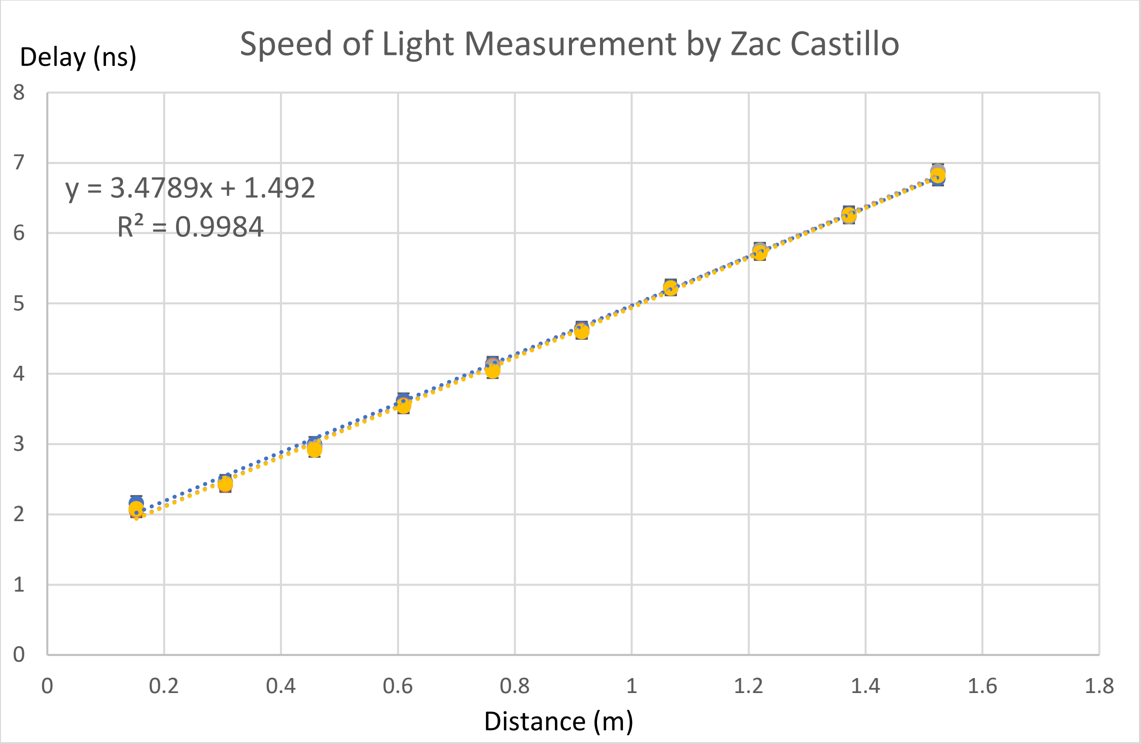
c) In your own words, what is the physical meaning of the y-intercept calculated?

d) Using the information in this plot, what is the calculated speed of light?

e) How does that compare to the known value?

f) Given (e), what does that imply about the data points and the line? Is it too steep? Too shallow? Is the y-intercept incorrect?

g) What is at least one physically plausible source of systematic error that would bias this measurement away from the true speed of light?



Checkpoint 2: Share your answers to Q6 – Q8 with the instructors on Teams.

Q9. Following the procedure and equations in Taylor Chapter 8 (pages 181 – 198, see equations on pages 197 and 198), for your data points.

a) Compute the slope and intercept of a straight line through least-squares fitting (calculate A and B for y = A + Bx, following equations 8.10, 8.11, and 8.12). **Use data points from all runs**.

b) Calculate the best estimate for the uncertainty in y, σ_y (here: time delay). Compare this to your estimated typical and maximum uncertainty from Q4 and Q5.

c) Calculate the uncertainties in A and B, σ_A and σ_B

d) Plot your data points with x- and y- error bars, along with the least-square fit line found in (a). Describe which uncertainty you chose to use for the error bars. Does the line pass through all points with error bars?

d) Which of these variables corresponds to the speed of light? What is the corresponding speed of light and associated uncertainty? Is the true value within the estimated uncertainties?

e) How does this compare with your estimated uncertainty in how well the speed of light would be measured from **Q7**?

Checkpoint 3. Share your results with the instructors including any problems with fitting, and the magnitude of the uncertainties calculated. What is your best value for the uncertainty in the speed of light measurement?

Section 2 – Understanding the limits of this experiment

Q12. Using your result from Section 1, what is the fractional uncertainty in the measured index of refraction of the entire optical path?

Q13. Imagine we went back into the lab and repeated the experiment, but all you were able to see is the output of the oscilloscope. The moving of the mirror has been automated and you are able to repeat the same set of data points vs distance.

We claim to have submerged the experiment completely in liquid.

Would you be able to confidently determine that this was true?

Would you be able to tell what liquid we used?

Use this table of common indices of refraction as a reference:

https://www.physlink.com/reference/indicesofrefraction.cfm

Q14. Now we drain the hidden experiment, back to air as the optical path, but we say we have placed a piece of silicon in the optical path. How thin of a piece of silicon would you be able to confidently detect?

Q15. If we told you nothing about the setup, how could you distinguish between the two situations in Q13 and Q14?

Section 3 – Other Methods to Measure the Speed of Light

Q18. Read this article and watch the video about another way to measure the speed of light:

https://www.smithsonianmag.com/smart-news/theres-easy-and-tasty-way-measure-speed-light-home-180952245/

What is one important limitation with this measurement, compared to the measurement we performed in lab?