

Experiment 2: Measuring the Speed of Light

Objective: To measure the speed of light using a pulsed dye laser, miscellaneous optical elements, a photomultiplier, and a fast oscilloscope. Beyond its technical aspects and historic significance, this experiment underscores the importance of statistical and systematic uncertainty.

Background: Physicists view the speed of light as one of the most fundamental constants of the physical universe. The invariance of c to the motion of observers, the assumed constancy of c over time, and the presumed invariance of c to the direction of propagation of light are indicators of its universality. As an invariant, the speed of light serves as a cornerstone of special relativity, and it appears in many theoretical expressions of physics. Since c was recently *defined* to be

$c = 2.9979246 \times 10^8$ m/sec, it might seem more appropriate to use c along with some light travel intervals Δt to make distance measurements $\Delta x = c\Delta t$ (such as the length of the laboratory). Here, however, we choose to “measure” c to underscore its importance and expose students to some state-of-the-art instrumentation. Our approach to this measurement should permit an accuracy of better than 99%, and the exercise lets the student participate in the rich tradition of measuring c , which began with lanterns and stopwatches on snow-covered hills.

Procedure: Figure 1 depicts the experimental layout. Light pulses of 8 nsec in duration are emitted at a rate of 10 pulses/sec by a pulsed dye laser. These pulses impinge upon a beamsplitter B, which reflects part of each pulse back along the distance BD to detector D. The remaining part of each pulse passes through the beamsplitter and propagates across the lab, passing through a lens and onto a flat mirror M before reflecting back to D. At D, both parts of the original laser pulse enter a fibre optic and pass on to a photomultiplier which converts them into electrical pulses. The first electrical pulse to arrive at the Tektronix 2467 oscilloscope “triggers” the scope so that both pulses can be displayed as negative-going peaks on a single screen. The scope's display represents a graph of pulses plotted vertically versus time plotted horizontally. The laser pulse that traverses the lab appears as the rightmost pulse on the screen since it travels a distance $(BM + MD)$, much greater than BD . We define ΔT to be the *difference* in arrival times at the fibre optic between the two parts of the laser pulse, or, equivalently, between the arrival times of the two electrical pulses at the oscilloscope. When the vertical

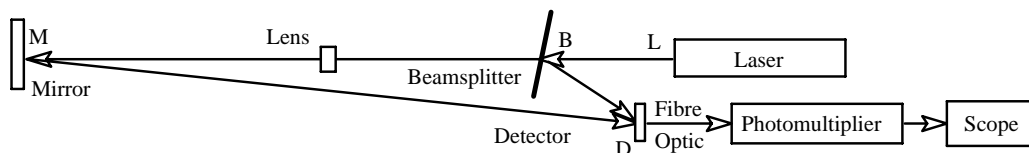


Fig. 1. Experimental layout for measurement of the speed of light.

cursor lines on the oscilloscope screen are carefully positioned so as to coincide with the centers of the pulses, the scope computes and displays ΔT automatically.

Part A. By examining Fig. 1 and ignoring the effect of the lens, derive a simple working expression for the speed of light $c = \Delta X / \Delta T$ appropriate to this particular experiment, where $\Delta X = \Delta X(\text{BM}, \text{MD}, \text{BD})$ is the *difference* in the distances travelled by the pulse fragments during the aforementioned time interval Δt .

Part B. With the lasers turned off, use a taut measuring tape to determine the distances BM and MD. Use a meter stick to measure BD. Think about and record the uncertainties, both statistical and systematic, in these distances as you measure them. Proceed to determine ΔX and its total uncertainty $\delta(\Delta X)_{\text{tot}}$. Be careful not to misalign the mirror, lens, beam splitter, and/or detector. Also be certain to heed the warning signs displayed in the lab. *The basic rule is: never look directly into a laser beam. Do not even bend over to look more directly at an oncoming beam.* Adjust the laser power, photomultiplier voltage, and/or beamsplitter orientation so that the two pulses displayed on the oscilloscope are similar in size and shape. Use the scope's cursors to locate the centers of the pulses, and read off the interval ΔT between their arrivals. Each student should make several determinations of ΔT . So as not to prejudice others' measurements, keep your values confidential until all members in your group have completed their measurements. Then find the group's average time interval ΔT and its uncertainties $\delta(\Delta T)_{\text{stat}}$ and $\delta(\Delta T)_{\text{sys}}$.

Part C. Calculate an average value for c for your group and determine its associated uncertainties δc_{stat} and δc_{sys} . Compare your results to the defined value quoted above.

Part D. As time permits, ponder the following questions:

- (i). Explain why, at least in principle, it is inappropriate to compare your measurement of c in this experiment to the defined value.
- (ii). Which would improve this experiment, longer or shorter pulses? Explain your answer. Longer or shorter path lengths? Explain.
- (iii). Does the lens affect your determination of c ? Estimate the magnitude of the effect.