

The Speed of Light

Fall 2008

Introduction

There are two parts to this experiment. In the first part, you will measure the speed of light using an apparatus set up in the hallway. In the second part, you will determine the speed of light in different reference frames using space-time diagrams.

Experiment A: Measuring the Speed of Light

The measurement of the speed of light is relatively straightforward. A schematic of the apparatus appears in Figure 1 below¹:

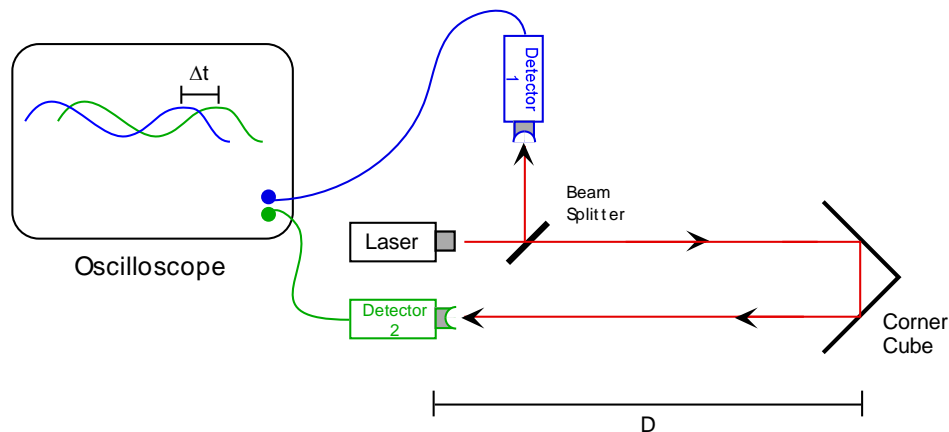


Figure 1 - Speed of light apparatus

A laser beam passes through a beam splitter, which is a semi-transparent mirror that both reflects and transmits the laser light. Part of the beam is directed at detector 1, and a trace is produced on the oscilloscope (your instructor will show you which trace is created by this detector). The rest of the beam passes down the hallway until it hits the *corner cube* mirror. A corner cube uses several mirrors together, so that an incident light ray striking the mirror at any angle is reflected directly upon itself (Figure 2), as opposed to a plane mirror which reflects light at the same angle as the incident ray (Figure 3). Note that the vertical distance in the corner cube of Figure 1 is insignificant.

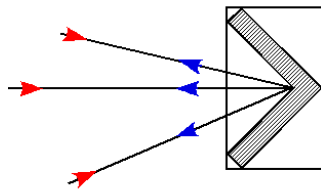


Figure 2 – Corner Cube

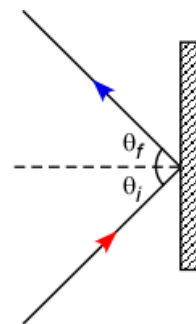


Figure 3 – Plane Mirror

The reflected ray leaves the corner cube and heads back toward detector 2, causing a second trace to appear on the oscilloscope. This second trace occurs a time Δt after the detector 1 trace. If you know the distance the beam

¹ Apparatus design adapted from “The Speed of Light: Making an Easy Time of It”, Burt Brody, *The Physics Teacher*, Vol. 41, p. 276, May 2003

travels (from the laser to the corner cube then to detector 2) and the time interval Δt , you can easily calculate the speed of light.

1. Your instructor will explain the operation of the laser and oscilloscope. You should look at the corner cube carefully (with the laser turned off!) to examine its optical properties.
2. Carefully measure the distance from the laser to the corner cube, and back to detector 2. Note that detector 2 is actually located further away from the corner cube than the laser.
3. Align the cross hairs on the oscilloscope with the peak for each trace. Your instructor will show you how to obtain a printout of this screen, which gives you the value of Δt .
4. Calculate the speed of light from your distance and Δt measurement (be careful of your units!). Calculate the % difference between your measured and the expected value of 'c'.

Experiment B: Coordinate Transformations

In this exercise you will determine the speed of light (in SR units) by calculating the time it takes for a pulse of laser light to travel a known distance to a mirror and back. Then you will set up the coordinates for the events for this measurement (in the Home Frame), and draw the worldline of the light pulse on a space-time diagram. Then you will transfer the events into a moving (Other) reference frame, first using the Galilean transformations and then the Lorentz transformations, make new space-time diagrams, and draw some conclusions about the speed of light in the other frame.

I. Calculating the speed of light

1. Let the laser be located at the origin and the mirror at $x = 30 \text{ m}$ (Figure 4). You will want to convert to SR units right away. Define the measuring events like this:

Event A: Light pulse leaves laser at $t = 0$.

Event B: Pulse reaches mirror and is reflected.

Event C: Pulse arrives at detector.

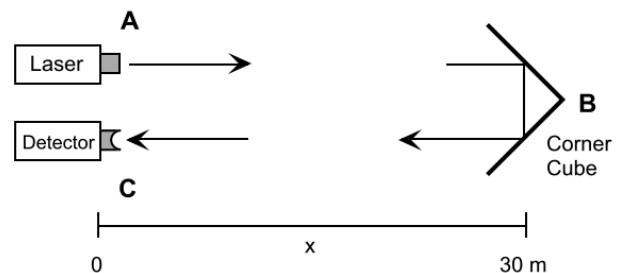


Figure 4

II. Describing the Experiment in the Home Frame (Boris)

2. Assuming that the pulse travels at $v = 1$ (SR units), fill in the event table below:

Event	x (ns)	t (ns)
A	—	—
B	—	—
C	—	—

3. Now make a space-time diagram showing these events and the worldline of the light pulse.

III. Describing the Experiment in the Other Frame (Natasha) – Newtonian World

4. Now consider another inertial frame moving in the +x direction with speed $\beta = 0.6$ and coincident with the Home Frame at $t' = 0$. Fill in the event table using the Galilean Transformations: $\begin{cases} x' = x - \beta t \\ t' = t \end{cases}$

Event	x' (ns)	t' (ns)
A	—	—
B	—	—
C	—	—

5. Make a new space-time diagram for the experiment.
6. Calculate the speed of the light pulse for both the outgoing and returning trip, using $\frac{\Delta x'}{\Delta t'}$.
7. Calculate the *average* speed of the light pulse (what is the definition of *average speed*? If you think it's simply the average of the two velocities, then you haven't been paying attention in class!).

IV. Describing the Experiment in the Other Frame (Natasha) – Relativistic World

8. Recalculate the event table using the relativistic Lorentz Transformations:

$$x' = \gamma(x - \beta t)$$

$$t' = \gamma(t - \beta x)$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

Event	x' (ns)	t' (ns)
A	—	—
B	—	—
C	—	—

9. Make a new space-time diagram for the experiment.
10. Calculate the speed of the light pulse for both the outgoing and returning trip.
11. Calculate the average speed of the light pulse (again, what is the definition of *average speed*?).

Report

- Restate your measured value of 'c'. What are some sources of error?
- Your report should include the filled in event tables, graphs of the three space-time diagrams, and the calculations for the speed of the light pulse. End with a brief summary of the differences in the Newtonian and Relativistic descriptions of the experiment.