

Physics 122
Winter 2012
Lab #1A

The Speed of Light

The speed of light is presently defined to be 299,792,458 m/s (in SI units). As this is an extremely high speed, physicists have used a wide variety of different indirect measurement techniques to measure the speed of light, dating back to the late 1600's.

In this lab, you will use modern tools to make a direct measurement of the speed of light by determining the time it takes light to travel across the laboratory and back (a distance of about ten meters). Your light source will be a pulsed diode laser, and your timing instrument will be a digital oscilloscope.

Pre-Laboratory Exercise

Calculate the time (in seconds) required for a pulse of light to travel ten meters. What timing resolution would you need to measure the speed of light to 1% uncertainty?

Part I: The Digital Oscilloscope

The main measuring device you will use for this lab will be a digital oscilloscope. As oscilloscopes are widely used in physics research, and will crop up in some of the other labs this term, it is a good idea to spend a little time learning the basic operating principles of the oscilloscopes we have in the lab.

An oscilloscope is a device which will record and display the voltage applied to its inputs as a function of time. This was originally accomplished by scanning an electron beam across a phosphorescent screen (an "analog oscilloscope"), but more modern devices use a computer to record voltage values at discrete intervals (a "digital oscilloscope"), and store them in memory to be displayed on the screen. The oscilloscopes we will be using are Tektronix model TDS210 digital real-time oscilloscopes, which can be triggered at a rate of 60 MHz, and which record the input signals at rates up to 1 giga-sample per second, or 10^9 data points per second.

1) Connect the signal generator provided to the Channel 1 input of your oscilloscope. Set the signal generator to produce a sine wave at about 10 kHz, and turn it on. Press the "Trigger Menu" button on the oscilloscope, and make sure that the "Mode" setting is "Auto." (Menus will be displayed on-screen, and you can change a setting by pressing the corresponding button next to the screen).

You should see a sinusoidal wave form displayed on the screen, with peaks and valleys that may change position from one shot to the next. In the auto-trigger mode, the oscilloscope triggers itself to record and display a new set of data as soon as it has finished displaying the previous set. Unless the frequency of the sine wave happens to be a multiple of the refresh rate of the scope display, you will see the peaks move around.

You can "zoom in" on the signal by using the "Volt/Div" and "Sec/Div" knobs on the oscilloscope. The "Volt/Div" knob changes the vertical scale on the display, and the "Sec/Div"

knob changes the horizontal scale. The values for each of these settings are shown near the bottom of the scope display. You can also change the position of the zero voltage point using the “Vertical Position” knob for Channel 1.

2) In order to make more precise measurements, we would like to be able to observe the peaks in a consistent position. You can arrange this by changing the trigger mode to “Normal,” and the “Source” to “CH 1.”

In “Normal” mode, the oscilloscope monitors the input, but does not record and display data until the signal on the source channel passes a particular voltage that you can set. This is the “trigger level,” and it is controlled by a small knob near the “Trigger Menu” button. The level is indicated by a small black arrow on the right-hand edge of the scope display. The trigger point (the point at which the scope began recording data) is indicated by a small black arrow on the top edge of the scope display. You can shift the trigger point around on the screen using the “horizontal position” knob.

a) Try moving the trigger level around to different points. What happens when you move it to a point above the peaks of the sine wave? What happens to the display as you change the trigger level?

b) Make a sketch in your notebook of the first few oscillations around the trigger point, for a few different trigger levels. Make sure the difference between curves is clear.

c) Another setting in the trigger menu is “Slope,” which can be set to either “Rising” or “Falling.” What happens to the signal when you change this setting?

3) You can make very precise measurements of time and voltage using cursors displayed on the screen. Pressing the “Cursor” button will give you a new menu on the screen, and changing the “Type” setting to “Time” will place two vertical lines on the display. You can move these cursors around using the vertical position knobs for Ch. 1 and Ch. 2. The positions of these cursors, and the difference in time between them are indicated on the right-hand side of the screen.

a) Use the cursors to measure the frequency of the sine wave from the signal generator. Is this consistent with the settings on the generator itself?

b) Change the frequency, and use the cursors to verify that the frequency changes as you expect. You may need to change the “Sec/Div” setting in order to make a good measurement of the frequency.

4) In the speed of light measurement, the input signal on Ch. 1 will have an amplitude of about 10 mV, and you will need to accurately measure the time between two pulses separated by the amount of time it takes light to travel ten meters. Change the “Volt/Div” and “Sec/Div” setting to the appropriate values. Turn on Channel 2, and adjust its “Volt/Div” setting as well.

Set-up

A very short time pulse from a diode laser is sent to a beam splitter from which it is partially reflected into a detector and partially sent down a long path and reflected back to a second detector. Each detector is a high-speed photodiode that produces a voltage proportional to the intensity of the light striking the detector. The two detectors are connected to a high-speed oscilloscope, which shows the arrival of the light as a pulse on the screen. By measuring the

distance that each beam travels, and the time interval between the pulses as seen on the oscilloscope display, the speed of light can be determined.

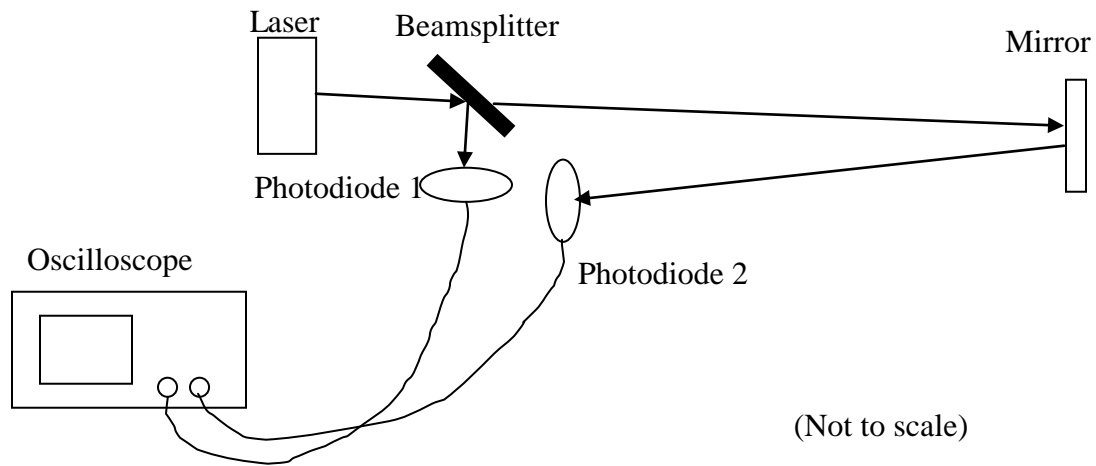


Figure 1: Schematic of the experimental apparatus.

Before beginning, measure all the important distances, and calculate what kind of time separation is expected between the pulses. Make sure that the time scale on the oscilloscope is set to a value that will allow you to clearly distinguish the two pulses.

Carefully draw the set-up in your notes.

When ready, turn on the laser power supply, and the pulse generator. The laser beam should be visible as a red spot on the detectors, or on a piece of paper placed in the path of the beam. Be extremely careful not to let the beam hit your eyes, or the eyes of any other students in the lab, as the light is very bright, and may cause vision damage.

Make sure that the laser hits the mirror on the far side of the room. If necessary, you can adjust the direction of the beam using the two screws on the laser mount, or by loosening the screw holding the laser in place, and moving the mount by hand.

Make sure that the light reflected from the beamsplitter hits Photodiode 1. If necessary, you can move the diode in its mount to center the beam on the active area of the detector (the small black square).

Make sure that the light reflected from the mirror hits Photodiode 2. If necessary, you can change the position of the beam using the two screws on the back of the mirror mount. You can have one member of your lab group look at the face of the diode, and call instructions to another member adjusting the screws.

When the two beams are hitting the detectors, connect the two detectors to the oscilloscope. You should see two pulses, one on Ch. 1 and one on Ch. 2. You may need to adjust

the trigger level to get a good signal.

Using the cursors on the oscilloscope, measure the difference in the arrival times of the two pulses. Use this difference to calculate your experimental value of the speed of light.

Calculate or estimate the uncertainties in all of your measurements, and propagate these uncertainties into a final uncertainty in your measurement in c . Does your experimental result in agreement with the textbook stated value of c to within experimental uncertainties?

What other constraints in the set-up are required to ensure an accurate measure of c , with no systematic errors? Remember that the oscilloscope only knows when the pulse signal enters its own port, not when the light pulse enters the photodiode.