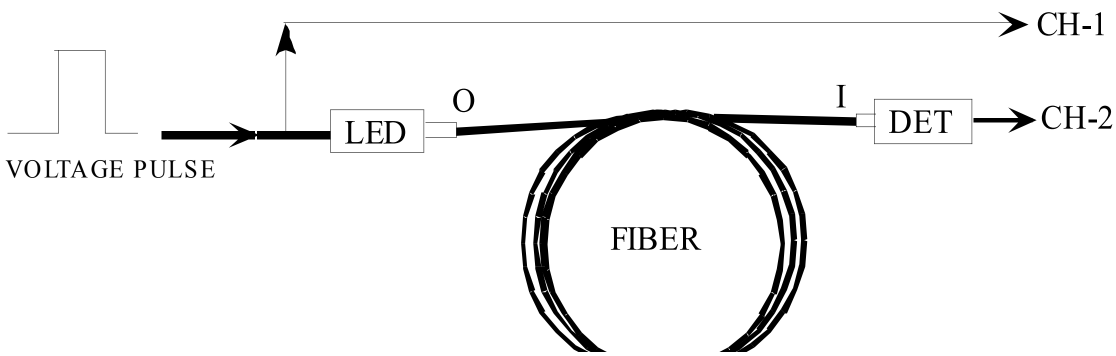
Speed of Light

1. Objective

The objective of this experiment is to measure the speed of light in an optical fiber by measuring the time a light signal takes to traverse a known length of fiber.

2. Theory

If a light signal travels a length ΔL in a medium of refractive index, n in time Δt, then the speed of light in that medium can be determined simply as $c_n = \Delta L/\Delta t$. The refractive index, n of a medium = c/c_n , where c is the speed of light in vacuum.



3. Experimental Details

The basis of this experiment is very simple. An LED (light emitting diode) is energized by a square voltage pulse. The time, Δt of travel of the resulting light pulse emitted by the LED, through the fiber of length ΔL, is measured and used to compute the speed of light. But here is the *caveat*. Since Δt is only tens of nanoseconds, and the signals from Channel 1(CH-01) and Channel 2(CH-02) travel through different electrical paths considerable errors can be introduced in the measurement of Δt. Therefore, the actual experimental execution of the measurement scheme outlined above is a bit more interesting. Suppose you tap the square pulse signal (divert part of it) at the input end of the LED and use its detection as $t = 0.0 sec$. It is instructive to know the various time delays that can be introduced before the signals of CH-01 and CH-02 are detected and displayed on the oscilloscope.

We have to make sure that the time delay we are measuring is only the time delay caused by the light traveling from O to I through the fiber and not due to any other electrical delays. The time delay between CH-01 and CH-02 can be expressed as $\Delta T = \Delta t + \Delta t'$ where Δt is the time light takes to travel through the fiber and $\Delta t'$ is the total differential time delay between CH-01 and CH-02 due to different electrical paths the signals travel through the two channels. In most experiments such differential time delays are of little concern and are often neglected. However, in the present experiment $\Delta t \sim 100$ ns and $\Delta t'$ has to be properly compensated for. To do this we have to calibrate the time axis , as detailed below, by finding ΔT when $\Delta t \sim 0$. This is done by using a short length (15cm) of an optical fiber and measuring ΔT. For a 15 cm fiber $\Delta t \sim 0.75$ ns and thus $\Delta T_0 = \Delta t + \Delta t' = 0.75\text{ns} + \Delta t'$. Since the expected $\Delta t \sim$ 100ns for a 20m fiber, $\Delta T_0 = 0.75\text{ns} + \Delta t'$ can be taken as a reasonably accurate measure of the differential electrical delay between CH-01 and CH-02. Thus if we subtract ΔT_0 from our time delay measurements, we can extract the time the light signal takes to travel through a given length of optical fiber.

3.1 Apparatus

1) A Speed of Light Apparatus with an associated power supply
   One each of a 15cm, 10m, and a 20m long fiber-optic cable.
2) A 100-MHz oscilloscope with two oscilloscope probes.

3.2 Experimental Procedure

Turn on the oscilloscope

3) Under **TRIGGER**:
   a. Press **Source** – select **1**
   b. Press **Mode** – select **Auto**
   c. Press **Slope/Coupling** –
      i. select the **Up-Slope (□)**
      ii. set **Coupling** to **AC**
4) Under **HORIZONTAL**:
   a. Press **Main/Delayed** and set the following
      i. **Horizontal Mode** : **Main**
      ii. **Vernier** : **Off**
      iii. **Time Ref** : **Cntr**
   b. Adjust Time/Div knob until divisions are presented in increments of 50ns (displayed on upper-right of screen)
5) Under **VERTICAL**:
   a. Adjust Volts/Div to 1 Volt/div for CH-01 and 0.5 Volt/div for Channel. The scale (Volt/div) will be displayed on the upper-left of screen.
   b. Press the **CH-01 button** and set the following
      i. **CH-01** : **On**
      ii. **Coupling** : **AC**
      iii. **Bw Lim** : **Off**

        iv. **Invert** : **Off**
        v. **Vernier** : **Off**
        vi. **Probe** : **1**
    c. Press the **CH-02 button** and apply the same settings as above for CH-01
    d. Adjust Position knobs until both CH-01 and CH-02 are at 0.00mv
6) Attach oscilloscope probes to the lead-outs under the position knobs of CH-01 and CH-02
7) Leaving the oscilloscope for now, turn your attention the SOL Apparatus. We will now begin the calibration of the SOL Apparatus.
    a. Set Calibration knob to the 12 o'clock position
    b. Using the 15cm fiber-optic cable, fit one end into the light blue **D3 Transmitter LED** (the cable should fit snuggly). If the cable does not fit snugly (it easily slips out) you may gently tighten (no more than ¼ to ½ turn) the fiber optic cinch nut. **CAUTION** : Overtightening will result in damaging the cinch nut assembly.
    c. Gently bend the fiber and insert the other end into the black **D8 Receiver Detector DET**
    d. Attach probe from CH-01 to SOL Apparatus on the Transmitter side
        i. Red Reference
        ii. Black Ground
    e. Attach probe from Channe 2 to SOL Apparatus on the Receiver side
        i. Red Delay
        ii. Black Ground
    f. Plug power supply cable into SOL Apparatus (at the far left of the circuit). When power is applied to SOL Apparatus the yellow light at the top left should be lit.
8) Returning our attention back to the oscilloscope:
    a. Under **HORIZONTAL**:
        i. Turn the Delay knob to the left or right until you see an obvious signal, there should be two – one for the trigger from CH-01 and one from the delayed signal from CH-02
        ii. Adjust the Calibration knob on the SOL Apparatus until the peaks of both signals are aligned vertically
        iii. Using the Horizontal Delay knob on the oscilloscope adjust the signals back to the center of the screen

The SOL Apparatus is now CALIBRATED!

9) Disconnect the power supply from the wall socket. Carefully remove the 15cm fiber-optic cable from the SOL Apparatus and replace it with the 10m long. Once more, plug in the power supply.

10) If you do not see an obvious signal on your screen, use the Horizontal Delay knob to locate it. The new signal should have a CH- 2 output that is some distance from the original trigger signal.
    a. Measurement of Δt: Under **MEASURE**, select **Cursors**:

i. On source 1
   1. select **t1** – use the knob within the gray box containing the Measure buttons to move this cursor to the peak of signal 1 from CH-01
   2. select **t2** by pressing the button below **t2**, adjust this cursor to the peak of the second signal

ii. Record the Δt between these two cursors given on the lower left hand part of the screen: Example: 51ns

b. Under **HORIZONTAL**, adjust the Time/Div knob to 20 ns/div and repeat Steps 1 and 2 above. The expanded scale (from 50 to 20ns/div will improve the precision of your readings).

c. Every member of your team should individually go through steps [a] and [b] above and record their readings in the data sheet that follows.

11) Remove the 10m fiber cable and replace it with the 20m cable. Determine Δt as in the step above. Record your readings in the Data sheet.

Gently pull out the end of the 20m fiber that is connected to **D8 Receiver Detector DET.** Using a coupling sleeve, couple the free end of the 20m cable to a 10m cable. Slide the free end of the 10m cable into **D8 Receiver Detector DET.** Again, determine Δt as above.

4. Pre-Lab

1. What is the value of the speed of light in vacuum?

2. How does the speed of light depend on the refractive index of the medium of propagation of light ?

3. From your text find the values of the refractive indices of

[i] Air
[ii] Water
[iii] Glass

5. Data

Fiber Length ΔL(m)		t1 (ns)		t2(ns)		Δt = t2 – t1 (ns)		Ave. Δt (ns)	
		50ns/div	20ns/div	50ns/div	20ns/div	50ns/div	20ns/div	50ns/div	20ns/div
10	1								
	2								
	3								
20	1								
	2								
	3								
30	1								
	2								
	3								

Analysis

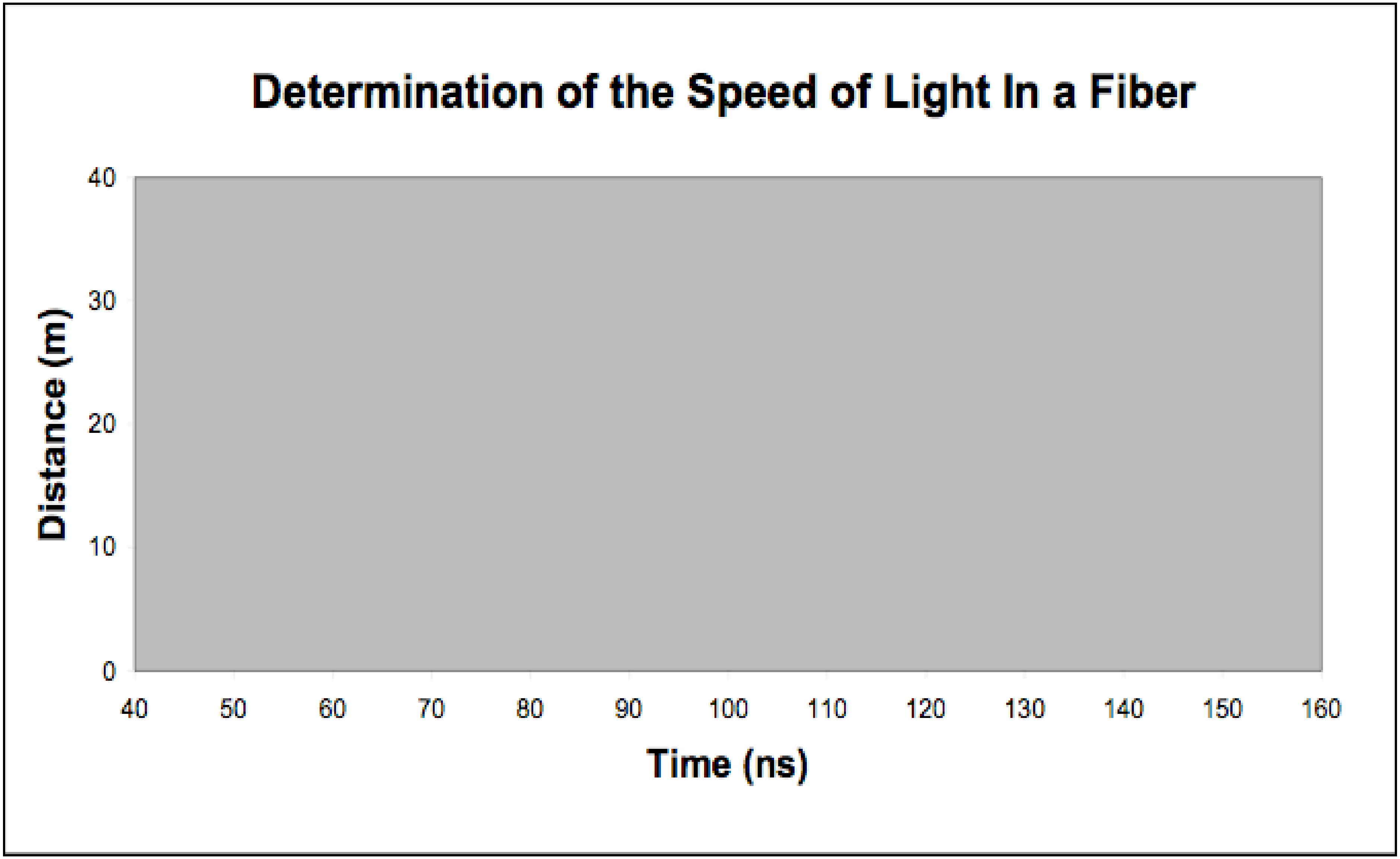
Plot ΔL vs. Δt for the three fiber lengths. From the slop of the straight line determine the velocity of light in the fiber, $c_n = \Delta L / \Delta t$.

Speed of light in vacuum, $c = nc_n =$
(take $n = 1.5$)

Error Estimate

What is the uncertainty in your measurement of Δt?

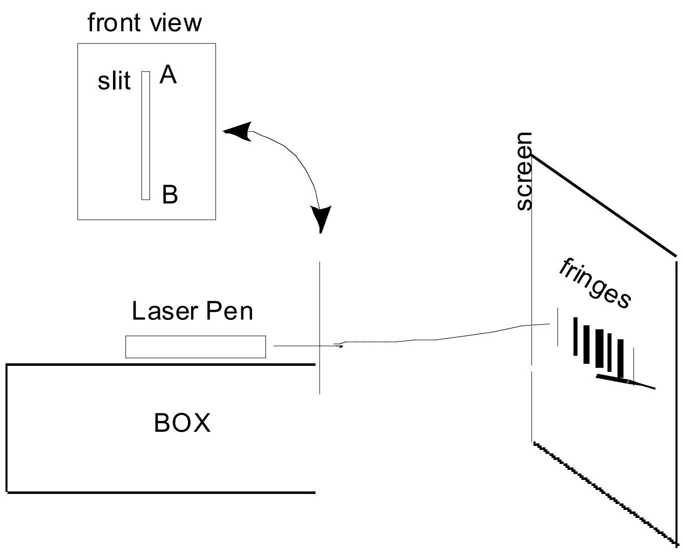
Suppose the length of the optical fiber is known to within a centimeter. What is the maximum estimated error in your measurement of the speed of light?



Determination of the Speed of Light In a Fiber
Distance (m)
40
30
20
10
0
40
50
60
70
80
90
100
110
120
130
140
150
160
Time (ns)

6. JUST FOR THE FUN OF IT

This part of the Lab is, as the name suggests, for fun. You don't have to write a report about this section. The idea is to introduce you to concepts that are very exciting but are normally not discussed in freshmen physics courses. The experiment will give you something to think about. If you would like to pursue these concepts further, we would be very happy to direct you to additional reading material and/or discuss the significance of observations you have made.



The laser light you have used for the SOL experiment can be viewed either as a wave or as a stream of photons (quanta of energy). When light interacts with objects that are comparable to its wavelength, it can behave in very counterintuitive ways. This experiment is designed to illustrate this.

Take a sheet from the pad and put it on a flat surface. With a razor blade make a cut about 3cm long. Turn the box upside down and paste the slit paper on the box as shown. Place the laser pen about 2 to 4 cm behind the slit. Adjust the position of the pen and/or slit so that the slit is roughly in the middle of the laser spot.

Let the laser light after passing through the slit fall on a flat vertical white or light-colored surface about a meter away from the laser. If there is no such surface within your convenient reach, use a sheet of white paper as a screen.
What you will see is a series of dark and bright fringes spread over several centimeters.

Explanation: The fringes are caused by the interference between light waves originating from different parts of the slit. Bright fringes are formed when the waves are superimposed in phase and dark fringes result when the waves meet on the screen out of phase.

You should also notice that the beam has spread only along the width but not the length (height) of the slit. Here, you are seeing Heisenberg's uncertainty principle in action. This is what is going on. The photons that end up at the screen *must* have passed through the slit of width Δx. Therefore the position of a photon is known with a maximum uncertainty of Δx. According to Heisenberg's uncertainty principle, in a simultaneous measurement of position and momentum, the uncertainties in position (Δx), and in momentum (Δp) must obey $\Delta x \Delta p \geq h / 2\pi$ where $h = 6.6*10^{-34} J.s$ is a fundamental constant of nature and is known as the Planck's constant. Thus if you decrease Δx, Δp – the uncertainty in the x-component of the photon's momentum - must increase. This is what makes the laser spot 'spread' in the direction of the slit's width (but not along the length where the confinement length is much larger) You can easily observe the inverse dependence of Δx on Δp by twisting/bending the slit gently (please ask your lab instructor how to do it.)