Prelab

Our group proposed two methods for measuring the speed of light as part of the prelab.

1.) Our group decided to use our knowledge of the refractive index to measure the speed of light. We know that the index of refraction of water is 1.33. We also know that an Olympic swimming pool has a length of 50 meters. We could measure the speed of light by using a beam splitter to send a pulse of light underwater and another pulse of light above the water. The pulse of light underwater would travel at \( v = \frac{c}{n} = \frac{3.00 \times 10^8}{1.33} \approx 2.26 \times 10^8 \) meters/second. The pulse of light would travel at approximately \( c \) since the speed of light through air is approximately 1.00. The two beams would arrive at the far end of the pool with a time difference of approximately 55 nanoseconds. This difference can be measured using an oscilloscope. To summarize, this method measures the speed of light by holding distance constant and measuring the difference in time of propagation through two different media with known refractive indices.

2.) To measure the speed of light, we proposed an optical experiment using similar materials to the actual lab. The materials needed for the experiment are 2 mirrors of length 1 m, a laser, and an oscilloscope. The beam of light will be shot in two different paths. One will shoot directly down the 1 m stretch to the oscilloscope, but the other will be much longer. The laser will be directed 1 cm to the right toward the opposite mirror. The beam will travel the distance of 5 m that the mirrors will be placed from each other. It will then reflect back in a direction 1 more cm to the right direction. This reflection will occur repeatedly until the beam reaches the end of the 1 m long mirror stretch. The beam will then be fed into the oscilloscope for a reading. The difference in time will be able to be read from the oscilloscope, and the difference between the short and long paths will be able to be calculated with our own measurements. Dividing the distance by the time will yield a calculation for the speed of light.
The purpose of this lab was to carry out two different types of experiments to measure the speed of light. One focused on optical methods while the other used non-optical, electrical pulse, methods.

**Hypothesis**

Based on research, we expect the value for the speed of light to be 299,792,458 m/s. We hoped to get a value with at least one correct significant digit from our measurements.

**Materials**

**Optical Set Up**
- Laser
- Beam Splitter
- 4 Mirrors
- 2 Detectors
- Oscilloscope
- Connecters
- Calculator
- Lab Notebook
- Pen

**Non-Optical Set Up**
- Coaxial Cable
- Oscilloscope
- Ruler
- Electrical Signal Splitter
- Oscilloscope
- Calculator
- Lab Notebook
- Pen

**Procedure**

**Optical Set Up:**
1. All optical alignments were pre-set and oscilloscope functioning as needed. If oscilloscope not functioning as needed, follow steps 4-9 in Winnie Ye Lab 2.
2. Record the difference in time of arrival of two pulses.
3. Measure distance of shorter path for light.
4. Measure distance of longer path for light.
5. Record difference in distance traveled.
6. Perform calculations (see Analysis for details).

Non-Optical Set Up:
1. Set up oscilloscope in same manner as optical set up.
2. Set up two different lengths of coaxial cable for electrical pulse to travel through.
3. Record the difference in time of arrival of the two pulses.
4. Measure distance of shorter path for pulse.
5. Measure distance of longer path for pulse.
6. Record difference in distance traveled.
7. Perform calculations (see Analysis for details).

<table>
<thead>
<tr>
<th>Method of Measurement</th>
<th>Time difference between arrival of pulses (Δt)</th>
<th>Difference in distance traveled by pulses (Δd)</th>
<th>Fraction Speed of Light in Medium (c_{medium}/c_{vacuum})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical (Air)</td>
<td>27.00 ns</td>
<td>8.12 m</td>
<td>1</td>
</tr>
<tr>
<td>Non-Optical (Coaxil)</td>
<td>33.00 ns</td>
<td>6.06 m</td>
<td>.67</td>
</tr>
</tbody>
</table>

**Analysis**

- Calculation of speed of light in medium:
  
  \[ c_{medium} = \frac{\Delta d}{\Delta t} \]
  
  o Explicitly, for our experiment:
    
    In optical measurement, \( c_{air} = \frac{8.12 \text{ m}}{27.00 \text{ ns}} = 3.01 \times 10^8 \text{ m/s} \)
    
    In non-optical measurement, \( c_{coaxial} = \frac{6.06 \text{ m}}{33.00 \text{ ns}} = 1.84 \times 10^8 \text{ m/s} \)
  
- Calculation of speed of light in vacuum:
  
  \[ c_{vacuum} = \frac{c_{medium}}{\text{fraction speed of light in medium}} \]
  
  o Explicitly, for our experiment:
    
    In optical measurement, \( c_{vacuum} = \frac{(3.01 \times 10^8 \text{ m/s})}{1.00} = 3.01 \times 10^8 \text{ m/s} \)
    
    In non-optical measurement, \( c_{vacuum} = \frac{(1.84 \times 10^8 \text{ m/s})}{.67} = 2.75 \times 10^8 \text{ m/s} \)
  
- Calculation of arithmetic mean, percent error, and deviation.
  
  o Arithmetic mean = \( \frac{[(3.01 \times 10^8 \text{ m/s}) + (2.75 \times 10^8 \text{ m/s})]}{2} = 2.88 \times 10^8 \text{ m/s} \)
  
  o Percent error:
Optical = \left( \frac{(3.01 \times 10^8 \text{ m/s}) - (3.00 \times 10^8 \text{ m/s})}{3.00 \times 10^8 \text{ m/s}} \right) = 0.33\% \\
Non-Optical = \left( \frac{(3.00 \times 10^8 \text{ m/s}) - (2.75 \times 10^8 \text{ m/s})}{3.00 \times 10^8 \text{ m/s}} \right) = 8.33\% \\
Average = \left( \frac{(3.00 \times 10^8 \text{ m/s}) - (2.88 \times 10^8 \text{ m/s})}{3.00 \times 10^8 \text{ m/s}} \right) = 4.00\% \\
Deviation = \left( \frac{(3.01 \times 10^8 \text{ m/s}) \cdot (2.75 \times 10^8 \text{ m/s})}{3.00 \times 10^8 \text{ m/s}} \right) = 8.67\%

Conclusion

The purpose of the lab was to measure the speed of light using optical and electrical methods. Beaming a light along two different paths tested the optical method. A short path reflected the light essentially directly into the oscilloscope. The long path of light was reflected several times before it reached the oscilloscope. The oscilloscope read the two different pulses; the time difference between the two paths was easily read from the oscilloscope. Using distance measuring tools and trigonometry, we calculated the distances of the short and long paths. The change in distance divided by the change in time yielded a result for an experimental speed of light calculation.

The electrical method was tested similarly. Instead of beaming a light, a pulse was sent down two different paths of coaxial wire. The short and long path pulses were also read into an oscilloscope. Another experimental speed of light calculation was made using the change in time read from the oscilloscope, the change in distance measured, and the fraction of the speed of light in the medium of the cable.

These experiments did not involve specific control of experimental groups. The time differences were measured using nanoseconds, and the distance differences were measured using meters. The calculated speed of light for the optical method was very accurate, $3.01 \times 10^8 \text{ m/s}$ (.33% error). Unfortunately, the non-optical method yielded $2.75 \times 10^8 \text{ m/s}$ (8.33% error). This large error may have resulted from the fraction of the speed of light, $.67$, given to us. This may have not been completely accurate, because it could depend upon the specific material of the coaxial cable. Another source of error could have been the length of the cable used in our data; we took the distance from the label on the cable and not from actual measurements.

Through this experiment, we learned that accuracy and precision of measurements are very important when dealing with calculations on the nanoscale. The optical method was much more successful for us, perhaps because we were not relying on accepted medium values, distance values, etc. that could vary for different experiments.

\footnote{http://www.britannica.com/eb/article-11358/electromagnetic-radiation}