Topic 17: Relativity

Source:	*Conceptual Physics* textbook, laboratory manual, concept-development book and CPO physics text and laboratory manual
Types of Materials:	Textbooks, laboratory manuals, demonstration, worksheet, websites and good stories
Building on:	The study of kinematics including time, mass, length, energy and momentum is necessary to explain relativistic physical quantities like time, mass, length, energy and momentum. A knowledge of relative motion is necessary to understand relativistic motion with time dilation and length contraction. A kinematics background is needed to understand and perform a speed of light experiment.
Leading to:	Relativistic mass understanding allows a student to do calculation on nuclear binding energy. Space travel to other planets will someday need the understanding of special relativity involving length contraction and time dilation.
Links to Physics:	Special relativity is used in the operation of high-energy accelerators such as the one at Fermilab located in Illinois. The charged particle approaches the speed of light so time, mass and distance have to be adjusted. As mentioned above, space travel will need to consider special relativity in future exploration. Relativity and quantum mechanics use the interrelationship of space and time and the constant value of the speed of light.
Links to Chemistry and Biology:	Indirect at most. High-speed travel would affect time, length and mass so biological aging is affected and chromosomes would be damaged by cosmic rays that affect the human DNA.

Materials:

(a) Hewitt*

(b) Hsu
1. Frames of Reference
2. Relativity

(c) My Activity*

(d) Worksheet*

(e) Demonstration
  1. Speed of light
  2. Simultaneity*

(f) Websites/Videos
  1. Alice in Physics Lab Sims
  2. NOVA “Time Travel” Video Guide

(g) Good Stories
  1. Einstein*
  2. Albert Michelson (1852-1931) – A Lot of Nothing
  3. Albert Michelson in Popular Culture

Topic 17: Demonstration: Speed of Light

Introduction: This demonstration is usually done as a lab, but for younger inexperienced students, a guided demonstration will be more effective and much less frustrating. The demo doesn't replicate Michelson's speed of light experiment with the spinning mirror and light pulses bouncing between mirrors on two mountain tops, but it does allow a reasonable "c" calculated value. This demo doesn't take years as Michelson's experiment, but takes minutes!

Materials:

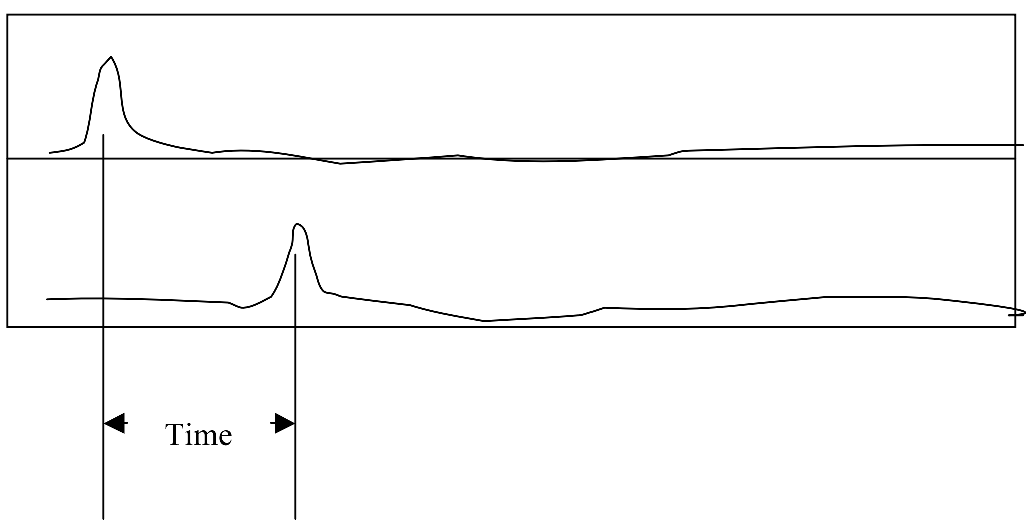
1. Speed of light "c" apparatus – Purchase through a scientific supply company such as Sargent-Welch. The 2006 catalog has this apparatus as CP32007-01 at $278.

2. 30 MHz dual channel oscilloscope (or faster) with two leads, one per channel. Scope cost will depend on speed and quality. One Internet search shows a 35 MHz, dual channel scope at $450.

<u>Working of Apparatus</u>:

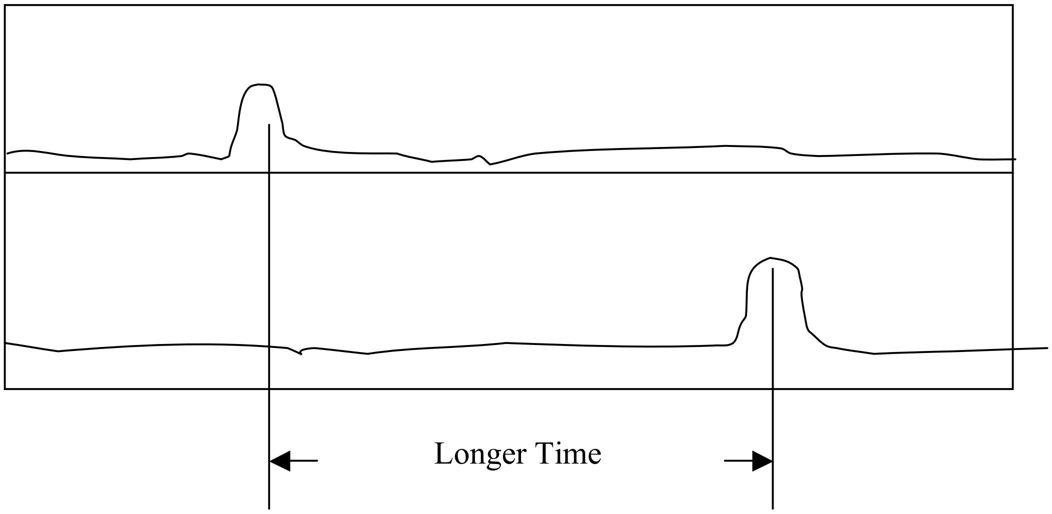
This electronic apparatus consists of a transmitting circuit that pulses a red LED diode at 1 MHz. A receiver circuit gathers the pulses after going through the optical fiber. First, the 15 cm fiber is connected between the transmitter and receiver. One scope lead is connected to the transmitting diode and fed into channel one of the scope and the second scope lead is connected to the receiver and fed into channel two of the scope. When the sweep speed is high on the scope, a sketch of the signals will look like this.

15 cm Fiber:

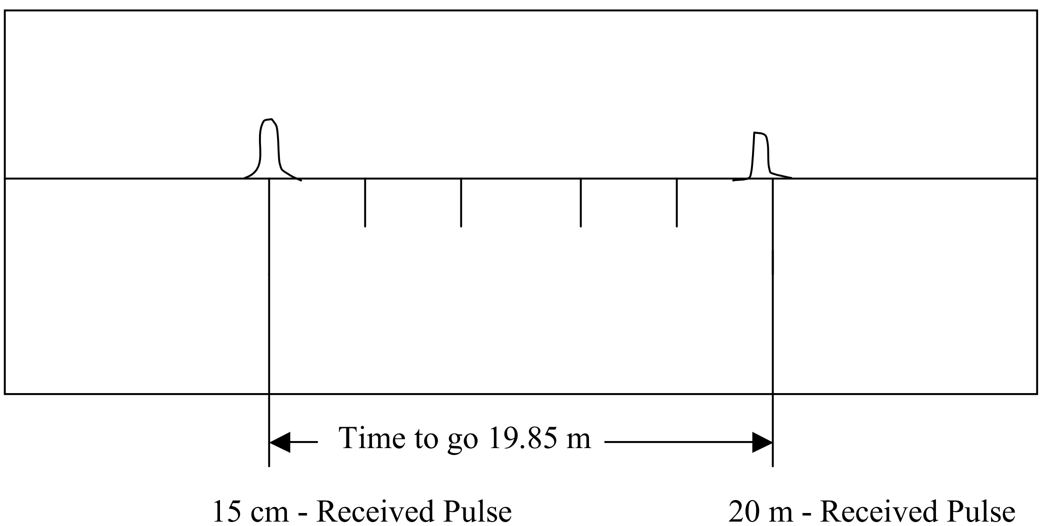


When repeated with a 20 m fiber, this is what is shown:

20 m Fiber:



The newer speed of light apparatus has a dial to position the transmitted pulse of the two trials at the same starting point. So, by recording the receiver pulse location of the two trials, the additional time to travel the 19.85 m can be read from the spaces on the scope screen.



Conceptually, students will see that the "time" for the pulse to travel 20 m is longer than for 15 cm.

The calculation (SAMPLE shown below) is as follows:

Time to travel 19.85 m is:

(time/division) x (# divisions) = 20 ns/division x 4.95 divisions = 99 ns

So, VELOCITY = distance/time. Thus, $19.85\ m/99 \times 10^{-9} s = 0.20 \times 10^{9}\ m/s = 2.0 \times 10^{8}\ m/s$. However, the light travels through a plastic fiber with an index of refraction of 1.5, and since

$$N = c/v,$$

$$1.5 = c/2.0 \times 10^{8}\ m/s$$

or

$$\text{“c”} = 3.0 \times 10^{8}\ m/s.$$

To one sig fig and a quality scope, you CAN get 3×10^{8} m/s!!!!!!!

Albert Michelson (1852-1931) – A Lot of Nothing

Born on the German-Polish border, he came to America and grew up in a mining town in California's gold rush country where his father ran a dry goods store. Too poor to pay for college, he traveled to Washington, D.C. and took to loitering by the front door of the White House so that he could fall in beside Ulysses S. Grant when the President emerged for his daily constitutional. In the course of these walks, Michelson so ingratiated himself with the President that Grant agreed to secure for him a free place at the U.S. Naval Academy. It was at Annapolis that Albert learned physics. Although he excelled in optics, heat, climatology and drawing, his grades in seamanship were below average.

It was at the Naval Academy that he conducted his first experiments of the velocity of light as part of a classroom demonstration. Michelson talked Alexander Graham Bell, the newly enriched inventor of the telephone, into financing his "interferometer," which could measure the velocity of light with great precision. The "master of light" embarked on years of delicate and sensitive experiments. The work was exhausting, and at one point had to be suspended, in order for Michelson to recover from a complete nervous breakdown; but by 1887, he had his results and they were not at all what he expected.

The speed of light turned out to be the same in all directions and at all seasons. It was the first hint in two hundred years that Newton's laws might not apply all the time everywhere—the most famous negative result in the history of physics.

Mostly from Bill Bryson

Albert Michelson in Popular Culture

The Bonanza television series commissioned a fictionalized teleplay entitled “Look to the Stars,” which was initially broadcast on March 18, 1962. The program had Ben Cartwright (Lorne Greene) helping the young Albert Abraham Michelson (portrayed by Douglas Lambert) obtain an appointment to the U.S. Naval Academy, despite the opposition of the anti-Semitic town schoolteacher (William Schallert). Bonanza was set in and around Virginia City, Nevada, where Michelson lived with his parents prior to leaving for the Naval Academy. In the postscript to the episode, Greene mentions Michelson’s 1907 Nobel Prize.

Internet Sources