PHY152H1S – Practical 10: Special Relativity

Don't forget:

- List the NAMES of all participants on the first page of each day's write-up. Note if any participants arrived late or left early.
- Put the DATE (including year!) at the top of every page in your notebook.
- NUMBER the pages in your notebook, in case you need to refer back to previous work.

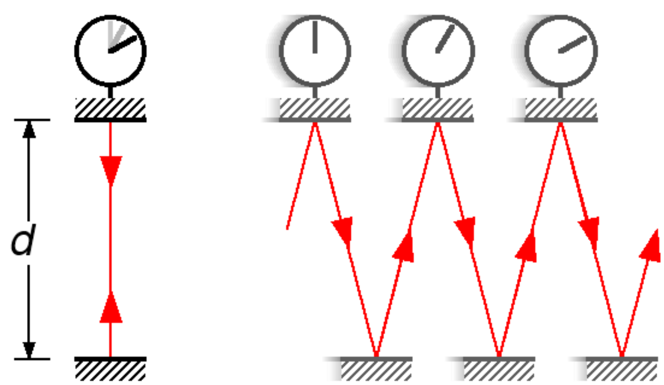
Today's Textbook Reference to review before lab:
"University Physics with Modern Physics" 1st Edition by W. Bauer and G.D. Westfall ©2011
Chapter 35 Relativity, Sections 35.2 and 35.3

Note that the activities below have numbers which refer to numbers in the Relativity Module at http://faraday.physics.utoronto.ca/Practicals/ .

Activity 15

A thought-experiment, sometimes called a Gedanken experiment, is an experiment that you can imagine in order to test or explore theories in physics or other fields. Typically, thought-experiments might be very inconvenient or practically impossible to set up in real life, and you might have no intention of actually setting up the experiment. Nevertheless, thought-experiments can be very helpful in testing and discussing theories.

One famous thought experiment is the "Light-Clock". A light clock is made up of two parallel mirrors, separated by a vacuum and held at a fixed distance of *d*, as shown in the figure. A short pulse of light bounces between the mirrors. Each time the light pulse reflects off the top mirror, the clock "ticks". The time between ticks for a stationary light clock then is the time for a round-trip of the light pulse: $t = 2d/c$, where c is the speed of light.



One of the most fundamental and surprising principles of Einstein's Theory of Relativity is "**light travels at speed *c* in all inertial reference frames.**" Here an inertial reference frame is just one that is not accelerating.

If the light clock is moving toward the right at speed v, the time between ticks is longer, because the light pulse must travel along the diagonal. This time-dilation, or slowing of time, can be computed using the Pythagorean theorem. This is done on page 1157 of Knight Physics for Scientists and Engineers 2nd Edition, and there is a nice applet showing this derivation at http://physics.ucsc.edu/~snof/Tutorial/ .

A. Please open this tutorial with your browser. Click on the [1] to view the #1 Tutorial. It should take about 2 minutes to go through this tutorial and see the derivation of equation 37.22 from Knight: $\gamma = \dfrac{1}{\sqrt{1 - v^2 / c^2}}$. At the end of the tutorial, it says "Type a number 1 through 7 to set the speed of the clock, then click 'Play' to watch it." When you click 1, what is the value of γ? What is the corresponding value of v? Using a stopwatch, measure the round-trip time of reflections of the pulse from the top mirror.
B. When you click 5, what is the value of γ? What is the corresponding value of v? Using a stopwatch, measure the round-trip time of reflections of the pulse from the top mirror.
C. Click on the [2] to view the #2 Tutorial. It should take about 1 minute to go through this tutorial and see why objects must be shorter along the direction of motion in order for light to obey the rule: "**light travels at speed *c* in all inertial reference frames.**" This is called Length Contraction. Note that while the authors of this applet state that the stick "appears" shorter, this is not an optical illusion or an effect caused by the delay-time of light as it travels to reach our eyes. The moving object truly is shorter as carefully measured by an observer that is at rest. Please describe, in your own words, using one or two sentences, why the horizontal mirrors must be closer than the vertical mirrors when the system is moving toward the right.

Activity 6

Here is another thought-experiment. Imagine we have a 120 m long car and a 100 m long garage, both as measured at rest relative to the car and the garage. We will assume the garage has both a front door and a back door, making it possible for the car to drive straight through the garage and out the other side.

A. Make a scale-diagram in your notebook of two rectangles: one representing the car, and one representing the garage, both at rest. Use a scale such that 1 cm in your notebook represents 50 m in real life. When parked, does this car fit in the garage?

Instead of buying a smaller car, you might be able to squeeze this huge car into the garage by driving it extremely fast! If the car is driving at 70% of the speed of light, its length will be contracted.

B. Assume the car is moving at 0.7 c in a direction parallel to its length. How long will the car be in the frame of reference of the garage? Make a scale-diagram in your notebook of two rectangles representing the car and garage, from the **garage** reference frame. Does the car fit in the garage?

But if we are riding along with the car, the car is at rest relative to us, so its length is not contracted. In fact, in the car's reference frame, the garage is actually moving in the opposite direction at 70% the speed of light. Therefore, the garage should be length contracted.

C. According to an observer sitting in the car, the garage is moving towards them at 0.7 c. How long will the garage be in the frame of reference of the car? Make a scale-diagram in your notebook of two rectangles representing the car and garage, from the **car** reference frame. Does the car fit in the garage?

There is a nice applet available at
http://www.physics.uq.edu.au/people/mcintyre/applets/relativity/relativity.html .

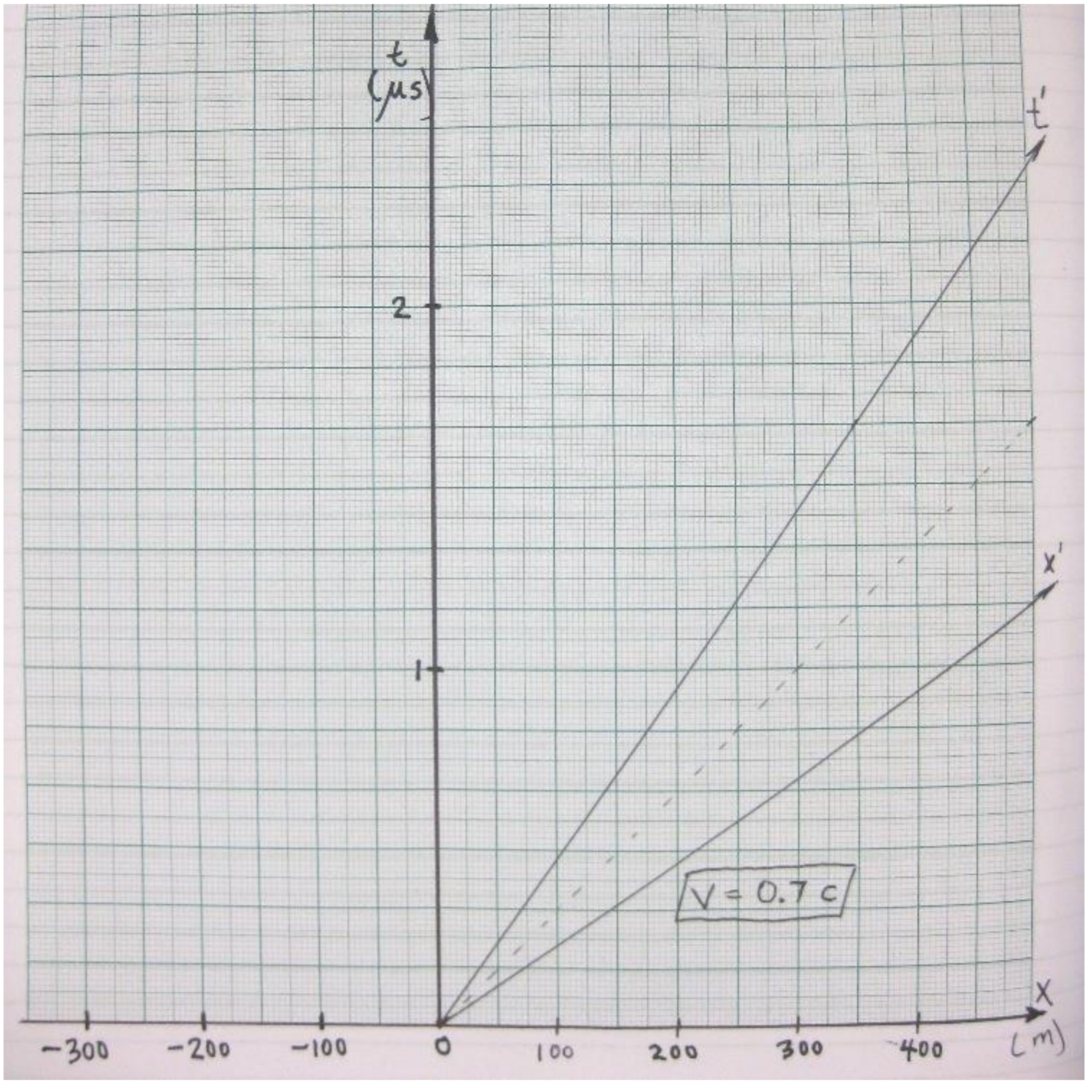
When you first open the page, or reload it, the blue car is pointed toward the red garage, with its center a distance of 200 m to the left of the center of the garage. The origin is defined to be the center of the garage, and the car is 120 m long when at rest, so the car's front begins at a position of $x = -140$ m, and the car's back begins at a position of $x = -260$ m.

D. Use the slider to adjust the speed of the car to be 0.7 c. The simulation shrinks the blue car, showing the instantaneous situation as observed by an observer at rest relative to the garage. Start the simulation, then pause it just after the car passes through the garage. A space-time diagram is plotted in the frame of reference of the garage. The blue lines show the front and back of the car, the red lines show the front and back of the garage. The c*t* axis defines where x=0, and it is parallel to the worldline for any object that is stationary in the garage frame. The x axis defines where t=0, and is parallel to any line connecting simultaneous events in the garage frame. Note where the back of the car enters the garage: call this event A. Note where the front of the car exits the garage: call this event B. Which event has a greater value of t as measured in the garage frame, A or B? So which event happened first? Does that mean the car was entirely in the garage at some time?

E. Make a space-time diagram to scale in your notebook in the frame of reference of the garage, similar to the one in the simulation. x is plotted on the horizontal axis, and t is plotted on the vertical axis, as shown in the photo on the next page.

   Use a horizontal scale of 1 cm on the page = 50 m in real life. Use a vertical scale of 6 cm on the page = 1 μs of time. Place the origin at the bottom of the graph, and leave 10 cm of space to the right of the origin (corresponding to 500 m). A dashed line extending from the origin up and to the right at a 45° angle represents the worldline of beam of light traveling along the x-axis.

   The t' axis represents the position of the origin in the frame of reference of the car which is traveling at 0.7 c. It has a slope of 10/7 on this scale. The t' axis is parallel to the worldline for any object that is stationary in the car frame. The x' axis defines where t'=0, and is parallel to any line connecting simultaneous events in the car frame. The x' axis has a slope of 7/10 on this scale.



F. As was done in the applet, add and label lines that show the front and back of the car, and lines that show the front and back of the garage. Note where the back of the car enters the garage: label this event A. Note where the front of the car exits the garage: label this event B.

Add lines that pass through A and B and are parallel to the x' axis (with slopes of 7/10). Note where these lines pass the t' axis. In the car frame, events that lie along these lines are simultaneous. Which event has a greater value of t' as measured in the car frame, A or B? So which event happened first? Does that mean the car was entirely in the garage at some time?

Activity 4 (If You Have Time)

George and Helen are twins, born at the same time (a biological impossibility). George stays at home on Earth, which we assume is a good inertial reference frame. Helen is an astronaut who blasts off for a distant star, travels to the star at high speed, and then turns around and returns to Earth. After she lands on Earth she will be younger than George.

A. Draw a spacetime diagram for a reference frame stationary relative to George. Include George's worldline and Helen's worldline. What can you conclude about the relation between the length of the two worldlines and which twin ends up younger?
B. Draw a spacetime diagram for an inertial reference frame in which Helen is stationary during her trip from Earth to the distant star. Include George's worldline and Helen's worldline. What can you conclude about the relation between the length of the two worldlines and which twin ends up younger? Is this consistent with your conclusion from Part A?
C. Do you think this is a general result: that when analysed from *any* inertial reference frame Helen's worldline is longer than George's, and she will end up younger than George?

The Relativity Module Student Guide was written by David M. Harrison, Dept. of Physics, Univ. of Toronto in January 2009. Activity 15 was written by Jason Harlow in July 2009. Last update by Jason Harlow Mar. 21, 2014