PHY151H1F – Practical 2: Relativity

Don't forget:

- Write your **Pod Number** clearly on the front of the booklet, and fill in "1" for the *book no*. – If you require more than one booklet during today's practical, ask your TA and fill out the book number and *total number of books used* on each booklet.
- List the **Names** of all participants on the cover of the booklet. You do not need to write your student numbers. Note if any participants arrived late or left early.
- Fill in the **Date** on the front page of the booklet.

Today's Textbook Reference to review before Practical:
"Principles & Practice of Physics" 1st Edition by Eric Mazur ©2015
Chapter 6 Principle of Relativity and Chapter 14 Special Relativity, Sections 14.1-14.3, 14.5, 14.6.

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

Mechanics Module 2, Activity 5

Assume that the speed of sound is exactly 344 m/s relative to the air. Assume that the speed of light is exactly 3×10^8 m/s relative to the observer.

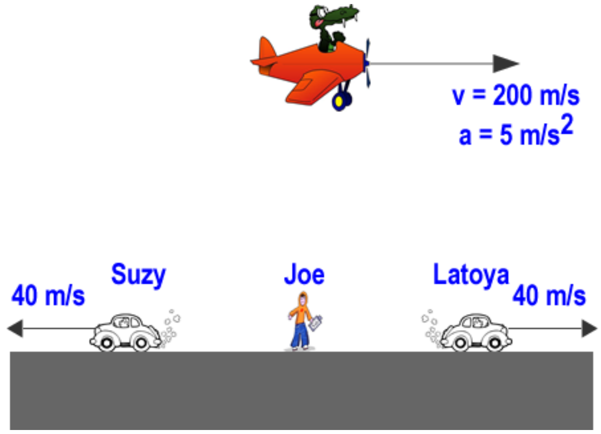
A. If you are pursuing a sound wave at a speed of 99% of the speed of sound, what is the speed of the sound wave relative to you?
B. If you are moving through the air at 99% of the speed of sound in the opposite direction to the velocity of a sound wave, what is the speed of the sound wave relative to you?
C. If you are pursuing a light wave at 99% of the speed of *sound*, what is the speed of the light wave relative to you?
D. If you are pursuing a light wave at 99% of the speed of *light*, what is the speed of the light wave relative to you?

Mechanics Module 2, Activity 7

You can swim at a speed *v* relative to the water. You are swimming across a river which flows at a speed *V* relative to the shore. The river is straight and has a constant width.

A. If you wish to swim directly across the river, in what direction should you swim relative to the water in the river?
B. If you wish to get across the river as quickly as possible and don't care where you land on the opposite bank, in what direction should you swim relative to the water?

Mechanics Module 2, Activity 8



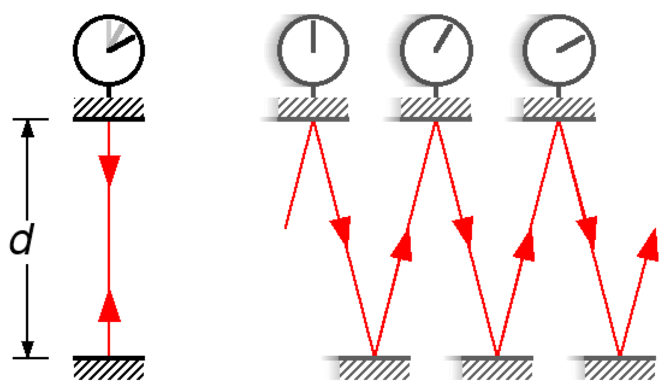
Joe is stationary on the ground, and sees an airplane moving to the right with a speed of 200 m/s and accelerating at 5 m/s^2. Suzy is driving to the left at a constant 40 m/s and Latoya is driving to the right at a constant 40 m/s.

A. Rank in order, from the largest to the smallest, the airplane's *speed* according to Suzy, Joe, and Latoya at the moment shown in the figure. Explain.
B. Rank in order, from the largest to the smallest, the magnitude of the airplane's *acceleration* according to Suzy, Joe, and Latoya. Explain.

Special Relativity Module, 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 pages 355-356 of Mazur "Principles" book, 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 14.6 from Mazur: $\gamma = \dfrac{1}{\sqrt{1-v^2/c^2}}$. 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.

Special Relativity Module, Activity 3

Assume Toronto and Montreal are exactly 500 km apart in the Earth frame of reference. Assume that Kingston is exactly half way between Toronto and Montreal. They are all, of course, stationary relative to each other and the Earth. Ignore any effects due to the Earth's rotation on its axis. Ignore any effects due to the Earth's gravitational field. Assume the surface of the Earth is flat. Assume that the speed of light in the air is exactly equal to *c*.

Note that if any object is moving relative to you, its length along the direction of motion is $L = L_0\sqrt{1-v^2/c^2}$, where L_0 is the "rest-length" of the object. For everyday speeds, L is almost exactly equal to L_0, which is why we don't normally notice length-contraction. However, for speeds approaching the speed of light, $L < L_0$, and as the speed of an object approaches *c*, its length approaches zero!

A powerful searchlight is in Toronto, pointed towards Montreal. A second searchlight is in Montreal, pointed towards Toronto. Initially the two searchlights are turned off. Assume that both searchlights are visible from each other and from any point between Toronto and Montreal.

A. You are in a very fast bullet-train traveling from Toronto to Montreal at 0.8 c relative to the Earth. [This is a thought-experiment; if your train was actually moving this fast in real-life you could get from Toronto to Montreal in 2 milliseconds!] For you, what is the distance between

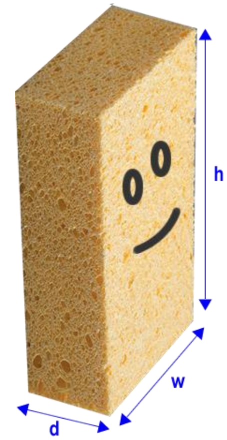
Toronto and Montreal? For you what is the distance between Toronto and Kingston? [Note that in your own personal reference frame, you and the train are stationary, and it is the earth and all the cities on it that are moving at 0.8 c.]

B. The two searchlights in Toronto and Montreal are quickly turned on and off, both emitting quick flashes of light. **For you, on the train, the two flashes were emitted simultaneously.** Imagine you were just leaving Toronto when the searchlight in Toronto is turned on. You see the flash from the searchlight in Toronto instantaneously. Sketch the positions of the two flashes of light a very brief moment after they are emitted, indicating their speeds and the distance between them for you. How long should it take before you see the flash from Montreal? Be sure to clearly indicate how you arrived at your answer.
C. Another member of your Team took a slightly earlier train, and is currently traveling from Toronto to Montreal at 0.8 c. What is your Teammate's speed relative to you? Imagine your Teammate is traveling through Kingston when the flashes are emitted. Are the two flashes of light emitted simultaneously for your Teammate? Will he/she see the flashes simultaneously? If yes, how long after the flashes will he/she see them? If no, which flash will he/she see first and by how much? Add your Teammate to your sketch from Part B.
D. Your Professor (Sabine Stanley) lives in a house in Kingston, and is stationary relative to Kingston and the Earth. What is your Professor's speed relative to you? Will your Professor see the flashes from the two searchlights of Part B simultaneously? If no, which flash will she see first and by how much as measured by you? Explain. You may find it useful to add your Professor to the sketch from Parts B and C.
E. Imagine your Professor has an iPhone that will begin playing music when it receives a flash of light, and quits when it receives a second flash of light. In the Professor's reference frame, stationary relative to the Earth, does the iPhone begin playing music, and if so, for how long? In the rocket's reference frame, moving at 0.8 c, does the iPhone begin playing music, and if so, for how long? Is there any music?

If You Have Time: Mechanics Module 2, Activity 6

We model Sponge Bob Square Pants as a simple sponge of width *w*, height *h*, and depth *d*. He is 6 cm wide, 12 cm high, and 4 cm deep.

It is raining. The raindrops are falling straight down at a constant speed of 9 m/s. Each raindrop has a diameter of 5 mm, and we can treat them as perfect spheres. There are 8000 raindrops per cubic meter.



A. Bob is stationary in the rainstorm. How many raindrops per second fall on the top of his head, i.e. the upper horizontal surface of the sponge? Do any raindrops strike his vertical surfaces?
B. Bob is now walking forward at 1.3 m/s. What is the velocity of the raindrops relative to Bob?
C. Now how many raindrops per second fall on the top of his head?
D. Bob is initially 50 m from a shelter. How many raindrops fall on the top of his head until he reaches the shelter?
E. How many raindrops per second strike his “face” i.e. the vertical surface of width *w* and height *h*?
F. How many raindrops strike his face before he reaches the shelter?
G. Instead of walking, Bob runs for the shelter at 2.5 m/s. What is the velocity of the raindrops relative to Bob?
H. Now how many raindrops per second strike his “face” i.e. the vertical surface of width *w* and height *h*?
I. Now how many raindrops strike his face before he reaches the shelter?
J. If it is raining, is it worth running for shelter instead of walking?

The Mechanics Module 2 Guide was written in July 2007 by David M. Harrison, Dept. of Physics, Univ. of Toronto. Some parts are based on Priscilla W. Laws et al, **Workshop Physics Activity Guide** (John Wiley, 2004) Unit 5. The Special 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 Sep. 22, 2014