

Introduction to Special Relativity

PHYS 1301

Introduction

This lab introduces you to special relativity and, hopefully, gives you some intuitive understanding of its basic phenomena of “time dilation,” “Lorentz length contraction” and the special way speeds of fast moving objects add together. You will use a computer simulation during this session that lets you examine the behavior of simple objects (rods and clocks) when they travel at very large speeds along a straight line. All of the motion takes place along a straight highway and objects are allowed only to go forward or in reverse. You will control the speed and direction of motion of these objects, subject only to the constraints that the physics of special theory relativity imposes on them, first discovered by Einstein in 1905. In case you were wondering, the “special” in special relativity stands for “special case” and signifies that the theory of special relativity is a simplification of the more complete theory of “General Relativity.”

There are two main points to special relativity. First, imagine you and your lab partner are each in special rooms that contain all of your lab equipment. You look out the window of your room and see that your partner’s room is moving at some constant speed with respect to you. She is either approaching or receding at a constant rate. After waving, you both close your respective windows so that neither of you can directly observe the outside world and perform all sorts of physics experiments. Based on the results of your experiments, you would not be able to tell whether you were moving or your lab partner was moving. That is, the results of the experiments are the same whether you are moving or standing still. Similarly, your lab partner would not be able to tell if she were the moving one or the one at rest. This is the meaning of relativity.

The second important point is that both you and your lab partner would measure the speed of light travelling through empty space as having the very **same** value, even though your lab partner is travelling with some speed with respect to you. Although not obvious, this implies that the speed of light is somehow the part of the essential fabric of the physical universe. The speed of light through empty space is typically given the symbol c and has been carefully measured to have the value $c = 3 \times 10^8$ m/sec. The velocity of any object as a fraction of c is called ‘beta’.

Our simulation program automatically calculates all the numbers we require to develop an understanding of how time, length and speed are affected by SR. You will need, however, to learn a small number of commands to manipulate the rods and clocks to send them on their way in the appropriate direction and with the appropriate speed.

Finally, it is important to understand that you will perform a simulation of special relativistic effects. The simulation assumes that special relativity is correct and lets you explore the consequences of this assumption.

Procedure

1. Locate the folder Spacetime. The instructor will help you if you can't locate it. Double click (left mouse button) on the icon Spacetime.

2. _____
 The Spacetime program was written for Mac computers, where you would click and drag. But you will be using it on a different system (Linux) which means you can't use the mouse but will need to use F keys to perform commands. You will need to play a bit with the keys so that you learn a few commands to get something interesting to happen. The instructor will help you. What is most relevant to you for today's lab is to know how to create rods and clocks. Also, you will need to know where to look to find things like the speed and position of things and the time reading in different reference frames. Play with the program to see what the various commands do! Try not to click the mouse on the black Spacetime window (it disables it).

3. Now we are ready to start by learning how lengths are modified by special relativistic effects. For reference, there is always a clock/rod A at position $x=0$, velocity $\beta = 0$, and length 1. Create 4 rods at position $x = 0$. Give them values of $\beta = 0.6, 0.8, 0.95$ and 0.99 (remember, this is fraction of light speed). We will refer to these rods as B, C, D, E.

4. **Question 1.** Look in the Object Table under menu Windows. How does the value of ' γ ' change with ' β '? γ is the factor by which time is dilated or length is contracted. You can also Select Objects individually to see information about them. The instructor will explain the significance of γ to you if you are unsure.

5. Fill in data table 1 below. Using a ruler for axes, on a piece of graph paper, plot γ v. β . Label the axes and mark a few values. The vertical axis should be γ and the horizontal axis should be β . Draw a smooth curve through the 5 points. (You can use the clock at the origin even though it isn't a rod because we are only interested right now in the relationship between β and γ .)

Question 2. What do you notice about the apparent length of the rods?

6. Fill in data table 2 below, with Rod A defined with length 1. Can you make a general statement about the lengths of objects when they are moving with respect to you?

7. This exercise illustrates that if we take into account special relativity, "moving objects" appear shorter than they do when their length is measured in their own rest frame. These objects are "Lorentz contracted" by an amount that depends on their speed, although only at speeds that are a significant fraction of the speed of light (large β) does the contraction become large enough to be noticeable.

8. We now examine how time behaves when we take into account special relativistic effects. Delete the rods you have previously created and start with a fresh screen. Create 4 clocks (not clock strings) B, C, D and E at $x=0$ and give them the beta values of 0.6 (clock B), 0.8 (C), 0.95 (D) and 0.99 (E). You should see a total of 5 clocks on your screen, including the one (clock A) that is at rest ($\beta=0$). Make certain you are in the reference frame of clock A (that's the one at rest) and advance the time on clock A until it reads 10.0 seconds. Examine the times on all the other clocks. Fill in data table 3. You may find it useful to use the so-called Object Table found under menu Windows.
9. **Question 3.** What clock seems to be running (i.e. ticking) the slowest? Write down a general statement about the rate at which a clock runs and the speed of the clock.
10. Jump to the reference frame of clock E (Select E, Transform F4, and Jump). Advance clock E until it reads 10.0 seconds. Examine the Object Table.
Question 4. Is there any difference between the Object Table now and when you were in reference frame A? Why do you think that is?
11. This exercise illustrates the phenomenon that according to special relativity, "moving clocks run slow." Actually, moving clocks do not run any slower than they should, unless they are mechanically defective. It is just that what we mean by a "second of time" depends on the reference frame we are in.
12. We will now examine how speeds add when we take into account special relativistic effects. Delete all the clocks you made previously. We will create 5 clocks in succession, each with a speed $0.5c$ faster than the clock before it. All of the clocks will be at $x=0$. Clock A with $\beta=0$ is already there. Next, create clock B with $\beta=0.5$ also at $x=0$. Jump to reference frame B and create a new clock C at $x=0$ that has a speed $0.5c$ with respect to clock B. This means that somebody standing on clock C will see clock B move away from them (the other way) with a speed equal to half of light speed. Continue by "transforming" (jumping) to clock C and creating a clock D that has speed $0.5c$ with respect to C. Finally, transform to D and create a clock E with $\beta=0.5$ with respect to D.
13. Transform to reference frame E (the frame of the last clock you made).
14. **Question 5.** What is the velocity of clock D as seen from clock E?
(Express your answer as $\beta= \dots$)
15. **Question 6.** What is the speed of clock A as seen by somebody standing on clock E?
16. Transform back to frame A, the original frame.
Question 7. What is the speed of clock E as seen from A?
Question 8. What is the speed of clock B as seen from A?
Question 9. What is the similarity between the object tables when you are standing on clock E and when you are standing on clock A?
Try to be as specific as possible about what this similarity is.

Did you notice that even though you kept creating clocks that were moving with half the speed of light compared to the previous one, no clock ever moved faster than light speed?

Data Table 1. γ vs. β

Object	β	γ
Clock A		
Rod B		
Rod C		
Rod D		
Rod E		

Data Table 2. length contraction. _____

Object	X-position	β	Length	$\left(\frac{\text{Rod A length}}{\text{Rod length}} \right)$	γ
Rod A	0.00	0.00	1.00	1.00	1.00
Rod _____					
Rod _____					
Rod _____					
Rod _____					

Data Table 3. Time dilation

Object	X position	β	Clock time (sec)	$\frac{\text{clock A time}}{\text{clock time}}$	γ
Clock A		0.00	10.0		1.00
Clock _____					
Clock _____					
Clock _____					
Clock _____					