Physics 209: Assignment #1

These questions should give you some preliminary experience in looking at things from different frames of reference, and in using the principle of relativity. The concept of frames of reference and the principle of relativity itself are set forth in Chapter 1 of the lecture notes, *The Principle of Relativity*. How the velocity of an object changes as you change frames of reference (when all speeds are small compared with the speed of light) is discussed in Chapter 2, *Nonrelativistic Addition of Velocities*.

Although you will often need to use numbers, formulae, and equations to answer these questions, your answers should always in the form of ordinary English prose: coherent paragraphs made up of complete sentences. There is no need to avoid numbers, formulae, or equations, but they should be integrated into the text, just as I have done in Chapter 2 of the lecture notes, and will be doing in subsequent Chapters. You can take the lecture notes to serve as a model. Ideally your responses to the question I ask should work well as supplementary lecture notes.

If you ever handed in homework in math or science courses consisting of isolated calculations, unadorned by complete grammatical sentences, this might seem irritatingly fussy of me. It is not. These questions are more subtle than you may think and subsequent questions will be even more subtle. If you do not state your answers with verbal care and precision, you can easily fool yourself into thinking you understand things when you do not. Darwin put it nicely:[1]

> *I have as much difficulty as ever in expressing myself clearly and concisely; and this difficulty has caused me a very great loss of time; but it has had the compensating advantage of forcing me to think long and intently about every sentence, and thus I have been often led to see errors in reasoning and in my own observations or those of others.*

If this is not sufficiently inspirational, please note that papers that do not incorporate their analytical arguments into ordinary English prose will receive grades of U, even if their pages are adorned with correct and beautiful figures and formulae.

[1] *The Autobiography of Charles Darwin: 1809-1882*, p. 136, W.W. Norton, New York, 1969.

Part I.

An object is going to move past you along a straight horizontal track at a fixed speed, too fast for you to run along with it.[2] You are provided only with a long tape measure and two clocks. Briefly (a page should suffice) describe how you and an assistant, who can be stationed somewhere else along the track, can plan a strategy to determine what that speed is, using only these instruments — e.g. no radar, no vehicles with speedometers, no radio communication between the two of you. After the object goes by you and your assistant can get together and compare any information you have each collected.

It should be clear from your answer why *two* clocks are needed. What tests should you and your assistant perform on the two clocks to make sure that the speed you get makes sense?[3]

Nothing profound is called for here. I just want you to state as explicitly as you can exactly what you have to do to measure the speed of something, why two clocks are needed, etc.

Part II.

If Alice throws a ball as hard as she can, the ball moves away from her at a speed of 50 feet per second (fps). Standing inside a train that moves down a long straight track, Alice throws a ball as hard as she can.

In each of the four cases that follow explain as clearly as you can the reasoning that led you to the answer. Avoid empty "explanations" that do nothing more than restate the arithmetic you did to get the answer. There are two different kinds of explanation you can give. An explanation of type (a) would be preferable; better still would be to give both explanations:

(a) You can make explicit use of the fact that the speed of a ball is the distance the ball goes divided by the time it took it to cover that distance, and then figure out where the ball gets on the train and where the train gets on the track in a given period of time.[4]

---

[2] Throughout this assignment assume that all speeds are so small compared with the speed of light (very nearly a billion feet per second) that "relativistic effects" are far too tiny to worry about. If this remark makes no sense, ignore it. The point of it will emerge in a week or two.

[3] To see what this last question is getting at, suppose you took the two clocks out of a drawer where they had been lying long enough to run down. Ask yourself all the things you would have to do with them to be sure you were getting a valid measurement.

[4] Because all speeds are tiny compared with the speed of light you can take "given period of time to be unproblematic." (If this remark makes no sense, ignore it.)

(b) You can apply the "nonrelativistic velocity addition law" (Equation (2.1) of the lecture notes). In this case you must take great great care to get the signs of all the velocities right.)

(1) How fast and in what direction does Bob, who sits on a bench next to the tracks say the ball is moving if the train is going 75 fps and Alice has thrown toward the front of the train?

(2) How fast and in what direction does Bob say the ball moves if the train goes 75 fps and Alice has thrown toward the rear.

(3) What does Bob say if the train goes 40 fps and Alice throws toward the rear?

(4) What does Bob say if the train is going 50 fps and Alice throws toward the rear?

Part III.

If you have completed Part II then you have acquired the ability to contemplate a single moving object (the ball) in more than one frame of reference (the train frame or the track frame). Visualizing a given state of affairs in more than one frame of reference is a surprisingly powerful tool for finding the answer to questions whose answers are not at all obvious. The trick is to discover a new frame of reference in which the question reduces to a question whose answer *is* obvious, take the known answer in the new frame and then translate it back into the language of the old frame. This is the approach you should take here. An example is given in the analysis of the collision problem in the lecture notes *The Principle of Relativity*. The questions that follow can be answered by the same kind of reasoning.[5]

A. Two identical sticky balls, depicted in the figure that follows as (X) and (Y), have the property that if they are fired directly at one another with equal speeds, then they stick together upon collision and the resulting compound ball (XY) is stationary. If a sticky ball is fired at 10 fps directly at another identical sticky ball that is stationary and the two stick together, with what speed and in what direction will the compound ball move after the collision?

This question can be answered using nothing but the principle of relativity. You should do this by finding a frame of reference in which the unknown situation turns into the one you know about, answering the question in the new frame, and then translating your answer back to the frame in which the original question was posed. You should keep

[5] Those of you who have had some previous exposure to physics should note that the questions that follow are *not* to be answered by invoking such arcane notions as "force", "mass", "energy", or "momentum". *None of these technical terms should appear in your essay.*

in mind as the reader of your essay a fellow student in this course who was not as clever as you were, and simply failed to see how to answer the question.[6] Feel free to include in your text well labeled figures like the ones given below, if this helps to make your essay clearer.

	Before Collision	**After Collision**
Case 1 (known):	$(X) \rightarrow \ \leftarrow (Y)$	(XY)
Case 2 (unknown):	$(X) \rightarrow \quad (Y)$	?

B. Consider two elastic balls. One of them (B) is very big and the other (s) is very small. If the big ball is stationary and the small ball is fired directly at it, the small ball simply bounces back in the direction it came from with the same speed, and the big ball stays at rest. Use the principle of relativity (in the same manner as you used it in Part A) to deduce what happens when the small ball is stationary and the big ball is fired directly at it with a speed of 15 fps.

	Before Collision	**After Collision**
Case 1 (known):	$(s) \rightarrow \quad (B)$	$\leftarrow (s) \quad (B)$
Case 2 (unknown):	$(s) \quad \leftarrow (B)$	?

[6] If you yourself are in that unfortunate position, reread pages 7 and 8 of Chapter 1. If you are still stuck, write a few paragraphs describing the attempts you made to get the answer. Often if you try to say carefully enough what you were trying to do it becomes clear what you should have done.