1.1: A Need for a New Model

In the world of Newtonian Mechanics, it was assumed that measured lengths and time intervals were **observer-independent**. A meter stick, for example, is one meter long for everybody, and something that lasts for one second will last one second for everybody. The discovery that the speed of light is the same regardless of the observer's state of motion, however, changed that. Let's use some thought experiments to see why.

Exercise 1.1.1

Diana is inside of a train car with glass walls that moves with a constant velocity relative to the ground. She puts a laser on the ground pointing straight up at a mirror on the ceiling. The laser sends a short pulse that reflects off the mirror on the ceiling and back to the floor.

Phaedra is outside watching the train car pass by.

What path does the light pulse follow from Diana's point of view? What path does the light pulse follow from Phaedra's point of view? Given that everyone observes the speed of light to be the same, do Diana and Phaedra agree on how long the light pulse takes to return to the floor? If not, is one of them wrong?

Answer

Diana sees the light pulse travel straight up and then straight back down. Phaedra sees the light travel a diagonal path up and then back down, which is a longer distance.

Since both Diana and Phaedra observe the same speed of light, the time it takes for the light pulse to reach the ground as measured by Phaedra must be greater than that measured by Diana.

Is one of them wrong? As long as neither Diana nor Phaedra made a measurement mistake, there is no way to judge whose conclusion is valid. We simply have to accept that the two observers disagree on how much time passed.

Exercise 1.1.2

Lionel is on a skateboard that moves with a constant velocity relative to the ground. He has installed a laser at each end of the skateboard; when he presses a button, the lasers simultaneously fire pulses toward the center of the skateboard. At the center of the skateboard, there is a device that will set off fireworks if the two lasers hit it at the same time.

Amit watches Lionel from the ground.

If Lionel presses the button, will the fireworks go off? Consider the situation as viewed by both Lionel and Amit.

Answer

You may think at first that Lionel would observe a faster speed of light for the light traveling from the front of the skateboard than the back. That would be true for everything except for light. In this case, both light pulses travel toward Lionel at the same speed, which means they would reach the center of the skateboard at the same time. We can conclude that the fireworks will go off.

Things look different from Amit's point of view. The light pulses travel in opposite directions at the same speed, but while they are doing that the skateboard moves toward one of them. It seems, then, that the device in the center of the skateboard will not register the two pulses as arriving simultaneously, and the fireworks will not go off.

So which is it, do the fireworks go off or not? Given that Lionel and Amit can meet up afterward and check to see if the fireworks went off, there must be an objective reality. We must conclude either that one of them was wrong or that one of our conclusions was incorrect because we made a faulty assumption. In the previous exercise, we discussed how as long as neither Diana nor Phaedra made a measurement mistake, we can't say that one of them is wrong. The same reasoning applies here, which means that we must have made a faulty assumption.

It turns out that there is a hidden assumption we made, which is that what is simultaneous for Lionel (the firing of the lasers) is also simultaneous for Amit. If Amit saw the laser pulse from the front of the skateboard fire *after* the one from the back, then it is plausible that the two could arrive at the center at the same time.

? Exercise 1.1.3

A fish flies past you. Devise a method for measuring the length of the fish *while it is moving*. If someone who is moving along with the fish watches you apply this method, will they agree with the result you come up with? Why or why not?

Answer

The key to making the measurement is to mark the locations of the ends of the fish at the same time, and then use a ruler to measure the distance between those locations. If you don't mark them at the same time, the fish will have moved in the meantime and the measurement will be wrong.

In the previous exercise, however, we found that two events that are simultaneous for one observer may not be simultaneous for another observer. So an observer moving along with the fish will not agree with your measurement of the length.

The previous thought experiments demonstrate that measurements of time intervals, lengths, and simultaneity are all relative. This is the main idea of the **Special Theory of Relativity**, where the word *special* here refers to the fact that the theory applies to constant velocity motion, which is a special case type of motion.

Definition: The Special Theory of Relativity

The Special Theory of Relativity relates time intervals and lengths measured by different observers in the special case of constant velocity motion. For brevity, I will often refer to it as simply Special Relativity.

Note

Some people without a solid understanding of Special Relativity think that it implies that *everything* is relative, but that is not the case. In fact, it is the exist of quantities that are *not* relative that allows us to make predictions.