26-1 Observers

Although Special Relativity is often thought of as applying to fast-moving objects, we can see some effects of Special Relativity at low speeds, too. Let's explore this, and get comfortable with the idea of how the same situation looks to different observers.

EXPLORATION 26.1 – Who needs magnetism?

Consider one observer, Jack, who is watching two pairs of charges, as shown in Figure 26.1. The charges are identical, and we will assume that the charges within each pair repel one another, but that the pairs of charges are far enough apart that one pair of charges does not influence the other pair. One pair of charges is initially at rest, with respect to Jack, while each charge in the other pair of charges has an initial velocity v directed to the right. There is also a second observer, Jill, who has a constant velocity v directed to the right with respect to Jack.

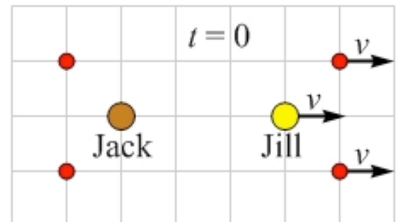

Figure 26.1: The situation at $t = 0$ involving two pair of charges, as seen from Jack's frame of reference. According to Jack, the charges in the left pair are released from rest, while each charge in the right pair have an initial velocity directed right. There is also a second observer, Jill, who is moving right at constant velocity with respect to Jack.

Step 1 – ***Jack observes that the charges that were initially at rest move apart more quickly than the charges that were initially moving with respect to him. Figure 26.2 illustrates what Jack sees after a time T has passed. Using principles of electricity and magnetism, explain Jack's observations.***

First, consider the electrostatic interaction between the charges. The charges are identical, so by Coulomb's law, Jack expects the charges that were initially at rest to repel and accelerate away from one another. Jack expects the charges that were initially moving to repel each other, too, but he also expects those charges to interact magnetically, because they are like two parallel currents. When Jack reviews Chapter 19, he recalls that two parallel currents attract one another. When Jack does the calculations, he finds that the repulsive electrostatic force is larger than the attractive magnetic force, so he expects the charges on the right to move apart, but not as fast as the charges on the left. This is exactly what he observes.

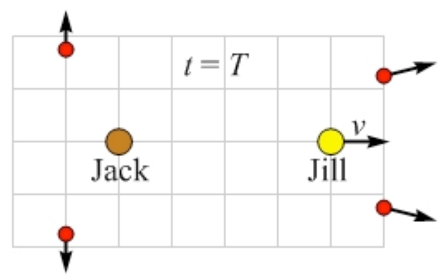

Figure 26.2: The situation at $t = T$, where the charges on the left have separated more than the charges on the right, according to Jack.

Step 2 – ***Now draw two more pictures, one showing the initial situation from Jill's frame of reference, and the other showing the situation at a time T after the charges are released, again from Jill's frame of reference. Once again, use principles of physics to explain what Jill observes.***

What Jill observes is a mirror image of what Jack sees. Initially, at $t' = 0$, where t' denotes times measured by Jill, Jill sees the charges on the right at rest and the charges on the left, and Jack, moving to the left with velocity v.

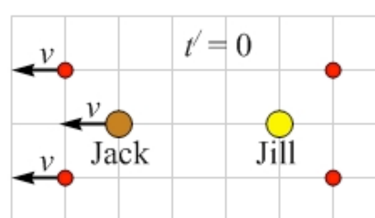

Figure 26.3: The initial situation from Jill's reference frame.

At a time $t' = T$, according to Jill, Jill's view of the situation is again a mirror image of what Jack sees. As shown in Figure 26.4, Jill sees the charges on the right, which were initially at rest with respect to her, move apart more quickly than the charges on the left, because of the attractive magnetic force associated with the charges on the left.

Step 3 – *What, if anything, about the previous steps does not make sense to you?* Possibly, it all makes sense. However, you may be bothered by the fact that the two observers disagree on which charges move apart more quickly. Jack observes that the charges on the left move apart more quickly, while Jill observes that the charges on the right move apart more quickly. For most people, that does not make sense – shouldn't everyone agree on what is happening? This is a key part of relativity – observers in different reference frames observe different things.

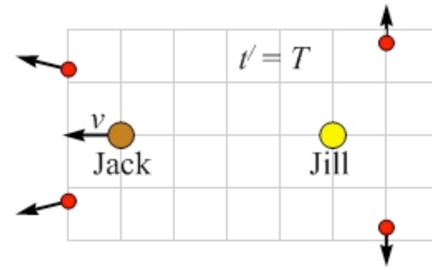

Figure 26.4: The situation at $t' = T$, where the charges on the right have separated more than the charges on the left, according to Jill.

Step 4 – *Come up with an alternate explanation for what Jack and Jill observe. Instead of using magnetism to explain why the initially moving charges move apart more slowly, come up with an alternate explanation involving how time works in different reference frames.* This is an unfair question, because we're asking you to be Einstein here. However, the relativistic argument is that there is no need to resort to magnetism. The charges simply repel one another, and move apart. However, observers observe time passing differently (moving more slowly) in reference frames that are moving with respect to that observer.

In this situation, the charges on the left are in Jack's reference frame, while the charges on left are in Jill's reference frame, which is moving at a constant velocity v to the right with respect to Jack's reference frame. Thus, Jack observes Jill's wristwatch running slowly, and everything in her reference frame (such as the charges on the right) to be moving in slow motion. Jill, on the other hand, observes her wristwatch to be running just fine, and the charges on the right to move apart as she expects, but she observes Jack's wristwatch to be running slowly, and the left-hand charges, which are in Jack's reference frame, to be moving in slow motion.

Key ideas: We investigated a variety of ideas in this Exploration. First, magnetism is a relativistic effect, which means that you can change the strength of a magnetic interaction simply by changing the relative velocity between you and a set of interacting charges. Second, observers in different reference frames can disagree on what happens in certain cases. However, any constant-velocity reference frame is just as good as any other reference frame in terms of making observations. In the situation above, for instance, Jill's reference frame is no better or worse than Jack's. Third, time works in a manner that is quite different from what we're used to based on our past experience, in that it runs at different rates in different reference frames (we will explore this in more detail in the sections that follow). **Related End-of-Chapter Exercises: 1, 2.**

Postulates of special relativity: Relativity is based on two simple ideas.

1. The speed of light in vacuum is the same for all observers.
2. There is no preferred reference frame. The laws of physics apply equally in all reference frames.

One implication of these postulates is that nothing can travel faster than the speed of light in vacuum, which is $c = 3.00 \times 10^8$ m/s.

Essential Question 26.1: (a) How fast are you moving right now? (b) What is your speed associated with being on the Earth while the Earth is spinning around its axis? (c) What is your speed associated with being on Earth while the Earth is orbiting the Sun?