3.4: Relativity of Simultaneity

"same time"? ordinarily true for only one frame!

The Principle of Relativity directly predicts effects that initially seem strange — even weird. Strange or not, weird or not; logical argument demonstrates them and experiment verifies them. One effect has to do with simultaneity: Let two events occur separated in space along the direction of relative motion between laboratory and rocket frames. These two events, even if simultaneous as measured by one observer, cannot be simultaneous as measured by both observers.

Train Paradox: Two lightning bolts strike simultaneously for ground observer

Einstein demonstrated the relativity of simultaneity with his famous Train Paradox. (When Einstein developed the theory of special relativity, the train was the fastest common carrier.) Lightning strikes the front and back ends of a rapidly moving train, leaving char marks on the train and on the track and emitting flashes of light that travel forward and backward along the train (Figure 3.4.1). An observer standing on the ground halfway between the two char marks on the track receives the two light flashes at the same time. He therefore concludes that the two lightning bolts struck the track at the same time — with respect to him they fell simultaneously.[1]

A second observer rides in the middle of the train. From the viewpoint of the observer on the ground, the train observer moves toward the flash coming from the front of the train and moves away from the flash coming from the rear. Therefore the train observer receives the flash from the front of the train first.

Two lightning bolts do not strike simultaneously for train observer

This is just what the train observer finds: The flash from the front of the train arrives at her position first, the flash from the rear of the train arrives later. But she can verify that she stands equidistant from the front and rear of the train, where she sees char marks left by the lightning. Moreover, using the Principle of Relativity, she knows that the speed of light has the same value in her train frame as for the ground observer (Section 3.3 and Box 3-2), and is the same for light traveling in both directions in her frame. Therefore the arrival of the flash first from the front of the train leads her to conclude that the lightning fell first on the front end of the train. For her the lightning bolts did not fall simultaneously.[2] (To allow the train observer to make only measurements with respect to the train, forcing her to ignore Earth, let the train be a cylinder without windows — in other words a spaceship!)

Did the two lightning bolts strike the front and the back of the train simultaneously? Or did they strike at different times? Decide!

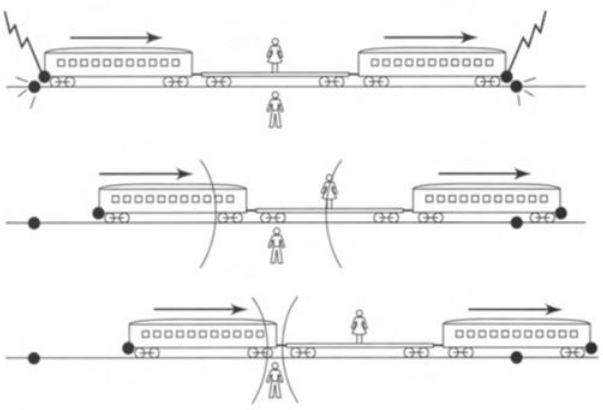

Figure 3.4.1: **Einstein's Train Paradox illustrating the relativity of simultaneity. Top:** Lightning strikes the front and hack ends of a moving train, leaving char marks on both track and train. Each emitted flash spreads out in all directions. **Center:** Observer riding in the middle of the train concludes that the two strokes are not simultaneous. Her argument: "(I) I am equidistant from the front and hack char marks on the train. (2) Light has the standard speed in my frame, and equal speed in both directions. (3) The flash arrived from the front of the train first. Therefore, (4) the flash must have left the front of the train first; the front lightning holt fell before the rear lightning bolt fell. I conclude that the lightning strokes were not simultaneous." **Bottom:** Observer standing by the tracks halfway between the char marks on the tracks concludes that the strokes were simultaneous, since the flashes from the strokes reach him at the same time.

Strange as it seems, there is no unique answer to this question. For the situation described above, the two events are simultaneous as measured in the Earth frame; they are not simultaneous as measured in the train frame. We say that the simultaneity of events is, in general, *relative*, different for different frames.[3] Only in the special case of two or more events that occur at the same point (or in a plane perpendicular to the line of relative motion at that point—see Section 3.6) does simultaneity in the laboratory frame mean

simultaneity in the rocket frame. When the events occur at different locations along the direction of relative motion, they cannot be simultaneous in both frames. This conclusion is called the **relativity of simultaneity**.

The relativity of simultaneity is a difficult concept to understand. Almost without exception, every puzzle and apparent paradox used to "disprove" the theory of relativity hinges on some misconception about the relativity of simultaneity.
