9.0: Special Relativity Introduction

Although it is not possible to drive through a city at nearly the speed of light, the video you have just viewed shows a computer simulation of a relativistic trip through Tubingen, Germany (Credit: Ute Kraus and Marc Borchers). However, not all of the effects of travel near the speed of light have been shown in this video. For example, the video does not show changes in color due to the Doppler shifting of the light. In this chapter, you will be introduced to the effects that are most commonly measured when objects travel at extremely high, constant speeds: time dilation and length contraction. More exotic effects, such as the warping of the buildings shown in the video, can be explored through resources available at the Spacetime Emporium.

Since human forms of transportation, such as bicycles, automobiles, and trains, do not really travel at the extremely high speeds needed to experience relativistic effects, how do we know these effects really exist? We can observe what happens when much smaller, rapidly moving particles known as cosmic rays move through Earth's atmosphere.

Cosmic rays are energetic particles (such as protons, atomic nuclei, etc.) that originate from outer space. When high-energy cosmic rays strike Earth's upper atmosphere, they interact strongly with the atoms there. Their energy is converted into a shower of particles that then cascade down into the lower atmosphere. Most of these particles are converted to energy at high altitudes, many kilometers above Earth's surface. However, some of the particles do make it to the surface, where they can be detected. Some of the particles produced are muons, particles that are similar to but more massive than electrons.

Muons are unstable and have a 50% probability of decaying after only about 2 millionths of a second. In that time, given that the muons are traveling near the speed of light, they should be able to travel about 650 meters before they decay. Of course, only half the muons decay in this time. The other half have a 50% probability of decaying after an additional 2 microseconds (and an additional 650 m), and so on. So, we expect that a small number of the muons will travel much farther than 650 m. However, the muons are produced at altitudes of 10 km or more. Given their half-life and the altitude at which they are produced, fewer than 20 out of every million muons should reach sea level. Nonetheless, many, many more than that are detected. How can this be?

The answer to this question is the subject of this chapter. It has to do with the unexpected character exhibited by space and time when objects travel close to the speed of light.