Brief Introduction to Special Relativity

The 20th century saw essentially two major triumphs in physics: the discovery of quantum mechanics and the discovery of relativity. In these notes, I'll discuss relativity. (I'll get to quantum mechanics in a few weeks.)

By the beginning of the 1900s, there were two main branches of physics: Newtonian mechanics, which describes the motion of everyday objects, and Maxwell's theory of electromagnetism, which describes how electricity and magnetism work. Both mechanics and electromagnetism were enormously successful in explaining the world up to this point. However, the two theories were fundamentally at odds with one another; they simply contradicted each other. They couldn't both be right; at most *one* of them could be right: Newton or Maxwell. In the end, it was Maxwell's theory which proved to be correct, although Newton's wasn't *entirely* wrong... it was just *incomplete*. As Einstein figured out, Newton's theory is actually a correct description of Nature only if one considers objects moving at slow speeds (in particular, much smaller than the speed of light). So, what Einstein did was to *fix* Newton's mechanics to make it agree with Maxwell's theory of electromagnetism. And this is the (original) program of Einstein's theory of relativity: to fix Newtonian mechanics.

The theory of relativity can be broken down into two parts: the special theory of relativity, and the general theory of relativity. The special theory deals with a world in which gravity is very weak, and the general theory deals with a world where gravitational effects are considerable. It turns out that special relativity is a *a lot* easier to deal with than general relativity, so I'll talk about special relativity first. (And I only talked about special relativity in the first class.) We just have to make the assumption that we're not somewhere where there's a lot of gravity.

The special theory of relativity consists of merely two postulates (or “axioms” or “assumptions”):

1. The laws of physics are the same for “everyone.”
2. The speed of light is the same for “everyone.”

Now, let me be a bit more precise by what I mean by “everyone.” By “everyone,” I mean all **inertial observers**. So, what's an inertial observer? Well, first, an observer is just a person that makes some measurements, like the speed of an object or its length, etc. An *inertial* observer is an observer that doesn't *accelerate*, meaning that the observer's speed does not change. (Well, technically, I should say “velocity” instead of “speed,” but I want to keep things simple here.) So, an inertial observer makes measurements of things while either being at rest or while moving at a constant speed. (You've probably learned about Newton's law of inertia, which is where this term comes from. An object in motion will stay in motion and an object at rest will stay at rest unless acted upon by an outside force.)

The first postulate simply says that the same laws of physics work for all inertial observers. This is pretty easy to accept, right? Nature is fair!

The second postulate, however, is truly mysterious. To show you just how crazy it is, first imagine that you're sitting on a bench and you see a train pass by at a constant speed. (This makes both you and anybody sitting on a seat in the train inertial observers, since neither of you are accelerating. Special relativity applies *only* to inertial observers.) Furthermore, suppose you see somebody walking on the train, in the direction that the train is traveling. Let's say you measure that the train is traveling at 40 mph and the person is traveling at 43 mph. (Remember, the person is traveling with the train, so, relative to you, the person is actually *walking* at 43 mph!) Now, somebody on the train will say that the train simply isn't moving. If he closes his eyes, then (assuming the train really isn't accelerating, so that it doesn't experience any bumps, for example) he will conclude that the train is at rest. Once he opens his eyes, and looks at the previous person walking on the train, he will conclude that the person is walking at 3 mph. And you could've easily guessed this: 43 mph – 40 mph = 3 mph.

This is relativity at its most basic. It's simply the relativity of speed: some observers measure one speed for an object, and other observers measure another speed. That's all relativity means.

Unfortunately, we run into a problem if we try to apply the "subtraction of speeds" rule, which we just used above to calculate 3 mph, to *light*. According to the second postulate, everyone will measure the *same* speed of light. Suppose you're sitting on your bench again, watching a train pass you by at 40 mph. If someone stands still on the moving train and turns on a flashlight, then, according to the second postulate, you will measure a certain speed for the light coming out of the flashlight. (It happens to be about 671,000,000 mph.) Now suppose the person who's operating the flashlight decides to measure the speed of the light coming out of it. Well, according to the second postulate, it will be the same speed that you measure! It will *not* be 671,000,000 mph – 40 mph. This goes completely against what we'd expect, but it's completely true. Numerous experiments have been conducted to test this postulate, and they've all confirmed it.

Indeed, Nature works in strange ways. I'll show you some more of its mysteries next class.

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