Special Relativity #1

These lecture notes contain hyperlinks, which appear in blue. So if you read them online, you can follow the links. If you're not seeing them, of if they don't work on your computer, please let me know.

Relativity before and after Einstein

Very roughly speaking ...

Before Einstein: Motion is relative. Time and space are absolute.
After Einstein: The speed of light is absolute. Time and space are relative.

Today we'll talk about relativity before Einstein (Galilean relativity). Then, for several weeks, we'll talk about what Einstein did (Special Relativity).

Galilean relativity

Galileo Galilei was born around the middle of the 16th century. He was one of the first people who practiced what we now call "physics," although I imagine that he probably thought of himself as a "natural philosopher." From his writings it was clear that he totally understood the relativity of motion, and so the fact that "motion is relative" is often referred to as "Galilean relativity." Galileo died the same year that Isaac Newton was born. By Newton's time everyone who studied such things was well aware of this kind of "relativity."

Inertial motion = constant velocity

Now, this does *not* mean that *all* motion is relative. What we are talking about here is what is called *inertial motion.* Inertial motion simply means motion with a constant velocity.

The term velocity includes both speed and direction. So if you are travelling one kilometer per hour east, this is a *different velocity* than if you were travelling one km/hour west. So, constant velocity also implies that you are traveling in a straight line. If you're going in a circle, for example, your velocity is changing at every moment (because your direction is changing).

Another way to define inertial or constant velocity is to say that it is *unaccelerated* motion. If a force is applied to an object, then the object accelerates, and – as long as the force is being applied – the motion is not constant.

So, before Einstein came along, "relativity" meant that:

Interial motion is relative to the reference frame of the observer.

What's a "reference frame?" Your reference frame is simply your point of view. How things look relative to you. So, for example, in your reference frame you are always standing still. Other things may or may not be moving.

This is, or course, assuming that you are not accelerating. If you're accelerating you can *feel* it. Picture that you're in a box out in space somewhere. There is no experiment you could do inside that box that would tell you whether or not you were "moving" (at a constant velocity). If you accelerate however, you can easily tell.

So, one of the main points about Galilean relativity and inertial motion is that *there is no possible experiment that can be performed inside a reference frame that can tell if the frame is "moving" or not.* Essentially, there is no "matter of fact" about whether a reference frame (or an object) is "moving" or "standing still." These terms really only have meaning *relative* to some other frame (or some other object).

But *acceleration* of a frame (or object) is very real, and is *not* relative.

Example of the usefullness of relativity of motion

(Note: This example is straight from chapter one of Mermin's book: It's about time.)

It would be nice to have a picture here. Maybe somebody will draw one and scan it in. In any event, here are some cryptic notes that will hopefully help recall what we had up on the board.

Scenario 1

Before: $---> \bullet\bullet <---$
After: $\bullet <-------> \bullet$ (Obvious?)

Scenario 2

Before: $---> \bullet\bullet$
After: (not so obvious?)

Conservation of momentum says: before the collision $p = mv$. After the collision you could have them both moving to the left at $\frac{1}{2}v$, or any number of other combinations as long as the total $p = mv$.

But conservation of (kinetic) energy says that before the collision $K = \frac{1}{2}mv^2$. So, after the collision we have to have *both* $mv_1 + mv_2 = mv$ and $\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 = \frac{1}{2}mv^2$.

The only simultaneous solution to both of these two equations (that makes sense physically) is: $v_2 = v$. The right moving mass stops, and the previously stationary mass moves right with the original velocity of the other mass.

Simpler solution using relativity

But we can find the solution in a much simpler way using Galilean relativity. Change your frame of reference so that you are looking at the problem from the point of view of an observer who is travelling to the left at $(1/2)v$. Now we have exactly Scenario 1 (except that the masses are travelling as $\pm(1/2)v$ instead of $\pm v$). Clearly, after the collision (in our new frame of reference) the masses are travelling apart at $(1/2)v$. Finally, go back to the original frame and we have the left-hand mass standing still and the right-hand mass travelling right with velocity v. There is no need to invoke 2 different conservation laws, or do any math other than one addition and one subtraction.

The situation at the the beginning of the 20th century

With the exception of gravity, you might argue that "most of physics" is ultimately explained by:

(1) Newton's 'laws of motion' and in particular the '2nd law'

$$F = ma$$

which is compatible with Galilean relativity, and

(2) Maxwell's Equations

$$\nabla \bullet \vec{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \bullet \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \times \vec{B} = \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t} + \mu_0 \vec{\mathbf{j}}$$

which predict the speed of light, but have no obvious frame of reference.

The Ether hypothesis attempts to establish a universal frame of reference for the propagation of EM waves, but has many philisophical and practical problems. The Michelson-Morley experiment in 1887 fails to find any difference in the speed of light, in what ought to be different reference frames.

This problem with the speed of light was, in retrospect, one of the two "great" unsolved problems of physics, around the turn of the 20th century.. The other one being the so called ultraviolet catastrophe.

Simplifying things a bit: the problems surrounding the speed of light led to Einstein's relativity and the ultraviolet catastrophe led to quantum mechanics.