Special Relativity - Introduction

Introduction
Albert Einstein graduated from college in 1900 with a focus on physics and math. He was unable to get a job at a university, and eventually settled for a job in the Swiss Patent Office in Bern. He enjoyed his job as he found it reasonably interesting and it also left him with time to think about physics. He continued to meet regularly with his college friends to discuss physics and philosophy. While he was not in an academic setting, he was in a thriving intellectual setting.

1905 - The Miracle Year
Einstein had a pretty good 1905. He finished his dissertation and received his PhD from the University of Zurich. He also published four papers, each of which was groundbreaking in its own right.

April	PhD dissertation accepted
June	Explanation of the photoelectric effect by arguing that light came in bundles (now called photons) and that the energy of a photon of light depended only on its frequency was $E = hf$. (This is the paper for which he would receive the 1921 Nobel prize in physics.)
July	Explanation of Brownian motion through statistical mechanics that was used as the first evidence for the existence of atoms.
September	Theory of Special Relativity.
November	Follow up to Special Relativity with derivation of $E=mc^2$ and the equivalence of mass and energy.

Inertial Reference Frames
In the beginning of the seventeenth century, Johannes Kepler and Galileo finally blew up the ancient assumption that the earth was at rest in the center of the solar system with the sun and planets traveled around the earth. Kepler discovered the mathematical laws that governed the orbits of the planets around the sun while Galileo disproved the large amount of scientific nonsense that went along with the geocentric model of the solar system. Going back to the ancient Greek scientists, the single biggest reason why the notion of the earth traveling around the sun was rejected was that people did not understand the idea of inertia. They (wrongly) felt that if the earth was moving around the sun, we would have to notice that motion.

After extensive experiments rolling balls down and then up ramps, Galileo came to the conclusion that if there were no frictional forces acting on an object, it would keep its state of motion forever. Galileo argued that the reason we can't feel the motion of the earth is because we have the same motion as the earth. He goes on to argue that there is no way to tell if one is moving with a constant velocity or is at rest - and uses demonstrations on ships on smooth water to illustrate his point. This comes to be known as the principle of relativity (motion is relative), and was further developed with Newton and his Three Laws of Motion.

A reference frame would be the coordinates that one is using as a reference to measure locations, velocities and times for an object. An *inertial reference frame* is simply one that is not accelerating, so there is no way to say if it is "really" at rest or is "really" moving with a constant velocity.

Maxwell's Equations & the Speed of Light
In 1865, James Clerk Maxwell proposed explaining electrical and magnetic interactions with the idea of an electromagnetic field. In this paper, he calculated how fast an electromagnetic wave would move through space and he found it to depend on two constants in nature and was about 3 $\times 10^8$ m/s. As this was about the speed of light, he concluded that light must be an electromagnetic wave.

Physicists had already concluded that light was a wave, and had thought this meant that space had to be filled with what was called the *luminiferous aether*, the medium through which light "waved."

Special Relativity - Introduction

Maxwell's discovery that the speed of light had to be a particular number then seemed to imply that there was a universal rest frame - that of the aether. This conflicted with the principle of relativity, and this really bothered Einstein, and is why he focused on light in his theory of special reltivity.

The Postulates of Special Relativity
Einstein's Theory of Special Relativity was really just two simple postulates that had far-reaching consequences:

1. The laws of physics are the same in all inertial reference frames.

2. The speed of light in a vacuum is the same in all inertial reference frames.

Postulate 1 was basically a restatement of what Galileo first argued in 1632. Postulate 2 was explicitly pointing out that Maxwell's equations were the same in all inertial reference frames, so that means every inertial reference frame has to measure the speed of light to be 3×10^8 m/s.

Unfortunately, insisting that everybody measure light to travel at the same speed means that we have to give up our notions of absolute space and time. The only way we all measure every ray of light to have the same speed is if space and time itself are relative. Different inertial reference frames measure space and time differently, and gives rise to the new terms *time dilation* and *length contraction*. It also turns out that mass and energy are not two separate things, but are really equivalent to each other, and we should really be talking about the conservation of mass-energy - not two individual conservation laws.

Ultimately, Einstein didn't have a "new" idea for his theory of special relativity. One could argue that "all he did" was to insist that the principle of relativity was true, even when taking into account electricity and magnetism. But he did strictly apply older physics concepts and just followed the logical outcomes, however odd those outcomes seemed. His genius in this case was his willingness to let the physics tell him what was true instead of assuming what had to be true.