

Relativity and E&M

- Thomas Young
 - Showed that light exhibited wave properties through his Double Slit experiment.
- Waves traditionally require a medium through which to travel, so what is waving in light waves?
- The Ether
 - Medium in which light waves propagate.
 - Proposed to permeate all of space.
- James Clerk Maxwell (1831 – 1879)
 - Light is caused by the oscillations of the electric and magnetic fields.
 - Unified electromagnetism with the propagation of light through the Ether.
- Testing the Ether
 - Since 1704, when Newton first proposed the ether, scientists had been trying to determine its properties.
 - Many proposed that it was “dragged” by heavy masses.
 - Others proposed an “ether wind” created because the ether was stable, and the earth moved through it. Michelson and Morley tested this theory.
- The Michelson-Morley Experiment
 - This experiment relied on the idea of a stationary ether.
 - This ether was said to be constant throughout the universe.
 - The experiment found no ether wind.
- Hendrik Antoon Lorentz (1853 – 1928)
 - Lorentz assumed an immobile ether.
 - In his theory, everything that moved through the ether shrank in length.
 - This explained the failure of the Michelson-Morley experiment because the measuring apparatus itself would have been contracted.
 - Lorentz saw his theory as a mathematical construct to relate the ether, carrying the field, to the inertial system in which matter interacts with charge.
- Einstein
 - His conception of relativity began with basic thought experiments examining the velocity addition of light.
 - Einstein and Lorentz differed in the philosophy behind the science. Lorentz began with many ad hoc assumptions, but Einstein started from two basic postulates. Lorentz manipulated the concept of the ether to make his equations work; Einstein discarded it completely.
- Special Relativity Postulates
 - The laws of physics are the same in all inertial reference frames.
 - All inertial observers measure the speed of light in a vacuum to be c , independent of the motion of the light source.
- Consequences of Special Relativity
 - Time Dilation
 - Length Contraction
 - Relativity of Simultaneity
 - New conceptualization of velocity addition

- When combined with what we know about electric fields, special relativity gives us magnetism.
- Magnetism as a Relativistic Phenomenon
 - Evidence for the existence of a magnetic force comes from the transformation of a distinctly electric force in a moving system to a system at rest with respect to the moving system. In this rest system, a force must still exist if Einstein's postulates are correct. Therefore, we infer that a force acts in the rest system to produce the same particle motion as in the moving system. The result is that a distinctly non-electric force is responsible for the motion of the particle. This motion is the same in both systems ("One man's electric field is another man's magnetic field").
- Electrodynamics
 - The study of moving charge
- Field Transformations
 - Fields are *not* equal for different reference frames
 - If we know E and B in one frame, we can calculate E and B in another frame (given a velocity v)
 - Called a TRANSFORMATION
 - Analogous to Lorentz' transformation for *position* and *time*
- Mathematical Formulation
 - **Goal:** express the unknown quantities E_{bar} and B_{bar} in terms of known quantities E and B
- Creation of E and B Fields
 - Parallel-plate capacitor in 'fixed' frame, $S_0 \rightarrow$ Electric Field
 - View capacitor from moving reference frame S
 - Plates are *charged* and *moving* \rightarrow Electric Current \rightarrow Magnetic Field
- The Trick
 - The charge density CHANGES due to length contraction in S
- Fields in S_{bar}
 - Use the same calculations we used in S to obtain similar equations for S_{bar}
- Velocity Composition
 - Express v_{bar} in terms of v and v_0 (use Lorentz' transformation)
 - In relativity, *velocities do not add* as expected
- Summary
 - **Goal:** Combine 8 EQ's to write E_{bar} and B_{bar} in terms of E and B
 - Irrelevant Details (that we wish to remove from eq's):
 - Origins of fields \rightarrow (sigma terms)
 - Frames' relationships to 'fixed space' (S_0) \rightarrow (v_{bar} and v_0)
- Conclusion
 - There are several ways to interpret the final equations
 - E and B fields are 'mixed up'
 - There is no such thing as a magnetic field, only electric fields seen from different perspectives
 - Einstein: "If a ... charge is in motion in an electromagnetic field, the force acting upon it is equal to the electric force which is present at the *locality* of the charge...."
 - Special case: $v = 0 \rightarrow$ all terms cancel and we get $E = E$ and $B = B$