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Goal

To publish a paper bridging Maxwell's equations and special relativity.

Mathematical background

Over the course of the last few months during the pandemic, I've learned vector calculus, linear algebra, and all of electrostatics.

Research Questions

Each research question is followed by a brief abstract of my understanding of the relevant idea.

1. **Why does special relativity suggest there be a displacement current in Ampere's law?**
   To my understanding, the displacement current is the consequence of an inconsistency in Ampere's law: it was inapplicable to situations involving parallel plate capacitors, because there is an electric flux through an amperian loop, but not through a gaussian surface! The key question, then, is why do we need the changing flux term in Ampere's law? We can approach this question from the conservation of charge, special relativity, or the above loophole.
2. **How can we create a Lorentz transformation under which Maxwell's equations are invariant?**
   The four equations are not conserved under a galilean transformation (how can we show this?), thus the need for the lorentz transformations.

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3. **How can we use the Electromagnetic Tensor to describe em waves in Space-Time?**
   The em tensor was used by minkowski to formulate the 4d formulation of special relativity and the minkowski metric, but I don't know much else.
4. **What is the metric tensor and how does it define the minkowski metric?**
   I know about the metric tensor as a form of correction to the pythagorean theorem. It helps us generalize the idea of distance to higher dimensions or curved regions of space.
5. **Does Maxwell's displacement current produce a magnetic field?**
   I'm not sure because the displacement current isn't even an actual electric current, but instead a correction to Ampere's original law.
6. **How does the principle of equivalence apply to Maxwell's equations?**
   A reference frame that is accelerating and one in a gravitational field are indistinguishable. This principle can likely be applied to maxwell's equations in the context of electric charges that are accelerating or in some kind of gravitational field (charges around black holes?)
7. **Can we derive special relativity directly from Newton's laws of motion and Maxwell's equations?**
   The laws of celestial mechanics and electromagnetics pave the way to special relativity and I hope to derive them in my paper.
8. **Can we use special relativity to generalize coulomb's law to apply to a charge a) moving at a constant velocity and b) accelerating**
   Coulomb's law, to my understanding, applies only to charges at rest or moving at constant velocity.

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9. **Can Special Relativity be used to generalize the biot-savart law?**
   The biot-savart law gives the magnetic field contribution of an infinitesimally small piece of wire. I wager that to generalize the biot-savart law, we must examine charges accelerating through space-time and identifying the magnetic field that they produce.
10. **How can we derive time dilation, length contraction and relativistic mass from electrodynamics?**
    This is really the crux of special relativity and actually, the first of these effects are a natural consequence of maxwell's equations! Simply consider an infinite sheet of charge moving along an axis at some velocity v. We then consider the Lorentz force experienced by some test charge near the infinite sheet of charge which is also moving at some velocity. From this, we should be able to derive the effect of time dilation without considering special relativity. In fact, this could be the very reason why Feynman's derivation of Maxwell's equations was invariant not only under the Lorentz transformations, but also under the galilean transformations!

Areas of Research

My hope is to unify some of the core ideas i've learned over the course of this journey and ideas i'm excited to explore, including eigenvectors, the principle of equivalence, maxwell's equations, the lorentz and galilean transformations, and tensors. My paper should tackle a problem that unifies all these ideas.