Overview

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August 12, 2023

Modern Electromagnetic Theory

- The Maxwell Equations

$$\vec{\nabla} \times \vec{\mathbf{B}} - \mu_0 \epsilon_0 \frac{\partial \vec{\mathbf{E}}}{\partial t} = \mu_0 \vec{\mathbf{J}} \qquad \vec{\nabla} \cdot \vec{\mathbf{E}} = \frac{1}{\epsilon_0} \rho$$

$$\vec{\nabla} \times \vec{\mathbf{E}} + \frac{\partial \vec{\mathbf{B}}}{\partial t} = 0 \qquad \vec{\nabla} \cdot \vec{\mathbf{B}} = 0$$

- The Lorentz Force Law

$$\vec{\mathbf{F}} = q(\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}})$$

Four Fundamental Forces

Force	Classical	Quantum
Strong	none	QCD
Electromagnetic	Maxwell Equations	QED
Weak	none	Electroweak Theory
Gravity	General Relativity	?

Three Theories in One

- Electricity
- Magnetism
- Optics

Electromagnetic Theory is the first and most important example of a *field theory*.

- In physics, a *field* is a function of space or spacetime.
- In a field theory, x, y, and z join t as independent variables.
- Fluid Dynamics and Electromagnetic Theory are examples of field theories.
- The most important fields are the *scalar field* (in which a number depends on position in space) and the *vector field* (in which a vector depends on position in space).
- Modern elementary particle theory is a quantum field theory, but in this course we restrict our attention to classical field theories.

Why are physicists so in love with electromagnetic theory?

(Why do you have to take two courses about it?)

- It describes one of the four fundamental forces of nature.
- It unites electricity, magnetism, and light into a single theory.
- It serves as the model for modern field theories of elementary particles.
- It obeys the laws of special relativity, even though it was developed 40 years earlier.
- It's the earliest theory that is still part of our current best understanding of the universe.
- If you only learn one field theory, it should be this one.

Brief History of Electromagnetic Theory

Physicist	contribution	when?
?	made first lenses	2500 BCE
Thales	studied static electricity	600 BCE
Chinese	invented the compass	0
Ibn al-Haytham	wrote *Book of Optics*	1020
Gilbert	wrote *On the Magnet*	1600
Dufay	identified two types of electricity	1733
Franklin	introduced lightning rod	1752
Coulomb	published *Coulomb's law*	1785
Volta	invented the battery	1799
Young	described wave optics	1803
Oersted	found current deflects compass	1820
Faraday	discovered electromagnetic induction	1831
Maxwell	published the *Maxwell equations*	1865
Planck	quantized light	1900
Einstein	used photons for photoelectric effect	1905
Feynman	worked on quantum electrodynamics	1940s
Yee	FDTD method for Maxwell Equations	1966

Connections between Electricity and Magnetism

1. Electric current produces magnetic field (Oersted's discovery, 1820).
2. Changing magnetic field produces electric field (Faraday's discovery, 1831).
3. Changing electric field produces magnetic field (Maxwell's discovery, 1865).
4. Light is a wave of electric and magnetic fields (Maxwell's discovery, 1865).

Why computers in electromagnetic theory?

1. Most physical situations are not exactly solvable.
2. Why wouldn't we want to use modern tools?
3. Programming is a valuable skill in itself.
4. The language of the code can help you understand the theory.