

Sneak Peak at Electromagnetic Theory

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Two aspects to electromagnetic theory

- ▶ Aspect 1: Charge creates electric field.

$$E = k \frac{|Q|}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{|Q|}{r^2}$$

Sometimes I call this equation Coulomb's law, although that can be confusing since the force equation with two particles is the original Coulomb's law.

- ▶ Electric field points away from positive charge.
 - ▶ Electric field points toward negative charge.
- ▶ Aspect 2: Electric field exerts force on charge.

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}}$$

The Lorentz force law expresses aspect 2.

Modern Electromagnetic Theory

- ▶ The Maxwell Equations (Aspect 1)

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

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

- ▶ The Lorentz Force Law (Aspect 2)

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

The Maxwell Equations

$$\begin{aligned}\vec{\nabla} \times \vec{\mathbf{B}} - \mu_0 \epsilon_0 \frac{\partial \vec{\mathbf{E}}}{\partial t} &= \mu_0 \vec{\mathbf{J}} & \vec{\nabla} \cdot \vec{\mathbf{E}} &= \frac{1}{\epsilon_0} \rho \\ \vec{\nabla} \times \vec{\mathbf{E}} + \frac{\partial \vec{\mathbf{B}}}{\partial t} &= 0 & \vec{\nabla} \cdot \vec{\mathbf{B}} &= 0\end{aligned}$$

describe how the electric field $\vec{\mathbf{E}}$ and the magnetic field $\vec{\mathbf{B}}$ are created by electric charge and current and how these fields evolve in time.

Four Fundamental Forces

Force	Classical	Quantum
Strong	none	Quantum Chromodynamics
Electromagnetic	Maxwell Equations	Quantum Electrodynamics
Weak	none	Electroweak Theory
Gravity	General Relativity	?

Electromagnetic Theory is Three Theories in One

- ▶ Electricity
- ▶ Magnetism
- ▶ Optics (Light)

Why are physicists so in love with electromagnetic theory?

(Why do physics majors take two full 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 was easy (relatively speaking) to adapt it to work with quantum theory.
- ▶ It's the earliest theory that is still part of our current best understanding of the universe.

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 <i>Book of Optics</i>	1020
Gilbert	wrote <i>On the Magnet</i>	1600
Dufay	identified two types of electricity	1733
Franklin	introduced lightning rod	1752
Coulomb	published <i>Coulomb's law</i>	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 <i>Maxwell equations</i>	1865
Planck	quantized light	1900
Einstein	used photons for photoelectric effect	1905
Feynman	worked on quantum electrodynamics	1940s