Assignment

Readings (Articles):

(1) Robert S. Elliott, "The History of Electromagnetics as Hertz Would Have Known It," IEEE Trans. Microwave Theory Tech., vol. 36, no. 5, pp. 806–823, 1988 (Available on the course BLACKBOARD site)

(2) Jeff Biggins, "Sketches of a History of Classical Electromagnetism," URL: http://history.hyperjeff.net/electromagnetism.html

(3) Leonard Taylor, "Gallery of Electromagnetic Personalities: A Vignette History of Electromagnetics," URL: http://www.ee.umd.edu/~taylor/frame1.htm

[For information on L. Taylor, see http://www.enee.umd.edu/~taylor]

Readings (Books):

(1) D. Bodanis, *Electric Universe*, Crown: New York, NY, 2005

(2) R. S. Elliott, *Electromagnetics*, IEEE: Piscattaway, NJ, 1993.

(The books are available on reserve at the library.)

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Electromagnetic History: Why Study It?

- Helps fulfill ABET requirements
  - — Outcome (g): An ability to communicate effectively
  - — Outcome (i): A recognition of the need for, and the ability to engage in lifelong learning
  - — But why does ABET care?
    ...their industrial advisory board told them they should care
  - — Okay, so why should industry or government care?
- Engineering jobs don't just involve engineering!
  - — Communication skills are critical in making things happen
  - — Technology is already changing and engineers must keep abreast
- ***Fields are hard to understand!***

  Thinking about where these ideas came from is useful…

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10.2

Einstein's theory of general relativity was essentially built to show that the field concept --- rather than action at a distance --- should be used for gravity as well as electromagnetism. While the field concept is difficult, it has completely triumphed. It is important to understand it.

Early Work (Before the 19-th Century)

Electricity and magnetism were thought to be unrelated phenomena!

- Electricity
  - — Before 1700: Static electricity was known without understanding
  - — Stephen Gray discovered that electricity could be conducted (1729)
  - — Franklin proposes two types of electricity (1747)
  - — Coulomb demonstrates Coulomb's law (1785)

    Coulomb's law is consistent with action at a distance and analogous to gravitational interactions!

Franklin, Priestley, Coulomb

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10.3

The development of reliable methods for generating and conducting electricity was a key advance. The early methods rubbed glass tubes to generate the electricity and metal wires and/or hemp cords to conduct the electricity to other objects (like ivory balls).

Franklin played an important role in the demonstration of Coulomb's law. He discovered that an object placed inside an electrified object experienced no force, which is only consistent with a 1/r^2 behavior. He communicated this information to Priestley who began doing experiments. Other experimentalists jumped into the picture, culminating in Coulomb's work.

Early Work (Before the 19-th Century)

Electricity and magnetism were thought to be unrelated phenomena!

- Magnetism
  - — Before 1200: Lodestones are known from ancient times
    Compasses are known to the Chinese before 300
    and in Europe by 1200
  - — Peregrinus introduces the two poles of a magnet (1269)
  - — Gilbert shows that Earth can be considered a magnet (1600)
  - — Mitchell proposes that the two poles exert opposite forces (1750)

No quantitative theory up to 1800!

Gilbert

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10.4

Lodestones are materials that attract iron. The Chinese, who discovered compasses also discovered how to make lodestones by heating iron red-hot and then cooling iron rods in a north-south orientation.

The quantitative theory of magnetostatics developed more slowly because charges ALWAYS come in pairs.

Early 19-th Century

Theoretical Advances

- Laplace introduces a potential field whose derivative yields the gravitational force (1777) [***First introduction of the field concept***]
- Poisson extends this idea to electrical forces (1811) and introduces Poisson's equation (1813)
- Gauss introduces Gauss's theorem and Gauss's equation (1813)
- Poisson shows that the field concept can be extended to magnetic systems through use of a "magnetic potential" (1824)

Laplace, Poisson, Gauss

Although the field concept was useful, it was viewed as just that --- a useful tool for calculations. The notion that the fields had any sort of independent reality was scoffed at.

It is FIELD DYNAMICS and DELAYED action at a distance that really make the field concept absolutely critical. Because of the TIME DELAY --- the delayed reaction of a charge in one location to the motion of a charge in another location [DELAY = DISTANC/(SPEED OF LIGHT)] --- there is a close relationship between EM Theory and Einstein's theory of relativity.

Early 19-th Century

Engineering advances

— Volta invents the first chemical battery (1800)
— Davy characterizes the conductivity of many metals (1821)
— Ohm discovers Ohm's law (1827)
— Kirchhoff discovers Kirchhoff's laws (1845)

The importance of the development of reliable, controllable current sources cannot be exaggerated!

Volta, Davy, Ohm, Kirchhoff

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10.6

Early 19-th Century

Magnetostatics

- Ampere, Biot, and Savart demonstrate forces between currents (1820)
- Ampere formulates Ampere's law (1825)
- Biot formulates the Biot-Savart law (1826)

This work was inspired by Oersted's work showing that a changing current deflects a compass needle

Ampere, Biot

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10.7

The different aspects of electromagnetism developed in parallel

Early 19-th Century

Electrodynamics

- Oersted shows that a changing current deflects a compass needle; speculates that a changing electric field produces a magnetic field (1820)
- Faraday shows that a changing magnetic field produces an electric field, which in turn produces a remote magnetic field… (1831)
- Henry makes the same discovery as Faraday, ***but does not publish*** (1830)
- In a series of experiments, Faraday develops the electrical generator and the electrical motor (1831–1851) [as do Henry and others]

Oersted, Faraday, Henry

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10.8

To publish or not to publish… Sometimes when working for a company, it is useful to keep results hidden. In my career, I have often been told by someone in industry that they "already did" something that I have published. That does not bother me in the least! Part of my role is to make knowledge available to the world. As a colleague of mine at NRL put it, "if you don't publish it, you might as well not have done it."

Maxwell's Equations

Lines of force; field equations; electromagnetic radiation

— Faraday develops the line of force concept over many years; publishes (1852)

— Maxwell develops the line of force concept mathematically (1855)

— Maxwell modifies Ampere's law to include displacement current (1861), ***leading to the first full formulation of Maxwell's equations***

— Maxwell predicts the existence of electromagnetic radiation; speculates that light is electromagnetic radiation (1865)

Maxwell

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10.9

Great scientists like Airy criticized the notion of lines of force, stating that he could "hardly imagine any one who knows the agreement between observation and calculation based on action at a distance to hesitate between this simple and precise action on the one hand and anything so vague and varying as lines of force on the other." It was very important to have a quantitative mathematical formulation, which is what Maxwell did. …But he went well beyond that!

Maxwell's motivation for speculating that light was electromagnetic radiation was that he estimated the propagation velocity of electromagnetic radiation as 193,088 miles/sec (note the large number of significant figures). Fizeau had found experimentally that the velocity of light is 195,647 miles/sec. [Maxwell's result is wrong in the third figure; I am not sure about Fizeau's; the speed of light in the vacuum is 186,282 miles/sec.

Electromagnetic Waves

Creation and detection of radio waves

- — Hertz demonstrates transmission of electromagnetic waves (1888)
- — Marconi demonstrates and later commercializes the first practical radio wave transmitter (1895); wins 1909 Nobel prize

I should mention: ***Fourier invents the Fourier transform (1807)***

Hertz, Marconi, Fourier

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10.10

Hertz died tragically of blood poisoning at age 37, just a few years after his great discovery --- precluding any chance that he would commercialize it.

Fourier did his work in the context of studying heat flow, but, of course, all the scientists working on electromagnetics were aware of it, and in fact Biot and Poisson both had priority battles with Fourier over some of his work. Clearly, Fourier’s work had an enormous impact --- and continues to have an enormous impact --- on the development of not only electromagnetics but on all of electrical and computer engineering. It is the basis for most modern signal processing, which is why it is taught in CMPE 323. All aspects of science are ultimately connected and one must keep an eye on what is going on outside of one’s own field.

National Electronics Museum*

WEB site: http://www.hem-usa.org

Location: 1745 West Nursery Road, Linthicum, MD 21090

Phone: 410-765-0230; Hours: M–F, 9–3; Sa 10–2; Su closed

Fundamentals Gallery:

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* Formerly the Historical Electronics Museum

10.11

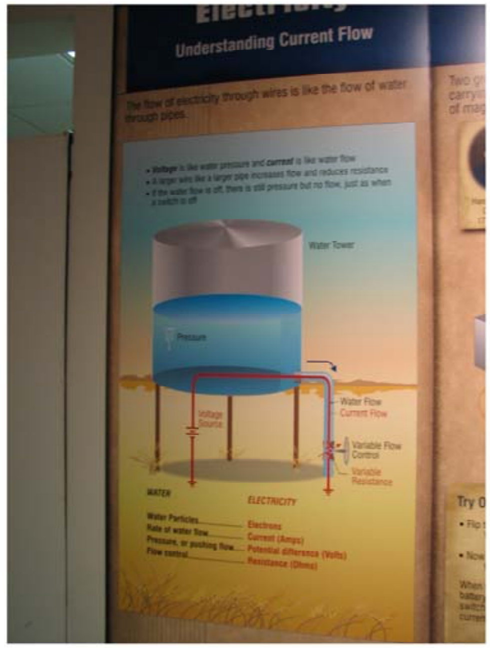
I will be asking students to visit the National Electronics Museum, study the five panels and the five experiments shown here (two on panel 4) and write a four page essay summarizing what these experiments show and answering some specific questions.

National Electronics Museum

Panel 1: Current Flow

How does current flow resemble water flow? How does it differ?

Hint: A water pipe is not surrounded by an electrical field.



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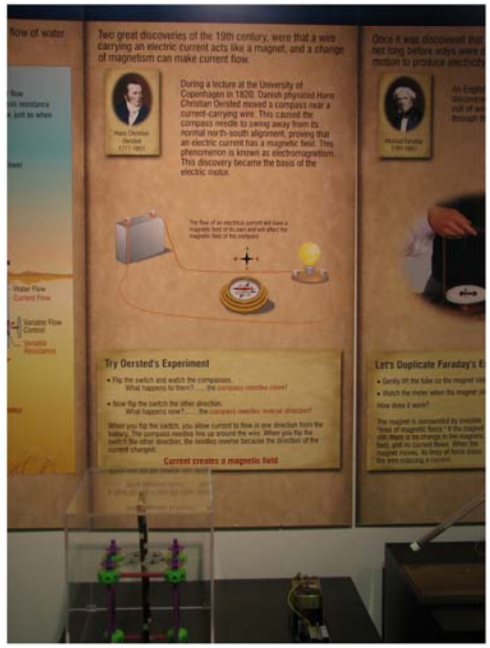
10.12

National Electronics Museum

Panel 2: Oersted's Expt

Describe the setup

Where are the fields? What is the relation to Maxwell's equations?



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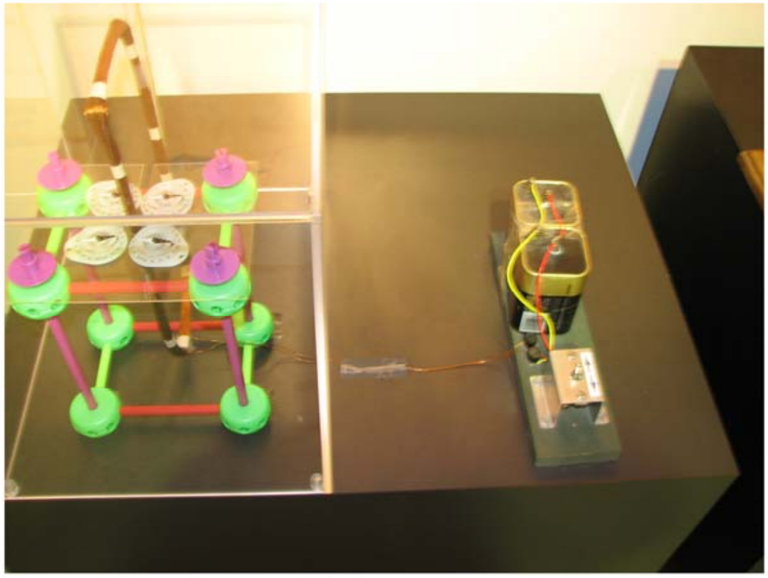
National Electronics Museum

Panel 2: Oersted's Experiment—Apparatus



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10.14

National Electronics Museum

Panel 3: Faraday's Expt

Describe the setup. How does it work? Which of Faraday's many experiments is this one?

Where are the fields? What is the relation to Maxwell's equations?

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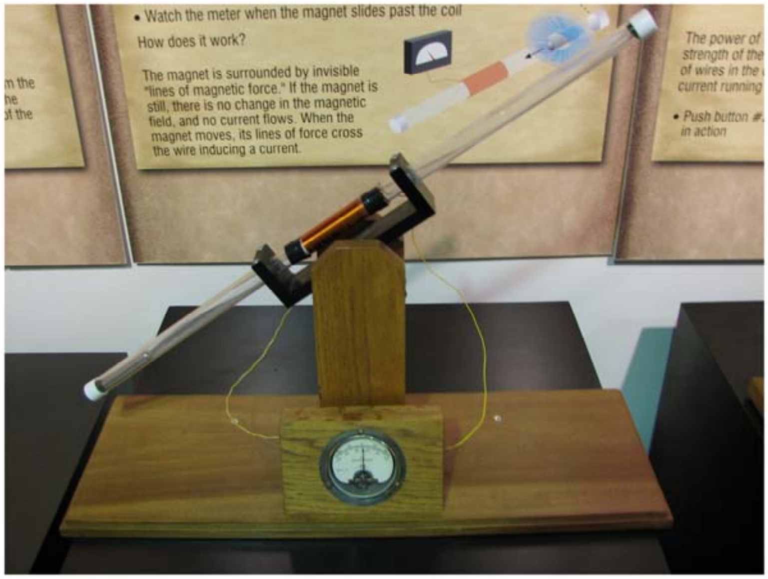
10.15

National Electronics Museum

Panel 3: Faraday's Experiment—Apparatus



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10.16

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Panel 4: Motor

There are two experiments here. Describe the setup for both. How do they relate to each other?

Where are the fields? What is the relation to Maxwell's equations?

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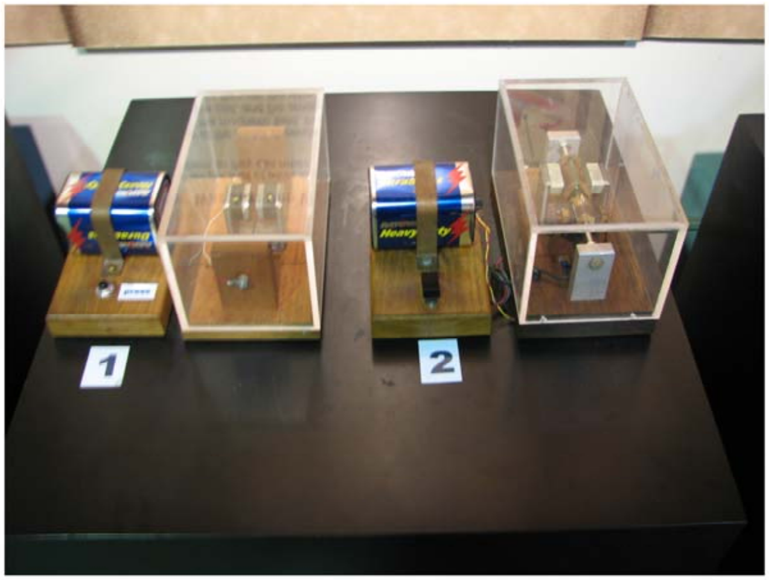
10.17

National Electronics Museum

Panel 4: Motor Apparatus—(1) single wire; (2) many wires



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10.18

National Electronics Museum

Panel 5: Generator

How is a generator related to a motor?

Where are the fields? What is the relation to Maxwell's equations?

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National Electronics Museum

Panel 5: Generator Apparatus

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10.20

Assignment

Writing:

- Visit the National Electronics Museum. Do the experiments and write a four-page essay in which you analyze each of the panels, answering the questions on slides 12, 13, 15, 17, and 19.

- The analysis should show that you understand the role that fields play in in each of these experiments and the relationship of each of these experiments to Maxwell's equations.

- Everything counts: Grammar, good organization, spelling, etc.

BUT

I will give the highest grades for a thoughtful and complete analysis.

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10.21