Electromagnetism and Light

Monday – Properties of waves (sound and light) – interference, diffraction [Hewitt 12]
Tuesday – Light waves, diffraction, refraction, Snell's Law.
[Hewitt 13, 14]
Wednesday – Lenses, polarization
[Hewitt 14]
Thursday – Magnetic fields, forces and motors [Hewitt 11]
Friday – Magnetic induction, generators [Hewitt 11]
THURSDAY

Fields of Magnets
How loops of wire are like magnets.
Magnetic force on a charge
Magnetic force on a current
Magnetic field of a wire
Magnetic field of a loop.
How motors work.
Magnetism and Electromagnetic Induction

“He who controls magnetism controls the universe.”

—Dick Tracy
Electricity and Magnetism

Electricity from the Greek *elektrum* (amber). The ancient Greeks were rubbing rods.

Magnetism from the Greek region of *Magnesia* where natural magnets were found.

Originally considered separate, now known to be tightly unified into “electromagnetism”
Electricity and Magnetism

Static Electricity – Forces & fields of non-moving charges. Voltage is potential energy per unit charge.

Currents and Circuits (Electrodynamics) – Practical electric circuits and the physics of how currents happen and what resistance means. [Last Week]

Static Magnetism – When currents in wires are constant, they create constant magnetic fields which exert force on moving charges (or currents) [Today]

Induction and electromagnetism – When currents change, they cause changing magnetic fields AND electric fields. [Tomorrow]
<table>
<thead>
<tr>
<th>Electricity</th>
<th>Magnetism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive charges emit electric fields, neg. charges absorb field lines.</td>
<td>North poles emit field lines, south poles absorb them.</td>
</tr>
<tr>
<td>Charges feel electric</td>
<td>Only moving charges or currents Feel magnetic fields</td>
</tr>
<tr>
<td>Fields whether the charges are moving or not.</td>
<td></td>
</tr>
<tr>
<td>$\vec{F} = q \vec{E}$</td>
<td>$\vec{F} = q \vec{v} \times \vec{B}$</td>
</tr>
</tbody>
</table>
B-Field lines are visible if decorated with iron filings

The top and bottom Pictures are:

[A] Two North poles and Two South Poles
[B] Two South Poles and Two North Poles
[C] A north-south pair And Two North Poles
[D] A north-south pair And either two North or Two south poles
Investigating current loops

A current loop hung by a thread aligns itself with the magnetic field pointing north.

The north pole of a permanent magnet repels the side of a current loop from which the magnetic field is emerging.
Whether it's a current loop or a permanent magnet, the magnetic field emerges from the north pole.

The north pole is the end from which the field emerges.
Where do magnetic fields come from?
(more than one “correct” answer)
Magnetic fields come from moving charges. If you have lots of moving charges, you have a current. So … magnetic fields come from currents.
But … magnetic fields also come from magnets!!
What can you conclude about magnets?
[A] Magnets are just different
[B] Magnets are made of magnetic materials, they don't need currents.
[C] Magnets contain currents
[D] Nothing makes sense, where is the battery in a magnet … how can there be a current w/ no voltage source?
[E] C and D.
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Building complex from simple

The simplest magnetic field makes circles around a wire.

The following set of slides shows you how you get something that looks like a “magnet” by vector addition of circular fields.

It also compares what we learned about electric fields last week to magnetic fields.
E-Field Around A Positive Charge
Electric Currents and Magnetic Fields

Connection between electricity and magnetism

- Magnetic field forms a pattern of concentric circles around a current-carrying wire
- When current reverses direction, the direction of the field lines reverse
Electric Currents and Magnetic Fields

Need a large current (50 amps) to get compasses to line up around a single wire.

If make lots of loops of wire can do it with small currents. You will build a “galvanometer” so you can show this to your class.
Magnetism and Electromagnetic Induction

E-Field Around positive and negative charge

R. SONNENFELD

As of: 08-Jul-2013
Resultant E-Field Around positive and negative charge
Vector Sum of B-Field Around Two Wires
B-Field Around A Wire Loop

R. SONNENFELD
What do I need to know?

Magnetic field around a straight wire is circular.

A loop of wire acts like a magnet with north pole given by right hand rule.

A “solenoid” acts like a bar magnet with north pole given by RH rule.

Given a magnetic field, what is the force on a current or on a moving charge?
Magnetic field is measured in “Tesla” (T).
Forces are at right angles to fields. Forces are velocity dependent.

\[
\vec{F} = q \, \vec{v} \times \vec{B}
\]

\[
F = q \, v \, B \, \sin(\theta)
\]
Find the magnitude of the magnetic force on a proton moving at \( v = 2.5 \times 10^5 \text{ m/s} \) Perpendicular, at 30 degrees, parallel to a \( B = 0.5 \text{ Tesla} \) magnetic field.

\[
\mathbf{F} = q \mathbf{v} \times \mathbf{B}
\]

\[
F = q v B \sin(\theta)
\]
The right-hand rules!

You can get by with two.

1) For magnetic field around a current.
2) For cross-products and everything else!
Let's do the force on an electron beam

Electrons move to the right and you point the north pole of a magnet at them (into the page).

The beam moves down! \[ \vec{F} = q \vec{v} \times \vec{B} \]
Magnetic Permeability \[ \rightarrow \quad \mu_0 = 4 \pi \times 10^{-7} \]

Electric Permeability \[ \rightarrow \quad \epsilon_0 = 8.86 \times 10^{-12} \]
Ampere's Law $\implies \int \vec{B} \cdot \text{d} \vec{r} = \mu_0 I_{\text{encircled}}$

Magnetic force $\implies \vec{F} = q \vec{v} \times \vec{B}$
on a charge

Magnetic force $\implies \vec{F} = nA L q \vec{v}_d \times \vec{B}$
on a current

$\vec{F} = I \vec{L} \times \vec{B}$

Time for the T-shirt!
Magnetic field of a wire encircles the current.

For infinitely long wire --> \[ B = \frac{\mu_0 I}{2 \pi d} \]
26.36 In standard household wiring, parallel wires about 1 cm apart carry currents of about 15 A. What is the magnetic field at 1 cm? What is the magnitude of the force per Unit length between the wires?

\[
B = \frac{\mu_0 I}{2\pi d}
\]

\[
\vec{F} = I \vec{L} \times \vec{B}
\]

\[
F = \frac{\mu_0 L}{2\pi d} I^2
\]
Two infinite parallel wires carry the same current. Like currents attract, opposite currents repel.

\[
B = \frac{\mu_0 I}{2\pi d} \\
F = \frac{\mu_0 L}{2\pi d} I^2 \\
\vec{F} = I \vec{L} \times \vec{B}
\]
Wire A having 10 Amps runs current parallel to wire B carrying 20 Amps. Which wire feels the greater attractive force?

A. A
B. B
C. Forces are the same
D. none of the above
Wire A having 10 Amps runs current parallel to wire B carrying 20 Amps. Which wire feels the greater attractive force?

A. A
B. B
C. Forces are the same ← Newton's third law is true even if you don't know ANYTHING about magnetism...
D. none of the above

\[ F = \frac{\mu_0 I_1 I_2}{2\pi d} \]
A weak and strong magnet repel each other. The greater repelling force is by the

A. stronger magnet.
B. weaker magnet.
C. both the same
D. none of the above
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*Explanation:*
Remember Newton’s third law!
Wave Barriers and Bow Waves

Wave barrier

- waves superimpose directly on top of one another producing a “wall”

example: bug swimming as fast as the wave it makes
Wave Barriers and Bow Waves

Supersonic
- aircraft flying faster than the speed of sound

Bow wave
- V-shape form of overlapping waves when object travels faster than wave speed
- an increase in speed will produce a narrower V-shape of overlapping waves.
Shock Waves and the Sonic Boom

Shock wave

- pattern of overlapping spheres that form a cone from objects traveling faster than the speed of sound
Sonic Boom

Shock wave consists of two cones

- a high-pressure cone generated at the bow of the supersonic aircraft
- a low-pressure cone that follows toward (or at) the tail of the aircraft

- it is not required that a moving source be noisy
- Why does the air condense?
Cerenkov Radiation and Tachyons

Particles traveling faster than light make a shock wave too!

Fast charged particles in the water bath of a nuclear reactor make a blue glow.

Tachyons would glow in a vacuum
Hewitt Problem 5
An electric field does 12 J of work on a charge of 0.0001 C as it moves from point A to point B. What is the voltage change between point A and point B?

How much work does this same field do on a charge of 0.0002 Coulombs?