May 4, 2011 Physics 122 Prof. E. F. Redish

- **Theme Music:** Earth, Wind, & Fire
  Magnetic
- **Cartoon:** Cantu & Castellanos
  Baldo

Outline

- Go over Q10
- Recap: Capacitors
  – Dielectrics
- Magnetism basics
- Magnetism and moving charge
- The magnetic field
- The magnetic force

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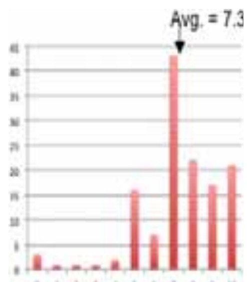
Quiz 10

	10.1		10.2.1	10.2.2		10.3
a	4%	s	4%	78%	a	5%
b	90%	d	93%	10%	b	0%
c	1%	b	1%	10%	c	40%
d	1%	p	1%	1%	d	22%
e	1%				e	26%
f	1%				f	39%
ab	3%				g	16%



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Capacitors: Foothold ideas

- Although local neutrality is almost always true, various configurations support local charge separations.
- Such separations are always associated with electric fields and hence with potential differences. $E\Delta x = -\Delta V$
- The ratio of the charge separation to the potential difference is the *capacitance*. $Q = C\Delta V$
- Charge separations take work to create and are associated with stored energy. $\Delta U = \frac{1}{2}Q\Delta V$

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Magnetism: A New Non-Touching Force

- What is your experience with magnets?
- Generate tentative foothold principles.

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Foothold ideas: Phenomenology of Magnets

- Certain objects (magnets) attract and repel other magnets depending on orientation.
- Magnets (all orientations) attract a certain class of other objects – iron, steel,… but not all metals (e.g., aluminum, copper,…).
- Objects that are attracted by magnets can be made into magnets by being stroked consistently in one direction with a magnet.
- Magnets can lose their magnetism by heating or hammering..
- Each part of a broken magnet still shows attraction and repulsion with other magnets.

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Is Magnetism a New Force?
Or is it a form of gravity or electricity?

- **It's not gravity**:
  Gravity only attracts.
  Magnets both attract and repel.
- **It's not electricity**:
  Freely pivoting magnets orient them with respect to N-S, charges do not.
  Magnets attract (stick to) different kinds of materials than charges do.

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Model of magnetism 1: Magnetic poles

- Magnets are made up of "magnetic charges" analogous to electric charges but different. We will call them "magnetic poles" – North and South to distinguish them from Positive and Negative.
- Magnetic materials have N and S just like they have + and -. When they are magnetized, the N's and S's separate.
- When magnetic materials are stroked with a magnet, the N's and S's are pulled apart.
- When a magnet is heated, the N's and S's jostle about and get mixed.

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Model of magnetism 2: Magnetic dipoles

- All matter contains small "magnetic dipoles" – little bar magnets that cannot be broken.
- When magnetic materials are magnetized, the little dipoles are aligned and the attractive/repulsive forces they exert on each other hold each other in place.
- When they are heated, the little magnets lose their alignment and go random.

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Is there "magnetic charge"?

- If you break a magnet in half, both parts are still full (N-S) magnets.
- You can do this all the way down to a single electron and it still holds true (and you can't break a single electron).
- Our "little dipoles" turn out to be electrons.

Basic Particles

- The fundamental particles making up matter (electrons and protons and neutrons) can be classified by how they behave in response to (and as sources of) gravity, electricity, and magnetism.

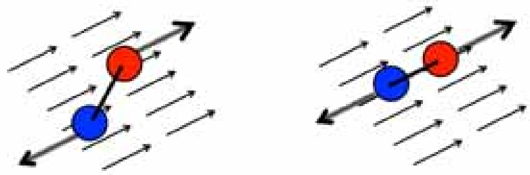
	Mass	*Charge*	*Magnetic Moment*
proton	1.67×10^{-27} kg	1.6×10^{-19} C	0.0015 Bohr magnetons
neutron	1.67×10^{-27} kg	0	0.0010 Bohr magnetons
electron	9.1×10^{-31} kg	-1.6×10^{-19} C	9.28 Bohr magnetons

Magnetic Fields?

- Magnetic forces – like gravitational and electrical ones – act at a distance.
- Is it useful to set up a third field – a "magnetic field" to describe this?
- As you know from lab, the force between dipoles is rather complex – but if we think about electric dipoles we can get an idea.

Electric dipole in an electric field

- A small electric dipole tends to align itself along the electric field (at its center).



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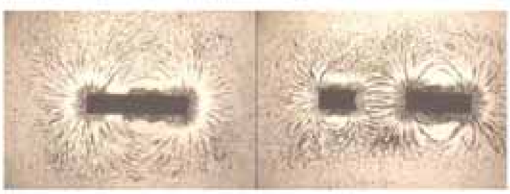
Iron filings become little magnetic dipoles in a magnetic field



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Defining a magnetic field

- Choose the direction of a magnetic field at a particular location in space to be given by the direction a small compass needle would point if placed at that location.
- Measure the magnitude by measuring the torque the field exerts on a compass needle attached to a spring.

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Moving Electric Charges Respond to Magnetic Fields

- We are saved from a very complicated definition of the magnetic field by a surprising and interesting connection between electricity and magnetism.
- Moving electric charges feel a force that is
  - proportional to their speed,
  - proportional to their charge
  - perpendicular to the direction of their velocity
  - perpendicular to the direction that a compass needle would point if placed in the charge's position.

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Definition of the Magnetic Field

- Choose the direction of a magnetic field at a particular location in space to be given by the direction a small compass needle would point if placed at that location.
- The magnitude is determined by passing a charge q through that location moving with a velocity v. The force it feels is (Lorentz force law)

$$\vec{F}_{B\to q} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

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The Cross Product

- We created the cross product when studying torque in order to produce a vector that was proportional to the magnitudes of two vectors and perpendicular to both of them.
- The cross product of two vectors
  - has a direction perpendicular to both vectors and given by a RH Rule
  - has a magnitude equal to the area of the parallelogram formed by the two vectors.

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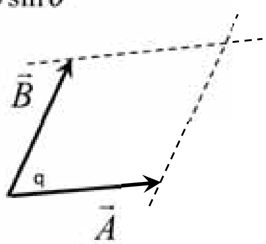
The First Right-Hand Rule

$$\left|\vec{A}\times\vec{B}\right| = \left|\vec{B}\times\vec{A}\right| = AB\sin\theta$$

$\vec{A}\times\vec{B}$ ⊙

$\vec{B}\times\vec{A}$ ⊗



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Motion of a Charge in a Constant B Field

- Since the force on a moving charge is always perpendicular to the velocity, only the direction will change, not the speed.
- The motion will be along a circular path.

$$ma = F$$

$$m\frac{v^2}{R} = qvB$$

$$R = \frac{mv}{qB}$$

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These forces are the basics behind many devices

- Cyclotron
- Mass spectrometer
- Electron microscope

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