Intro:
The effects of magnetic fields will be the topic for this week. We’ll carefully study the field of a coil of wire and the torque on a current loop in a magnetic field. This is critical for the design of the motors. The problems are a problem mix on electric and magnetic fields.

Reading:
- For Friday: HRW 26.1 - 2 (reading on current) and 29.1
- Monday: HRW 28 (Some of this was reading for last week.)
- Wednesday: HRW 28. If we move quicker than I expect then we will start on ‘light as a wave’, Chapter 33.

Our study of magnetic fields will encompass all of Chapter 28 and Sections 1 to 3 of Chapter 29. We started with the material from Chapter 29 (hence the order of the problem set). We’ll save the delightful material on the dynamics of electric and magnetic fields in Chapters 30-32 for Phys 295.

Physics Topics:
- "$\vec{B}$ from moving charges" or the Biot-Savart Law
- Magnetic moment
- Lorentz force $qv \times B$ and $I\ell \times B$

Math Topics:
- Cross products in cartesian and polar coordinates
- More line integrals

Problem Set: Due Friday, April 13 at the beginning of class.
(1) Find the electric potential $V = V(x, y)$ of the electric field $E_x = E_0 x$, $E_y = E_0 y$, and $E_z = 0$, where $E_0$ is a constant. It looks like this:
One way to do this is to integrate along the paths shown as dotted lines in the diagram. To check your result, differential your potential and be sure to find the above electric field.

(2) HRW 24.35

(3) Dipoles
   (a) Suppose you have an electric dipole with $Q = 4.20 \text{ nC}$, $|d| = 1.00 \text{ cm}$. This dipole is placed in a uniform electric field of strength 201 N/C and is oriented 130.0 degrees from the direction of the field. What is the torque on the dipole?
   (b) Find the expression for the angular frequency of oscillation of a dipole in a uniform electric field when the angle between the dipole moment and the electric field is small. Assume the dipole has a moment of inertia $I$ and express your result in terms of $E$, $p$, and $I$.

(4) The electric field in the $(x, y)$ plane is constant and points in the $+y$ direction so that $\mathbf{E} = E_0 \hat{\mathbf{j}}$. Find the potential $V = - \int \mathbf{E} \cdot d\ell$

at $(d, d)$ in two ways:
   (a) First, integrate along a path from $(0, 0)$ to $(0, d)$ and then from $(0, d)$ to $(d, d)$.
   (b) Second, integrate directly from $(0, 0)$ to $(d, d)$.
   (c) Must your two answers be equal? If so, why?

In both cases assume the potential is zero at $(0, 0)$.

(5) Energy in electric field:
   (a) HRW 25.30
   (b) Find the energy stored by the electric field in 1.00 m$^3$ of air just before a lighting strike. During a thunderstorm the typical electric field just before a cloud-ground lightening strike is $3.0 \times 10^6 \text{ V/m}$.
   (c) Comment on the magnitude of your result, e.g. how high could this energy raise a full Nalgene bottle? (Or, how hot would it make a 100 ml of water?)

(6) Magnet testing You have two identical magnets in your motor kit. This problem allows you to map out the magnetic field of these magnets. You can measure the (relative) strength of the magnetic field with a paperclip: Place a paperclip on a level surface. Hold a ruler perpendicular to the surface, and hold the magnet so that it is parallel with the surface. Slowly lower the magnet down towards the paperclip. At some point the paper clip “leaps” up to the magnet. Record the heights at which this occurs for all three orientations of the magnet. In lab we will have the mapping tool available, too. Based on your results, carefully sketch the magnetic field of your magnet. Use a two dimensional sketch of the field lines.

(7) A compass sitting on a table is pointing north because of the earth’s magnetic field. A magnet is brought near the compass and the needle deflects to the east by an angle $\theta$ and comes to rest.
   (a) If the angle of deflection is $\theta = 81^\circ$, how does the magnitude of the magnetic field of the magnet compare to the magnitude earth’s magnetic field?
   (b) Using what you just found what is the general relation between the strength of the magnetic field and the deflection angle?
(8) Based on this photograph by Ahmed Mater titled *Magnetism IV* determine the locations of the poles. (Since we are working with iron filings we can identify the locations of the poles tell but not which is “North” and which is “South”.)

(9) *An uncertainty ‘warmup’ or ‘cool down’ from lab* Suppose you measure two independent variables as $x = 12 \pm 2$ and $\theta = 43 \pm 3^\circ$, and use these values to compute

$$q(x, \theta) = \frac{x + 2}{x + \cos 4\theta}.$$  

What is your result for $q$ with uncertainty?

(10) Using the expression we derived in class on Wednesday, April 11 - or from the last line of the notes on the magnetic field of a solenoid - for the magnetic field of a solenoid on the axis of symmetry, find the expression for the magnetic field as a function of $z$ far away from the solenoid, when $z \gg R$. 

Lab:
Magnetic field mapping

A look ahead . . .
Magnetic forces on charges