* 1. Set up an adjustable magnetic field. Place a coil of wire in that field, oriented so that it *encircles* some field lines. Use a galvanometer to find out what happens to electrons in the wire when the strength of the magnetic field is changed. Then write an opening statement which describes your discovery *clearly*. (Use page 310 in the textbook and the title of this page.)

2. Lenz's Law: Use the galvanometer to find out which way electrons are propelled in that coil:
   a. Whenever you *start* a clockwise electron flow in the "primary" coil (by plugging in the electromagnet) a magnetic emf in the *secondary* coil tries to propel electrons __________wise.
   b. When you *stop* a clockwise electron flow in the primary coil (by pulling the plug) a magnetic emf tries to propel electrons __________wise through the secondary coil.

3. There must be a formula which predicts the magnetic emf in #1 & 2:
   a. Do you think the emf may depend on the resistance of the circuit? ____ -If so, how? ___________
   b. Do you think the emf may depend on the strength of gravity? ____ -If so, how? _______________
   c. Each loop (or "turn") in the coil behaves like a battery. Are they connected in series, or in parallel?
   d. Do you think the emf may depend on the number of turns in the coil? ____ -If so, how? _________
   e. Do you think it may depend on how rapidly the field strength is changing? ___ -If so, how? ______
   f. Can you think of any other variables which it may depend on? _____ *If so, please name them.*

4. Suppose a magnetic field decreases at a steady rate from a positive value to a negative value:
   a. Sketch a graph of that magnetic field vs time.
   b. Make the simplest *reasonable* guess about the resulting emf vs time graph. (Sketch it.)
   c. Does this guess contradict what you said in #3?____ (If so, explain why you haven't fixed it.)

* 5. Choose symbols for each of the relevant variables mentioned in #3. Define those symbols clearly.

* 6. Using those symbols, combine the opinions in #3 into a single equation and simplify it as much as you can. Figure out what fundamental units its proportionality constant must have if you guessed right.

7. Michael Faraday wondered if a single equation might correctly predict *all* magnetic emfs. He noticed that every formula for magnetic emf involves either the rate at which an *area* changes, or else the rate at which the magnetic *field strength* changes. In other words, if "A" represents loop area and "B" represents magnetic field strength then the emf seems to depend upon the rate at which the product "AB" changes. For that reason, he decided to give that product a special name:
   "**Magnetic Flux**" = ___, *by definition.* (Copy the given definition into the blank *and* onto RS XV.)

8. "Flux" is a latin word meaning "flow". If a net is held diagonally in a stream, you can calculate the water's *flow rate* through it (in cubic meters per second) from the water's flow *speed* (in _____per____) and the ***projected area*** (in ______) of the part of the net that is in the water, *projected into a plane perpendicular to the flow.* This rate could be called the water's "flux" through the net. Because of similarities between fluid flow lines and magnetic field lines, we use the same terminology to describe both fluid flow and magnetic fields. How must we define the "area" mentioned in #7?

9. The usual abbreviation for flux is the greek letter "Φ" ("phi"). The standard unit for magnetic flux is the "***Weber***". The usual abbreviation for magnetic field strength is "**B**". The the standard unit for magnetic field strength is the "***Tesla***". Obviously one Weber must be defined as one_____ times one______. *Please keep it simple! -Does #9 contradict #7?*___

10. Use the data that you saved from the current balance experiment to estimate the flux through the core of the solenoid that you used in the electron mass experiment. Express the estimate as a *range* and *explain* your estimate clearly. Also record the amount of coil current which generated that flux.

11. Imagine a coil of wire in a magnetic field. Changing the strength of the magnetic field creates an emf in the coil, *except* under certain unusual circumstances. To some people it seems likely (despite dimensional clues) that the emf will be proportional to the *strength* of the magnetic field as well as to the rate at which that field strength is changing. To *test* that strange idea we could observe the emf while steadily reducing the magnetic field strength from a positive value to a negative value, as in #4:
   a. Sketch the graph of *emf vs time* that will result *IF* that strange hypothesis is correct.
   b. Sketch the emf vs time graph predicted by *Faraday's* hypothesis. -Which one agrees with #4? ____
   c. Describe the unusual circumstances which *could* cause the induced emf to be zero. (See #1.)

1. Imagine a rectangular loop which is moving to the left and right with simple harmonic motion. The left end of the loop stays in a uniform magnetic field which is perpendicular to the plane of the loop; the right end is always on the other side of the field boundary. The length of the side perpendicular to the motion (parallel to the boundary) is "L"; the distance from the left side to the boundary is "X". (Notice that X is always positive.) Please draw and label the loop and the boundary. Then sketch graphs of X vs time, Area vs time (Area = XL), and Rate at which area changes vs time. (Remember, a "rate" is the *slope* of a graph.) Label the graphs clearly and *use the same time scale for each one.* You may also write equations describing the graphs if you care to.

2. Which one resembles the emf vs time graph? (See #2 on RS XV.) ________

3. What does the emf seem to be proportional to? _____ Does this agree with #6 on page 131? ____

4. What fundamental units must the proportionality constant have in #3? *Explain your logic briefly.*

5. What units would the constant have if the "strange" hypothesis in #11 on page 131 were correct?

6. Now let's move the loop to the right with a constant velocity:
   * a. Make sketches and write equations to describe each of the graphs listed in #1 for this type of motion. Define your symbols and show how each equation is deduced from basic principles or from the previous equation. Remember that any equation which describes a function of time must contain a symbol representing time.
   * b. Use #2 on RS XV to construct an equation describing the graph of emf vs time graph.
   * c. Compare this equation with those in 6a and make a conclusion about the relation between emf and flux. Write it as a statement that is *always* true, regardless of the way in the loop moves, regardless of the way in which the field changes. Give the value of the proportionality constant, with its units, if it has any.

   d. Show how a familiar mathematical symbol defined back in Chapter IV and reviewed in #6 on page 100 makes it possible to write this law as a very short equation.
   e. After reviewing #6 on page 131, decide whose name should be given to this new law.
   f. If 3 & 4 above do not agree with #6 OR if you aren't bothering to keep a copy then check here ___ to indicate that you don't want credit for any of those answers.

* 7. Using the law that you named in 6e, predict numerical values for the magnetic emf in each of the following situations. Remember to show how the emfs are calculated from the given data. If the new law does not work, please explain why. (Use page 132R if necessary.)
   a. A square loop one meter wide is placed entirely within a uniform magnetic field with a strength of 2.0 Tesla, in a plane perpendicular to the field, and is moved at 3.0 m/sec. in that plane.
   b. The same loop is pulled out of the same magnetic field with a speed of 3.0 m/s in a direction parallel to two of its sides.
   c. With the square loop set up as in 7a, we change the strength of the magnetic field at the rate of 10 Tesla per second.
   d. The loop is positioned as in 7a and is deformed so that its area reduces to zero in half a second.
   e. A circular loop with radius = 0.50 meter is placed in the same magnetic field and rotated like a wheel at 4.0 radians per second.
   f. The same loop is rotated at the same rate about a diameter which is parallel to the field.
   g. The same loop is rotated at the same rate about a diameter which is perpendicular to the field.

8. How must your answers to #7 be modified if we use a coil with "N" turns instead of just one?

* 9. Which scheme in #7 explains how a "generator" works? --Which one explains "transformers"? (Both devices are discussed in your textbook.)

Ch. XV Predicting the EMF in a Rotating Loop 132R

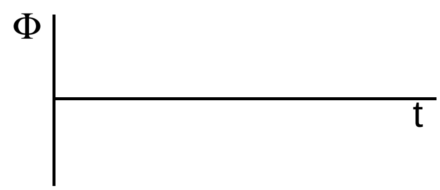
1. Imagine a wire loop rotating in a magnetic field as in the armature of a generator. Let "A" represent the area of the loop. Let "**B**" represent the strength and direction of the magnetic field.
   a. When the plane of the loop is perpendicular to **B** then the magnetic flux through the loop is:

   Φ = ____.

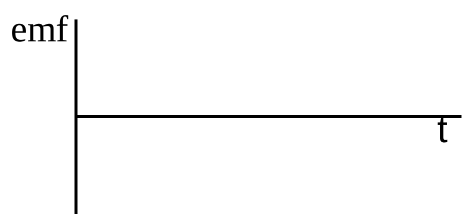
   b. When the loop has rotated until its plane is parallel to **B** then the flux through the loop is ____.
   c. Let "θ" represent the angle between the plane of the loop and B. When that angle is *NOT* 90 degrees we must use the "projected" area of the loop to determine the magnetic flux in terms of A, B, and the angle, as explained on page 131:

   Φ = _____

2. As the loop rotates, the angle mentioned in 1c steadily __creases.
   a. Sketch a graph of the angle vs time.
   b. The shape of that graph indicates that the angle is __________ly proportional to _____.
   c. We conclude from 2b that the graph of flux vs time has the same shape as the graph of flux vs _____.
   d. Sketch the graph of flux vs time:
   e. Does 2d contradict 1c? ___
   (* If so, explain why that mistake hasn't been corrected.)



3. Mr. Faraday tells us that the magnetic emf in the rotating loop can be calculated by ____________ing the graph of flux vs time. In other words, the graph of emf vs time is the _____________ of the graph that you sketched in 2d. (Copy the words from RS II.)
   a. Sketch that graph of emf vs time here:
   b. How is the period of the new graph related to the period of the loop's rotation? ________
   c. The rotation frequency is the _______________ of that period, as you wrote on RS I.



4. On RS VIII and again on RS XII you wrote that the steepest slope on a sine or cosine curve can be calculated by multiplying ____ times the product of the ____________ and the frequency. On RS XII you wrote that same formula in terms of amplitude and period:
   "Amplitude of the derivative = amplitude of original sine or cosine function times _________."

5. According to #4, the amplitude of the rotating loop's emf vs time graph can be calculated from A, B, and the rotation frequency with a simple formula:

   emf amplitude = ________

6. In 7f on p. 132 we discussed a circular loop with a radius of 0.50 m. It rotated at 4.0 radians per sec.
   a. The area of the loop was ____ m^2 and the period of rotation was ______ ___.
   b. Inserting those numbers into equation 5 above, we find that the emf amplitude is ______ volts.