A. Using a Magnetic Field to Propel Electrons In A Wire

1. In the previous chapter you saw that a magnetic field can exert a force on a moving charged particle. Perhaps we can use that force to propel electrons through a wire, making batteries unnecessary:
  a. To do so, that force must be directed __________ to the wire
  b. Do you think the wire will have to be *in* the magnetic field? ___
  c. List the variables which the magnetic force *on a charged particle* depends on. (See #17 on RS XIV.)
* d. Copy the general rule for predicting the direction of that force from #18 on RS XIV.
  e. To maximize the magnetic emf the wire must be ___________ to the magnetic field. (Use 1c.)
  f. In addition to 1b and 1e, *another* condition is necessary for *maximum* emf: The wire must be ______ing in a direction _________ to the ________ ______ and _________ to the wire. (Use 1d.)

2. Suppose the wire is vertical and the magnetic field points eastward: To make the electrons in the wire feel a *downward* magnetic force we must _______ the wire in the ______ward direction. (Use #1d)
-Does #2 contradict 1a, 1d or 1f? ___

* 3. What four conditions are necessary *and sufficient* for a magnetic emf to exist in a wire?
(This is *not* the same question as 1f, which asks how to get *maximum* emf. But don't forget 1b & 1f.)

4. What *additional* condition is necessary for a magnetic emf to cause a flow of charge in the wire?

5. Suppose you know the magnetic emf in a circuit: With one additional piece of information you can *predict* how much current will be induced. What is that additional information? ________ --How can it be used to make that prediction? (Use RS IX.) *Predicting is NOT the same as measuring!* **I =** ____

6. Pretend that the magnetic field lines are threads, and that the wire is a sword. In each case below use 1d to decide if the electrons will be pushed *along* the wire, *across* the wire, or *not pushed at all:*
  a. If the sword is thrust between the threads, electrons will be pushed _______ the wire.
  b. If the sword is swung between the threads, electrons will ________
  c. If the sword *cuts* the threads, electrons will be pushed _______ (See p. 307-309 in the book.)

7. To get a magnetic emf we must use the magnetic field to propel electrons ______ a wire, as in 1a, and also as in part __of #6, above. Do 1f & 3 agree? __

8. What variables must the magnetic emf depend upon? In other words, what information do you think a physicist would need in order to *predict* (not measure) the strength of a magnetic emf? Cross out the absurd suggestions below, circle the good ones, and *ADD at least one variable to the list:*
    Angle between wire's velocity and B
    Angle between wire and field
    Angle between wire and velocity
    Length of the part of the wire which is cutting across field lines
    Length of the part which is outside of the magnetic field
    Speed of the wire's motion
    Speed of electrons
    Charge of the electrons
    Resistance of wire
    Current in the wire

9. How many angles are circled in #8? ___ Can you get a magnetic emf if any one of them is zero? ___ Does this answer contradict 1f? ___ Did you mention all three angles in #3? ___ *If not, correct that mistake.* -What values should those angles have if you want to get *maximum magnetic emf*? _____

10. A formula for the ***maximum magnetic emf*** was mentioned in 1e and 1f. To discover that formula, imagine a magnetic force propelling an electron from one end of a wire to the other end:
  a. The formula predicting the *maximum* strength of that force is in #17 on RS XIV: **F =** ______
  b. Does that formula contradict #1c or #8 or #9? _____ --Does it give results with the right units? ____
  c. Suppose we multiply that force by the distance travelled by the electron, which is simply the length of the wire. Copy the *name* of that product from RS III or VI: ________
  d. If we divide that product by the electron charge, the quotient is called ________ _______ _________ (See 5c on p. 126 or RS X.) -Does that agree with the *name* that is in ***boldface type*** above? ___
  e. Does 10d agree with #8? ____

11. Write a new equation summarizing what you learned in #10. (Try not to contradict #8 or 9 or the textbook.) Define each symbol in the formula. *Also describe the limitations of that formula carefully.* (See #9.) A copy of this new discovery is being saved for future use in # ___ on RS ____.

1. Copy the magnetic EMF formula from #2 on RS XV. (Use "L" to represent the wire's length.)

2. In Chapter XIV you discovered that whenever a wire carries electric current in a magnetic field which is not __________ to the wire, a magnetic force is exerted on the wire by the field. Now let's imagine that the current exists *because* the wire is moving through the magnetic field, cutting across field lines. (This wire might be part of a **generator**, for example.) No other force acts on the wire:
   a. Suppose the magnetic force acts in the same direction as the coasting wire's velocity, causing the wire to speed up. If that is the case, the kinetic energy of the wire ___creases. At the same time the induced current in the wire causes the wire to become warmer because the wire has some resistance. Can you identify the source of those two growing amounts of energy?___ (If so, do it.)
   -Does this imaginary scenario appear to violate the energy conservation principle? _____
   b. Now suppose the magnetic force acting on the wire is in the direction *opposite* to the wire's velocity. If that is the case it will cause the coasting wire's kinetic energy to ___crease. Because the wire still has resistance and still carries current, the ______ energy in the wire must ___crease as it did in 2a.
   -Does this scenario violate the energy conservation principle? ____
   * c. After reviewing 2a and 2b, write a conclusion about the direction of the magnetic force acting on a wire carrying *induced* current. Write it as a clear opening statement. Use the word "always".

* 3. "Hand rules" can also predict the direction of that magnetic force. Imagine a wire moving in a magnetic field, cutting field lines as in 1 and 2 above, or as in #2 on page 129:
   a. Choose and describe appropriate directions for B and v, and an appropriate orientation for the wire. (Use words like "up", "east", "north", etc.)
   b. Use #17 on RS XIV to predict the direction of the induced electron flow in 3a, as we did on p. 129.
   c. Use the *other* hand rule (#13 on RS XIV) to predict the direction of the magnetic *force* on the wire. Explain how this prediction agrees or disagrees with 2c.

* 4. Show that the work needed to push a wire through a magnetic field can be calculated from B, L, s, R, and Δt. Then show how the generated electrical energy can be calculated. (See #14 on RS IX.)

5. A hand-cranked DC generator can be used to charge up a capacitor with a light bulb in series. If the capacitance is very great, the charging process can take a long time.
   a. How must the voltage across the bulb be related to the emf and the capacitor voltage? (See RS IX.) V_{bulb} = __________
   b. While the capacitor is charging the capacitor voltage must __crease.
   c. According to 5a & 5b, the bulb voltage must ___crease, so the current must __crease.
   d. The effort required to turn the generator must therefore gradually __crease.
   e. The direction of the magnetic force on a moving wire in the generator must be _____________ to the direction of its velocity, as in 2c.

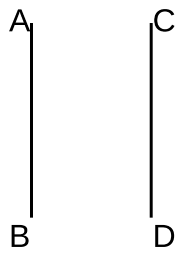
6. What happens if you release the generator crank when you have finished charging the capacitor?
   a. Electrons are now propelled through the circuit by the ________, instead of the ________.
   b. The direction of electron flow is therefore _________ed, causing the direction of the magnetic force on the moving wires in the generator to be ________ed. (reversed, unchanged)
   c. That force causes the generator handle to turn all by itself in the direction ______ ___ its previous direction if there is not too much friction. (same as, opposite to)

7. In #2 and #3 you showed that the magnetic force on a moving wire is a type of "damping" force. In some ways a damping force is similar to friction: both are directed opposite to the velocity, and both forces can convert mechanical energy into heat. The important *difference* between damping forces and friction forces is in the way in which they depend on velocity:
   * a. How does the strength of a friction depend on sliding speed? (See #11 on RS II or 15 on RS III.)
   * b. How must a magnetic damping force depend on speed? (See #11 on page 129.)

8. Magnetic damping is used to prevent "see-saw" motion in laboratory balances, galvanometers, and stereo loudspeakers. In each of these devices it is important for a moving object to come to a stop at its equilibrium position. Why can't that be accomplished with friction forces?

More About Magnetic EMF

1. Pretend that there is a magnetic field perpendicular to this page, directed into the paper. A segment of wire moves with constant velocity from position AB to position CD. If that wire is part of a complete circuit then the magnetic emf induced by the motion will cause electrons to flow in the wire during the trip. An electron initially at the center of the wire will be a bit off-center at the end of the trip.
   a. Mark the initial and final positions of the electron with an "E" and a "P".
   b. Draw a dotted line from E to P to show the path followed by the electron.



2. Let "__" represent the angle between the dotted line and a line **perpendicular** to AB. That angle will be very small if the resistance is very ______.

3. During the electron's trip from E to P it will experience a magnetic force.
   a. Using the hand rule on RS XIV, draw an arrow on the diagram to show the direction of that force. Label that arrow with the letter "F".
   b. Copy the formula for that force from RS XIV and define the symbols in it: **F =** ___

4. The definition of "work" involves the strength ("F") of the force acting on an object, the distance the object is moved ("X"), and the angle between **those two vectors.** Copy that definition from RS VI, using the given symbols: **W =** ______

5. According to that definition, whenever the angle is 90 degrees the work is ____. (See #2 on RS VI.) For example, the work done by a level road on a coasting vehicle is ___ if friction can be ignored. The work done by a planet's gravitational pull on a satellite in a circular orbit is ____ for the same reason.

6. In #3, how much of an angle is there between the electron's displacement and the magnetic force acting on it? __ -We must conclude that the work done on the electron by the magnetic field is ____.
   a. Does #6 contradict #5? ___ Does it agree with what you said on page 127? ___
   b. What must we conclude about the method used on page 129? ____

7. Remember that the electron is free to move along the wire, but cannot escape from the wire.
   a. That clue tells us that a force exerted on the electron by the wire can only be directed _____ to the wire. What symbol above represents the angle between that force and the electron displacement?
   b. Write a formula for the work done on the electron by the wire in terms of the wire force, distance EP, and the angle. *Try not to contradict #4.* **W =** ______

8. Think about the sum of the "wire force" (7a) and the magnetic force acting on the electron:
   a. Since it is this vector sum which propels electrons *along* the wire, we know that the vector sum must be directed __________ to the wire. Draw that vector sum. Label its parts clearly.
   b. Label the angle in your drawing which is equivalent to the one mentioned in 7b.
   c. Use that force triangle to figure out the strength of the force exerted on the electron by the wire. (Express that force in terms of B, q, v, and the angle.) **F =** ______
   d. Use the new force formula in 8c to eliminate the "wire force" from 7b: **W =** _____

9. Copy the displacement triangle formed by EP and the x- and y- components of EP carefully from #1. Choose symbols to represent those components, and use them to label your diagram.
   a. Is the displacement triangle similar to the force triangle? ___
   b. Which side is equivalent to EP times the sine of the angle defined in #2? __
   c. Use that equivalence to simplify the work formula in 8d: **W =** _____

10. The work formula also involves the product of the electron velocity and the cosine of the angle. That product is equivalent to the velocity of some other object. Use a velocity vector diagram to figure out what object that is. Then use that result to simplify the work formula: **W =** ______

11. Equation 10 gives us the work done on the electron as it moves along the wire a distance equal to the __-component of EP. To determine the work done on the electron as it moves the full length of the wire we must multiply the work found in #10 by the length ratio _____________, where "L" represents the length of the wire. Then, using the definition of "voltage" on RS IX, we must ____________ that work by _____ to obtain the formula for magnetic emf: **Emf =** ______