Objective: to investigate the electromagnetic induction between magnets and coils, and its modulation by various solid core rods.

Equipment: 2 D batteries in holders, galvanometer, 6 wires, outer and inner long green coils, iron cores, cow magnet, small magnetic compass, masking tape, rubber bands, switch, cardboard roll, box cutter, scissors, clear tape, flat cardboard, protractor, rheostat (about 44 ohms), resistors, ohmmeter

Definitions: Induction:

Definitions: Lenz's Law:

Definitions: Permeability of a material:

Procedure:
1. Current induced by a permanent magnet
   We want to mark the posts of the galvanometer so that you can distinguish between positive and negative current directions. This is easiest to do with a 1.5 volt battery and a large (> $10^5$ ohm) resistor in series with it. (Be gentle with the sensitive galvanometer, please, and just touch its contact post briefly.) Remove the batteries from the galvanometer.
   Mark the N-seeking pole of the magnet with a rubber band. (Be gentle with the little compass, please.)

   a) The permanent magnet moving
      Set the larger diameter coil vertically on the table. Attach its posts to the posts of the galvanometer. Record the reading when each of the following is done.
      Magnet (N down) thrust into the coil.
      Magnet (N down) held inside the coil.
      Magnet (N down) jerked out of the coil.
      Describe the direction of the current in each case, as seen from above the coil.

      Magnet (S down) thrust into the coil.
      Magnet (S down) held inside the coil.
      Magnet (S down) jerked out of the coil.
      Describe the direction of the current in each case, as seen from above the coil.
b) The coil moving
Hold the magnet steady in your hand and thrust the coil up or down around the magnet.
   - Coil thrust around the N pole of the magnet.
   - Coil held around the N pole of the magnet.
   - Coil jerked away from the N pole of the magnet.
Describe the direction of the current in each case, as seen from above the coil.
   - Coil thrust around the S pole of the magnet.
   - Coil held around the S pole of the magnet.
   - Coil jerked away from the S pole of the magnet.
Describe the direction of the current in each case, as seen from above the coil.

Try to place the coil around the magnet without producing a deflection in the galvanometer.
Describe your technique:

Conclusion: To produce an induced electric field ________________________________

2. Response to an electromagnet
   Attach two flashlight batteries in series to the narrow coil. Record the reading when each of the following is done.
   - Primary (narrow) coil thrust into the secondary (fat) coil.
   - Primary held steady.
   - Primary coil jerked out of the secondary coil.
Describe the direction of the current and the magnetic field of the primary coil:

3. Current induced by another current
   Attach the two flashlight batteries in series to a contact switch and then to the primary coil. Place the primary coil all the way inside the secondary coil (larger diameter, finer wire, more turns).
   Record the galvanometer reading when each of the following is done.
   - Closing the switch and so completing the circuit.
   - Holding the switch closed for several seconds.
   - Opening the switch suddenly.
Reverse the leads to the battery pack and repeat above.

4. Response with a core inside the primary coil.
   a) Insert the shiny iron core inside the primary coil.
   Record the galvanometer reading when each of the following is done.
   - Closing the switch and so completing the circuit.
   - Holding the switch closed for several seconds.
   - Opening the switch suddenly.

   b) Insert another core inside the primary coil. Try various cores (wood dowel, large nail, huge nail, pencil, pen, copper rod, etc.)
Record the galvanometer reading when the switch is closed and then opened.

**5. Response as a function of overlap distance**
Move the best coil out by two centimeter increments and record what happens when you close and open the switch.

**6. Measuring the Earth’s magnetic field (__________ Tesla)**
a) Cut a window near the center of your cardboard tube about 2 x 2 cm. Cover it with clear tape. Wind 100 turns of enameled wire around the tube, leaving tails of about 20 cm on each end. Use a knife to clean the enamel off about 2 cm at the end of each tail, so that there is good electrical conductivity.
Cut a piece of flat cardboard into a rectangle whose width is a little less than the diameter of the tube, and whose length is longer than the tube. Check to see that this rectangle can slide into the tube easily.
b) Roughly at the center of a sheet of white paper draw a point, then a vertical line through it. Using the protractor draw the perpendicular to the line at that same point. Using the protractor draw the 45 degree lines through the same center point.
c) Place this paper on a wooden surface (table), place the small compass on the center point. Gradually turn the paper until the long line matches the direction “North” as shown by the compass. Tape the paper down to the table. Remove the compass.
d) Using a loop of tape, fasten the compass to the middle of the rectangle with “North” facing one short side. Slide this into the tube so that you can see the compass through the window. Position the whole tube along the East-West line on the paper.

e) Calculate what current through this coil would produce a magnetic field equal to the Earth’s magnetic field. I = ______________
Which direction will this field point? ______________
Calculate the resistance that would produce this current when powered by a D battery. R = ________
f) Gather the supplies and wire the circuit. Start with a large resistance, then gradually reduce it until the compass needle points 45 degrees from North. Disconnect the battery, measure your resistance, calculate the strength of the Earth’s magnetic field ____________.
Calculate your percent error.

**7. Discussion questions:**
a) What is the source of energy for the current when the bar magnet is inserted into the coil?

b) Explain your percent error on the Earth’s magnetic field.

c) How does this topic apply to your life?