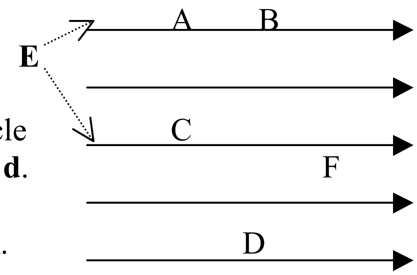
EXPERIMENT 1: ELECTROMAGNETIC FIELDS

The concept of vector fields is useful in describing electromagnetic phenomena. While these fields are mathematically precise, getting a feel for them is difficult. Thus it helps to do an experiment where their visualization is possible.

ADVANCED STUDY ASSIGNMENT



1. If the lines at right represent a uniform electric field, **E**, between which two points could you move a charged particle so that the electric field does no work? Remember W = **F•d**.
2. On the field lines at right, draw a set of 5 lines which show a number of paths for which the electric field does no work.

BACKGROUND

If necessary, review the concept of electric field in chapter 22 of the text. To discover the electric field, we are going to make use of a concept from chapter 24, electric potential. Potential energy for electric fields is defined similar to potential energy for gravity, $U = k\, q\, q_0 / r$ (note that for gravity, we had a negative sign, which we get also for electricity, if we have attractive forces, when q_1 and q_0 have opposite charges). Then we can define electric potential (notice the difference, just electric potential, not potential energy) as $V = U/q_0$. Thus electric potential is potential energy per unit charge. Since potential energy changes with r, distance between two charges, then electric potential may change with r, distance from a single charge, or charge distribution.

A family of points (or in mathematical terms, the locus of points, or set of points) with the same value of electric potential, is called an equipotential. In three dimensions, this equipotential will be a surface, so it is commonly called an equipotential surface. Since no work is needed to move a charge on an equipotential surface (because the potential energy per charge is the same everywhere on the surface), there must be no component of electric field parallel to the surface, or the electric field is everywhere perpendicular to the surface. Thus, if we find a family of equipotential surfaces, we have a prescription for finding the electric field lines due to the set of charges causing the equipotentials: start at a surface, draw perpendicular lines to the surface, and curve the lines as you approach the next surface, to be perpendicular to that surface also, and then the next, and so on for all the surfaces. Note that the lines you draw as the answer to ASA 2 are five equipotential surfaces.

Magnetic field lines are both easier and harder to deal with. Easier, because the equipment we have allows us to draw the fields directly from experiment. Harder, because the magnetic field is more indirectly defined than the electric field.

PROCEDURE A

(Note that although this procedure is described first, you should do this procedure any time during the lab period when the equipment is available. Typically there are only two sets of equipment set up, but PROCEDURE A takes only 10 minutes or so, leaving adequate time for seven or eight groups to share two sets of equipment.)

1. As we will discuss in the second part of the semester, magnetic fields arise from moving charges, either as currents in wires, or as motion of charged particles in matter. Magnetic fields have the property of affecting iron and causing iron to line up with the magnetic field lines. Thus, if we sprinkle iron filings, or powdered iron, around a magnet, the filings will line up and show the magnetic field.
2. In order to prevent the filings from sticking to the magnet, NEVER SPRINKLE THE FILINGS DIRECTLY ONTO THE MAGNET. USE ONLY THE STIFF PLASTIC SHEETS PROVIDED, AND NOTICE THE WORDS "*THIS SIDE UP*" ON THE SHEETS, SINCE THE FILINGS TEND TO STICK TO THE PLASTIC. IF THE WRONG SIDE IS TURNED TO THE MAGNET, THE FILINGS WILL STICK TO THE MAGNET, AND BE DIFFICULT TO REMOVE. Keep the magnets away from the iron filings and their supply shakers or beakers.
3. Examine the bar magnet supplied, marked N and S for North pole and South pole. Place it on the table, with two half-meter sticks around it to help support the plastic sheet with "*THIS SIDE UP*" showing the correct orientation. Now sprinkle the iron filings on the plastic sheet, and notice the patterns they form. Sketch the bar magnet on a piece of paper, and sketch the magnetic field lines indicated by the iron filings. Mark this piece of paper Data Table A, and include it with your lab report. When you are finished, carefully remove and bend the plastic sheet and pour the iron filings into the beaker provided, being sure not to get any of the filings on the magnet.
4. Use a small compass around the bar magnet, and verify that unlike poles attract each other. (If not marked N, the colored end of the compass needle is North.) Also notice that the compass would also allow you to sketch the same magnetic field lines by moving it around the magnet.
5. On the same piece of paper, sketch the rectangular magnet, and again using the half-meter sticks (or perhaps two on each side, or one meter stick and one half-meter stick stacked to the right height to keep the plastic sheet horizontal), discover and sketch the magnetic fields from this magnet by sprinkling iron filings on the plastic sheet. Mark the poles on your sketch by using the compass to discover which pole is North.
6. Finally, repeat the process with the coil provided, this time standing the half-meter sticks on end to support the plastic sheet. The coil should be connected to a DC power supply, but be careful to limit the current to no more than 3 amps as read on the meter on the power supply. Always start with the voltage on the 0 to 12 volt scale, and the voltage adjust knob turned to minimum (all the way counter-clockwise).
7. When you are done, all used iron filings should be in the beaker. If you have spilled any on the white paper under the apparatus, pick the paper up and dump the spill in the beaker also.

PROCEDURE B

8. In this part, we seek to find equipotential surfaces between two charge distributions, set up by wires connected to the positive and negative terminals of a power supply. Note the experiment board on spring-loaded legs, with connections for the battery or power supply. We will use a DC power supply connected to these terminals, adjusted to 6.0 V (or 6.0 volts).
9. Note also that your equipment box should have several black boards, about the size of a piece of paper, with silver colored patterns, either two dots, two lines, or a line and a dot. Place one of these boards on the bottom of the experiment board with legs, with the pattern showing on the bottom, and in contact with the nuts. These nuts are in contact with the power supply by the wires you can see.
10. Place a piece of paper on top of the experiment board, held in place either by the black nubs above the spring loaded legs, or by tape. If you use tape, make sure you remove all traces of it when you are done.
11. Now find the two clear plastic templates with a variety of holes. One of the templates should have a pattern of holes matching the pattern on the board you selected. Place this template on top of the experiment board, with the small pegs on top of the board through holes in the template, and with the pattern on the template matching the pattern showing on the bottom board. Trace out the pattern of the board you are using on the paper. Check after you trace that the pencilled pattern on top matches the "silver" pattern on the board underneath.
12. You are now to mark equipotentials on the paper, by using a galvanometer, a sensitive device for measuring potentials, or potential differences. Connect one terminal of the galvanometer, using a banana plug to banana plug connector, to the leftmost end of the row of plugs at the top of the experiment board. Connect the other terminal of the galvanometer to the long U-shaped arm, using a spade-to-spade connecting wire. The wire connects to the metal knob at the base of the U. The U-shaped arm slips over the experiment board, with the metal contact on the bottom, against the pattern board, and the hole in the other arm on top of the paper.
13. To use the galvanometer you must depress one of the two buttons. Always watch the needle on the galvanometer as you depress the button, and if the needle goes off scale (moves all the way past the left or right end of the scale), immediately release the button, to protect the galvanometer. The galvanometer is sensitive, and can easily be burned out. Always press the less sensitive button first (the one with the larger number) to protect the meter. If you see only small motion (or none) then press the more sensitive button, to choose the smaller scale. Move the arm around on the pattern, and note how the galvanometer reading changes.
14. Your goal now is to find a line of 0 readings as you move the arm around on the paper (and the pattern underneath). When you find a 0 reading, use a pencil to mark a small circle on the paper where the reading is 0. Now move from this small circle to other points nearby, to find the equipotential surface (actually, the intersection of the equipotential surface with the plane of the paper). Continue moving the arm and drawing small circles in a line, until you approach opposite ends of the paper.
15. Next, unplug the banana plug going from the galvanometer to the plug on the top of the experiment board and move to the next plug. You now will have a different

equipotential surface when you find 0 points with the galvanometer. Continue as in procedure 14, and then move the banana plug again, until you have worked across all the banana plugs on top of the experiment board.

16. As a last step, mark which side of the pattern boar was connected to the positive terminal of the DC power supply, and which to the negative terminal. If you need to, mark the different lines, particularly if they are close together. Mark the paper DATA TABLE B.

PROCEDURE C

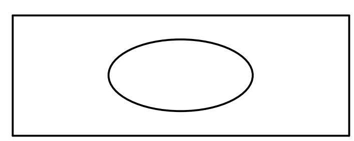
17. When you are finished with the first pattern board, choose a second with a different pattern and repeat procedures 9 to 15, and label the paper DATA TABLE C.

PROCEDURE D

18. Now use the theory described in BACKGROUND section to draw in the electric field lines for the two patterns. It is preferable to use a different color for the electric field lines than the pencil or ink you used for the equipotentials. If you don't have a different color available, make one set of lines dotted. Label the electric field lines with a vector **E**, as the diagram in the Advanced Study Assignment is. Also include an arrow on the electric field lines to indicate the direction of the electric field.

QUESTIONS

1. Does the pattern of equipotentials you drew look correct (think symmetry and smoothness)? If not, can you think of a reason for the way it looks? Look carefully at the boards, or think of the way the boards appeared when you did the experiment.
2. Do the perpendicular lines you drew from the equipotential surfaces look like they might be reasonable electric field lines for the patterns you used? Recall that the silver patterns on the boards are essentially locations of opposite charges set up by the power supply, and electric field lines should go from positive to negative charge.
3. Draw in electric field lines you might reasonably expect to find for the conductors sketched at right, if they were oppositely and equally charged with a smooth charge distribution on each.



4. For the three sketches of magnetic fields, are any two of the sketches similar? Which, if any?