MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

8.02 **Spring 2005**

Experiment 1: Using the TEAL Visualizations

OBJECTIVES

1. To explore the types of visualizations available through the TEAL website.
2. To become familiar why they are there, which is to help you with geometry, mathematics, and physics.
3. To explore how electrostatic forces hold matter together.

INTRODUCTION

Electromagnetism is a subject that is highly complex and mathematical, and we hope to help you develop a better intuition about this subject through passive and interactive visualizations, without the use of advanced mathematics.

These visualizations are for three purposes.

1. To help you with the geometric issues. Because electromagnetism involves vector cross products, the subject is innately three-dimensional, and many of our animations are built using 3D tools.

2. To help you with the math. We do a lot of different kinds of integrals in electromagnetism (line, surface, and volume), many of which you do not see until the end of 18.02, and we want to help you understand those using visualizations of the mathematical concepts

3. To help you with the physics. Electromagnet fields mediate the interaction of the material objects that produce them by transmitting energy and momentum between those objects. In particular, fields exert a tension parallel to field lines and a pressure perpendicular to field lines, and that is most obvious when you use an interactive applet demonstrating this phenomena.

You will not have seen a lot of the materials we will discuss today, but don't panic. We just want to get you familiar with why the visualizations exist and what you can use them for as we proceed in the course.

PLATFORMS

We have three different kinds of animations, which run on the following platforms.

1. Movie files, which should run on server, Windows PCs, and MACs with no additional software added to your computer.

2. Java 3D Applets, which run on server, Windows PCs, and MACs. If you want to run these on your own computer at home, you must download and install Java 3D

source code. Directions for doing that are given at http://evangelion.mit.edu/802TEAL3D/visualizations/resources/download.htm.

3. Macromedia ShockWave files, which run only on Window's PCs and MACs. You must download the free Shockwave player from Macromedia's website. The first time you try to play one of our Shockwaves it is programmed to go to that website and download the player (assuming you want to of course).

If your computing resources do not include one of these platforms, use the server PC Cluster. This Cluster is heavily used during the day for classes, but is available outside of scheduled classes.

We now go through examples of each of these kinds of visualizations in each of the categories we mentioned above—i.e. geometry, mathematics, and physics.

PART 1. GEOMETRY

Navigation: Go to the 8.02 public web page at http://web.mit.edu/8.02t/www. The bottom link on the left will bring you to the Teal Visualization Page. Once there, select *Vector Fields* from the links on the right.

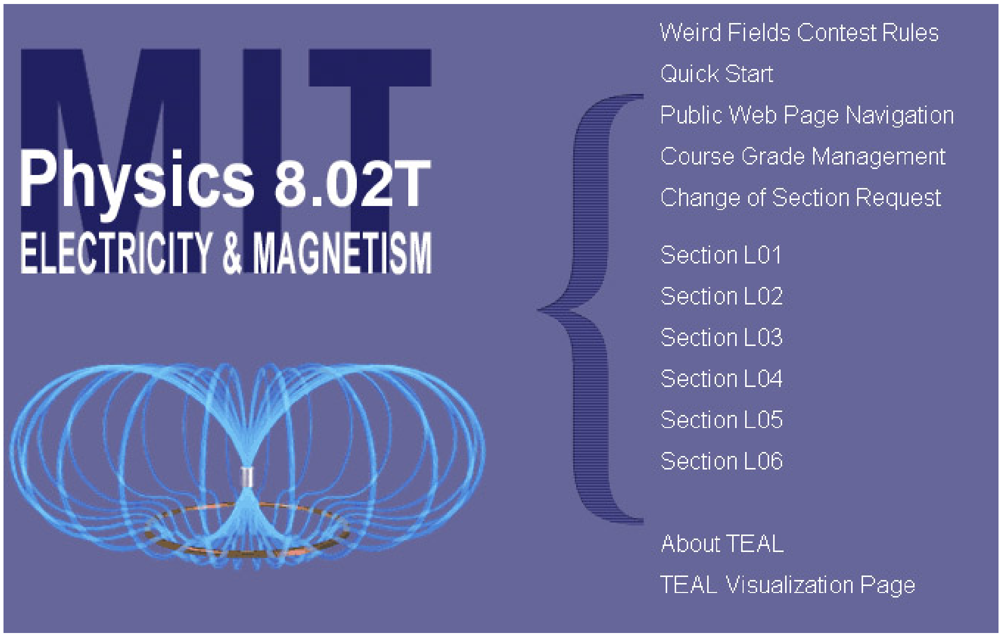
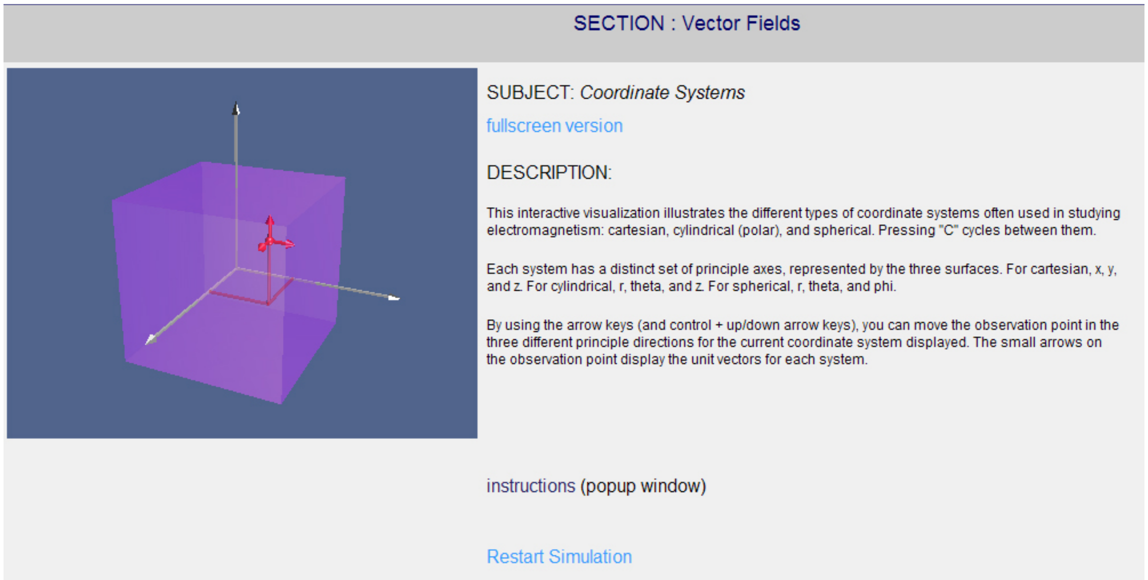


Figure 1 The TEAL Visualization page at http://web.mit.edu/8.02T/www/802TEAL3D/

Coordinate Systems

Select the *Coordinate Systems* Shockwave on the next to bottom left column of the *Vector Fields* page. Once it loads you will see the following page:



The text on the right explains the purpose of the visualization. To get instructions for the interface, click in the *instructions (popup window)*. To get a full screen version of the shockwave, click on the *fullscreen version* link.

Exercise 1: Go to the full screen version of the shockwave do all of the following:

1. Explore all three of the coordinate systems contained in it.
2. Move your observation point around in all three directions.
3. Change your viewpoint by clicking and dragging in the window.
4. Move the viewpoint in and out using the keyboard controls.

Question 1 (*answer on the tear-sheet at the end*):

What is it about the coordinate axes in cylindrical and spherical coordinates that makes those axes very different from the axes in a Cartesian coordinate system?

PART 2. MATHEMATICS

Line Integrations

Return to the TEAL visualization page, http://web.mit.edu/8.02T/www/802TEAL3D/ (see Figure 1 above). Now choose *Electrostatic*s from the links on the right, and go to the *Ring of Charge* Shockwave (fifth visualization down on the column to the ***right***). This is a visualization of the mathematical equation

$$\vec{\mathbf{E}} = k_e \int \frac{dq}{r^2} \hat{\mathbf{r}} \tag{1.1}$$

applied to the situation where we have a ring of charge and the integration in Equation (1.1) is a line integral over the ring. In the visualization we have broken our integration up into a sum over 30 charge elements on the ring, and do a sum to calculate the electric field. That is, we have replaced (1.1) with

$$\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r_i^2} \hat{\mathbf{r}}_i \tag{1.2}$$

Exercise 2: Look at the instructions on the pop-up menu and then go to the full screen version of the shockwave do all of the following:

1. Move your observation point around the two directions in the plane of the map. Be careful to first move "down", as there is a bug that crashes the shockwave if you move sideways to begin with.

2. Turn the *grass seeds* map on and off. Note that the vector sum of our thirty individual electric fields due to each charge element is always parallel to the *grass seeds* correlation direction, as it should be.

3. Change your viewpoint by clicking and dragging in the window.

4. Move the viewpoint in and out using the keyboard controls.

5. Select one of the 30 "charge elements" as explained in the instructions, and note what electric field it produces.

Question 2 (*answer on the tear-sheet at the end*): What is the magnitude of the electric field right at the center of the circle of charge? Why does it have that value?

Grass seeds from analytic formulas

Go to
http://web.mit.edu/8.02t/www/802TEAL3D/visualizations/vectorfields/licapplet/licapplet.htm and bring up the applet at that link by left clicking on the picture.

Exercise 3:

1. The applet starts out with the vector function $\vec{\mathbf{F}}(x, y) = -y\,\hat{\mathbf{i}} + x\,\hat{\mathbf{j}}$ in the boxes. Hit the *Grass Seeds* button near the bottom of the right panel of the applet to see what this vector function looks like in *grass seeds*.

2. Try entering a new and different $\vec{\mathbf{F}}(x,y) = g(x,y)\,\hat{\mathbf{i}} + h(x,y)\,\hat{\mathbf{j}}$ in the text boxes labeled by these functions. You must use the usual symbolic nomenclature, e.g. "x*y" to multiply x and y, "x^2" for the square of x, and so on. You can also use "sin(x)", ln(x), and so on for various analytic functions.

3. Use the "Examples" pull down menu to explore various pre-set functions.

Note that the Weird Field Contest uses this applet.

PART 3. PHYSICS

Charged Particle Motion in An Ion Trap

Go to the page

http://web.mit.edu/8.02T/www/802TEAL3D/visualizations/electrostatics/Trap/trap.htm

This is a visualization of the motion of 12 charges in an external electric field given by

$$\vec{\mathbf{E}} = -\frac{E_0}{d}\vec{\mathbf{r}} \tag{1.3}$$

That is, the electric field always points toward the origin and it grows with distance from the origin as the first power of the radial distance. This field pushes the positive charges toward the origin with a force that grows with distance. The mutual repulsion of the charges keeps them from collapsing to the origin.

Exercise 4: Look at the instructions on the pop-up menu and then go to the full screen version of the shockwave and do all of the following:

1. Let the charges settle down and then generate a surface of symmetry based on the particle positions (hit "s" on the keyboard)

2. If you do not have a charge at the center of a ring of charges, select one of the charges on the ring and try to move it into the center to see if you can get a stable configuration with a charge at the center. If you do have a charge at the center of the ring, select that charge and try to move it outward from the center so it sits on the ring.

3. Add additional charges and see how many you have to add until you get two charges sitting inside a "cage."

Question 3 (*answer on the tear-sheet at the end*): How many additional positive charges do you have to put in your "Ion Trap" shockwave to get two to sit in the center, surrounded by the rest? What now is the total number?

Magnetic Levitation

Go to
http://web.mit.edu/8.02t/www/802TEAL3D/visualizations/magnetostatics/floatingcoilapp/floatingcoilapp.htm

This applet illustrates the forces on a current carrying coil sitting on the axis of a permanent magnet. For current flowing in one direction in the coil the force on the coil will be upward, and if the current is strong enough the coil will levitate, floating on the magnetic fields of the coil plus the magnet. For the other direction of current the coil is attracted to the magnet.

Exercise 5:

1. Vary the current in the coil by using the slider at the upper right, and note how the field configuration changes.

2. To let the coil move under the effect of the magnetic field, press play on the "play" icon at the bottom of the left panel.

A quantitative problem at **this link** gives you an idea of the currents you need to get levitation in the simple experiments which this applet illustrates.

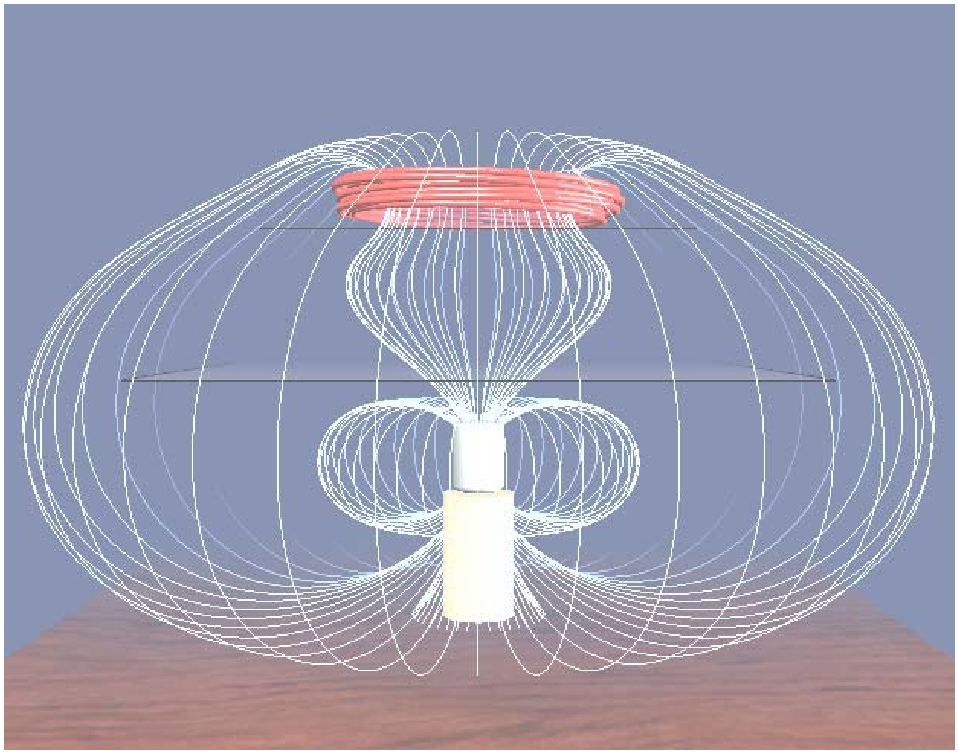
Question 4 (*answer on the tear-sheet at the end*): How much current do you have to put through the coil to get it to just barely levitate? The easiest way to determine this is to type in trial current values in the box next to the top slider and hit return. Give both the sign and magnitude of the current necessary to levitate the coil. You need be only accurate to one amp.

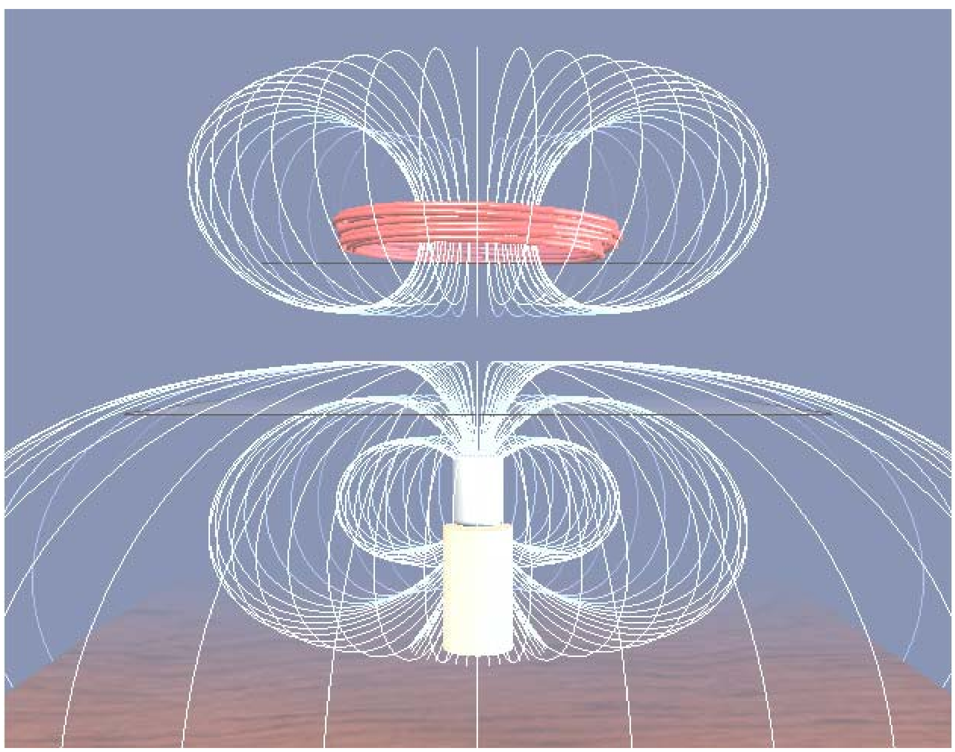
Note: we will actually do this experiment (levitating a coil of wire) in Experiment 6.

Question 5 (*answer on the tear-sheet at the end*): The two figures on the next page show the magnetic field lines of the magnet and the coil of wire for the two directions of the current in the coil. Which statement below is true? [Hint: Faraday through trial and error deduced that field lines exert a tension along the field line and a pressure perpendicular to the field line].

a. The top figure on the next page corresponds to the field configuration when the coil was attracted to the magnet, and the bottom figure to when the coil was repelled by the magnet.

b. The top figure on the next page corresponds to the field configuration when the coil was repelled by the magnet, and the bottom figure to when the coil was attracted to the magnet.





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Tear off this page and turn it in at the end of class.

Note:
Writing in the name of a student who is not present is a Committee on Discipline offense.

Experiment Summary 1: Using the TEAL Visualizations

Group and Section ___________________________ **(e.g. 10A, L02: Please Fill Out)**

Names _____________________________________

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OBSERVATIONS

Part 1: Geometry

Question 1: What is it about the coordinate axes in cylindrical and spherical coordinates that makes those axes very different from the axes in a Cartesian coordinate system ?

Answer:

Part 2: Mathematics

Question 2: What is the magnitude of the electric field right at the center of the circle of charge? Why does it have that value?

Answer:

Part 3: Physics

Question 3: How many ***additional*** positive charges do you have to put in your "Ion Trap" shockwave to get two to sit in the center, surrounded by the rest?

Answer:

______________ additional charges

Question 4: How much current do you have to put through the coil to just get it to levitate? Give both the sign and magnitude of the current necessary to levitate the coil. Accuracy to the nearest amp ok.

______________ Amps

Question 5: The two figures on page E1-7 show the magnetic field lines of the magnet and the coil of wire for the two directions of the current in the coil. Which statement below is true? [Hint: Faraday through trial and error deduced that field lines exert a tension along the field line and a pressure perpendicular to the field line].

a. The top figure on the page above corresponds to the field configuration when the coil was attracted to the magnet, and the bottom figure to when the coil was repelled by the magnet.

b. The top figure on the page above corresponds to the field configuration when the coil was repelled by the magnet, and the bottom figure to when the coil was attracted to the magnet.

Answer: