Experiment 1: Using the TEAL Visualizations

OBJECTIVES

1. To explore the types of visualizations available through the TEAL website.

2. To become familiar with their three purposes, which are to help you with Geometry, Mathematics, and Physics.

3. To explore how matter is put together and how it behaves in a gravitational field, using a Shockwave visualization.

INTRODUCTION

Some of the material used in the TEAL course has been developed as part of an NSF sponsored project (http://web.mit.edu/jbelcher/www/NSF.html) to explore the use of visualization in the teaching of freshman electromagnetism. Electromagnetism is a subject that is highly mathematical, and we hope to convey some aspects of the physics visually without the use of advanced mathematics.

Our visualizations are award winning, e.g. we have a Semifinalist entry in the NSF/Science Magazine Science and Engineering Visualization Challenge for 2003 (see http://www.nsf.gov/od/lpa/events/sevc/results.htm).

These visualizations are for three purposes.

1. To help you with the geometric issues that arise in electromagnetism. Because we use cross products, the subject is innately three-dimensional, so 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 itself. In particular, we show a lot of animations that indicate the direction of electromagnetic energy flow. This direction is always given in electromagnetism by the Poynting vector, \( \mathbf{S} = \frac{1}{\mu_0} \mathbf{E} \times \mathbf{B} \). We will expand on this as we move along in the course.
A lot of the material today you have not seen yet, we just want to get you familiar with why they are there and what you can use them for as we go along in the course.

PLATFORMS

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

1. Movie files, which should run on Athena, Windows PCs, and MACs
2. Java 3D Applets, which should run on Athena, Windows PCs, but not MACs
3. Macromedia ShockWave files, which run only on Window’s PCs and MACs.

If your computing resources do not include one of these platforms, use the Athena PC Cluster in 37-312. This Cluster is heavily used during the day for classes, but is available outside of scheduled classes. For the availability of this room, check http://web.mit.edu/windows/cluster/calendar/.

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. Go to L02, then to “Current Assignment”, and then choose “Visualizations” on the left navigation bar. That will bring you to the TEAL visualizations page.

![Figure 1](http://web.mit.edu/8.02T/www/802TEAL3D/)

Select “Vector Fields” from the links on the right.
**Coordinate Systems**

Select the Shockwave on the 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 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/](http://web/mit.edu/8.02T/www/802TEAL3D/) (see Figure 1 above). Now choose electrostatics, 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

\[
\vec{E} = k_e \int \frac{dq}{r^2} \hat{r}
\]  

(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

\[
\vec{E} = k_e \sum_i \frac{q_i}{r_i^2} \hat{r}_i
\]  

(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 keyboard input**

Go to [http://web.mit.edu/8.02t/www/simulations/grass_seeds.htm](http://web.mit.edu/8.02t/www/simulations/grass_seeds.htm) and play with the applet at that link.

Try the vector function \( \vec{F}(x,y) = -y^2 \hat{i} + x \hat{j} \) in the grass seeds applet. Does the result look like what you expect?

**PART 3. PHYSICS**
**Charged Particle Motion In An Ion Trap**

Go to the page


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

\[
\vec{E} = -\frac{E_0}{d}\vec{r}
\]  

(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 3:** 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?

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**Charged Particle Motion Near A van de Graaff**
Go to the page


This is a visualization of the motion of a particle repelled by the charge on a van de Graaff. The motion of the “grass seeds” is in the direction of the energy flow in the electromagnetic field. As the charge moves away from the van de Graaff, you see that energy is flowing from the field to increase the kinetic energy of the particle. As the charge moves toward the van de Graaff, you see that the energy flows from the kinetic energy of the charge to the field. We will discuss this whole process in detail when we are more sophisticated at the end of the term.

**Crystal Formation**

Go to the http://evangelion.mit.edu/oxford/index.htm and select the “Lattice Collisions Program” link. This is a visualization of the motion of a two $4 \times 4$ lattices colliding. Press “start”. Let the lattices collide and then let them settle down. Add a particle by pressing “p”. Select the particle you have added by “shift-right-clicking”. Add field lines to that particle after it is selected by pressing “f”. Use the new particle to move around the lattice and try to bend it at the middle. Do this slowly and you can deform the structure into something like an “L”.

The particles in this simulation interact via the classical Coulomb force, as well as a repulsive quantum-mechanical Pauli force, which acts at close distances (accounting for the “collisions” between them). Additionally, the motion of the particles is damped by a term proportional to their velocity, allowing them to “settle down” into stable (or meta-stable) states.

If there is time, play with some of the other shockwave particle visualizations at http://evangelion.mit.edu/oxford/index.htm
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? What now is the total number?

**Answer:**