**WEEK 1: Go to class 1, 2**
Homework assignments

***SOME USEFUL REFERENCE STUFF:*** Greek alphabet, metric prefixes, conversion factors

Electric pickle
http://www.youtube.com/watch?v=tMhXCG6k6oA

Elementary charge humor
This neutron walks into a bar and orders a beer.
The bartender gives him a beer and the neutron asks "How Much?"
And the bartender replies "For you, no charge!"

Two atoms were walking down the street and one says to the other "I think I lost an electron."
So the second atom asks "Are you sure?" And the first atom replies "Yeah, I'm positive!"

We don't allow faster than light neutrinos in here, said the bartender.
A neutrino walks into a bar.

Coulomb's Experiment
http://www.youtube.com/watch?v=6wINp468p1k

**CLASS 1:**
OPENING COMMENTS: Overview, syllabus, this book, these notes, other on-line resources

This file is an attempt to provide some class notes to supplement your own notes from class, or to provide you with an overview of the material *before* class. If it works, great. If not, then we'll use our time productively doing something else. Either way, please let me know whether you find these notes useful.

**"ADVERTISEMENT", p. xi**
This part of the book, right after the preface (one of the last places you would expect to find useful information) actually has some very useful information. Here's what I think is important. First of all, there is the list of four fundamental forces. This is something you should know, independent of this course. But you should also have an idea of the relative sizes of these four forces (which is not given by the text). Below is a table of the relative strengths of the four forces.

| | |
|---|---|
| Strong nuclear force | = 1 |
| Electromagnetic force | $= 10^{-2}$ |
| Weak nuclear force | $= 10^{-6}$ |
| Gravitational force | $= 10^{-38}$ |

These values are only approximate: take them with a grain of salt, because two electrons, for example, having the same electromagnetic force between themselves as two protons, will not have the same gravitational force. Still, this gives you a general idea of the relative sizes. The second thing to take from this "advertisement" is its description of the "field formulation" of electrodynamics. What is *this* all about? Well, we will begin Chapter 2 by describing the force between two charges. But how do these two charges interact if they're not even touching? One way of approaching this is to postulate a field that permeates all space which is produced by one of the charges, and acts on the other. This is what we mean by the field formulation. So, for one thing, it allows us to shift the "blame" for the electrostatic force from an electric charge to the field produced by that charge. The other thing it allows us to do is to look at the collective effect of a collection of charges, or even a continuous charge distribution in some region of space without having to consider each individual charge responsible for it.

The third thing in the "advertisement" is a list of properties of electric charge. The book gives three, I will give you an extra one at no extra "charge". These properties are

1) Charge comes in two types or "flavors", arbitrarily called positive and negative.
2) Charge is conserved.
3) Charge is quantized. For our purposes, charge always comes in multiples of $1.602\times10^{-19}C$, the magnitude of the charge of an electron.
4) Charge is relativistically invariant. We shall come back to this near the end of this course.

The final thing to take from this "advertisement" is the subject of units. The textbook for this course is written in SI units, also known as MKS units (i.e. meters, kilograms, and seconds). The other principal competing system of units for measuring electric fields are known as CGS units for centimeters, grams, and seconds. For decades we used a marvelous textbook for this course that, unfortunately, used CGS units. Feel free to thank me at some point during the semester for switching textbooks, as our students always hated having to convert between the two systems of units, especially since the units for resistance and capacitance in CGS units were S/cm and cm, rather than ohms and farads. (Just try finding a 100S/cm resistor in our stockrooms.)

Even within the SI units, you will need to get used to some "formula conversions": you may recall Coulomb's constant, $k = 9\times10^9\,N\cdot m^2/C^2$ from Introductory Physics. This book often uses the expression $\frac{1}{4\pi\varepsilon_0}$ in place of *k*. Become familiar with this equality ($k = \frac{1}{4\pi\varepsilon_0}$) now, and you will save yourself having to ever look up a value for $\varepsilon_0$ -- the "permittivity of free space" -- again.

**CHAPTER 1: VECTOR ANALYSIS**

We will skip this chapter in this course (This is because Mathematical Physics is a prerequisite for this course.) but we'll come back to use its results from time to time in the course of this book. Familiarize yourselves however with the various vector derivatives, vector identities, and fundamental theories in the inside front cover of your textbook. At the very least, know where to look for them when you need them.

**CHAPTER 2: ELECTROSTATICS**

COULOMB'S LAW, Section 2.1.2

A recurring theme in all of Physics is that, in order to understand a complex phenomenon, you start with the simplest instance of that phenomenon, and then add as much complexity as you need later. And so we will start with the simplest electronic interaction, namely the force between two charges, also known as Coulomb's law.

$$\vec{F} = \frac{kQq\hat{\mathscr{r}}}{\mathscr{r}^2} \qquad\qquad \vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{Qq\hat{\mathscr{r}}}{\mathscr{r}^2}$$

Aside from the obvious importance of learning the equation itself, there are few other items that I want you to pay attention to. First, it is important to notice the difference between the source charge, q, and the test charge, Q. This may seem to you like tedious intellectual pedantry, particularly because the force exerted on either charge by the other charge is equal and opposite from Newton's third law. But I will insist on the making this distinction because it comes in handy later on.

The next seemingly hairsplitting thing I'll ask you to remember is to use a curly r for the distance between the two charges. Why? Because there are several different position vectors of importance here: the position of the test charge, $\vec{r}$, the position of the source charge, $\vec{r}\,'$, and the difference between the two of them, $\vec{\mathscr{r}} = \vec{r} - \vec{r}\,'$. This distinction becomes critically important when we start to consider charge distributions, and have to integrate over the coordinates of the *source* (not *test*) charges.

Just one aside that I may or may not bring up in class: in CGS units, the big difference in Coulomb's law is the absence of a constant in front (i.e. $k = \dfrac{1}{4\pi\varepsilon_0}$ ). The price we pay for this simplicity is that the CGS units of charge, also known as the electrostatic units or esu, are different from the SI units of Coulombs. (1 esu = 1/3 nC.)

## SUPERPOSITION AND SYMMETRY

OK, now how do we reintroducing complexity to this problem? We can consider the forces acting on one [test] charge due to several other [source] charges. We can no longer use Coulomb's law as stated, but we can add the effect of more than one source charge on a single test charge, as long as we add the effects as vectors. If I give you a collection of say four charges sitting on the corners of a square and I ask you for the force on one of them, then it is important for you to separate the charges in your thinking into one "test charge", and the other "source" charges. Add together the vector forces of each source charge on the single test charge, and you get the total force on the test charge. The trick of course is adding the vector forces due to each “source” charge. As you probably recall, this requires you to break each factor into its x-, y-, and maybe z- components, add those components separately, and then find the magnitude and direction of the resulting force.

**CLASS 2**

THE ELECTRIC FIELD, Section 2.1.3

Now we will introduce something called the electric field. Why? There are a number of different motivations for introducing this concept. First of all, we might be trying to describe and/or predict the force on some charge as it enters some region of space without having to catalogue every source charge that bears some responsibility for that force. Or suppose that we want to characterize in some region of space by introducing some test charge and noticing the force that it experiences at different locations.

Here's a stupid analogy: We are trying to separate out how much of the *effect* (force) on the charge is due to each separate *cause*: its own charge and its "environment". This is like the "nature vs nurture" debate on human behavior: how much is our own behavior predetermined by our own genetics, and how much is determined by our environment? At least in electrostatics, the answer is pretty much cut-and-dried.

Now, since Coulomb's law says that the force acting on a test charge *Q* is proportional to its charge, the force acting on a test charge due to a collection of charges will also be proportional to *Q*. We can say that this force is due jointly to the test charge's charge *Q* and to its environment, as described by a vector field we will denote as $\vec{E}$. (So, both “nature” and “nurture”.) And that is, $\vec{F} = Q\vec{E}$. Now in the real world, that test charge produces its own electric field in its own vicinity, and so to be more precise, we would say that the electric field $\vec{E}$ is equal to the limit, as *Q* approaches zero, of $\vec{F}$ /Q.

$$\vec{E} = \frac{kq\hat{\mathscr{r}}}{\mathscr{r}^2} \qquad \vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q\hat{\mathscr{r}}}{\mathscr{r}^2}$$

Now consider calculating the electric field due to a collection of say two or three different charges. Just as for calculating the force due to a collection of charges, we add the contributions from each source charge vectorially. We will do some examples in class and in the homework.

CONTINUOUS CHARGE DISTRIBUTIONS, Section 2.1.4

The interesting mathematics comes when we look at distributions of charge. (We can go onto a philosophical tangent about what is meant by a continuous distribution of charge when we've already just said that charge is quantized. But as long as we consider distributions of charges that are much larger than the distances between atoms, we are safe to use this approximation.) There are three types of distributions that we will consider. In these we will consider an increment of charge to be proportional to (a) an increment of distance, (b) an increment of area, and (c) an increment of volume.

$$dq = \begin{cases} \lambda\, dl \\ \sigma\, da \\ \rho\, d\tau \end{cases}$$

To calculate the electric field due to any of these three types of distributions, simply integrate the vector equation, replacing *q* with whichever version of *dq* above is most appropriate to the charge distribution of the specific problem.

TIPS FOR INTEGRATION

There are a number of integrations that come up again and again, and so we will spend some time in class practicing these. I will expect you, at exam time, to be able to do all of these basic integrations. Here are the most common, basic integrations:

Cartesian symmetry: $d\tau = dxdydz$ , $da = dxdy$ or $dxdz$ *or* $dydz$

2D polar symmetry: $da = rdrd\theta$

Thin ring: (Integrate the above over $\theta = 0$ *to* $2\pi$) $da = 2\pi rdr$

3D spherical symmetry: $d\tau = r^2 \sin\theta dr d\theta d\phi$

Hollow shell (integrate the above over $\varphi$ and $\theta$): $d\tau = 4\pi r^2 dr$

Here are some of the problems that we may do, or that I may assign to students to do on the board: (a) using the expression above for a thin ring, calculate the area of a circular disk, (b) using the expression above for the area of a hollow three-dimensional shell, calculate the volume of a sphere. By the way, these two results are results that you should memorize, or if you have a hard time it memorizing them, you should write them down somewhere where you can find them quickly. I will assume in all exams that you know the area and circumference of a circle, and the volume and surface area of a sphere, as well as other common geometrical lore.

In class we will do a bunch of examples, probably including problems 3-7 from the book. Notice that for problem 4, we can use the results of problem 1. This is something I want you to learn quickly about this book: it is structured in such a way that a lot of the later problems build on earlier problems. I want you to see how we build up our tool kit of useful results from simpler problems. You should be working towards doing that yourself. Familiarize yourself with the simplest problems, and be able to apply them to more complicated problems.

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Go to YSBATs

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And now for something completely different:

*"Electricity"*: Captain Beefheart & the Magic Band
http://www.youtube.com/watch?v=HE32tcojArI