MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

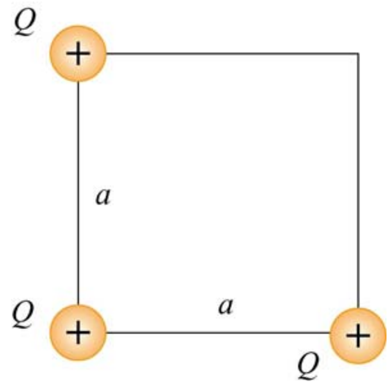
8.02 **Fall 2007**

Turn in at your table labeled with your name and group (e.g. L01 6B)

Problem Set 3

Due: Wednesday, September 26 at class beginning (before 10:15/12:15)

<u>Warm Up</u>
Problem 1: Charges on a Square



Three identical charges $+Q$ are placed on the corners of a square of side a, as shown in the figure.

(a) What is the electric field at the fourth corner (the one missing a charge) due to the first three charges?

(b) What is the electric potential at that corner?

(c) How much work does it take to bring another charge $+Q$ from infinity to that corner?

(d) How much energy did it take to assemble the pictured configuration of three charges?

Problem 2: Electric Potential

Suppose an electrostatic potential has a maximum at point P and a minimum at point M.

(a) Are either (or both) of these points equilibrium points for a negative charge? If so are they stable?

(b) Are either (or both) of these points equilibrium points for a positive charge? If so are they stable?

<u>Exam Problem</u>

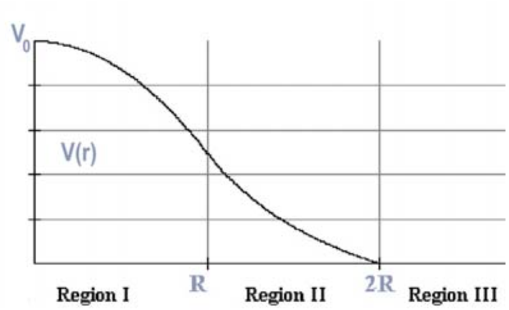
Problem 3: A potential for finding charge

The electric potential *V(r)* for a distribution of charge with spherical symmetry is:

Region I: $V(r) = -\dfrac{V_0 r^2}{2R^2} + V_0$ for $0 < r < R$

Region II: $V(r) = \dfrac{V_0 R}{r} - \dfrac{V_0}{2}$ for $R < r < 2R$

Region III: $V(r) = 0$ for $r > 2R$



Where V_0 is a constant of appropriate units. This function is plotted to the right.

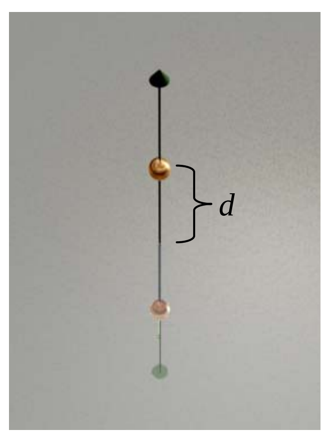
(a) What is the electric field $\vec{\mathbf{E}}(r)$ for this problem? Give your answer analytically for the three regions above and also plot the magnitude. Be sure to indicate the maximum value on the vertical axis for E.

(b) Use Gauss's Law arguments to determine the distribution of charges that produces the above electric potential and electric field. When making a Gauss's Law argument, state the Gaussian surface you are using and what you conclude about the charge distribution by applying Gauss's Law to that surface.

<u>Analytic Problems…</u>

Problem 4: Reflecting on a Conducting Plane

A charge *q* lies a distance *d* above an infinitely large, uncharged, perfectly conducting, shiny piece of metal. (As you know from the first lab, conductors are equipotential surfaces).



(a) Draw this in a 2D view (as opposed to the perspective of the picture at right) and sketch some field lines. Pay close attention to (i.e. comment on) what they do when they hit the conductor.

(b) What is the electric field at the surface of the conductor directly beneath the point charge. HINTS: (1) From your field lines it should be clear that this is not just the field from the point charge. The conductor is doing something! (2) Your field lines should look familiar. What does your picture remind you of? If the field lines are the same then the field is the same!

(c) What is the magnitude of the electric field at the surface of the conductor as a function of distance *r* (in the plane) from the point just below the charge?

(d) What is the force (magnitude and direction) on the charge?

Problem 5: Dipole

Consider two equal but opposite charges, both mass m, on the x-axis, $+Q$ at $(a, 0)$ and $-Q$ at $(-a, 0)$. They are connected by a rigid, massless, insulating rod whose center is fixed to a frictionless pivot at the origin. This is a dipole. A uniform field $\vec{\mathbf{E}} = E\hat{\mathbf{i}}$ is now applied.

(a) What is the force on the dipole due to this external field?

The dipole is rotated and held at a small angle θ_0 (positive clockwise) from the x-axis.

(b) Now what is the force on the dipole?

(c) How much did the potential energy of the dipole change when it was rotated?

(d) What is the torque on the dipole?

(e) Now the dipole is released and allowed to rotate due to this torque. Describe the motion that it undergoes (i.e. what is its angle $\theta(t)$?) HINT: Make an approximation that makes this very straightforward. HINT 2: Remind yourself of rotational motion

Problem 6: Line of Charge

Consider a very long conducting rod, radius R and charged to a linear charge density λ.

a) Calculate the electric field everywhere outside of this rod (i.e. find $\vec{\mathbf{E}}(\vec{\mathbf{r}})$).

b) Calculate the electric potential everywhere outside, where the potential is defined to be zero at a radius $R_0 > R$ (i.e. $V(R_0) \equiv 0$)

<u>Approximations, Fermi Problems, Back of the Envelope Calculations…</u>

Problem 7: Stupid Hobbies…

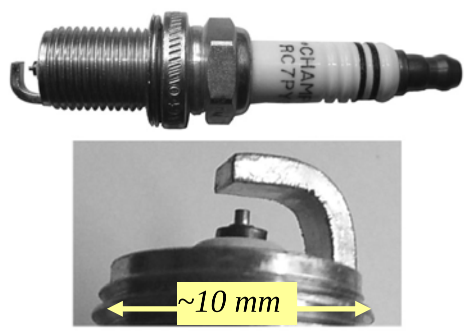
Some people like to do incredibly dangerous things. Like a guy I went to grad school with, Austin Richards (also known as Dr. Megavolt – see a movie of him at http://www.drmegavolt.com/index_gallery.html). Or Criss Angel, who performed a similar stunt on the "Tesla Coil" episode of his show *Mindfreak*. Here are some pictures.

Pictures care of http://www.mindfreakconnection.com/

You'll note that while Dr. Megavolt takes strikes directly from the Tesla Coil (a device capable of making insanely high voltages), Criss Angel decides to get shocked from a small ball attached to the coil instead – convenient for the purposes of answering this question. At about what voltage was the Tesla coil for the strikes pictured above and about how much excess charge was on his hand (in the right picture) the instant before the strike was initiated?

(HINT: Dry air breaks down at an electric field strength of about 3×10^6 V/m)

Problem 8: Spark Plug



Pictured at right is a typical spark plug (for scale, the thread diameter is about 10 mm). About what voltage does your car ignition system need to generate to make a spark, if the breakdown field in a gas/air mixture is about 10 times higher than in air? For those of you unfamiliar with spark plugs, the spark is generated in the gap at the left of the top picture (top of the bottom picture). The white on the right is a ceramic which acts as an insulator between the high voltage center and the grounded outer (threaded) part.

Problem 9: High Voltage Power Lines

Estimate the largest voltage at which it's reasonable to hold high voltage power lines. Then check out this video, care of a Boulder City, Nevada power company. (Hint: A few problems on this problem set should give you suggestions on how to approach this problem).