Massachusetts Institute of Technology - Physics Department

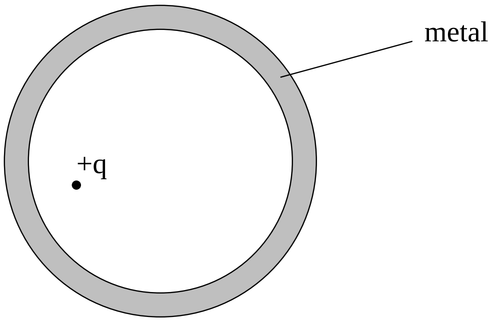
Physics - 8.02 **Assignment #2** February 15, 2002.

***Do yourself a favor and prepare for lectures!***
We recommend strongly that you read about the topics before they are covered in lectures. To read through the new concepts (in half an hour or so) **before the lectures** would be a great help to you! Thorough reading and studying the material, of course, is needed before you start the problems.

| Lecture Date | Topics Covered | Reading from Giancoli |
|---|---|---|
| #6 Tue 2/19 | High-voltage breakdown - Lightning<br>*Sparks - St Elmo's Fire (take notes in lecture)* | Page 591, Page 596 Example 23-5, Page 643 Example 25-9 |
| #7 Wed 2/20 | Capacitance - Field energy | Chapter 24 through Sect. 24-4 |
| #8 Fri 2/22 | Polarization - Dielectrics<br>The Van de Graaff - More on Capacitors | *Lecture Supplement (available on 8.02 web site)*<br>Sect. 24-5 & 24-6 & page 1115 |

***Due before 4 PM, Friday, February 22 in 4–339B.***

**Problem 2.1**
*Electric field of a point charge inside a hollow metallic sphere - Gauss's Law in action.*
A hollow metallic sphere is initially uncharged. Now imagine that a positive concentrated charge $q$ is placed somewhere (not in the middle) inside the sphere without touching the walls.




(a) Qualitatively, what is the charge distribution on the inner surface of the metal and what is it on the outer surface? Indicate (make a sketch) the relative concentration of induced surface charge densities using the symbols $+$ and $-$. Make a fairly careful sketch of the electric field lines inside and outside the sphere.

(b) Suppose that you move the charge $q$ around inside the cavity. Does the charge distribution on the outer surface of the sphere change? Explain your answer.

(c) You now bring the point charge $q$ in contact with the *inner* surface of the sphere. What is the charge distribution then on the inner surface and on the outer surface? Make a fairly careful sketch of the electric field lines inside the sphere and outside.

**Problem 2.2**
*Electric field and potential of a charged cylinder.*
Consider a very long cylinder of radius $a$ with its axis along the $z$-axis of a cartesian coordinate system. The cylinder is uniformly charged; its constant *volume* charge density is $\rho$ (positive).

(a) Using symmetry arguments show that $\vec{E}$ should be radial both inside and outside the cylinder.

(b) Using Gauss's Law find the magnitude of $E$ as a function of $r$, for $0 \le r \le a$, and for $r > a$. Do the two results match at $r = a$?

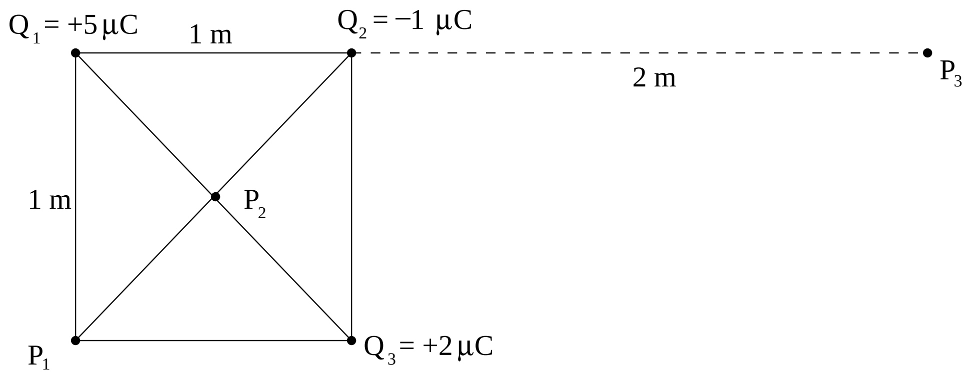
*Hint: for $0 \le r \le a$, figure out first how much charge $Q(r)$ is contained within a cylindrical gaussian surface of radius $r$ and length $\ell$. Of course, the axis of the gaussian surface should coincide with that of the cylinder; if it didn't, it wouldn't help you to solve the problem!*

(c) Using your answers in part (b) calculate the potential difference, $\Delta V$, between a point at a distance $r$ from the $z$-axis and a point on the $z$-axis. Make a qualitative plot of $\Delta V$ as a function of $r$ for all $r$'s ($0 \le r < \infty$).

**Problem 2.3**
*Electric Field, Potential, and Electrostatic Potential Energy.*
Giancoli 23-66.

**Problem 2.4**
*Electric Field, Potential, and Electrostatic Potential Energy.*
*This problem contains (just about) all the new concepts introduced so far.*

Point charges $Q_1$, $Q_2$, and $Q_3$ reside on three corners of a square with sides of 1 m; the distance from $Q_2$ to $P_3$ is 2 m (see diagram).




(a) What is the electric potential, $V$, in $P_1$, $P_2$, and $P_3$? (Normalize the potential to be zero at $\infty$).

(b) Are there points or surfaces in space (other than infinity) where $V$ is zero?

(c) There are two points where the electric field equals zero. Could you guess approximately where these points are? State your reasons.

(d) Sketch roughly the electric field lines.

(e) What is the electrostatic potential energy of the system?

(f) Suppose we release the three charges so that they can move freely in empty space. How much energy is released in the form of kinetic energy? Does it matter in what sequence one releases the charges? *Don't be too hasty in answering this last question!*

**Problem 2.5**
*Electric potential of flat ring with hole in its center.*
Giancoli 23-78. Assume that the charge $Q$ is uniformly distributed.

**Problem 2.6**
*Electric breakdown fields. This problem may help you qualitatively to understand why the observed value of the breakdown field in air (1 atm) is of the order of* $10^6$ *V/m. Recall from the lectures that it takes about* 10 *eV to ionize an air molecule.*
Under standard conditions of temperature and pressure, dry air will break down (i.e., lose its insulating quality), and sparking will result when the electric field exceeds about $3 \times 10^6\,\mathrm{V/m}$.

(a) Suppose that we wish to maintain an isolated metallic sphere at $-4000\,\mathrm{V}$. What is the minimum radius of the sphere for which there is no sparking?

(b) At this minimum radius, what is the total charge on the sphere?

(c) Now consider a free electron in the air, very near the charged sphere. If the electron is initially at rest, what radial distance will it travel before reaching a kinetic energy of 10 eV? Assume that no collision with the air molecules takes place during this interval of travel.

(d) Compare your answer in (c) with the typical electron mean-free path in air which is about $10^{-6}\,\mathrm{m}$.
*Note: the mean free path is the distance that a particle travels on average between two successive collisions; it is an experimentally measurable quantity.*

**Problem 2.7**
*5.2 keV protons.*
Giancoli 23-72.

**Problem 2.8**
*Dropping charged objects in the Earth' electric field.*
Giancoli 23-74.

**Recitations.**

There are 28 recitation sections (see the 8.02 Website). If *for any reason* you want to change section, please see Maria Springer in 4-352.