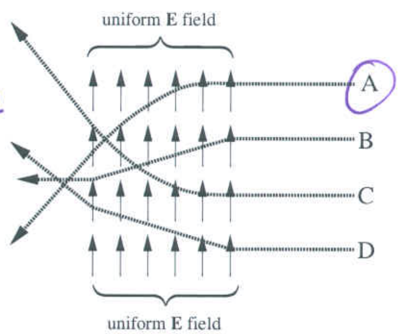
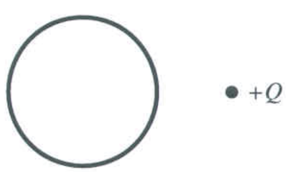
Select the letter of the single best answer. Each answer is worth 1 point.

Physical Constants:
proton charge $= e = 1.60 \times 10^{-19}$ C
proton mass $= m_p = 1.67 \times 10^{-27}$ kg
electron mass $= m_e = 9.11 \times 10^{-31}$ kg
permittivity $= \varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$
Coulomb constant $= k = 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$

1. An electron is moving at high speed through a field-free region. It enters (and soon exits) a region in which the electric field points up. Which path best represents the path of the electron?



2. The figure below shows a hollow conducting metal sphere which was given initially a positive (+) charge on its surface. Then a positive charge $+Q$ was brought up near the sphere as shown. What is the direction of the electric field at the center of the sphere after the positive charge $+Q$ is brought up near the sphere?

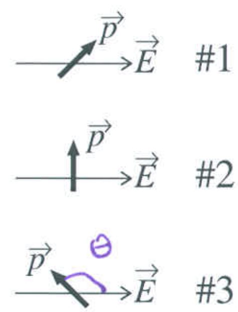


   A. Right
   B. Left
   C. Zero field
   D. None of the above

3. There is no net charge on a conducting sphere. The force between a nearby positively charged rod and the sphere is:

   A. zero
   B. attractive
   C. repulsive
   D. at first repulsive, but then attractive

4. The following figure shows three different configurations of an electric dipole $\vec{p}$ placed in a uniform electric field $\vec{E}$. Which of the below options best describes the relationship between the magnitude of the torque experienced by the dipole in these configurations. (τ_1 denotes the magnitude of the torque in configuration #1, etc.)

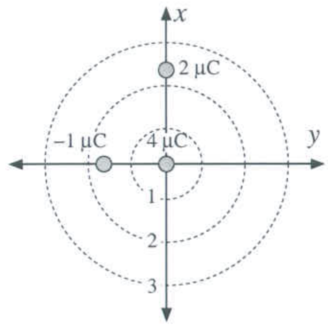


   A. $\tau_1 > \tau_2 > \tau_3$
   B. $\tau_1 < \tau_2 < \tau_3$
   C. $\tau_1 = \tau_2 = \tau_3$
   D. $\tau_1 = \tau_3 < \tau_2$

5. Consider the potential energy of the electric dipole in the uniform electric field of the previous problem. Which of the below options best describes the relationship between the potential energy of the dipole in these configurations. (U_1 denotes the potential energy in configuration #1, etc.)

   A. $U_1 > U_2 > U_3$
   B. $U_1 < U_2 < U_3$
   C. $U_1 = U_2 = U_3$
   D. $U_1 = U_3 < U_2$

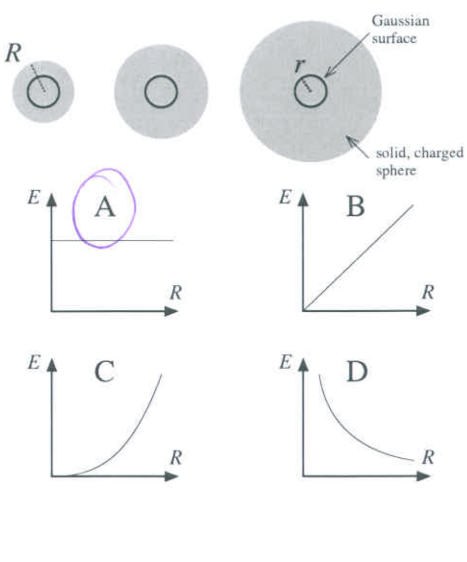
6. The below figure shows the location and charge on three tiny conductors sitting in the xy plane. Consider the electric flux ($\Phi_E = \oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}}$) through three Gaussian spheres centered on the origin with radii as shown in the figure. Which of the below options best describes the relationship between the flux through these three spheres. (Φ_1 denotes the electric flux through sphere 1, etc.)



A. $\Phi_1 > \Phi_2 > \Phi_3$
B. $\Phi_1 < \Phi_2 < \Phi_3$
C. $\Phi_2 < \Phi_1 < \Phi_3$
D. $\Phi_2 < \Phi_1 = \Phi_3$

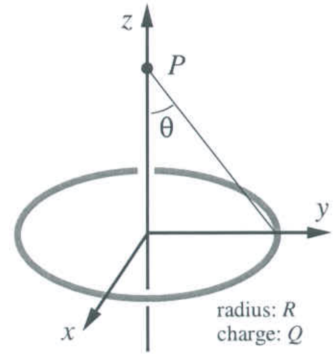
Gauss enclosed charge

7. The below figure shows three uniformly charged solid spheres with different radii (R) but the same volume charge density ρ. Consider the electric field E on the surface of identical Gaussian spheres of radius r. (Note that in all cases: $r < R$, i.e., the Gaussian sphere lies fully within the charged ball.) Which of the the below graphs best displays how E at r depends on the radius R of the charged ball?



enclosed charge

8. A uniformly charged ring (radius R, total charge Q) sits in the xy plane with its center at the origin. Consider the problem of finding the electric potential, V, directly above the center, i.e., on the z axis at a point $P = (0, 0, z)$.



A. Since the distance from the center determines the potential:

$$V = \frac{Q}{4\pi\epsilon_0 z}$$

B. Since all of the charge is the same distance from P:

$$V = \frac{Q}{4\pi\epsilon_0\sqrt{R^2 + z^2}}$$

C. Since the V field is in the z direction we need to include the angle:

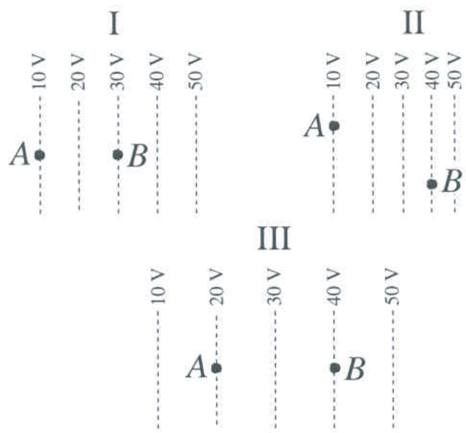
$$V = \sum V_z = \frac{Q}{4\pi\epsilon_0\sqrt{R^2 + z^2}} \cos\theta$$

D. Since the V field is in the z direction we need to include the angle:

$$V = \sum V_z = \frac{Q}{4\pi\epsilon_0\sqrt{R^2 + z^2}} \sin\theta$$

Voltage is not a vector!

9. The following figures faithfully show (with one-to-one scale) the location of equipotential lines (displayed as the dotted lines with corresponding voltages). In each case, an object with charge $+1\ \mu$C is moved from A to B.



Which of the below statements best describes the amount of work needed to move this charge in the three cases.

A. The smallest work is required in I.

B. The largest work is required in II.

C. The largest work is required in III.

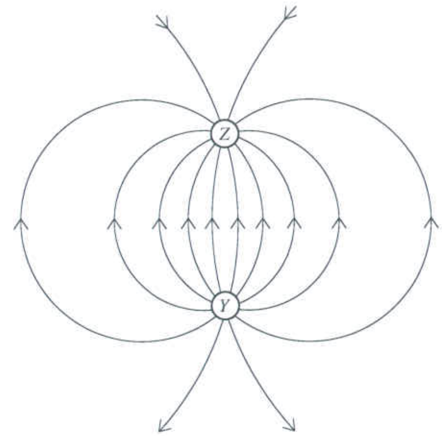
D. All three require the same amount of work.

this is the opposite of the work done by $\vec{E}$

work needed = $\Delta U = q\,\Delta V$

ΔV largest in II

10. The following diagram shows the electric field lines in a region of space containing two small charged spheres (Y and Z). Which of the below statements best describes this situation.



A. Y carries a positive charge; Z carries a negative charge.

B. The strongest electric field is midway between Y and Z.

C. Both of the above.

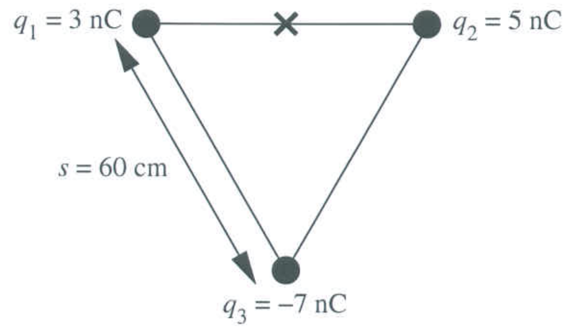
D. None of the above.

The following problems are worth 10 points each

11. As shown below three charges are arranged in an equilateral triangle with side 60 cm.

A. Find the electric field vector at the spot marked X (i.e., the mid-point of the horizontal segment).

B. Find the voltage at the spot marked X. (Assume as usual: $V(\infty) = 0$.)



done 1-3

12. A. A uniform volume charge density of $\rho = 1\ \mu\text{C/m}^3$ fills a sphere with radius 4 cm. Consider a cubical Gaussian surface with center coincident with the sphere's center. (i) What is the electric flux through this cubical surface if the cube's edge length is 1 cm? (ii) What is the electric flux through this cubical surface if the cube's edge length is 10 cm?

B. A uniform surface charge density of $\sigma = 1\ \mu\text{C/m}^2$ sits on the surface of a disk with radius 4 cm. Consider a cubical Gaussian surface with center coincident with the disk's center. (i) What is the electric flux through this cubical surface if the cube's edge length is 1 cm? (ii) What is the electric flux through this cubical surface if the cube's edge length is 10 cm?

done 2-3

13. Consider an infinite-length cylinder (radius R) filled with constant charge density ρ material. Using Gauss' Law derive the formula for electric field inside the cylinder (i.e., for $r < R$). Don't forget to report the direction of $\vec{E}$!

day 2-5 textbook problem 22-40

14. A charged wire (linear charge density λ) extends along the positive x axis from the origin to $x = L$. Derive the electric field vector at the point $x = -d$ on the x axis. Don't forget to report the direction of $\vec{E}$!

done 1-5

15. The below diagram shows the equipotentials that result from parallel line conductors. (This is very similar to the equipotentials you studied in the last lab, although here we have a different configuration of conductors.) The bottom conductor is at 0 V; the top is at 10 V. The voltage on each equipotential is labeled. (A) Calculate the magnitude and draw the direction of the electric field at the point labled A. (Rulers are provided to measure distances). (B) Draw the electric field line that goes through the point labeled B. Don't forget to show direction! (It should connect the bottom and top conductors.)