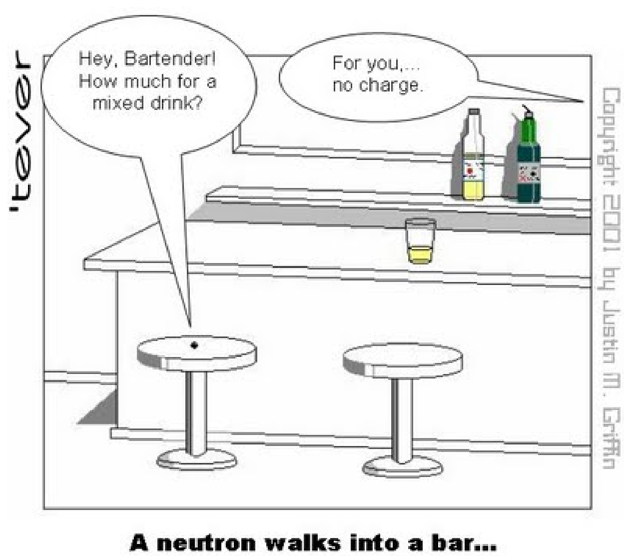
PHYS 2250 Exam I

Thursday, October 15, 2020

> ***Instructions***: *You will have at least 2 hours to complete this exam. Take a deep breath and relax! Read each question carefully, and let me know if anything is unclear. Partial credit may be awarded, so you are encouraged to clearly and legibly show your work for each problem. Extra paper is available at the front of the room if you need it. Write your name on every extra sheet you use, and clearly label what problem you are working on. Staple this to the back of your exam when you turn it in. You may use any information contained within this exam, as well as a calculator.*
> *Good luck!*

Name: ____



A neutron walks into a bar...

Potentially useful information

Unit analysis

Power	Prefix	Name
10^{12}	T	tera
10^{9}	G	giga
10^{6}	M	mega
10^{3}	k	kilo
10^{0}	—	—
10^{-3}	m	milli
10^{-6}	μ	micro
10^{-9}	n	nano

Constants

$$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C}^2/\left(\mathrm{N}\cdot\mathrm{m}^2\right)$$

$$\frac{1}{4\pi\epsilon_0} = k = 9 \times 10^{9}\ \mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2$$

$$e = 1.6 \times 10^{-19}\ \mathrm{C}$$

$$m_{proton} = 1.67 \times 10^{-27}\ \mathrm{kg}$$

$$m_{electron} = 9.11 \times 10^{-31}\ \mathrm{kg}$$

Electrostatics

Dipole, on-axis:

$$|\vec{E}| \approx \frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$$

Dipole, perpendicular:

$$|\vec{E}| \approx \frac{1}{4\pi\epsilon_0}\frac{p}{r^3}$$

Uniformly charged disk, central axis:

$$|\vec{E}| = \frac{Q/A}{2\epsilon_0}\left[1 - \frac{z}{\left(R^2+z^2\right)^{1/2}}\right]$$

Capacitor:

$$|\vec{E}| = \frac{Q/A}{\epsilon_0}$$

Uniformly charged shell:

$$|\vec{E}|(r<R) = 0$$

$$|\vec{E}|(r>R)| = \frac{Q}{4\pi\epsilon_0}\frac{1}{r^2}$$

Uniformly charged solid sphere:

$$|\vec{E}|(r<R) = \frac{Q}{4\pi\epsilon_0}\frac{r}{R^3}$$

$$|\vec{E}|(r>R) = \frac{Q}{4\pi\epsilon_0}\frac{1}{r^2}$$

1. At a certain point in space, a point charge with a charge of $+5\ \mu$C experiences a force $\vec{F}=< -1, 2, 0 >$ N.

   (a) What is the electric field vector $\vec{E}$ responsible for this force?

   (b) The original $+5\ \mu$C charge is removed and replaced with another point charge with a charge of $-2\ \mu$C. What is the force $\vec{F}$ (both magnitude and direction) experienced by this new charge?

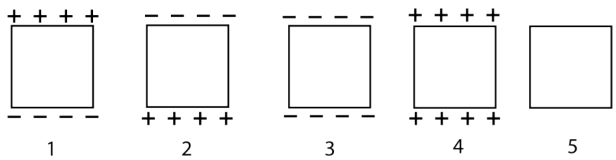
   (c) You find that the charge responsible for this electric field is a point charge with a charge of $-1\ \mu$C. How far away is this charge from the point where $\vec{E}$ was measured?

2. Answer all of the questions

   (a) You hold a negatively charged rod (rod 1) near a second rod (rod 2), which is suspended by an insulating thread, and find that the second rod is attracted to the first one. Which of the following are possible? (Check all that apply)

   ☐ Rod 2 is positively charged
   ☐ Rod 2 is negatively charged
   ☐ Rod 2 is neutral

   (b) In the diagram below, there is an electric field in the upward direction due to charges not shown. Which diagram best describes the charge distribution on a neutral metal block?

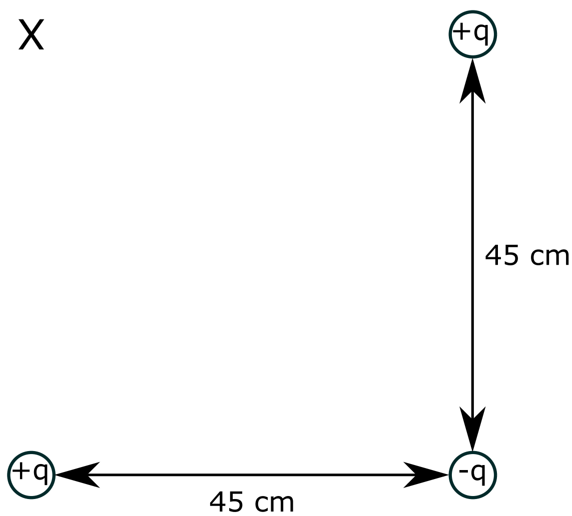


   (c) Which of the following are true statements? (Check all that apply)

   ☐ In equilibrium, the average velocity of electrons $\bar{v}$ within a metal is 0
   ☐ The electric field inside of a metal is 0 under all circumstances
   ☐ Excess charge on an insulator cannot reside on the surface
   ☐ Conductors cannot be polarized
   ☐ In a metal any excess charge must be on the surface

   (d) Which is a better test of the existence and sign of the charge on an object, repulsion or attraction to a charged tape? Why? Explain briefly but clearly.

3. Three charges with the same magnitude, two positive and one negative, are arranged as shown in the figure.

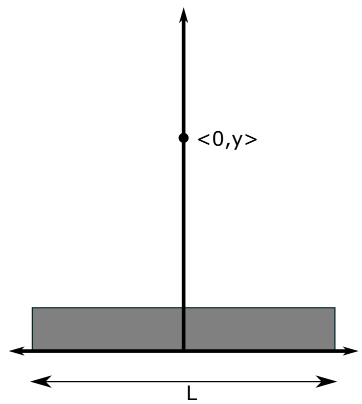


(a) Find the electric field vector $\vec{E}$ at the top left corner of the figure. Let $q = 2\ \mu$C.

(b) Still using $q = 2\ \mu$C, find the electric potential (i.e., the potential difference relative to infinity) at the top left corner of the figure.

4. A thin, uniformly charged rod of length L carrying total charge Q lies on the $x-$axis, centered on the origin.

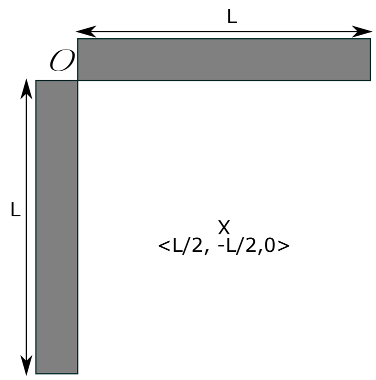
   (a) Neglecting the thickness of the rod, write an expression for the electric field $\vec{E}$ of the rod at a point along its central axis (the $y-$axis). You may leave your expression in integral form.



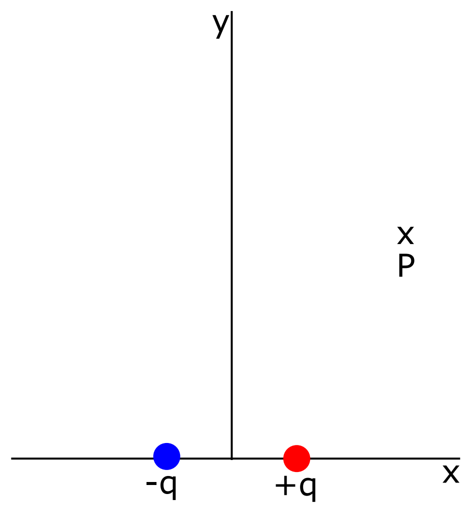
(b) If your expression from part (a) is correct, the integral evaluates to

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\left[\frac{Q}{y\sqrt{y^2+(L/2)^2}}\right]\hat{y}$$

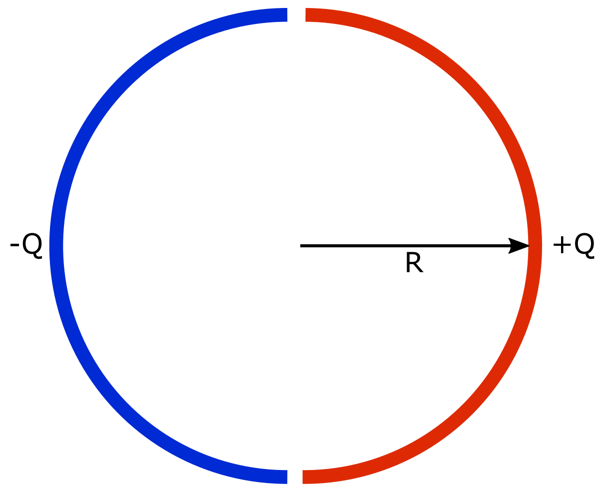
Where y is the vector pointing from the center of the rod to a point along its perpendicular axis.
Use this information to answer the following question:
Two thin, uniformly charged rods, both with length L =4 cm and charge Q =6 μC, have their ends at the origin and lie perpendicular to one another as shown in the figure. What is the force $\vec{F}$ on a proton placed at the point $< L/2, -L/2 >$ (the intersection of the axes of the rods)?



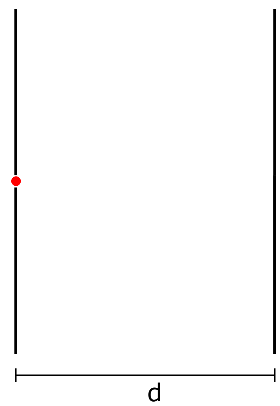
5. A dipole with dipole moment $p = 6 \times 10^{-30}$ C·m is centered at the origin.The two charges are separated by a total distance of 4×10^{-12} m, with the positive charge lying on the positive side of the $x-$axis. What is the electric field $\vec{E}$ at the point $P = < 8 \times 10^{-12}, 5 \times 10^{-12}, 0 >$ m?



6. An insulating ring of radius R is arranged such that one half has charge $+Q$ uniformly distributed and another half has charge $-Q$ uniformly distributed. What is the electric field vector $\vec{E}$ at the center of the ring?



7. A proton is released from rest at one end of a capacitor with area $A = 4$ cm^2 and begins to accelerate. At the other end of the capacitor, the velocity of the proton is 3×10^3 m/s. The plates of the capacitor are separated by a distance $d = 0.5$ mm.



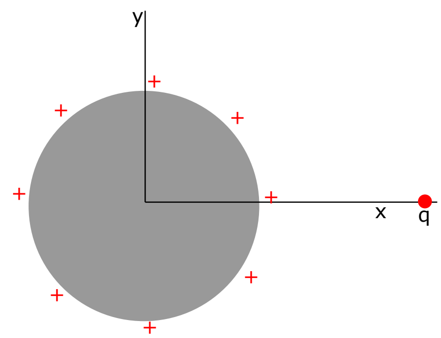
(a) What is the potential difference ΔV of the right plate relative to the left one?

(b) What is the magnitude and direction of the electric field inside the capacitor?

(c) What is the charge on each capacitor plate? Which plate, right or left, carries negative charge?

(d) An electron is shot through the tiny hole on the left side of the capacitor with an initial speed of 8×10^5 m/s moving from left to right. What is the velocity of the electron at the right plate?

8. An insulating sphere of radius $R = 1$ cm lies with its center at the origin. The sphere has positive charge of $Q = 5\ \mu$C spread uniformly over its surface. A point charge with charge 8 μC lies on the $x-$axis at $< 1.5, 0, 0 >$ cm. You may neglect the polarization of the insulator (assume the polarizabilityα is 0)



(a) What is the net electric field at the point $< 0, 0.5, 0 >$ cm (inside the sphere)?

(b) What is the net electric field at the point $< 0, 5, 0 >$ cm (outside the sphere)?

(c) The insulating sphere is now replaced with a conducting sphere with the same charge ($Q = 5\ \mu$C). What is the net electric field at the point $< 0, 0.5, 0 >$ cm?

(d) What is the induced electric field due to the polarized conductor at $< 0, 0.5, 0 >$ cm?