- Print your name and student number (9 digit Georgia Tech ID number) in the spaces below.
- You may use a calculator that cannot store letters, but no other aids or electronic devices.
- Free-response questions are numbered I–III. Show all your work clearly, including all steps and logic. Do not write in the top margin. Box your answer. Make no marks and leave no space on your answer sheet.
- Multiple-choice questions are numbered 1–7. For each, select the answer most nearly correct, circle this answer on your quiz, and bubble it on your answer sheet, which is the last page of your quiz form.
- Your score will be posted when your quiz has been graded. Quiz grades become final when the next is given.

Pages 9 and 10 had no questions.

Quiz and Exam Formulæ & Constants

$$K = \frac{1}{4\pi\epsilon_0}$$
$$\Delta V = -\int \vec{E}\cdot d\vec{s}$$
$$V = K\frac{q}{r}$$
$$\Delta U = q\,\Delta V$$
$$I = dq/dt$$
$$P = I\,\Delta V$$
$$R = \frac{\Delta V}{I}$$

Series :
$$\frac{1}{C_{\mathrm{eq}}} = \sum \frac{1}{C_i}$$
$$R_{\mathrm{eq}} = \sum R_i$$

Parallel :
$$\frac{1}{R_{\mathrm{eq}}} = \sum \frac{1}{R_i}$$
$$C_{\mathrm{eq}} = \sum C_i$$

$$\vec{E} = K\frac{q}{r^2}\hat{r}$$
$$\vec{F} = K\frac{q_1 q_2}{r^2}\hat{r}$$
$$\vec{F} = q\vec{E}$$
$$\vec{p} = q\vec{d}$$
$$\vec{\tau} = \vec{p}\times\vec{E}$$
$$U = -\vec{p}\cdot\vec{E}$$
$$|\vec{E}| \propto \frac{|\vec{p}|}{r^3}$$
$$\Phi_{\mathrm{E}} = \int \vec{E}\cdot d\vec{A}$$
$$\epsilon_0 \oint \vec{E}\cdot d\vec{A} = q_{\mathrm{enclosed}}$$
$$\oint \vec{E}\cdot d\vec{\ell} = -\frac{d\Phi_{\mathrm{B}}}{dt}$$
$$C = \frac{Q}{\Delta V}$$
$$C = \epsilon_0\frac{A}{d}$$
$$U = \tfrac{1}{2}C\,[\Delta V]^2$$
$$R = \rho\frac{\ell}{A}$$
$$\tau_{\mathrm{C}} = RC$$
$$u_{\mathrm{E}} = \tfrac{1}{2}\epsilon_0 E^2$$

$$\vec{B} = \frac{\mu_0 q}{4\pi}\,\frac{\vec{v}\times\hat{r}}{r^2}$$
$$d\vec{B} = \frac{\mu_0 I}{4\pi}\,\frac{d\vec{\ell}\times\hat{r}}{r^2}$$
$$\vec{F} = q\vec{v}\times\vec{B}$$
$$\vec{F} = I\vec{\ell}\times\vec{B}$$
$$\vec{\mu} = NI\vec{A}$$
$$\vec{\tau} = \vec{\mu}\times\vec{B}$$
$$U = -\vec{\mu}\cdot\vec{B}$$
$$\Phi_{\mathrm{B}} = \int \vec{B}\cdot d\vec{A}$$
$$\oint \vec{B}\cdot d\vec{A} = 0$$
$$\oint \vec{B}\cdot d\vec{\ell} = \mu_0(I_{\mathrm{c}} + I_{\mathrm{d}})$$
$$L = \frac{\Phi_{\mathrm{B}}}{I}$$
$$L = \mu_0 N^2\frac{A}{\ell}$$
$$U = \tfrac{1}{2}LI^2$$
$$B = \mu_0 nI$$
$$\tau_{\mathrm{L}} = L/R$$
$$u_{\mathrm{B}} = \frac{1}{2\mu_0}B^2$$

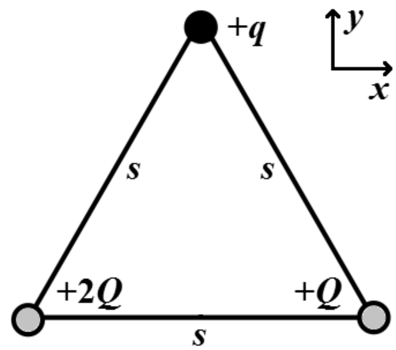
$$q = q_{\max}\left(1 - e^{-t/\tau_{\mathrm{C}}}\right)$$
$$q = q_0 e^{-t/\tau_{\mathrm{C}}}$$
$$I = I_{\max}\left(1 - e^{-t/\tau_{\mathrm{L}}}\right)$$
$$I = I_0 e^{-t/\tau_{\mathrm{L}}}$$
$$I = \int \vec{J}\cdot d\vec{A}$$
$$\vec{J} = \sigma\vec{E}$$
$$\mathcal{E} = -N\frac{d\Phi_{\mathrm{B}}}{dt}$$
$$I_d = \epsilon_0\,\frac{d\Phi_{\mathrm{E}}}{dt}$$
$$\mathcal{E} = -L\,\frac{dI}{dt}$$
$$c = f\lambda = \frac{|\vec{E}|}{|\vec{B}|}$$
$$\vec{S} = \frac{1}{\mu_0}\,\vec{E}\times\vec{B}$$

Fundamental Charge $e = 1.602\times10^{-19}\,\mathrm{C}$
Earth's gravitational field $g = 9.81\,\mathrm{N/kg}$
Coulomb constant $K = 8.988\times10^{9}\,\mathrm{N{\cdot}m^2/C^2}$
Speed of Light $c = 2.998\times10^{8}\,\mathrm{m/s}$

Mass of an Electron $m_{\mathrm{e}} = 9.109\times10^{-31}\,\mathrm{kg}$
Mass of a Proton $m_{\mathrm{p}} = 1.673\times10^{-27}\,\mathrm{kg}$
Vacuum Permittivity $\epsilon_0 = 8.854\times10^{-12}\,\mathrm{C^2/N{\cdot}m^2}$
Vacuum Permeability $\mu_0 = 4\pi\times10^{-7}\,\mathrm{T{\cdot}m/A}$

Unless otherwise directed, friction, drag, and gravity should be neglected, and all batteries and wires are ideal.
All derivatives and integrals in free-response problems must be evaluated.

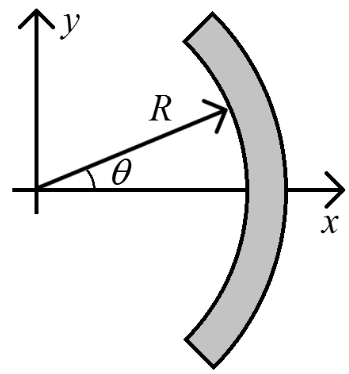
I. (16 points) Three point particles with charges $+q = +1.6\,\mu\text{C}$, $+Q = +2.2\,\mu\text{C}$, and $+2Q = +4.4\,\mu\text{C}$ lie on the vertexes of an equilateral triangle with sides of length $s = 2.5\,\text{cm}$, as shown. What is the electric force on the particle with charge $+q$?



1. (6 points) A non-uniform thin rod of charge is bent into an arc of radius R. It extends from $\theta = -\pi/4$ to $\theta = +\pi/4$, as shown. The linear charge density λ of the rod depends on θ according to

$$\lambda = \frac{\lambda_0 \theta^2}{\cos\theta}$$

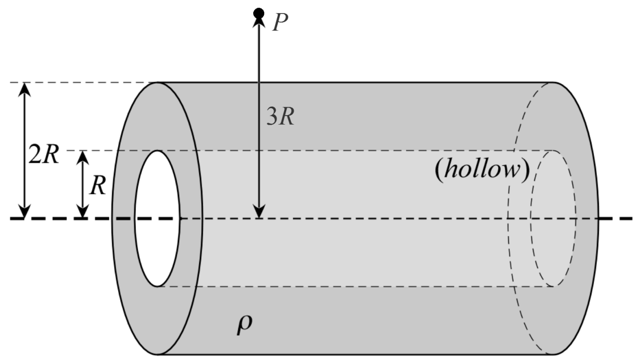
where λ_0 is a positive constant. In what direction is the electric field at the origin?



(a) In the $+y$ direction.
(b) In the $-y$ direction.
(c) In the $+x$ direction.
(d) In the $-x$ direction.

II. (16 points) In the problem above, what is the magnitude of the electric field at the origin? Express your answer in terms of parameters defined in the problem, and physical or mathematical constants.

III. (16 points) An infinitely long hollow insulating cylinder has uniform volume charge density ρ. Its inner radius is R, and its outer radius is $2R$. What is the magnitude of the electric field at point P, a distance $3R$ from the cylinder axis? Express your answer in terms of parameters defined in the problem, and physical or mathematical constants.

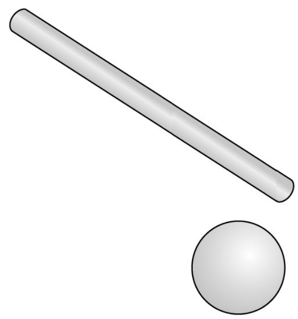


2. (6 points) In the problem above, let the magnitude of the electric field at point P be E_0. What is the magnitude of the electric field at a distance $R/3$ from the cylinder axis?

(a) $27E_0$
(b) Zero
(c) $9E_0$
(d) $81E_0$
(e) $3E_0$

3. (8 points) A rod is rubbed with fabric to give it a non-zero charge. When the rod is brought near a neutral object, the neutral object will ...

(a) be attracted to the rod if the rod is positive, but be repelled if the rod is negative.
(b) be repelled by the rod if the rod is positive, but be attracted if the rod is negative.
(c) be attracted to the rod.
(d) be repelled by the rod.
(e) experience no net force from the rod.



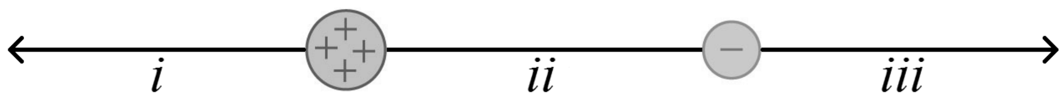
---

4. (8 points) An electric dipole is near a positively-charged particle, as shown. If the particle is fixed in place but the dipole is free to move, what will the motion of the dipole be?

(a) The dipole will rotate and move away from the particle.
(b) The dipole will rotate and move toward the particle.
(c) The dipole will remain stationary.
(d) The dipole will just move toward the particle.
(e) The dipole will just move away from the particle.

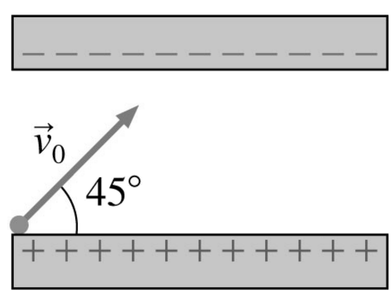
5. (8 points) Consider two charged particles, one with positive charge $+4Q$ and one with negative charge $-Q$, as shown. Is there any point along a line through the two particles, other than at infinite distance, at which the electric field due to the two particles is zero?

   (a) Yes, there are two such points, one to the left of the positively charged particle (region i), and one to the right of the negatively charged particle (region iii).
   (b) Yes, somewhere to the right of the negatively charged particle (region iii).
   (c) Yes, somewhere between the particles (region ii).
   (d) Yes, somewhere to the left of the positively charged particle (region i).
   (e) No, there is no such point.



6. (8 points) An electron is given an initial velocity $\vec{v}_0$ inside an ideal parallel-plate capacitor, as shown. Describe the path of the electron's motion.

   (a) The electron's path will be a half-cycle of a sine curve.
   (b) The electron's path will be a straight line until it stops, then it will turn right 90° and follow another straight line.
   (c) The electron's path will be a straight line.
   (d) The electron's path will be a semi-circle.
   (e) The electron's path will be a parabola.



7. (8 points) A hollow conducting sphere has a solid conducting sphere at its center, as shown in cross-section. The outer, hollow, sphere has a net positive charge $+Q_0$, while the inner, solid, sphere has a net positive charge $+q_0$. The solid sphere is now moved until it touches the inner surface of the hollow sphere, then is returned to the center. How, if at all, will charge have moved between the spheres?

   (a) All the charge on the inner, solid, sphere moves to the outer, hollow, sphere.
   (b) Some, but not all, of the charge on the inner, solid, sphere moves to the outer, hollow, sphere.
   (c) All the charge on the outer, hollow, sphere moves to the inner, solid, sphere.
   (d) Some, but not all, of the charge on the outer, hollow, sphere moves to the inner, solid, sphere.
   (e) No charge moves between the spheres.