**AFTER I GIVE THE SIGNAL TO BEGIN YOU CAN REMOVE THIS SHEET. DO NOT TURN IT IN!**

**163fa22 Exam 1A –** Once the exam has officially started, remove the top sheet. The remaining sheets comprise your exam. It is each student's individual responsibility to ensure the instructor has received her or his completed exam. Any exams not received by the instructor earn zero points. Smart watches, phones, or other devices (except scientific calculators) are not permitted during the exam.

$e = 1.602 \times 10^{-19}\ \mathrm{C}$ $\quad k = 8.99 \times 10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}$ $\quad c = 3.00 \times 10^{8}\ \frac{\mathrm{m}}{\mathrm{s}}$ $\quad \varepsilon_0 = 8.85 \times 10^{-12}\ \frac{\mathrm{C^2}}{\mathrm{N\cdot m^2}}$

$h = 6.626 \times 10^{-34}\ \mathrm{J\cdot s}$ $\quad hc \approx 1240\ \mathrm{eV\cdot nm}$ $\quad \mu_0 = 4\pi \times 10^{-7}\ \frac{\mathrm{T\cdot m}}{\mathrm{A}}$ $\quad 1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$

$m_p = 1.673 \times 10^{-27}\ \mathrm{kg}$ $\quad m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$

$\vec{F} = q\vec{E}$ $\quad k = \frac{1}{4\pi\varepsilon_0}$ $\quad \Delta x = v_{ix}t + \frac{1}{2}a_x t^2$ $\quad v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x$

$\vec{F}_{1on2} = \frac{kq_1q_2}{r_{12}^2}\hat{r}_{1to2}$ $\quad \vec{E} = \frac{kq}{r^2}\hat{r}$ $\quad V = \frac{kq}{r}$ $\quad U_{12} = \frac{kq_1q_2}{r_{12}}$

$\oint \vec{E}\cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$ $\quad q_{enc} = \int \rho dV$ $\quad E_{\parallel\, plates} = \frac{|\Delta V|}{d} = \frac{\sigma}{\varepsilon_0}$ $\quad E_{plate} = \frac{\sigma}{2\varepsilon_0}$

$E_{ring} = \frac{kQz}{(R^2+z^2)^{3/2}}$ $\quad V_{ring} = \frac{kQ}{(R^2+z^2)^{1/2}}$ $\quad E_x = -\frac{dV}{dx}$ $\quad V_b - V_a = -\int_a^b \vec{E}\cdot d\vec{s}$

$\Delta U = q\Delta V$ $\quad U_C = \frac{1}{2}Q_C\Delta V_C$ $\quad Q_C = \Delta V_C C$ $\quad I_C = -C\frac{dV_C}{dt}$

$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$ $\quad C_{eq} = C_1 + C_2 + \cdots$ $\quad C_{plates} = \frac{\varepsilon_0 A}{d}$ $\quad C' = \kappa C$

$R_{eq} = R_1 + R_2 + \cdots$ $\quad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\quad R = \frac{\rho L}{A}$ $\quad \rho = \rho_0(1 + \alpha\Delta T)$

$\Delta V_R = I_R R$ $\quad \mathcal{P}_R = I_R\Delta V_R$ $\quad X(t) = X_f + (X_i - X_f)e^{-t/\tau}$ where $\tau = RC$ or $\frac{L}{R}$

$\vec{F} = q\vec{v}\times\vec{B}_{ext}$ $\quad \vec{F} = I\int d\vec{s}\times\vec{B}_{ext}$ $\quad \vec{\tau} = \vec{\mu}\times\vec{B}_{ext}$ $\quad \vec{\mu} = NI\vec{A}$

$U = -\vec{\mu}\cdot\vec{B}_{ext}$ $\quad B_{sol} = \frac{\mu_0 NI}{L}$ $\quad B_{ring} = \frac{\mu_0 I r^2}{2(r^2+z^2)^{3/2}}$ $\quad B_{straight} = \frac{\mu_0 I}{2\pi a}$

$\oint \vec{B}\cdot d\vec{s} = \mu_0 I_{enc}$ $\quad I_{enc} = \int \vec{J}\cdot d\vec{A}$ $\quad \vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{s}\times\hat{r}}{r^2}$ $\quad \Phi_B = \int \vec{B}\cdot d\vec{A}$

$EMF = -N\frac{d}{dt}\Phi_B$ $\quad EMF = B_\perp Lv$ $\quad L = \frac{\Phi_B}{I}$ $\quad U_L = \frac{1}{2}LI^2$

$\frac{\Delta V_2}{\Delta V_1} = \frac{N_2}{N_1}$ $\quad \Delta V_L = -L\frac{dI_L}{dt}$ $\quad Z = \sqrt{R^2 + (X_L - X_C)^2}$ $\quad \tan\phi = \frac{X_L - X_C}{R}$

$X_L = \omega L$ $\quad X_C = \frac{1}{\omega C}$ $\quad V_{source} = V_0\sin\omega t$ $\quad i = i_{max}\sin(\omega t - \phi)$

$\Delta V_{Rmax} = i_{max}R$ $\quad \Delta V_{Lmax} = i_{max}X_L$ $\quad \Delta V_{Cmax} = i_{max}X_C$ $\quad V_{source\ max} = i_{max}Z$

$\Delta V_{max} = \frac{\Delta V_{pk-pk}}{2}$ $\quad \Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}}$ $\quad \omega_0 = \frac{1}{\sqrt{LC}}$

$\mathcal{P}_{avg} = I_{rms}\Delta V_{rms}\cos\phi = I_{rms}^2 R$

$c = f\lambda$ $\quad k = \frac{2\pi}{\lambda}$ $\quad \omega = 2\pi f = \frac{2\pi}{\mathbb{T}}$

$\vec{S} = \frac{\vec{E}\times\vec{B}}{\mu_0}$ $\quad I_{avg} = S_{avg} = \frac{E_{max}B_{max}}{2\mu_0} = \left(\frac{1}{c}\right)\frac{E_{max}^2}{2\mu_0} = c\frac{B_{max}^2}{2\mu_0}$

$\frac{E_{max}}{B_{max}} = c$ $\quad E_\gamma = hf = \frac{hc}{\lambda}$

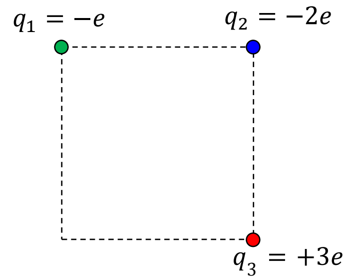
$Rad.Pressure = \frac{Force}{Area} = \frac{S_{avg}}{c}$ $\quad Photon\ momentum = p_\gamma = \frac{E_\gamma}{c}$

| **Material** | **Resistivity** at 20° C (in SI units) | **Temp. Coefficient** (in SI units) |
|---|---|---|
| Silver | $1.62 \times 10^{-8}$ | $4.1 \times 10^{-3}$ |
| Copper | $1.69 \times 10^{-8}$ | $4.3 \times 10^{-3}$ |
| Aluminum | $2.75 \times 10^{-8}$ | $4.4 \times 10^{-3}$ |
| Nichrome | $1.00 \times 10^{-6}$ | $0.4 \times 10^{-3}$ |
| Carbon | $3.5 \times 10^{-5}$ | $-0.5 \times 10^{-3}$ |
| Germanium | 0.46 | $-48 \times 10^{-3}$ |

| | |
|---|---|
| $\int \frac{x\,dx}{(x^2+a^2)^{3/2}} = \frac{-1}{\sqrt{x^2+a^2}}$ | $\int \frac{dx}{\sqrt{x^2 \pm a^2}} = \ln\left\lvert x + \sqrt{x^2 \pm a^2}\right\rvert$ |
| $\int \frac{dx}{(x^2+a^2)^{3/2}} = \frac{x}{a^2\sqrt{x^2+a^2}} = \frac{1}{a^2}\sin\theta$ | $\int \frac{x\,dx}{\sqrt{x^2 \pm a^2}} = \sqrt{x^2 \pm a^2}$ |
| $\int \frac{dx}{x^2+a^2} = \frac{1}{a}\tan^{-1}\frac{x}{a}$ | $\int \sqrt{x^2 \pm a^2}\,dx = \frac{1}{2}x\sqrt{x^2 \pm a^2} \pm \frac{a^2}{2}\ln\left\lvert x + \sqrt{x^2 \pm a^2}\right\rvert$ |
| $\int \frac{x\,dx}{x^2+a^2} = \frac{1}{2}\ln\lvert x^2 + a^2\rvert$ | **Binomial expansion:** $(1 \pm \delta)^n \approx 1 \pm n\delta + \cdots$ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\mathrm{T} = 10^{12}$ | $\mathrm{G} = 10^{9}$ | $\mathrm{M} = 10^{6}$ | $\mathrm{k} = 10^{3}$ | $\mathrm{c} = 10^{-2}$ | $\mathrm{m} = 10^{-3}$ | $\mu = 10^{-6}$ | $\mathrm{n} = 10^{-9}$ | $\mathrm{p} = 10^{-12}$ | $\mathrm{f} = 10^{-15}$ | $\mathrm{a} = 10^{-18}$ |

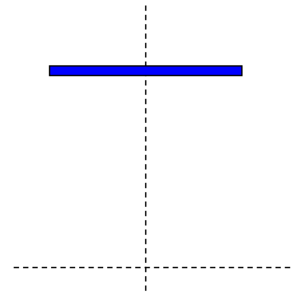
**WRITE YOUR NAME AT THE TOP OF THIS PAGE!**




Three charges are placed on the corners of a square of side $s$.
**1a) Determine the electric potential energy associated with this group of charges. Answer in terms of $k, e, \& s$.
**1b) Determine electric potential *at the bottom left corner of the square*. Answer in terms of $k, e, \& s$.
***1c) Determine the *magnitude* of the Coulomb force acting on $q_1$. Answer in terms of $k, e, \& s$.
*1d) Determine the direction of the Coulomb force acting on $q_1$. Answer as *numerical value of angle* between $-180°$ & $+180°$ from the standard positive $x$-axis (e.g. $+120°$ would be in quadrant 2 while $-120°$ would be in quadrant 3).

| | |
|---|---|
| 1a | |
| 1b | |
| 1c | |
| 1d | |

A rod of length $2d$ is centered on the $y$-axis as shown in the figure. The center of the rod is distance $2d$ from the origin. The rod carries total charge $Q$ distributed uniformly over the length of the rod.



******2) Determine the electric field at the origin.
Cartesian form is fine. Show work & simplify your result for credit.

| | |
|---|---|
| 2 | |

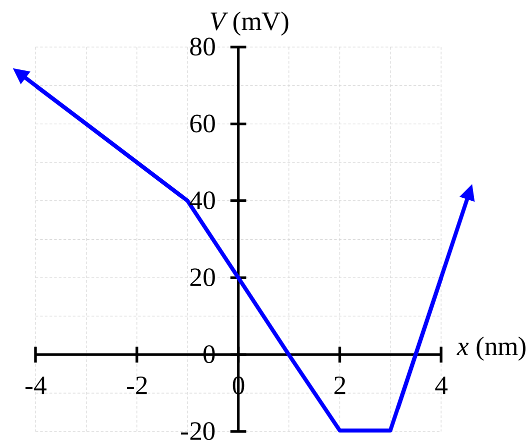
An electric field near the origin can be modeled by the equation

$$E_x = \frac{c}{b^2 + x^2}$$

3a) What units are assumed on the constant $b$?
3b) What units are assumed on the constant $c$?
***3c) Determine potential difference between the origin & a point distance $d$ to the right of the origin.

| | |
|---|---|
| 3a | |
| 3b | |
| 3c | |

A plot of potential versus position is shown at right. The following questions refer to this plot. Assume potential in other dimensions is zero. Assume plot extends to $x = -\infty$ with the same slope as at $x = -4$ nm. Assume plot extends to $x = +\infty$ with the same slope as at $x = +4$ nm.




4a) What position or region of space has the *strongest* electric field magnitude? I'm expecting an answer like "at $x = 0$ nm" or "between $x = 0$ & 2 nm".

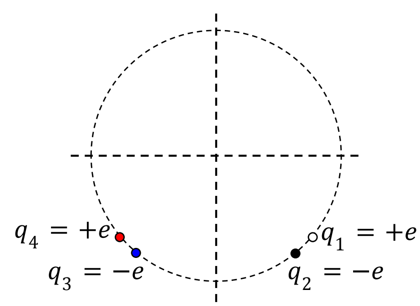
4b) Suppose an electron was placed at $x = 1.0$ nm and released from rest. Which best describes the motion of the electron at the instant just after it is released?

| | | | | |
|---|---|---|---|---|
| Moves up & to the left | Moves up & to the right | Moves up | Moves right | Remains at rest |
| Moves down & to the left | Moves down & to the right | Moves down | Moves left | Impossible to determine without more info |

4c) Again, suppose an electron was placed at $x = 1.0$ nm and released from rest. Which best describes the electron's motion over time?

| | | | |
|---|---|---|---|
| Moves away with constant *acceleration*, never return | Moves away, *acceleration decreases*, never to return | Moves away, *acceleration increases*, never to return | Impossible to determine without more info |
| Moves away with constant *velocity*, never to return | Remains at rest | Oscillates back and forth | |

Four charges are arranged around a circle centered at the origin.




5a) Which best describes the *electric potential* at the origin?

| | | | |
|---|---|---|---|
| Positive | Negative | Zero | Impossible to determine without more info |

5b) Which best describes net electric field (*horizontal* component) at the origin?

| | | | |
|---|---|---|---|
| $E_{NETx} < 0$ | $E_{NETx} = 0$ | $E_{NETx} > 0$ | Impossible to determine without more info |

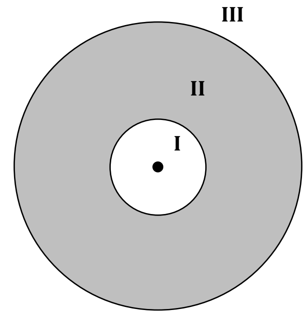
5b) Which best describes net electric field (*vertical* component) at the origin?

| | | | |
|---|---|---|---|
| $E_{NETy} < 0$ | $E_{NETy} = 0$ | $E_{NETy} > 0$ | Impossible to determine without more info |

5c) Which best describes the *electric potential energy* associated with this assembly of charges? Figure to scale.

| | | | |
|---|---|---|---|
| Positive | Negative | Zero | Impossible to determine without more info |

A conducting cylindrical shell concentrically surrounds a line charge (cross-sectional view at right). Regions of space are labeled in the figure as **I**, **II**, & **III** for ease of communication. Assume the line charge and shell both have length $L \gg R$ (dimension into the page). The shell has inner radius $R$ and outer radius is $3R$. The line charge has negligible radius; we needn't worry about a region *inside* the line charge. The shell carries total charge $-Q$ while the line carries total charge $3Q$ distributed uniformly.




**For this page, all answers should be written in terms of the $\boldsymbol{k, Q, L, r}$, & $\boldsymbol{R}$.**

6a) Does the *inner* surface of the shell carry positive, negative or zero charge? Answer in the box.

6b) Determine surface charge density on the *outer* surface of the cylindrical shell.

6c) Determine electric field magnitude in region **I** (arbitrary distance $r$ from center).

6d) Determine electric field magnitude in region **II** (arbitrary distance $r$ from center).

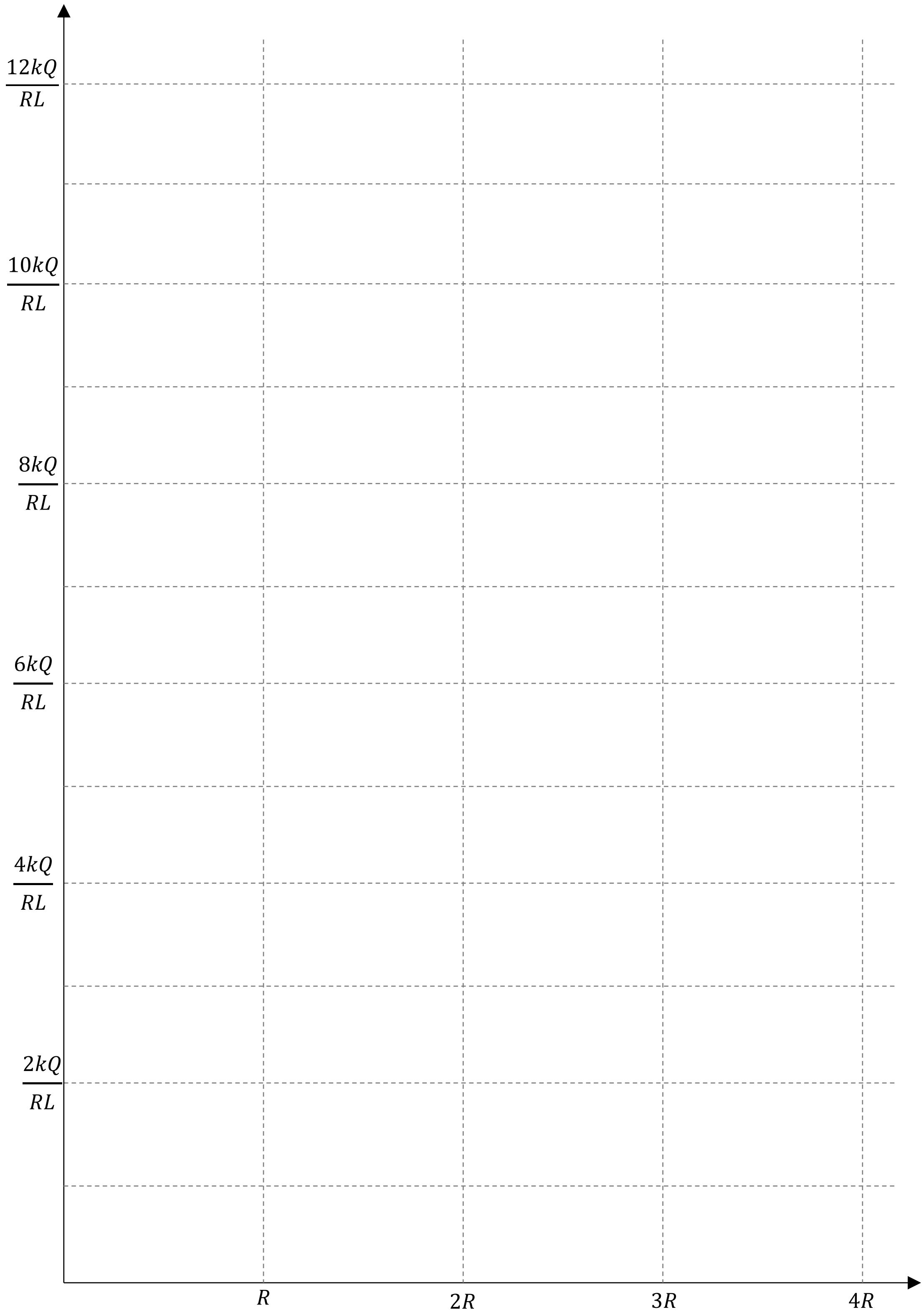
6e) Determine electric field magnitude in region **III** (arbitrary distance $r$ from center).

**6f) Sketch field magnitude versus radial position on the plot on the next page.

It's only two points but can be time consuming…skip if running out of time.

| | |
|---|---|
| 6a | |
| 6b | |
| 6c | |
| 6d | |
| 6e | |

| **Optional**<br>I filled in this table to help me figure out the plot | |
|---|---|
| **Radius** | **Field Mag** |
| $r = \frac{R}{2}$ | |
| $r = R$ for region I | |
| $r = R$ for region II | |
| $r = 2R$ | |
| $r = 3R$ for region II | |
| $r = 3R$ for region III | |
| $r = 4R$ | |


$\frac{12kQ}{RL}$
$\frac{10kQ}{RL}$
$\frac{8kQ}{RL}$
$\frac{6kQ}{RL}$
$\frac{4kQ}{RL}$
$\frac{2kQ}{RL}$
$R$
$2R$
$3R$
$4R$

Consider the snippet of code shown at right.

***7) Write additional lines of code which correctly compute and *output* the electric field *magnitude* at the point $(2.22, -7.77, 15.38)$. Please use the table shown below.

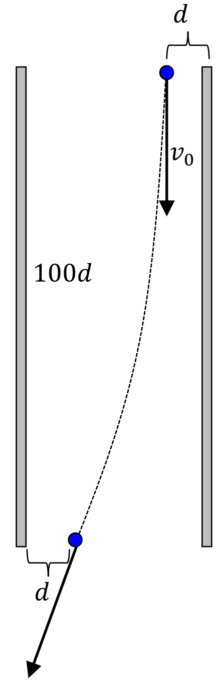
When I first thought it through, I think I wanted to use 8 lines of code.
I think everyone should be able do this with 5-10 lines, but if you need extra just add a few below the table or ask me if you run into trouble. There are many different correct ways to do this. Write neatly or you may lose points.

Note: you get zero points for computing the field with paper and pencil (or your calculator. I want lines of code that would compute and output the result.

```
1  GlowScript 3.1 VPython
2  #assume SI units on all numbers
3
4  q1 = sphere()
5  q1.pos = vec(1.245, 2.346, -3.03)
6  q1.mass = 1e-6
7  q1.velocity = vec(0,0,0)
8  q1.acceleration = vec(0,0,0)
9  q1.charge = 1e-8
10
11 q2 = sphere()
12 q2.mass = 1e-6
13 q2.velocity = vec(0,0,0)
14 q2.acceleration = vec(0,0,0)
15 q2.charge = 1e-8
16
```

| | |
|---|---|
| **Line 17** | |
| **Line 18** | |
| **Line 19** | |
| **Line 20** | |
| **Line 21** | |
| **Line 22** | |
| **Line 23** | |
| **Line 24** | |
| **Line 25** | |
| **Line 26** | |

An electron is launched vertically downwards with speed $v_0$ between two parallel plates. The plate *spacing* is $5d$ while the plate *length* is $100d$ (figure not to scale). Assume the plates are infinitely large going into and out of the page. Assume fringing fields are negligible.




8a) Is it reasonable to ignore gravitational forces in this problem? Briefly explain why or why not for credit.

8b) What direction best describes the electric field between the plates?

| | | | | |
|---|---|---|---|---|
| $E_x = 0$ & $E_y > 0$ | $E_x > 0$ & $E_y = 0$ | $E_x > 0$ & $E_y > 0$ | $E_x < 0$ & $E_y > 0$ | Impossible to determine without more info |
| $E_x = 0$ & $E_y < 0$ | $E_x < 0$ & $E_y = 0$ | $E_x > 0$ & $E_y < 0$ | $E_x < 0$ & $E_y < 0$ | No field at the origin |

8c) Which plate must be held at higher potential for the electron to travel in the trajectory shown?

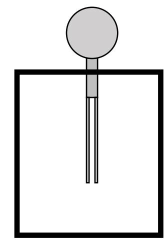
| | | |
|---|---|---|
| Right plate must be held at higher potential | Left plate must be held at higher potential | Impossible to determine since either plate could be held at higher potential |

*****8d) Determine the *magnitude* of the potential difference between the plates.

| | |
|---|---|
| 8d | |

**Extra Credit 1:**
My YouTube logo looks like the figure *at left*. Which famous music act sometimes uses the figure shown *at right* as their YouTube logo?

*****Extra credit 2:** Clearly explain the phenomena of charging by induction. Imagine you are trying to tell a stranger in the class exactly how to charge an electroscope by induction. Include multiple figures to clarify your words. I have started the process for you to give you an inkling of the level of detail I might expect. Note: I plan to grade this harshly. If your wording & figures make no sense to me, you get zero. As such, I would complete this only if you have completed the rest of the exam.



An isolated, neutral electroscope is shown at right.

- Notice no *excess* charge resides on any part of the electroscope.
- Notice the leaves of the electroscope hang vertically.

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