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

163fa23t1a – 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 $\frac{L}{R}$

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

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

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

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

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

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

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

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

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

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

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

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

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

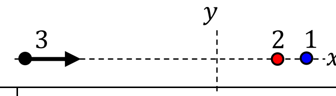
Material	**Resistivity** at 20° C (in SI units)	**Temp. Coefficient** (in SI units)
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	4.3×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Nichrome	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}

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

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

Rip off the eqt'n sheet and put your name on this page. **NAME:____________________________________**

Three charges ($q_1 = -e,\ q_2 = 2e,\ \&\ q_3 = e$) are aligned perfectly along the x-axis. All charges have equal mass m. Charges 1 & 2 are fixed in place. Charge 1 is distance $4d$ from the origin. Charge 2 is distance $3d$ from the origin. Charge 3 is initially *very* far from the origin with some initial velocity to the right. Figure not to scale.



****1a) Determine the minimum initial *speed* required for q_3 to reach the origin.

1a	

1b) Suppose the experiment was repeated but the positions of charges 1 & 2 were swapped.
Which of the following statements is true? Circle the best answer.

It is no longer possible for q_3 to reach the origin.	Charge q_3 could still reach the origin; *less* initial speed is required.	Impossible to determine without more information
Charge q_3 could still reach the origin; *more* initial speed is required.	Charge q_3 could still reach the origin; *the same* initial speed is required.	

Consider the code snippet shown at right. Your goal is to add lines of code which will animate the motion of the charged ball during its first 5 seconds of motion while it is affected by an electric field and gravity.

Note: when I tested my code I found I had to finish LINE 15 plus 5 additional lines of code.

```
1  Web VPython 3.2
2
3  #E_field is a UNIFORM electric field vector
4  E_field = vec(7.832, -4.516, -6.097)
5  ball = sphere()
6  ball.m = 1.2345     #mass in units of kg
7  ball.q = -3.0548    #charge in units of C
8  ball.v = vec(0,0,0) #velocity in m/s
9  ball.a = vec(0,0,0) #acceleration in m/s**2
10
11 k = 8.99e9          #in units of N*m**2/C**2
12 g = 9.8             #in unis of m/s**2
13
14 #compute forces
15 F_elec =
16 F_grav = vec(0, -ball.m*g, 0)
17
18
19
20
21 t=0
22 dt=0.1
23 sim_speed = 1
24 while t<5:
25     rate(sim_speed/dt)
26
27
28
29
```

2a) What should be typed in LINE 15 to compute the electric force?

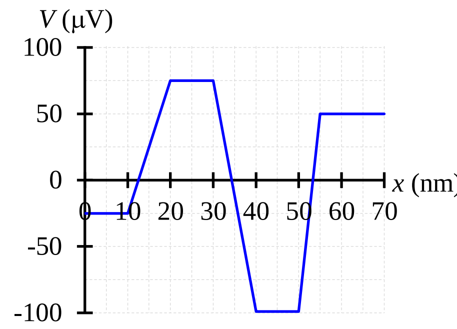
LINE 15	F_elec =

***2b) Assuming line 15 is done correctly, use the table below to write out a set of 5 lines of code which will correctly animate the motion for the first 5 seconds. **In the left column of the table,** indicate the line number where each line of code should be typed.

Line #	**Code**

An electron is constrained to move along the x-axis. The plot at right shows electric potential energy versus position.

***3a) Determine the largest possible *force* on the electron between $x = 0 \rightarrow 70$ nm. Include $\pm$ to account for direction.

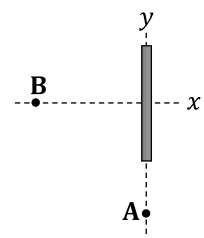


3a	

**3b) Suppose the electron was released from rest at $x \approx 33$ nm. Describe the electron's motion in the table below.

Which direction will the electron intially move?	
Will the electron reverse direction or not? **If yes,** at what position? **If no,** explain why not?	

A molecule centered at the origin is modeled as a rod of length d carrying non-uniform charge density given by $\lambda = \alpha y^5$ where α is a positive constant. Points **A** & **B** are distance d from the origin (figure not to scale). To be clear, no charge is located at either point.



4a) In the boxes below, draw an arrow indicating the direction of the electric field at points **A** & **B**.
If no field is present, write "`No Field`" in the box.

Direction of $\vec{E}$ at **A**		*Direction* of $\vec{E}$ at **B**	

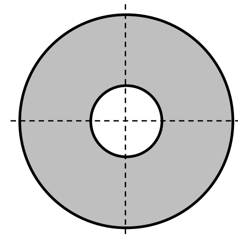
4b) Which best describes the *electric potential* at point **A**. Circle the best answer.

Positve	Negative	Zero	Impossible to determine without more info

4c) Which best describes the *electric potential* at point **B**.

Positve	Negative	Zero	Impossible to determine without more info

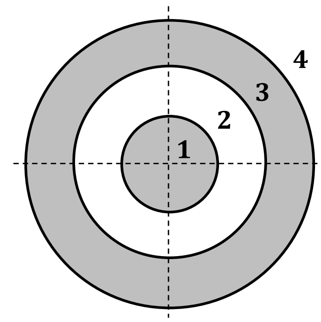
An insulating cylindrical shell of length L, inner radius R and outer radius $3R$ carries non-uniform charge density $\rho = \frac{\beta}{r^2}$. A cross-section of the shell is shown at right. You may assume $L \gg R$ for this problem.



5a) Determine the units assumed for the constant β.
**5b) Determine total charge on the rod in terms of β, L, and/or R.
**5c) Determine the electric field for radii between R & $3R$.
Please leave this answer in terms of ϵ_0 to save time!

5a	
5b	
5c	

A sphere of radius a is an insulator with total charge $-3Q$ uniformly distributed. The insulating sphere is surrounded by a concentric conducting spherical shell carrying total charge Q with inner radius $2a$ and outer radius $3a$. The numbers in the figure indicate regions of interest (**1** is inside the conductor, **2** is between the conductor and insulator, etc).



6a) Determine surface charge density (if any) on the *outer* surface of the conductor.

6b) Determine the electric field in region **1.**

Note: for electric field results, I will assume *negative* answers point radially *inwards*.

6c) Determine the electric field in region **2**.

6d) Determine the electric field in region **3**.

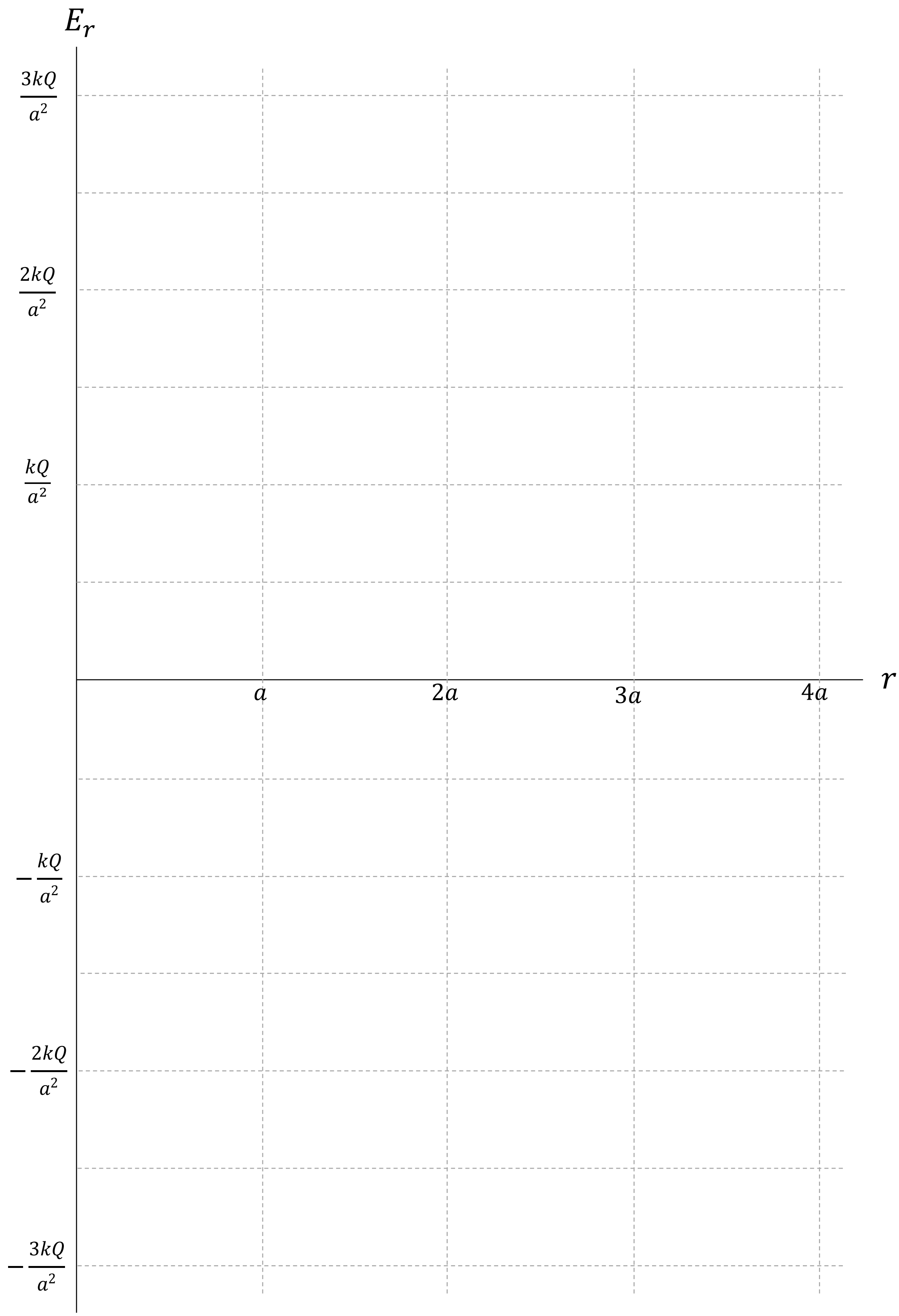
6e) Determine the electric field in region **4**.

**6f) Sketch a plot of the radial component E_r of the electric field versus radial position (next page).

To be clear, if the field is directed *inwards* E_r should be a *negative* value on the plot.

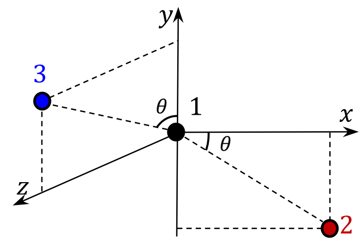
You may want to do this part last since it is time consuming for only 2 points.

6a	
6b	
6c	
6d	
6e	
6f	On next page



E_r
$\frac{3kQ}{a^2}$
$\frac{2kQ}{a^2}$
$\frac{kQ}{a^2}$
r
a
$2a$
$3a$
$4a$
$-\frac{kQ}{a^2}$
$-\frac{2kQ}{a^2}$
$-\frac{3kQ}{a^2}$

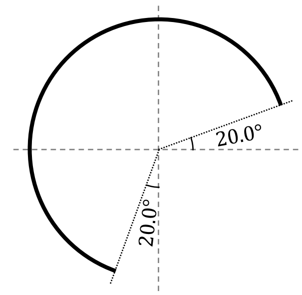
This problem took me the longest. Consider attempting problems 1-6 first.
Don't forget problem 8 on the next page.



Assume the charges in the figure are $q_1 = 10\underline{0}$ μC, $q_2 = 30\underline{0}$ μC, & $q_3 = -30\underline{0}$ μC.
The angle in the figure is $\theta = 22.2°$. Charges 2 & 3 are each 4.00 m from the origin.
Figure not to scale. To be clear, q_2 lies in the xy-plane while q_3 lies in the yz-plane.
***7a) Determine $\hat{r}_{32}$ which describes the *direction* of displacement from q_3 to q_2.
*****7b) Determine the Coulomb force *magnitude* **on $\boldsymbol{q_1}$** due to the other two charges.

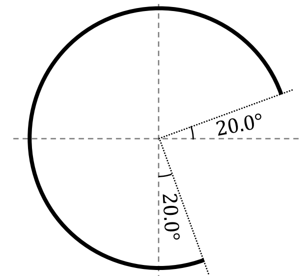
7a	
7b	

A rod with uniform charge distribution is bent into an arc of radius R as shown.
The rod carries *unknown* total charge Q.
The *magnitude* of the electric field at the origin is E.
Please notice part 8b at the bottom of the page. Figure not to scale.
******8a) Determine Q.
Answer using a decimal number with 3 sig figs times an expression involing $\boldsymbol{E}$ & $\boldsymbol{R}$.



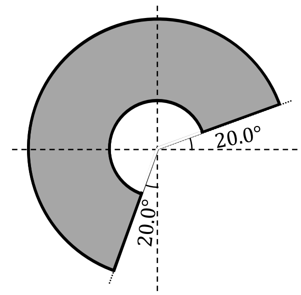
8a	

8b) Suppose the a *new* arc shown at right had the same charge density as the arc in part a. How would the *new* electric field magnitude at the origin (E') compare to the original electric field magnitude at the origin. Circle best answer.



$E' > E$	$E' < E$	$E' = E$	Impossible to determine without more info

*****Extra Credit (only 3 points, do the rest of the test first):** Consider the partial washer shown at right. Assume charge Q is uniformly distributed over the partial washer. Inner radius is R and outer radius is $3R$ (figure not to scale).



Determine the electric field at the origin and put a box around your answer.

Credit may be obtained if you give pseudocode which could produce the result for $Q = 1$ C and $R = 1$ m. To get code credit, you have to be detailed about the following:

- limits chosen for your 1-2 loops
- conditions for the if statements
- how dq is computed

Page intentionally left blank for scratch paper.

Page intentionally left blank for scratch paper.