Rules: This exam is to be completed by you unaided by textbook, web, notes, homework solutions, friends etc.... As described in the syllabus, the one external aid you may use during the exam is a $8\frac{1}{2} \times 11$ 'formula sheet'. You make the formula sheet before the exam to help recall formulae and then turn it in with the exam. (You are of course also encouraged to use a calculator.) If, during the exam, you think you need an additional formula or hint, ask me and I may be willing to provide it. Questions may be asked via personal chat or directly, but note that chat will not be continuously monitored.

Working remote typically takes additional time; you can use up to 50% more time than the last in-person student. When you've completed this assignment, convert all your work to a pdf and email it to me at `tkirkman@csbsju.edu`. Typically students make a pdf by combining cell phone photos into one pdf using a cell phone app. The file `Assignment_Scanning_Tutorial.pdf` in the same web folder as the exam may provide guidance (but phones & apps differ).

Remotes will enable video and audio (but perhaps turn down the speakers to reduce incidental noise) and be on screen 100% of the time. Zoom should be providing a clear image/sound of you taking the exam. If there is incidental noise in the room you are using, consider moving to a different room. If you need to temporarily mute or leave the room, please explain when making that request.

Clearly the above will hardly deter the determined cheater. Your personal integrity is the only real deterrent to cheating. To engage that, sign the below statement (and turn it in with the exam) just before you turn in the exam.

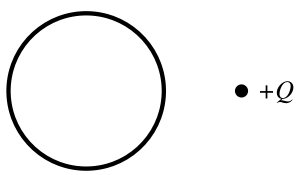
In answering these questions I have not aided any other student or used any external aids other than the 'formula sheet'.

Your Signature: ______________________________

Circle 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 = $\varepsilon_0 = 8.85 \times 10^{-12}$ $C^2/(N \cdot m^2)$
Coulomb constant = $k = 9 \times 10^9$ $N \cdot m^2/C^2$

1. 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?

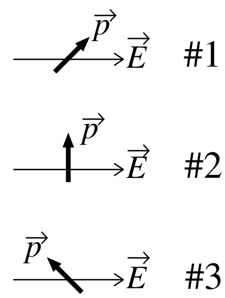


   A. Right
   B. Left
   C. Zero field
   D. None of the above

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

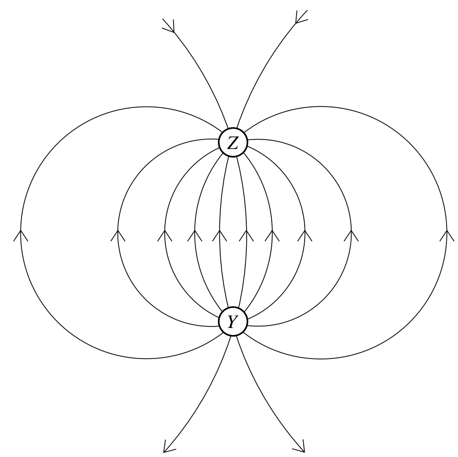
   A. zero
   B. attractive
   C. repulsive
   D. at first repulsive, but then attractive

3. The following figure shows three different configurations of an electric dipole $\vec{\mathbf{p}}$ placed in a uniform electric field $\vec{\mathbf{E}}$. Consider the potential energy of the electric dipole. 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.)



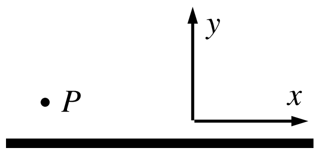
   A. $U_1 > U_2 > U_3$
   B. $U_1 < U_2 < U_3$
   C. $U_1 = U_2 = U_3$
   D. $U_1 = U_3 < U_2$

4. 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.



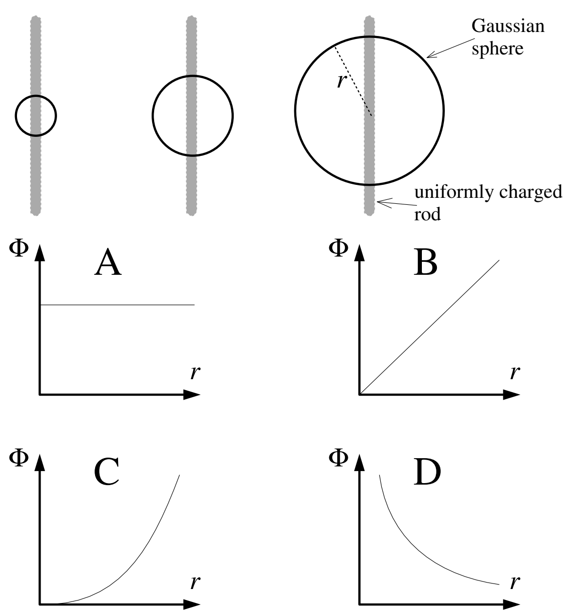
   A. Y carries a positive charge; Z carries a negative charge.
   B. The strongest electric field is midway between Y and Z.
   C. This is an electric dipole pointed up the page.
   D. More than one of the above.

5. A uniformly positively charged rod sits parallel to the x axis with the point P above the rod as shown in the below figure. Consider the signs of E_x and E_y, the x and y components of the electric field vector at P. Which of the below options is correct?

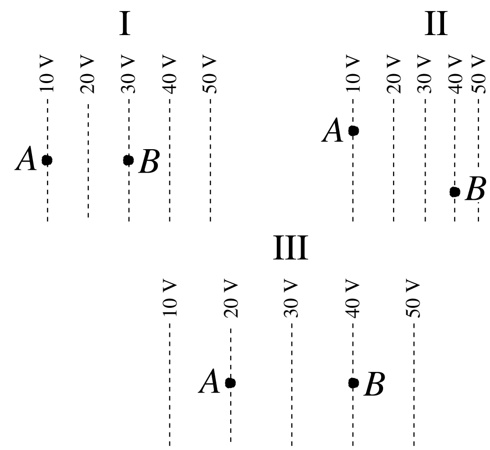


A. $E_x > 0$ & $E_y > 0$
B. $E_x > 0$ & $E_y < 0$
C. $E_x < 0$ & $E_y > 0$
D. $E_x < 0$ & $E_y < 0$

6. The below figure shows the same uniformly charged rod (length: $2L$) whose center is at the center of three Gaussian spheres of increasing radius r, but $r < L$. Consider the electric flux Φ_E through the surface of these spheres. Which of the the below graphs best displays how Φ_E depends on the Gaussian sphere radius r ?



7. 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 $+1$ μC is moved from A to B.



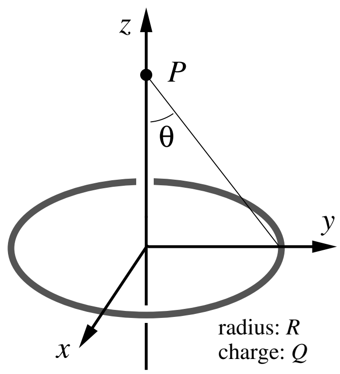
Which of the below statements best describes the amount of work needed to move this charge in the three cases.

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.

8. How does the magnitude of the electric field at A compare in the three cases?

A. $E_{III} > E_{II} > E_I$
B. $E_I > E_{III} > E_{II}$
C. $E_{II} > E_I > E_{III}$
D. $E_I = E_{II} > E_{III}$

9. 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 voltage (a.k.a. electric potential), V, directly above the center, i.e., on the z axis at a point $P = (0, 0, z)$. Select below the result that correctly calculates the voltage at P.



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:

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

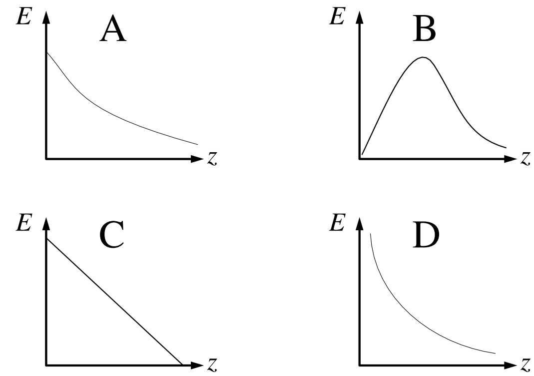
C. Since V is in the z direction we need to include the angle:

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

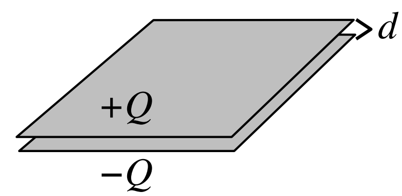
D. Since V is in the z direction we need to include the angle:

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

10. Now consider the electric field on the z-axis for the previous problem (a uniformly charged ring in the xy plane with its center at the origin). Which of the below graphs of E vs. z best displays the relationship.



11. A parallel plate capacitor, with parallel plates separated by a tiny distance d, is charged with equal/opposite charges Q as shown below and then isolated (disconnected from all sources). If d is increased slightly, *how many* of the following statements describe changes that might be measured:



- the voltage difference between the plates increases
- the capacitance of the capacitor decreases
- the energy stored by the capacitor increases
- the electric field in the middle of the capacitor decreases

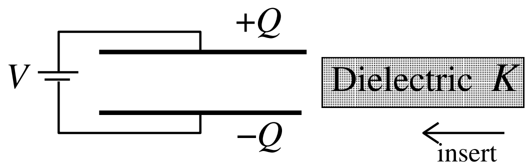
A. one

B. two

C. three

D. four

12. A closely-spaced parallel-plate capacitor is connected to a fixed voltage source V and as a result the top plate carries charge $+Q$; the bottom plate $-Q$.



Dielectric material is then inserted between the plates. *How many* of the following statements describe the resulting changes:

- the capacitance increases
- the charge on the plates stays constant.
- the voltage difference between the the plates increases
- the electric field in the middle of the capacitor decreases.

A. one

B. two

C. three

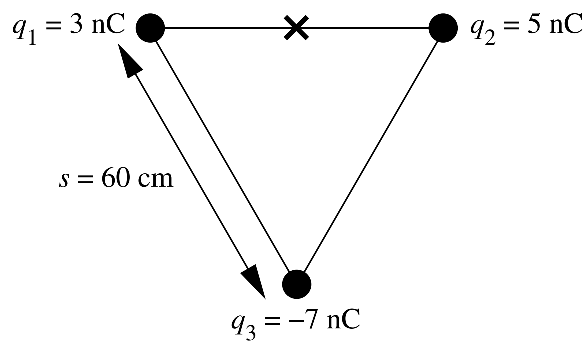
D. four

The following problems are worth 12 points each

Record your steps! (Grade based on method displayed not just numerical result)

To receive full credit your answers should have exactly three significant figures

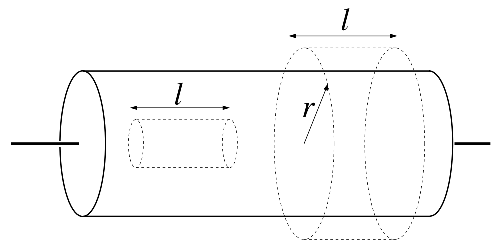
13. As shown below three charges are arranged in an equilateral triangle with side 60 cm.



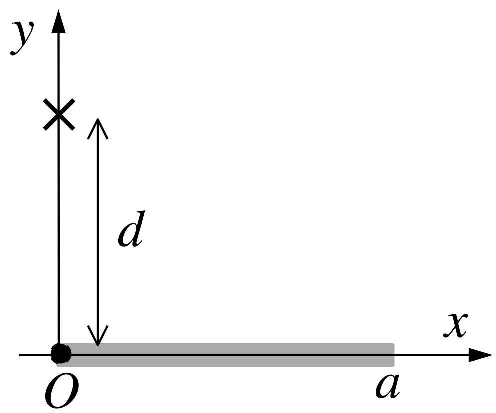
A. Calculate the electric field vector ($\vec{\mathbf{E}}_{net}$) at the spot marked X (i.e., the midpoint of the horizontal segment). Begin by displaying (by drawing directly on the diagram) the electric field of each charge separately. (For example, draw the electric field vector at X due to q_1 and label it $\vec{\mathbf{E}}_1$.). Draw directly on the diagram the arrow that is net electric field vector (the vector sum of the $\vec{\mathbf{E}}_i$). Calculate its magnitude and direction; to display the direction, label the angle you've calculated.

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

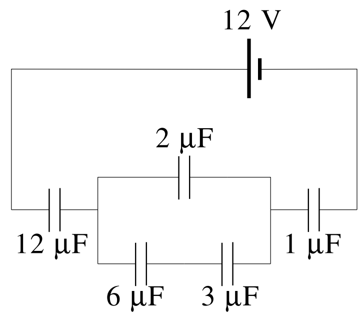
14. Consider an infinite cylinder of radius R with uniform charge density ρ (units: $\mathrm{C/m^3}$) Aim: Derive using Gauss' Law the formula for the electric field inside and outside the cylinder. The below diagram shows a section of the infinite charged cylinder and displays two coaxial Gaussian cans: one totally inside the cylinder the other totally outside the cylinder. The Gaussian cans have some length ℓ and radius r. For each Gaussian cans (separately) report: (A) the enclosed charge (in terms of the geometry of the Gaussian can and the charge density ρ) (B) the flux through the can (in terms of the geometry of the Gaussian can and the electric field E on the surface of the can). Finally (C) use Gauss' Law and (A) and (B) to derive a formula for the electric field.



15. A uniformly charged wire (linear charge density λ) extends along the positive x axis from the origin to $x = a$. Derive by integration the electric potential (voltage) at the point marked X which is on the y axis, a distance d above the origin. You need not evaluate the resulting integral; simply setting up the correct integral will produce full credit.



16. Calculate the equivalent capacitance for this circuit. Calculate voltage across and the charge stored on the 3 μF capacitor.



When finished: insert your formula sheet inside this booklet, make sure your name is on the front cover, and place the resulting packet in the pile at the front of the classroom. Failure to include your formula sheet will result in lost points!