Student #: ____________________________ Student Name: ___________________________________

AP PHYSICS C: ELECTROSTATICS & CAPACITORS

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

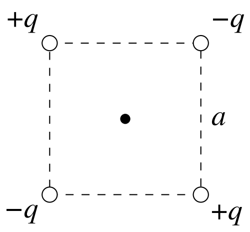
1. Two electric objects experience a repulsive force. What happens to that force if the distance between the objects is doubled?

   (A) It decreases to one-fourth its value.
   (B) It decreases to one-half its value.
   (C) It stays the same.
   (D) It doubles.
   (E) It quadruples.

2. An electron and a proton are separated by 1.50×10^{-10} m. If they are released, which one will accelerate at a greater rate, and what is the magnitude of that acceleration?

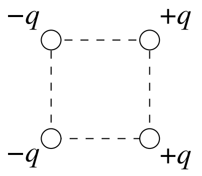
   (A) The electron; $1.12 \times 10^{22}\ \mathrm{m/s^2}$
   (B) The proton; $1.12 \times 10^{22}\ \mathrm{m/s^2}$
   (C) The electron; $6.13 \times 10^{18}\ \mathrm{m/s^2}$
   (D) The proton; $6.13 \times 10^{18}\ \mathrm{m/s^2}$
   (E) They both accelerate at the same rate; $1.02 \times 10^{-8}\ \mathrm{m/s^2}$

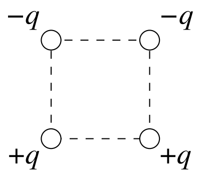
3. Four charges are arranged at the corners of a square of side a as shown. Which of the following is true of the electric field and the electric potential at the center of the square?

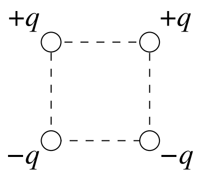


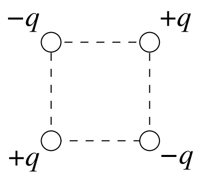
	Electric Field	Electric Potential
(A)	zero	zero
(B)	$\frac{kQ}{a\sqrt{2}}$	zero
(C)	$\frac{kQ^2}{2a^2}$	$\frac{kQ}{2a}$
(D)	zero	$\frac{kQ}{\sqrt{2}a}$
(E)	$\frac{kQ^2}{2a}$	$\frac{kQ}{a\sqrt{2}}$

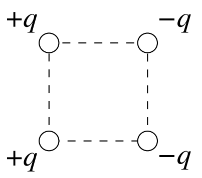
4. Which of the following diagrams best represents how you might rearrange the charges so that the electric field at the center would point directly toward the top of the page?

(A) 

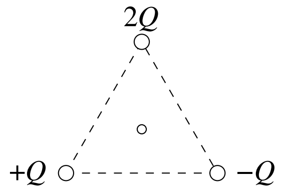
(B) 

(C) 

(D) 

(E) 

5. Three charges, $+Q$, $-Q$, and $+2Q$, are arranged in an equilateral triangle as shown. Which of the arrows below best represents the direction of the electric field at the center of the triangle?



   (A) ↓
   (B) ↑
   (C) ↘
   (D) ↙
   (E) ↗

6. A non-conducting sphere does not have a uniform charge density, but the density ρ varies with the distance r from the center of the sphere according to the equation $\rho = \beta r$ where β is a positive constant. The electric field inside the sphere ($r < R$) at a distance r from the center of the sphere is

   (A) $\frac{\beta r^2}{12\epsilon_0}$
   (B) $\frac{\beta r^3}{3\epsilon_0}$
   (C) $\frac{\beta r}{2\epsilon_0}$
   (D) $\frac{\beta r^2}{2\epsilon_0}$
   (E) $\frac{\beta r^2}{4\epsilon_0}$

7. The electric potential at the surface of the sphere from the last question is

   (A) $\frac{\beta R^3}{12\epsilon_0}$
   (B) $\frac{\beta R}{2\epsilon_0}$
   (C) $\frac{\beta R^3}{3\epsilon_0}$
   (D) $\frac{\beta R^2}{2\epsilon_0}$
   (E) $\frac{\beta R^2}{4\epsilon_0}$

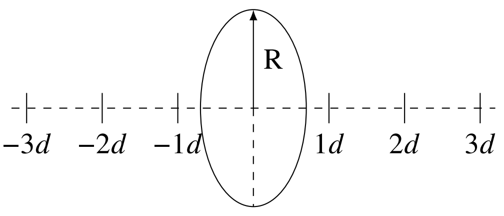
8. According to Gauss's law, the net electric flux passing through a closed surface is
   (A) positive if the flux is entering the surface
   (B) negative if the flux is exiting the surface
   (C) positive if the net charge inside the surface is zero
   (D) negative if the net charge inside the surface is zero
   (E) zero if the net charge inside the surface is zero

9. According to Gauss's law, which of the following statements is true?
   (A) It is possible to have a nonzero electric field, but zero electric flux.
   (B) It is possible to have a nonzero electric flux, but zero electric field.
   (C) It is possible to have a nonzero electric flux through a closed surface even if the enclosed charge in a surface is zero.
   (D) If a surface is not closed (such as a sheet of paper), the flux through it must be zero.
   (E) It is possible for charges located outside a closed surface to produce a net positive flux through the surface.

10. Electric potential
   (A) is a vector quantity that depends on the direction of the electric field
   (B) is a scalar quantity that depends on the magnitude and sign of charges in the vicinity
   (C) is a scalar quantity that depends on the square of the distance from the charges in the vicinity
   (D) is a vector quantity that depends on the sign of the charges in the vicinity
   (E) is a vector quantity that must point from high to low potential

11. Gauss's law is most convenient to use when calculating an electric field due to
   (A) charges outside a closed surface
   (B) charges inside a closed surface that has high symmetry
   (C) charges inside a closed surface that has low symmetry
   (D) a potential difference that is negative
   (E) a potential difference that is positive

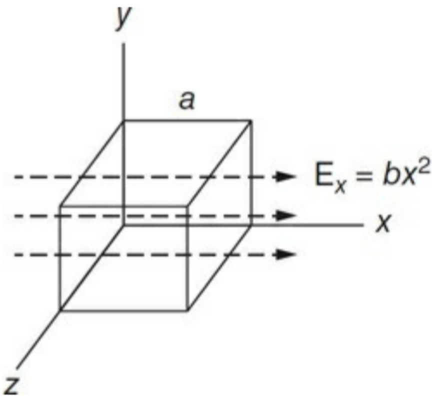
12. A positively charged ring of radius R is made of conducting material and has a charge Q distributed uniformly around it. The center of the ring is located at point 0 on the x-axis. The potential V at a distance $3d$ from point 0 on the x-axis is



   (A) $V = \dfrac{kQ}{9d^2}$
   (B) $V = \dfrac{kQ}{3d^2}$
   (C) $V = \dfrac{kQ}{R^2 + 9d^2}$
   (D) $V = \sqrt{\dfrac{kQ}{R^2 + 9d^2}}$
   (E) $V = \dfrac{kQ}{\sqrt{R^2 + 9d^2}}$

Question 13-14

13. A cube has sides of length a. The cube rests so that one side rests on the x-axis as shown. An electric field is established in the x-direction according to the function $E_x = bx^2$, where b is a positive constant. Which of the following statements is true?



   (A) There is a net charge inside the cube.
   (B) There is no net charge inside the cube.
   (C) The flux passing through the cube is negative.
   (D) The flux passing through the cube is zero.
   (E) The flux diminishes while passing through the cube.

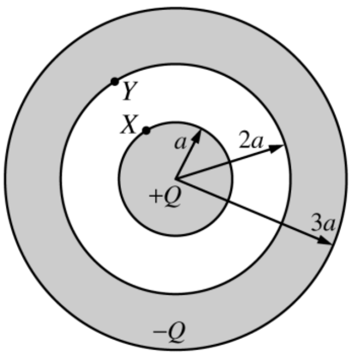
14. The charge inside the cube can be expressed by the equation
   (A) $\epsilon_0 ba$
   (B) $\epsilon_0 ba^2$
   (C) $\epsilon_0 ba^3$
   (D) $\epsilon_0 ba^4$
   (E) $\epsilon_0 b^2 2a^2$

15. Which of the following statements is true of electric field and equipotential lines?
   (A) The electric field vector always points in the same direction as the equipotential lines.
   (B) The electric field always points in the opposite direction of the equipotential lines.
   (C) The electric field always points perpendicular to the equipotential lines.
   (D) The electric field is always equal to the equipotential lines.
   (E) Equipotential lines always form a circle around electric field lines.

16. The potential V as a function of distance r for a particular charge distribution is given by the equation $V = ar^{-1}$. The electric field as a function of distance r from the charge distribution is
   (A) $1/3\ ar^{-3}$
   (B) $2ar^{-1}$
   (C) ar^{-2}
   (D) $-a(\ln r)$
   (E) $-ar^{-2}$

AP PHYSICS C: ELECTROSTATICS & CAPACITORS
SECTION II
6 Questions

Directions: Answer all questions. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your solutions and explanations, so you should show your work. Credit also depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should clearly indicate which part of a question your work is for.



1. In the figure above, a nonconducting solid sphere of radius a with charge $+Q$ uniformly distributed throughout its volume is concentric with a nonconducting spherical shell of inner radius $2a$ and outer radius $3a$ that has a charge $-Q$ uniformly distributed throughout its volume. Express all answers in terms of the given quantities and fundamental constants.

   (a) Using Gauss's law, derive expressions for the magnitude of the electric field as a function of radius r in the following regions.

      i. Within the solid sphere ($r < a$)

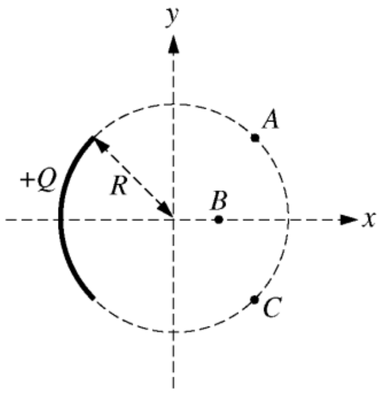
      ii. Between the solid sphere and the spherical shell ($a < r < 2a$)

      iii. Within the spherical shell ($2a < r < 3a$)

      iv. Outside the spherical shell ($r > 3a$)

   (b) What is the electric potential at the outer surface of the spherical shell ($r = 3a$)? Explain your reasoning.

   (c) Derive an expression for the electric potential difference $V_X - V_Y$ between points X and Y shown in the figure.

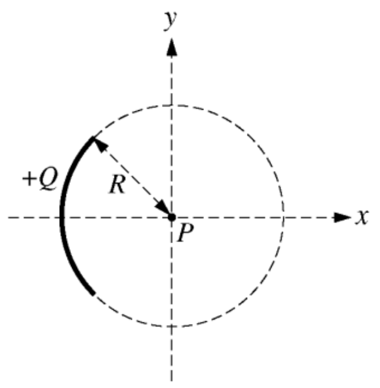


2. A charge $+Q$ is uniformly distributed over a quarter circle of radius R, as shown above. Points A, B, and C are located as shown, with A and C located symmetrically relative to the x-axis. Express all algebraic answers in terms of the given quantities and fundamental constants.

   (a) Rank the magnitude of the electric potential at points A, B, and C from greatest to least, with number 1 being greatest. If two points have the same potential, give them the same ranking. Justify your rankings.

   _____ V_A _____ V_B _____ V_C

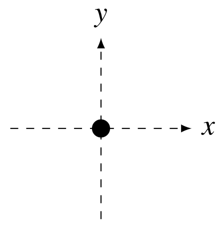
   Point P is at the origin, as shown below, and is the center of curvature of the charge distribution.



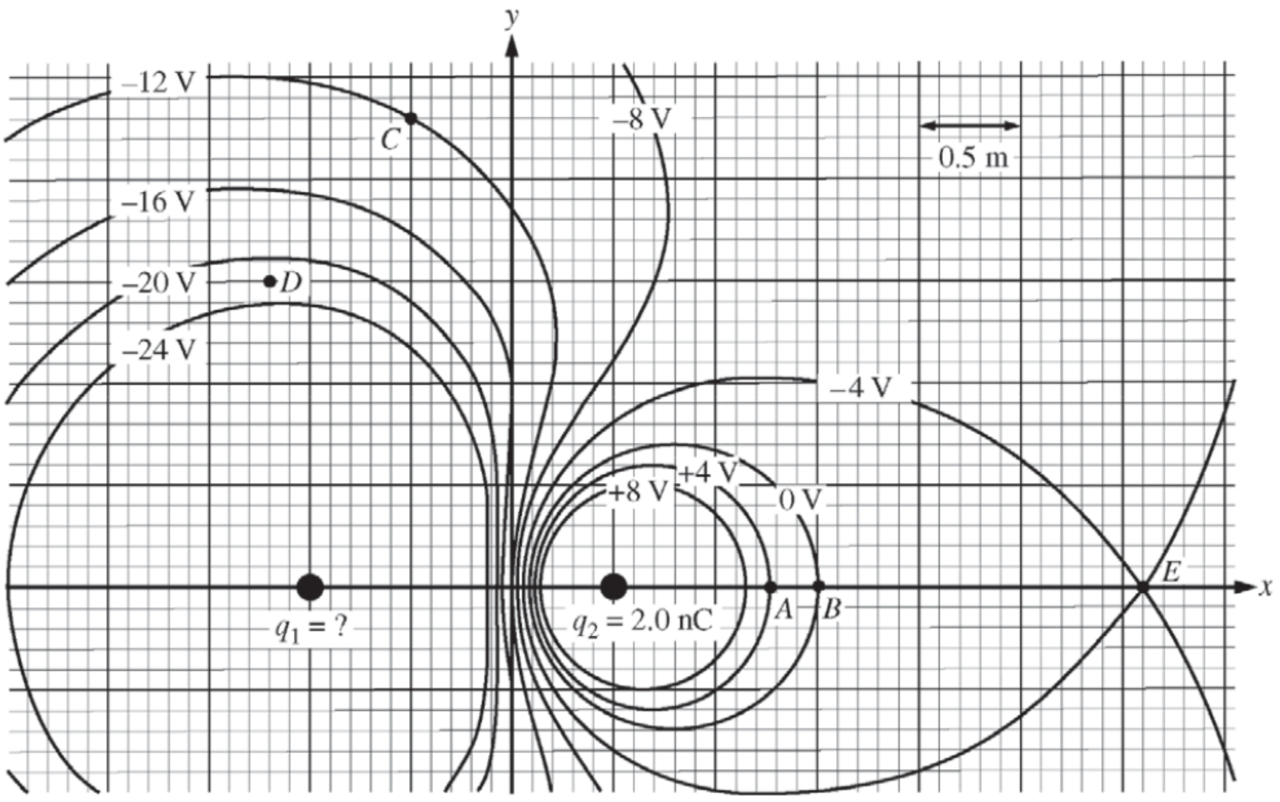
   (b) Determine an expression for the electric potential at point P due to the charge Q.

   (c) A positive point charge q with mass m is placed at point P and released from rest. Derive an expression for the speed of the point charge when it is very far from the origin.

   (d) On the dot representing point P below, indicate the direction of the electric field at point P due to the charge Q.



   (e) Derive an expression for the magnitude of the electric field at point P.



3. Two point charges, q_1 and q_2, are fixed in place on the x-axis at positions $x_1 = -1.00$ m and $x_1 = +0.50$ m, respectively. Charge q_2 has a value of +2.0 nC. Values of electric potential are illustrated by the given equipotentials in the diagram shown above, which is drawn to scale.

   (a) Calculate the value of q_1.

   (b) At point C on the diagram, draw a vector representing the direction of the electric field at that point.

   (c) Calculate the approximate magnitude of the electric field strength at point D on the diagram.

   (d) The equipotential labeled 0 V is the cross section of a nearly spherical surface. Calculate the electric flux for this surface.

   (e) A proton is placed at point A and then released from rest.

      i. Calculate the work done by the electric field on the proton as it moves from point A to point E.

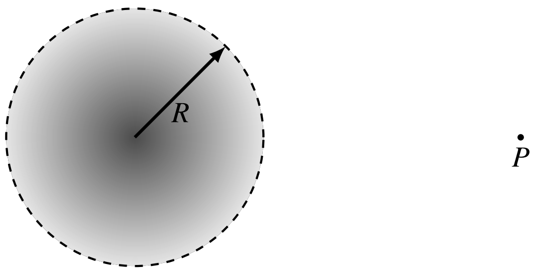
      ii. Calculate the speed of the proton when it reaches point E.

   (f) An electron is released from rest at point B. Which of the following indicates the direction of the initial acceleration, if any, of the electron?

   ____ Up ____ Down ____ Left ____ Right ____ Into the page ____ Out of the page

   ____ The direction is undefined since the acceleration is zero.

   Justify your answer.



4. A spherical cloud of charge of radius R contains a total charge $+Q$ with a nonuniform volume charge density that varies according to the equation

$$\rho(r) = \rho_0 \left(1 - \frac{r}{R}\right) \text{ for } r \le R \text{ and}$$
$$\rho(r) = 0 \text{ for } r > R$$

where r is the distance from the center of the cloud. Express all algebraic answers in terms of Q, R, and fundamental constants.

(a) Determine the following as a function of r for $r > R$.

i. The magnitude E of the electric field

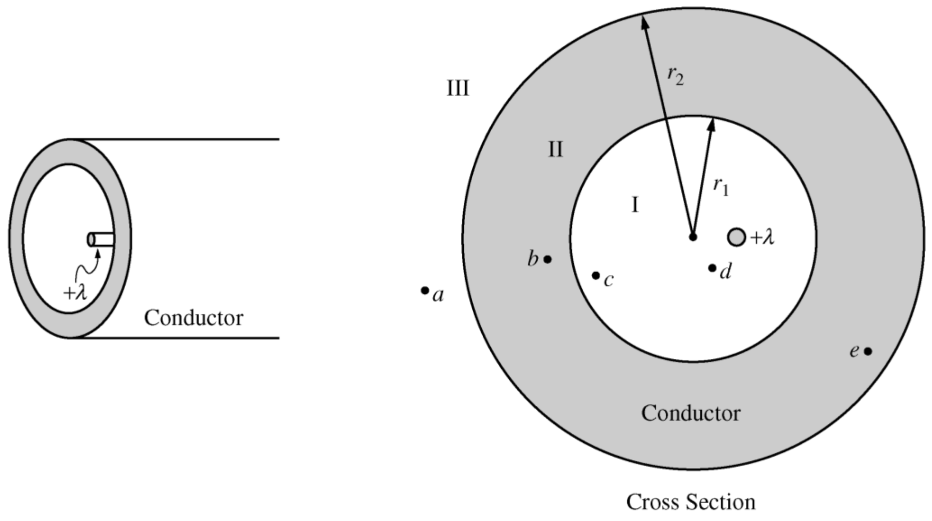
ii. The electric potential V

(b) A proton is placed at point P shown above and released. Describe its motion for a long time after its release.

(c) An electron of charge magnitude e is now placed at point P, which is a distance r from the center of the sphere, and released. Determine the kinetic energy of the electron as a function of r as it strikes the cloud.

(d) Derive an expression for ρ_0.

(e) Determine the magnitude E of the electric field as a function of r for $r \le R$.



5. The figure above left shows a hollow, infinite, cylindrical, uncharged conducting shell of inner radius r_1 and outer radius r_2. An infinite line charge of linear charge density $+\lambda$ is parallel to its axis but off center. An enlarged cross section of the cylindrical shell is shown above right.

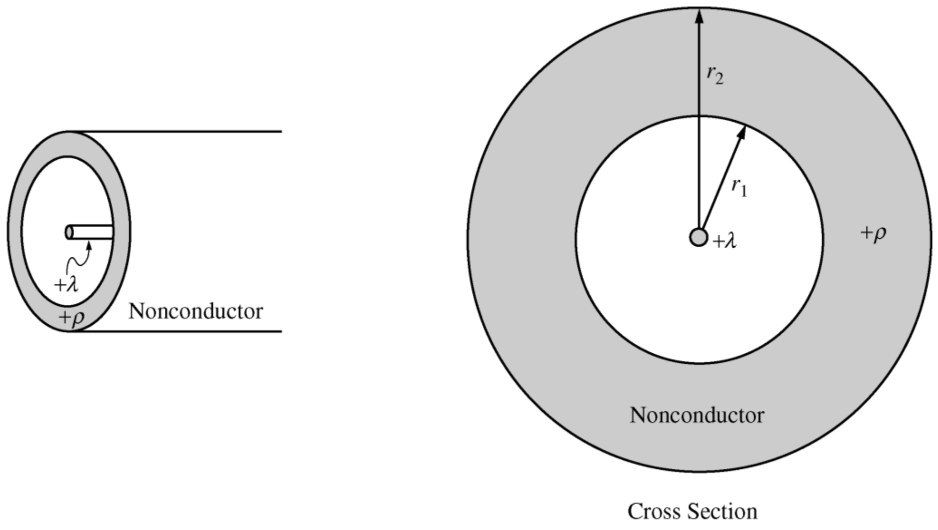
   (a) On the cross section above right,

   i. sketch the electric field lines, if any, in each of regions I, II, and III and

   ii. use + and − signs to indicate any charge induced on the conductor.

   (b) In the spaces below, rank the electric potentials at points a, b, c, d, and e from highest to lowest (1 = highest potential). If two points are at the same potential, give them the same number.

   ___ V_a ___ V_b ___ V_c ___ V_d ___ V_e



   (c) The shell is replaced by another cylindrical shell that has the same dimensions but is nonconducting and carries a uniform volume charge density $+\rho$. The infinite line charge, still of charge density $+\lambda$, is located at the center of the shell as shown above. Using Gauss's law, calculate the magnitude of the electric field as a function of the distance r from the center of the shell for each of the following regions. Express your answers in terms of the given quantities and fundamental constants.

   i. $r < r_1$

   ii. $r_1 \le r \le r_2$

   iii. $r > r_2$

6. A spherically symmetric charge distribution has net positive charge Q_0 distributed within a radius of R. Its electric potential V as a function of the distance r from the center of the sphere is given by the following

$$V(r) = \frac{Q_0}{4\pi\epsilon_0 R}\left[-2 + 3\left(\frac{r}{R}\right)^2\right] \text{ for } r < R$$
$$V(r) = \frac{Q_0}{4\pi\epsilon_0 r} \text{ for } r > R$$

Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) For the following regions, indicate the direction of the electric field $E(r)$ and derive an expression for its magnitude.

i. $r < R$

_____ Radially inward

_____ Radially outward

ii. $r > R$

_____ Radially inward

_____ Radially outward

(b) For the following regions, derive an expression for the enclosed charge that generates the electric field in that region, expressed as a function of r.

i. $r < R$

ii. $r > R$

(c) Is there any charge on the surface of the sphere ($r = R$)?

_____ Yes _____ No

If there is, determine the charge. In either case, explain your reasoning.

(d) On the axes below, sketch a graph of the force that would act on a positive test charge in the regions $r < R$ and $r > R$. Assume that a force directed radially outward is positive.