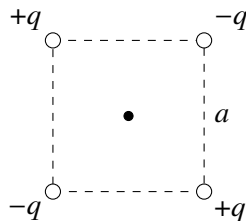# AP PHYSICS C: ELECTROSTATICS & CAPACITORS

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

GO ON TO THE NEXT PAGE.

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?
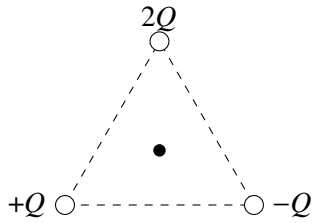
(A) $\downarrow$

(B) $\uparrow$

(C) $\searrow$

(D) $\swarrow$

(E) $\nearrow$

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) $\dfrac{\beta r^2}{12\epsilon_0}$

(B) $\dfrac{\beta r^3}{3\epsilon_0}$

(C) $\dfrac{\beta r}{2\epsilon_0}$

(D) $\dfrac{\beta r^2}{2\epsilon_0}$

(E) $\dfrac{\beta r^2}{4\epsilon_0}$

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

(A) $\dfrac{\beta R^3}{12\epsilon_0}$

(B) $\dfrac{\beta R}{2\epsilon_0}$

(C) $\dfrac{\beta R^3}{3\epsilon_0}$

(D) $\dfrac{\beta R^2}{2\epsilon_0}$

(E) $\dfrac{\beta R^2}{4\epsilon_0}$

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

Question 12-13

12. 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?
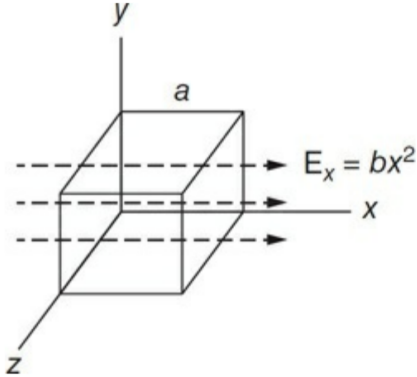

(A) There is a net charge inside the cube.
(B) There is no net charge inside the cube.
(C) The flux passing through the cube is negative.
(D) The flux passing through the cube is zero.
(E) The flux diminishes while passing through the cube.

13. 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) $\epsilon_0 b^2 2a^2$

14. 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.

15. 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) $-ar^{-2}$

16. 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
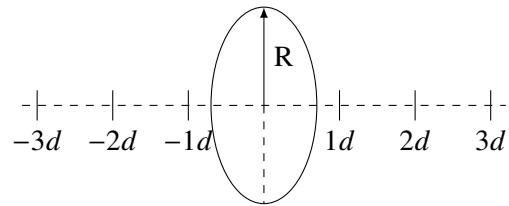

(A) $V = \dfrac{kQ}{9d^2}$

(B) $V = \dfrac{kQ}{3d^2}$

(C) $V = \dfrac{kQ}{R^2 + 9d^2}$

(D) $V = \sqrt{\dfrac{kQ}{R^2 + 9d^2}}$

(E) $V = \dfrac{kQ}{\sqrt{R^2 + 9d^2}}$

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.
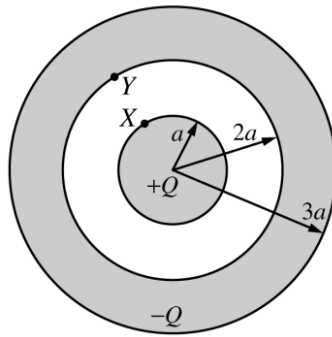
1. In the figure above, a nonconducting solid sphere of radius a with charge $+Q$ uniformly distributed throughout its volume is concentric with a nonconducting spherical shell of inner radius $2a$ and outer radius $3a$ that has a charge $-Q$ uniformly distributed throughout its volume. Express all answers 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.
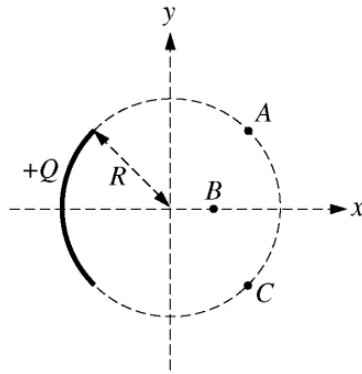
2. A charge $+Q$ is uniformly distributed over a quarter circle of radius R, as shown above. Points A, B, and C are located as shown, with A and C located symmetrically relative to the x-axis. Express all algebraic answers in terms of the given quantities and fundamental constants.

   (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.
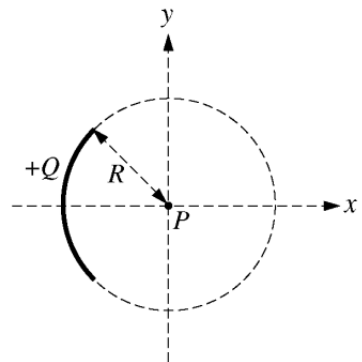

   (b) Determine an expression for the electric potential at point P due to the charge Q.

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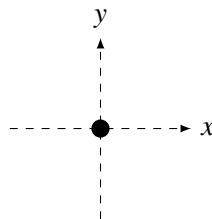
   (e) Derive an expression for the magnitude of the electric field at point P.

3. In the Bohr model of the hydrogen atom, the electron moves in a circular orbit of radius r around the proton.

   (a) Find an expression for the kinetic energy of the electron as a function of r. Show that at any distance r the kinetic energy is half the potential energy.

   (b) Evaluate kinetic energy K, potential energy U and the total energy $W = K + U$ in electron volts for $r = 0.529 \times 10^{-10}$ m, the radius of the electron's orbit in hydrogen. (The energy $|W|$ that must be supplied to the hydrogen atom to remove the electron is called the ionization energy.)
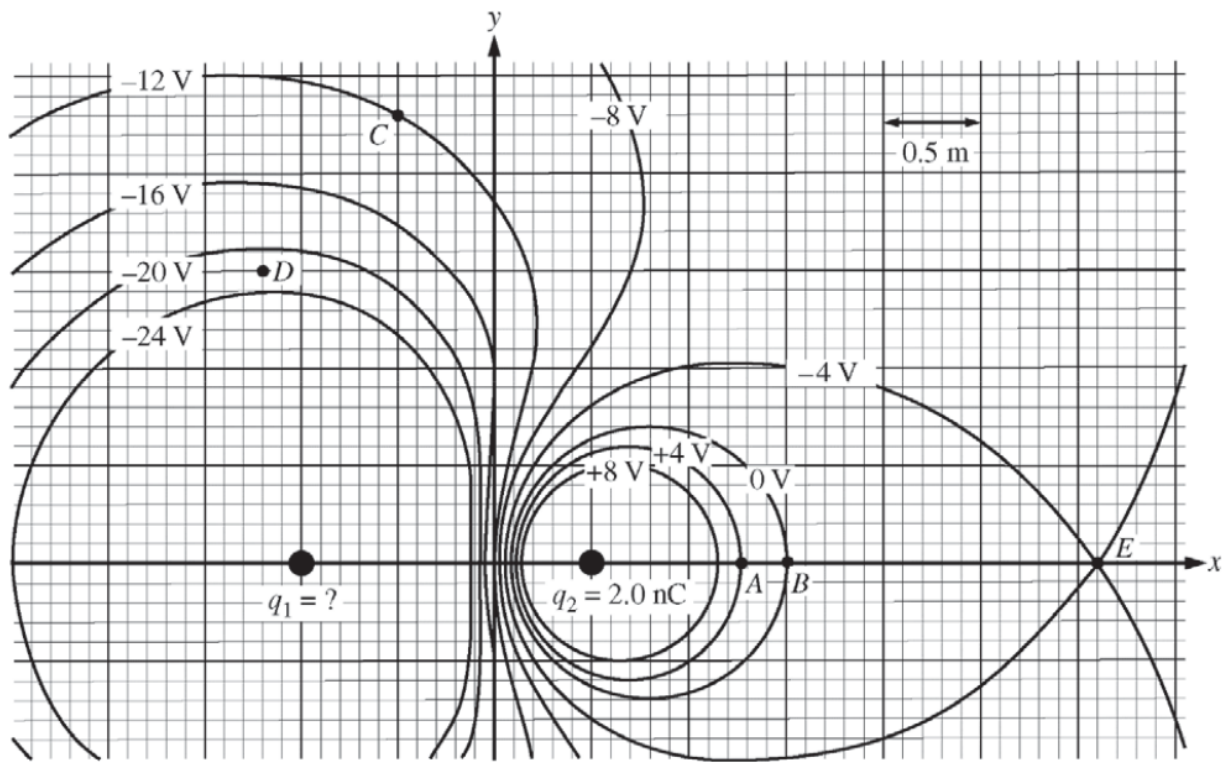
4. Two point charges, q_1 and q_2, are fixed in place on the x-axis at positions $x_1 = -1.00$ m and $x_1 = +0.50$ m, respectively. Charge q_2 has a value of $+2.0$ nC. Values of electric potential are illustrated by the given equipotentials in the diagram shown above, which is drawn to scale.

(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.

5. Two positive charges $+q$ are on the y axis at $y = +a$ and $y = -a$.

   (a) Show that the electric field on the x axis is along the x axis with $E_x = 2kqx(x^2 + a^2)^{-3/2}$.

   (b) Show that near the origin, when $x \ll a$, $E_x \approx 2kqx/a^3$.

   (c) Show that for $x \gg a$, $E_x \approx 2kq/x^2$.

   (d) Explain why you should expect the result in (c) even before calculating it.

   A bead of mass m with a negative charge $-q$ slides along a thread that runs along the x axis.

   (e) Show that for small displacements $x \ll a$, the bead experiences a restoring force that is proportional to x and therefore undergoes simple harmonic motion.

   (f) Find the period of the motion.

6. Using Gauss's law, find

   (a) the electric field strength inside and outside of a uniformly charged hollow sphere of radius R and surface charge density σ (charge per unit area).

   (b) the electric field inside and outside an infinitely long cyclindrical shell of charge of radius R with charge discibution σ (charge per unit area).

   (c) the electric field strength inside and outside a infinitely long solid cylinder of radius R carrying a linear uniform charge density ρ (charge per unit volume).

   Hint: In all cases, think about where to put the Gaussian surface. Take advantage of symmetry.

7. A parallel-plate capacitor has a capacitance C_0 and plate separation of d. To dielectric slabs of constants κ_1 and κ_2, each of thickness $d/2$ and having the same area as the plates, are inserted between the plates as shown in the figure below. When the free charge on the plates are Q,

   (a) find the electric field in each of the dielectric

   (b) find the potential difference between the plates

   (c) show that the new capacitance is given by: $C = \dfrac{\kappa_1 \kappa_2}{\kappa_1 + \kappa_2} C_0$

GO ON TO THE NEXT PAGE.