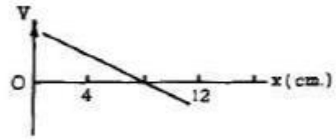
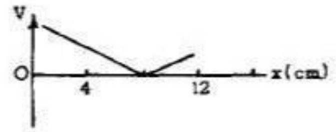
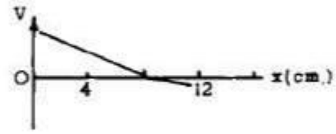
SECTION C – Electric Potential and Energy

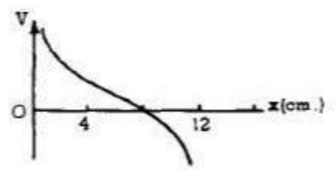
1. **A distribution of charge is confined to a finite region of space. The difference in electric potential between any two points P_1 and P_2 due to this charge distribution depends only upon the**
   (A) charges located at the points P_1 and P_2
   (B) magnitude of a test charge moved from P_1 to P_2
   (C) value of the electric field at P_1 and P_2
   (D) path taken by a test charge moved from P_1 to P_2
   (E) value of the integral $-\int_{P_1}^{P_2} E \cdot dr$

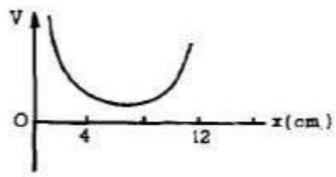
2. **Two small spheres having charges of +2Q and –Q are located 12 centimeters apart. The potential of points lying on a line joining the charges is best represented as a function of the distance x from the positive charge by which of the following?**

(A)


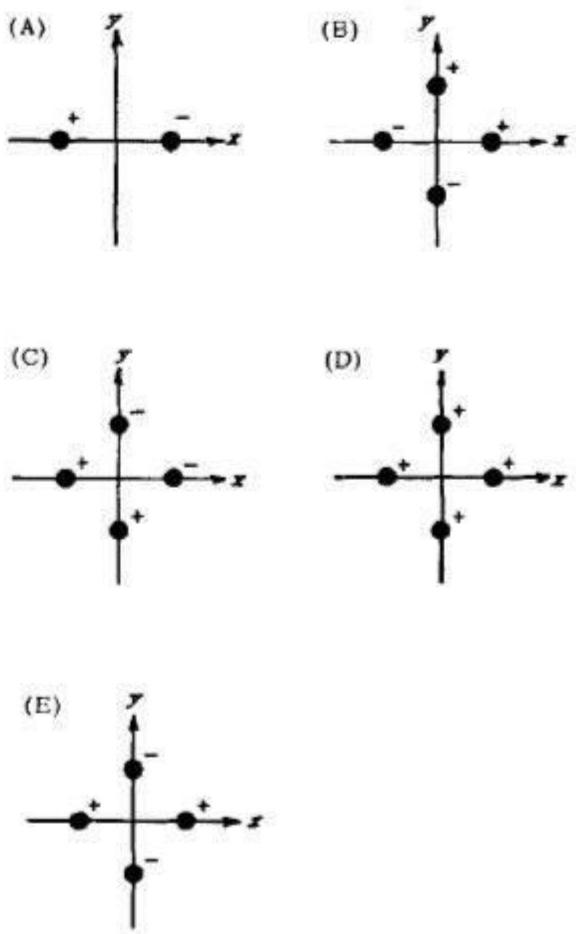
(B)


(C)


(D)


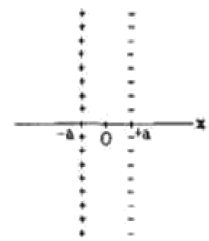
(E)


Questions 3-4 refer to five different charge configurations on the xy-plane using two or four point charges of equal magnitude having signs as indicated below. All charges are the same distance from the origin. The electric potential infinitely far from the origin is defined to be zero.

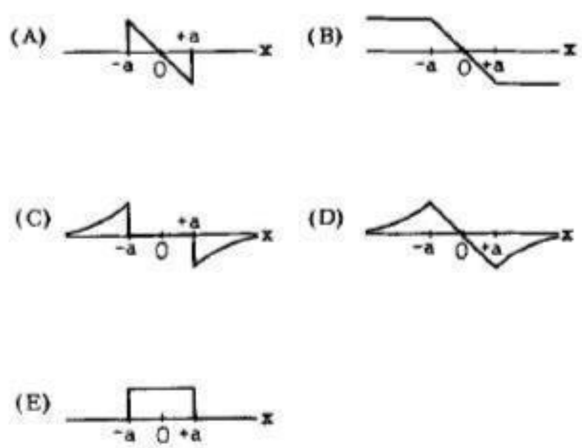


3. In which configuration are both the electric field and the electric potential at the origin equal to zero?
(A) A (B) B (C) C (D) D (E) E

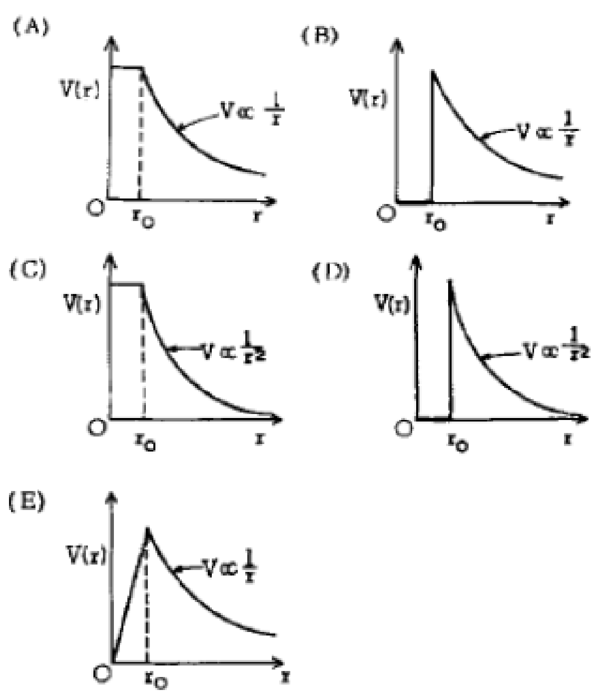
4. In which configuration is the value of the electric field at tile origin equal to zero, but the electric potential at the origin not equal to zero
(A) A (B) B (C) C (D) D (E) E

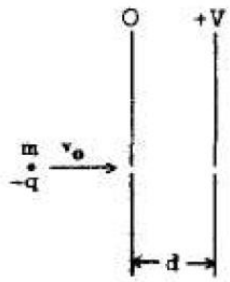


5. **Two infinite parallel sheets of charge perpendicular to the x-axis have equal and opposite charge densities as shown above. The sheet that intersects x = -a has uniform positive surface charge density; the sheet that intersects x = +a has uniform negative surface charge density. Which graph best represents the plot of electric potential as a function of x ?**



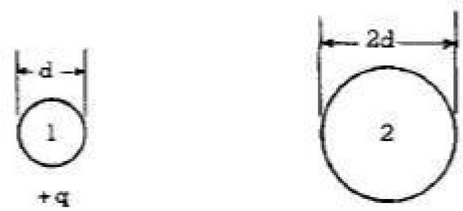
6. **An insulate d spherical conductor of radius ro carries a charge q. The electric potential due to this system varies as a function of the distance r from the center of the sphere in which of the following ways? (The potential is taken to be zero at r = $\propto$)**



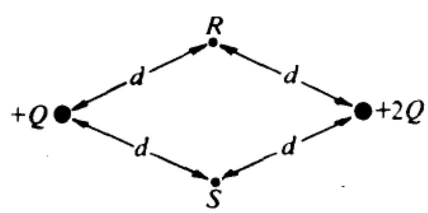


7. As shown in the diagram above, a charged particle having mass m and charge -q is projected into the region between two parallel plates with a speed vo to the right. The potential difference between the plates is V and they are separated by a distance d. What is the net change in kinetic energy of the particle during the time it takes the particle to traverse the distance d ?

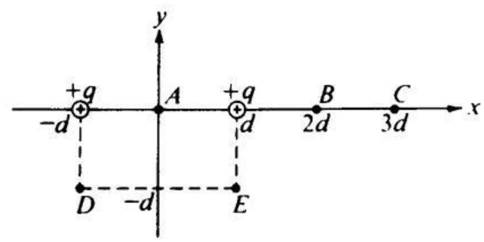
   (A) $+\frac{1}{2} mv_0^2$ (B) –qV/d (C) $\frac{+2qv}{mv_0^2}$ (D) +qV (E) None of the above



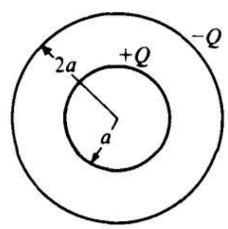
8. 42. Two conducting spheres, one having twice the diameter of the other, are shown above. The smaller sphere initially has a charge +q. When the spheres are connected by a thin wire, which of the following is true?
   (A) 1 and 2 are both at the same potential.
   (B) 2 has twice the potential of 1.
   (C) 2 has half the potential of 1.
   (D) 1 and 2 have equal charges.
   (E) All of the charge is dissipated.



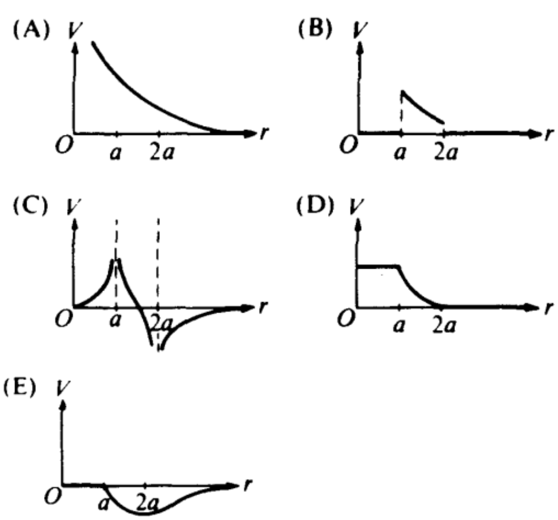
9. Points R and S are each the same distance d from two unequal charges, +Q and +2Q, as shown above. The work required to move a charge -Q from point R to point S is
   (A) dependent on the path taken from R to S
   (B) directly proportional to the distance between R and S
   (C) positive
   (D) zero
   (E) negative



10. **Two positive charges of magnitude q are each a distance d from the origin A of a coordinate system, as shown above. At which of the following points is the electric potential greatest in magnitude?**
    (A) A **(B) B** **(C) C** **(D) D** **(E) E**



11. **Concentric conducting spheres of radii a and 2a bear equal but opposite charges +Q and -Q. respectively. Which of the following graphs best represents the electric potential V as a function of r ?**



12. **Which of the following statements about conductors under electrostatic conditions is true?**
    (A) Positive work is required to move a positive charge over the surface of a conductor.
    (B) Charge that is placed on the surface of a conductor always spreads evenly over the surface.
    (C) The electric potential inside a conductor is always zero.
    (D) The electric field at the surface of a conductor is tangent to the surface.
    (E) The surface of a conductor is always an equipotential surface.

13. A positive charge of 3.0×10^{-8} coulomb is placed in an upward directed uniform electric field of 4.0×10^{4} N/C. When the charge is moved 0.5 meter upward, the work done by the electric force on the charge is
(A)6×10^{-4}J (B)12×10^{-4}J (C)2×10^{4}J (D)8×10^{4}J (E)12×10^{4}J

14. Two conducting spheres, X and Y. have the same positive charge +Q, but different radii ($r_x > r_y$) as shown above. The spheres are separated so that the distance between them is large compared with either radius. If a wire is connected between them, in which direction will current be directed in the wire?
(A) From X to Y
(B) From Y to X
(C) There will be no current in the wire.
(D) It cannot be determined without knowing the magnitude of Q.
(E) It cannot be determined without knowing whether the spheres are solid or hollow.

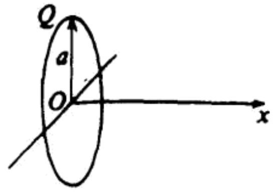
Questions 15-16 refer to a sphere of radius R that has positive charge Q uniformly distributed on its surface

15. Which of the following represents the magnitude of the electric field E and the potential V as functions of r, the distance from the center of the sphere, when r < R ?

	E	V
(A)	0	kQ/R
(B)	0	kQ/r
(C)	0	0
(D)	kQ/r^2	0
(E)	kQ/R^2	0

16. Which of the following represents the magnitude, of the electric field E and the potential V as functions of r, the distance from the center of sphere, when r > R ?

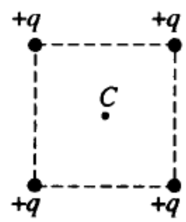
	E	V
(A)	kQ/R^2	kQ/R
(B)	kQ/R	kQ/R
(C)	kQ/R	kQ/r
(D)	kQ/r^2	kQ/r
(E)	kQ/r^2	kQ/r^2



17. **Positive charge Q is uniformly distributed over a thin ring of radius a that lies in a plane perpendicular to the x-axis. with its center at the origin 0, as shown above. The potential V at points on the x-axis is represented by which of the following functions?**

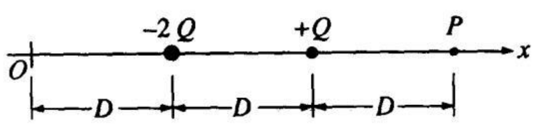
(A) $V(x) = \dfrac{kQ}{x^2 + a^2}$ (B) $V(x) = \dfrac{kQ}{\sqrt{a^2 + x^2}}$

(C) $V(x) = \dfrac{kQ}{x^2}$ (D) $V(x) = \dfrac{kQ}{x}$ (E) $V(x) = \dfrac{kQ}{a + x}$



18. **Four positive charges of magnitude q are arranged at the corners of a square, as shown above. At the center C of the square, the potential due to one charge alone is Vo and the electric field due to one charge alone has magnitude Eo. Which of the following correctly gives the electric potential and the magnitude of the electric field at the center of the square due to all four charges?**

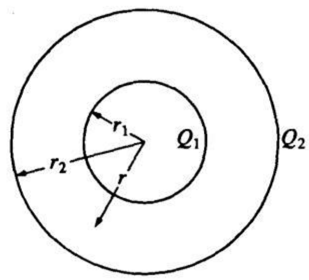
	Electric Potential	Electric Field
A)	**Zero**	**Zero**
B)	**Zero**	**$2E_o$**
C)	**$2\ V_o$**	**$4E_o$**
D)	**$4\ V_o$**	**Zero**
E)	**$4\ V_o$**	**$2E_o$**



19. **Two charges, -2Q and +Q, are located on the x-axis, as shown above. Point P, at a distance of 3D from the origin O, is one of two points on the positive x-axis at which the electric potential is zero. How far from the origin O is the other point?**
A) (2/3) D B) D C) 3/2 D D) 5/3 D E) 2D

20. **What is the radial component of the electric field associated with the potential $V = ar^{-2}$ where a is a constant?**
A) $-2ar^{-3}$ B) $-2ar^{-1}$ C) ar^{-1} D) $2ar^{-1}$ E) $2ar^{-3}$

Questions 21-22



Two concentric, spherical conducting shells have radii r_1 and r_2 and charges Q_1 and Q_2, as shown above. Let r be the distance from the center of the spheres and consider the region $r_1 < r < r_2$.

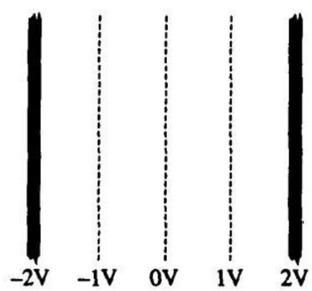
21. In this region the electric field is proportional to

A) Q_1/r^2 B) $(Q_1 + Q_2)/r^2$ C) $(Q_1 + Q_2)/r$ D) $Q_1/r_1 + Q_2/r$ E) $Q_1/r + Q_2/r_2$

22. In this region the electric potential relative to infinity is

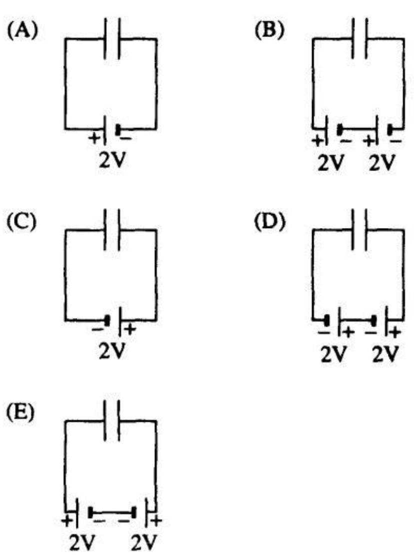
A) Q_1/r^2 B) $(Q_1 + Q_2)/r^2$ C) $(Q_1 + Q_2)/r$ D) $Q_1/r_1 + Q_2/r$ E) $Q_1/r + Q_2/r_2$

Questions 23-24



A battery or batteries connected to two parallel plates produce the equipotential lines between the plates shown above.

23. Which of the following configurations is most likely to produce these equipotential lines?

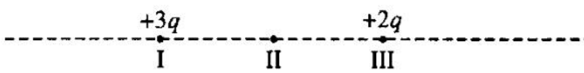


24. The force on an electron located on the 0-volt potential line is
   A) 0 N
   B) 1 N, directed to the right
   C) 1 N, directed to the left
   D) directed to the right, but its magnitude cannot be determined without knowing the distance between the lines
   E) directed to the left, but its magnitude cannot be determined without knowing the distance between the lines

25. The potential of an isolated conducting sphere of radius R is given as a function of the charge q on the sphere by the equation V = kq/R. If the sphere is initially uncharged, the work W required to gradually increase the total charge on the sphere from zero to Q is given by which of the following expressions?

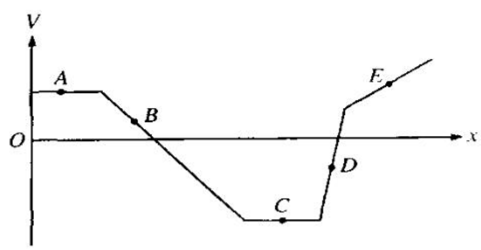
A) $W = kQ/R$ B) $W = kQ^2/R$ C) $W = \int_0^Q (kq/R)dq$ D) $W = \int_0^Q (kq^2/R)dq$
E) $W = \int_0^Q (kq/R^2)dq$

<u>Questions 26-27</u> refer to two charges located on the line shown in the figure below, in which the charge at point I is +3q and the charge at point III is +2q. Point II is halfway between points I and III.



26. Other than at infinity, the electric field strength is zero at a point on the line in which of the following ranges?
   (A) To the left of I (B) Between I and II (C) Between II and III
   (D) To the right of III (E) None; the field is zero only at infinity.

27. The electric potential is negative at some points on the line in which of the following ranges?
   (A) To the left of I (B) Between I and II (C) Between II and III
   (D) To the right of III (E) None; this potential is never negative.



28. The graph above shows the electric potential V in a region of space as a function of position along the x-axis. At which point would a charged particle experience the force of greatest magnitude?
   (A) A (B) B (C) C (D) D (E) E:

29. The work that must be done by an external agent to move a point charge of 2 mC from the origin to a point 3 m away is 5 J. What is the potential difference between the two points?
   (A) 4×10^{-4} V (B) 10^{-2} V (C) 2.5×10^{3} V (D) 2×10^{6} V (E) 6×10^{6} V

30. Suppose that an electron (charge -e) could orbit a proton (charge +e) in a circular orbit of constant radius R. Assuming that the proton is stationary and only electrostatic forces act on the particles, which of the following represents the kinetic energy of the two-particle system?

(A) $\frac{1}{4\pi\varepsilon_0}\frac{e}{R}$ (B) $\frac{1}{8\pi\varepsilon_0}\frac{e^2}{R}$ (C) $-\frac{1}{8\pi\varepsilon_0}\frac{e^2}{R}$ (D) $\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^2}$ (E) $-\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^2}$

Questions 31-32

In a region of space, a spherically symmetric electric potential is given as a function of r, the distance from the origin, by the equation $V(r) = kr^2$, where k is a positive constant.

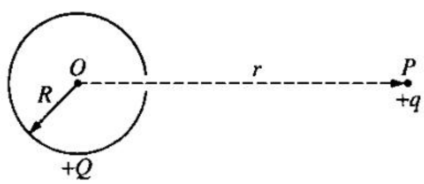
31. What is the magnitude of the electric field at a point a distance r_0 from the origin?

(A) Zero (B) kr_0 (C) $2kr_0$ (D) kr_0^2 (E) $2kr_0^3/3$

32. What is the direction of the electric field at a point a distance r_0 from the origin and the direction of the force on an electron placed at this point?

	Electric Field	Force on Electron
(A)	Toward origin	Toward origin
(B)	Toward origin	Away from origin
(C)	Away from origin	Toward origin
(D)	Away from origin	Away from origin
(E)	Undefined, since the field is zero	Undefined, since the force is zero

33. A positive electric charge is moved at a constant speed between two locations in an electric field, with no work done by or against the field at any time during the motion. This situation can occur only if the
(A) charge is moved in the direction of the field
(B) charge is moved opposite to the direction of the field
(C) charge is moved perpendicular to an equipotential line
(D) charge is moved along an equipotential line
(E) electric field is uniform



34. The nonconducting hollow sphere of radius R shown above carries a large charge +Q, which is uniformly distributed on its surface. There is a small hole in the sphere. A small charge +q is initially located at point P, a distance r from the center of the sphere. If $k = {}^1/_4\pi\varepsilon_0$, what is the work that must be done by an external agent in moving the charge +q from P through the hole to the center O of the sphere?
(A) Zero (B) kqQ/r (C) kqQ/R (D) kq(Q-q)/r (E) kqQ(1/R - 1/r)

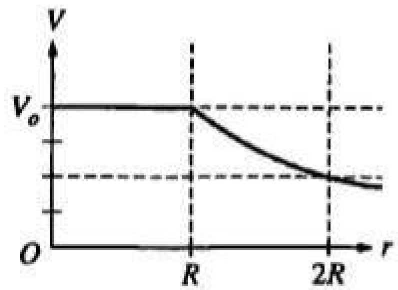
35. In a certain region, the electric field along the x-axis is given by E = ax + b, where a = 40 V/m2 and b = 4 V/m, The potential difference between the origin and x = 0.5 m is
(A) -36 V (B) -7 V (C) -3 V (D) 10 V (E) 16 V

36. A 20 μF parallel-plate capacitor is fully charged to 30 V. The energy stored in the capacitor is most nearly

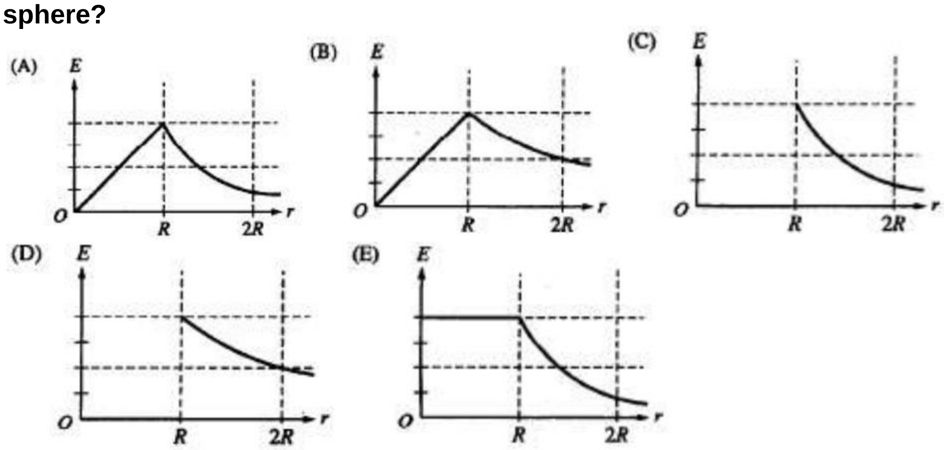
(A) 9×10^{3} J (B) 9×10^{-3} J (C) 6×10^{-4} J (D) 2×10^{-4} J (E) 2×10^{-7} J

37. A potential difference V is maintained between two large, parallel conducting plates. An electron starts from rest on the surface of one plate and accelerates toward the other. Its speed as it reaches the second plate is proportional to

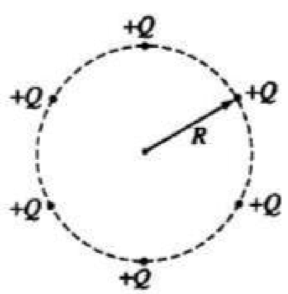
(A) 1/V (B) $1/\sqrt{V}$ (C) $\sqrt{V}$ (D) V (E) V^2



38. A solid metallic sphere of radius R has charge Q uniformly distributed on its outer surface. A graph of electric potential V as a function of position r is shown above. Which of the following graphs best represents the magnitude of the electric field E as a function of position r for this sphere?



Questions 39-40



As shown in the figure above, six particles, each with charge +Q, are held fixed and ate equally spaced around the circumference of a circle of radius R.

39. What is the magnitude of the resultant electric field at the center of the circle?

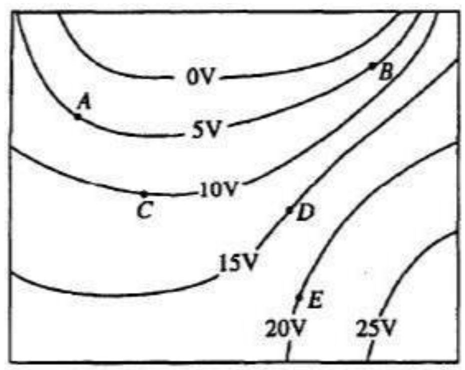
(A) 0 (B) $\frac{\sqrt{6}}{4\pi\varepsilon_0}\frac{Q}{R^2}$ (C) $\frac{2\sqrt{3}}{4\pi\varepsilon_0}\frac{Q}{R^2}$ (D) $\frac{3\sqrt{2}}{4\pi\varepsilon_0}\frac{Q}{R^2}$ (E) $\frac{3}{2\pi\varepsilon_0}\frac{Q}{R^2}$

40. **With the six particles held fixed, how much work would be required to bring a seventh particle of charge + Q from very far away and place it at the center of the circle?**

(A) 0 (B) $\frac{\sqrt{6}}{4\pi\varepsilon_0}\frac{Q}{R}$ (C) $\frac{3}{2\pi\varepsilon_0}\frac{Q^2}{R^2}$

(D) $\frac{3}{2\pi\varepsilon_0}\frac{Q^2}{R}$ (E) $\frac{9}{\pi\varepsilon_0}\frac{Q^2}{R}$

Questions 41-42



The diagram above shows equipotential lines produced by an unknown charge distribution. A, B, C, D, and E are points in the plane.

41. **Which vector below best describes the direction of the electric field at point A ?**

(A)  **(B)** 

(C)  **(D)** 

(E) None of these; the field is zero.

42. **At which point does the electric field have the greatest magnitude?**
(A) A (B) B (C) C (D) D (E) E

43. **How much net work must be done by an external force to move a -1μC point charge from rest at point C to rest at point E?**
(A) -20μJ (B) -10μJ (C)10 μJ (D)20 μJ (E)30 μJ

44. **A physics problem starts: "A solid sphere has charge distributed uniformly throughout. . . " It may be correctly concluded that the**
(A) electric field is zero everywhere inside the sphere
(B) electric field inside the sphere is the same as the electric field outside
(C) electric potential on the surface of the sphere is not constant
(D) electric potential in the center of the sphere is zero
(E) sphere is not made of metal

Solution		Answer
1.	By definition	E
2.	$V = \sum kQ/r$, positive and approaching infinity as it nears the positive charge and negative & approaching negative infinity near the negative charge. Since the positive charge is larger, the zero point is closer to the smaller charge.	D
3.	For potential to be zero, we need two positive and two negative charges. For the electric field to be zero, we need symmetry about the origin to cancel the fields.	E
4.	With all positive charges, the potential can never be zero at the origin, while the symmetry allows the electric fields to cancel	D
5.	The field from an infinite sheet of charge is uniform and, in this case, equal in magnitude, pointing away from the sheet on the left and toward the sheet on the right. The E field cancels outside the sheets. With E = 0, the potential is uniform outside the sheets, positive on the left and negative on the right, with a linear transition between as E is uniform.	B
6.	E = 0 inside a conductor, which means V is constant. Outside the sphere, V varies as 1/r	A
7.	$W_{field} = -q\,\Delta V$	D
8.	When charged conductors are connected, charge flows when there is a difference in potential, until there is no longer a difference in potential.	A
9	$V = \sum kQ/r$, with the symmetry $V_R = V_S$. W = qV = 0	D
10	$V = \sum kQ/r$, point A represents the largest sum of Q/r for the two charges	A
11	Outside the spheres E = 0 so V is constant (and zero relative to infinity). Once inside the negative shell, the potential is that for a positively charged conducting sphere (constant inside, proportional to 1/r outside)	D
12.	E = 0 in and on conductors which means V is constant throughout	E
13.	W = q V = qEd	A
14.	V = kQ/r so the smaller sphere is at a higher potential. Current flows from higher to lower potential.	B
15.	For a spherical shell of charge, E = 0 inside, which means V is constant, equal to its value on the surface	A
16.	Standard spherical charge distribution formulae	D
17.	V = kQ/r, every point on the ring is equidistant from any given point on the x axis so V = kQ/r, where r is the distance from a point on the ring to a point on the x axis (Pythagorean theorem)	B
18.	V = kQ/r and all are positive so they all add. The electric field vectors cancel.	D
19.	There is a locus of points around +Q that satisfy the condition $k(-2Q)/r_1 + k(+Q)/r_2 = 0$. On the x axis, one is at point P, the other is between the charges (and closer to the smaller charge)	D
20.	E = –dV/dr	E
21.	From the spherical symmetry, the electric field between the shells is only dependent on the inside shell.	A

22. Relative to infinity, on the outer surface of the larger shell, the potential is $k(Q_1 + Q_2)/r_2$. Once inside there is no more change to the potential due to Q_2, but still varies as 1/r due to Q_1 until the final position is reached. **E**

23. The potential difference between the plates is 4V, this can be produced with two 2V batteries in series (note the positive plate is on the left) **D**

24. Electrons are forced from low potential toward high potential. The electric field strength is necessary to know the magnitude. **D**

25. The incremental amount of work required to bring a small amount of charge dq is dW = V(dq) where V is the potential relative to infinity at that time, which is kq/R (q being the amount of charge currently on the sphere) **C**

26. E is zero closer to the smaller charge and where the vectors will point in opposite directions **C**

27. V = kQ/r, with no negative charges in the vicinity, V can never be zero **E**

28. E is proportional to the gradient of V, in this case, the slope. F is largest where E is largest which is where the greatest slope occurs. **D**

29. V = W/q (distance is not needed) **C**

30. $F = ke^2/R^2 = mv^2/R$ and $K = ½ mv^2$ (K > 0) **B**

31. E = –dV/dr **C**

32. Since E = –dV/dr = –2kr the field points toward the origin and electrons experience forces opposite in direction to electric fields **B**

33. With no work done by the field, the charge must be moving along an equipotential, which is perpendicular to E fields. $W = -q\Delta V$ with $\Delta V = 0$ **D**

34. No work is required to move the charge inside the sphere so the only work done is to move the charge to the surface. $W = q\,\Delta V = q(V_R - V_r)$ where $V_R = kQ/R$ and $V_r = kQ/r$ **E**

35. **B**

$$V = -\int_0^{0.5} \boldsymbol{E} \cdot \boldsymbol{dx}$$

36. (misplaced question) $U_C = {}^{1}/_{2}\, CV^2$ **B**

37. $q\,\Delta V = ½ mv^2$ **C**

38. The magnitude of E is the slope of the graph, which is zero for r < R and since V is proportional to 1/r for r > R, then E is proportional to $1/r^2$ for r > R **C**

39. Due to symmetry, all fields cancel **A**

40. The potential at the center is $V = \sum kQ/R = 6kQ/R$ and W = Q V **D**

41. E points from high to low potential and E lines are perpendicular to equipotential lines **A**

42. E has the greatest magnitude where V has the largest gradient (the lines are closest) **B**

43. $W = q\,\Delta V$ **B**

44. For charge to be distributed throughout an object, it must not be a conductor, otherwise the charge would move to the surface of the object **E**