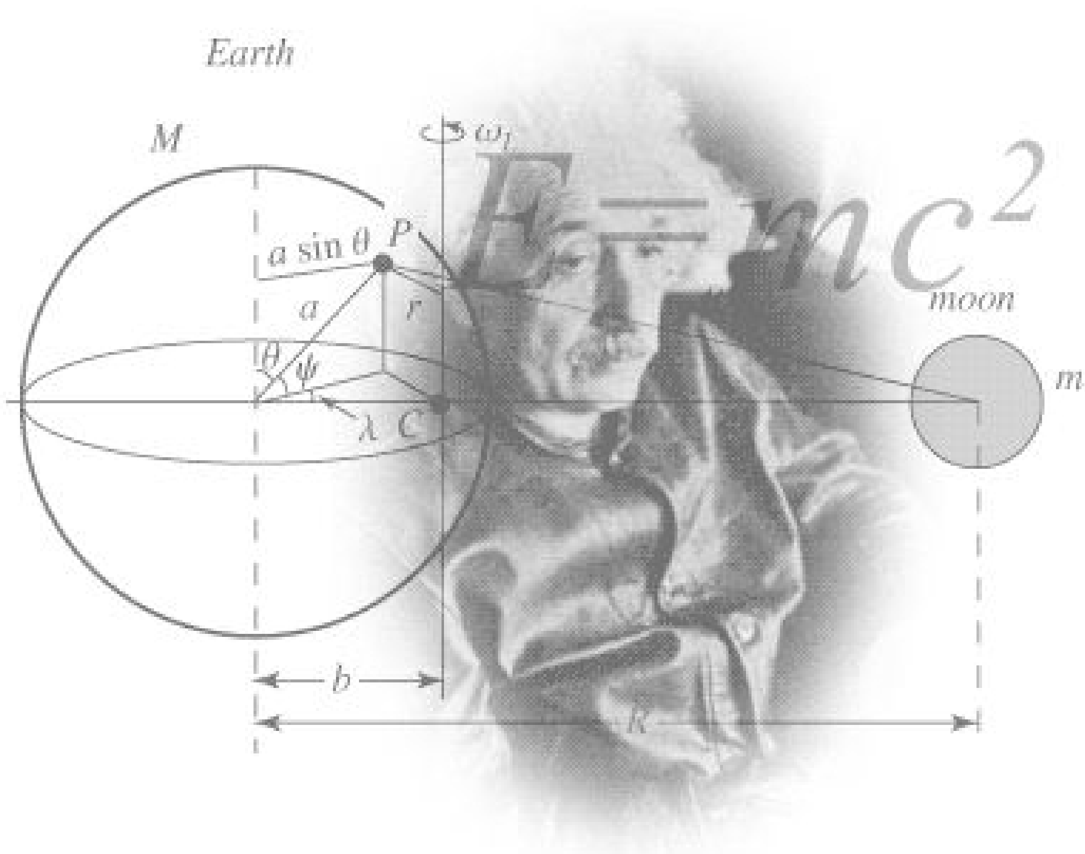
AP Physics 2 – Practice Workbook – Book 2

Electricity, Magnetism, Fluids, Thermodynamics, Optics and Modern Physics



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Appendix 2

IMPORTANT:

This book is a compilation of all the problems published by College Board in AP Physics B and AP Physics C that **were** appropriate for the AP B level as well as problems from AAPT's Physics Bowl and U.S. Physics Team Qualifying Exams organized by topic.

DISCLAIMER

The Multiple Choice Questions in this workbook have been compiled and modified from previous AP Physics B and C examinations and Physics Bowl exams. They are **not** meant to be representative of the new AP Physics courses.

The Free-Response Questions have not been edited and might not represent the topics covered nor the style of questions in the new exams.

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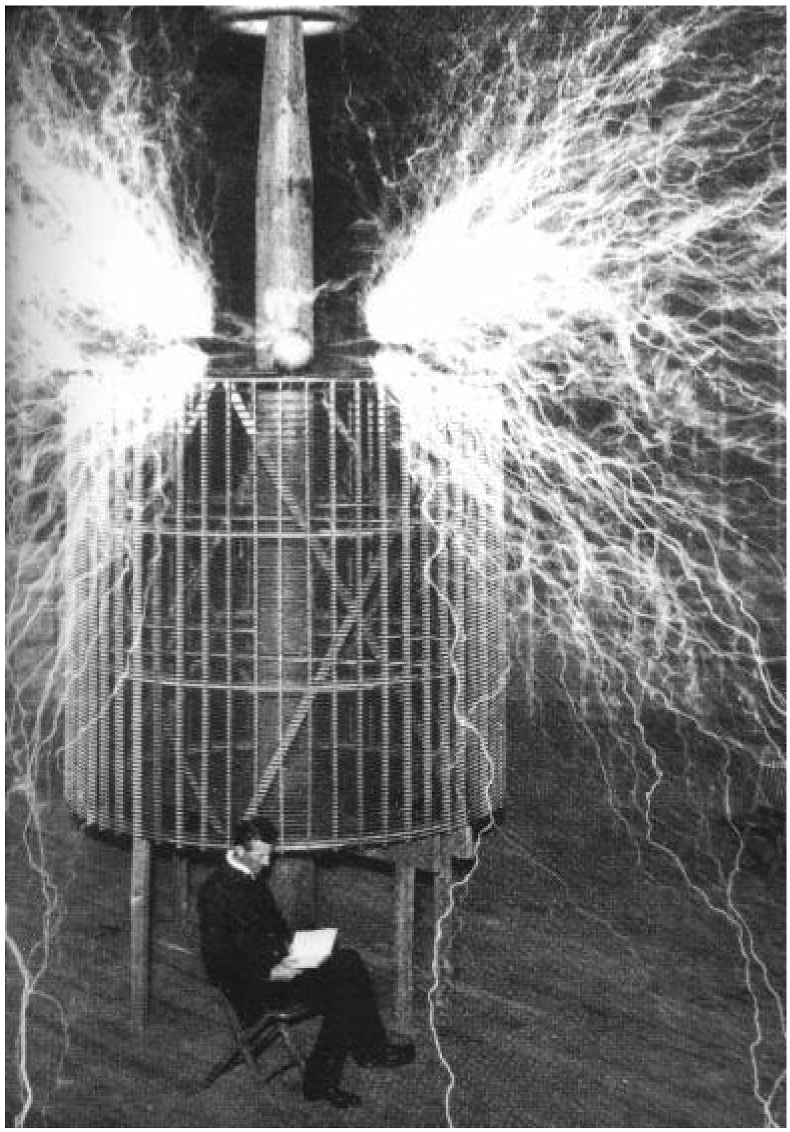
The answers as presented are not the only method to solving many of these problems and physics teachers may present slightly different methods and/or different symbols and variables in each topic, but the underlying physics concepts are the same and we ask you read the solutions with an open mind and use these differences to expand your problem solving skills.

Finally, we *are* fallible and if you find any typographical errors, formatting errors or anything that strikes you as unclear or unreadable, please let us know so we can make the necessary announcements and corrections.

Chapter 12

Electrostatics



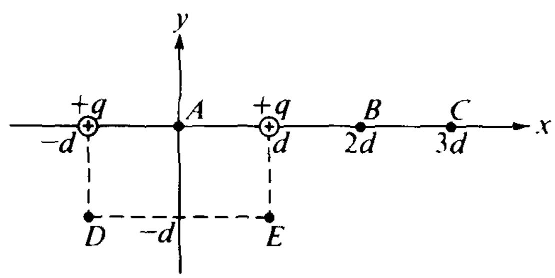
AP Physics Multiple Choice Practice – Electrostatics

1. A solid conducting sphere is given a positive charge Q. How is the charge Q distributed in or on the sphere?
   (A) It is concentrated at the center of the sphere.
   (B) It is uniformly distributed throughout the sphere.
   (C) Its density decreases radially outward from the center.
   (D) It is uniformly distributed on the surface of the sphere only.

2. A parallel–plate capacitor is charged by connection to a battery. If the battery is disconnected and the separation between the plates is increased, what will happen to the charge on the capacitor and the voltage across it?
   (A) Both remain fixed. (B) Both increase. (C) The charge increases and the voltage decreases. (D) The charge remains fixed and the voltage increases.

3. One joule of work is needed to move one coulomb of charge from one point to another with no change in velocity. Which of the following is true between the two points?
   (A) The current is one ampere.
   (B) The potential difference is one volt. (C) The electric field strength is one newton per coulomb.
   (D) The electric field strength is one joule per electron.

Questions 4-5

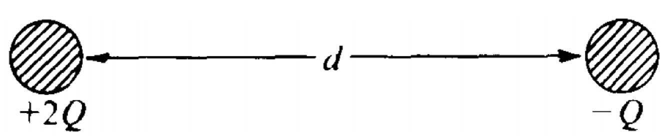


Two positive charges of magnitude q are each a distance d from the origin A of a coordinate system as shown above.

4. At which of the following points is the electric field least in magnitude?
   (A) A (B) B (C) C (D) D

5. At which of the following points is the electric potential greatest in magnitude?
   (A) A (B) B (C) C (D) D

6. A parallel–plate capacitor has a capacitance C_o. A second parallel–plate capacitor has plates with twice the area and twice the separation. The capacitance of the second capacitor is most nearly
   (A) ¼C_o (B) C_o (C) $2C_o$ (D) $4C_o$



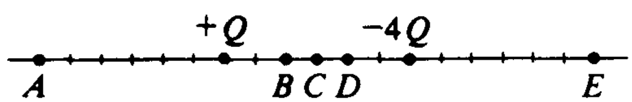
7. Two identical conducting spheres are charged to +2Q and –Q. respectively, and are separated by a distance d (much greater than the radii of the spheres) as shown above. The magnitude of the force of attraction on the left sphere is F_1. After the two spheres are made to touch and then are re-separated by distance d, the magnitude of the force on the left sphere is F_2. Which of the following relationships is correct?
   (A) $2F_1 = F_2$ (B) $F_1 = F_2$ (C) $F_1 = 2F_2$ (D) $F_1 = 8 F_2$

8. The capacitance of a parallel–plate capacitor can be increased by increasing which of the following?
(A) The distance between the plates (B) The charge on each plate (C) The area of the plates
(D) The potential difference across the plates

9. A hollow metal sphere of radius R is positively charged. Of the following distances from the center of the sphere, which location will have the greatest electric field strength?
(A) 0 (center of the sphere) (B) 3R/2 (C) 2R
(D) None of the above because the field is of constant strength

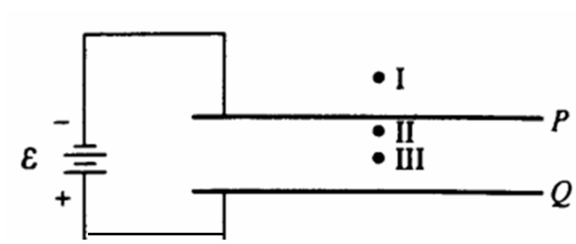
10. Two isolated charges, + q and – 2q, are 2 centimeters apart. If F is the magnitude of the force acting on charge –2Q, what are the magnitude and direction of the force acting on charge +q?

	Magnitude	Direction
(A)	(1/2) F	Toward charge – 2q
(B)	2 F	Away from charge –2q
(C)	F	Toward charge – 2q
(D)	F	Away from charge – 2q

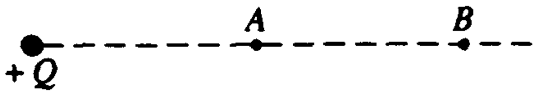


11. Charges + Q and – 4Q are situated as shown above. The net electric field is zero nearest which point?
(A) A (B) C (C) D (D) E

12. A positive charge of 10^{-6} coulomb is placed on an insulated solid conducting sphere. Which of the following is true?
(A) The charge resides uniformly throughout the sphere.
(B) The electric field in the region surrounding the sphere increases with increasing distance from the sphere.
(C) An insulated metal object acquires a net positive charge when brought near to, but not in contact with, the sphere.
(D) When a second conducting sphere is connected by a conducting wire to the first sphere, charge is transferred until the electric potentials of the two spheres are equal.

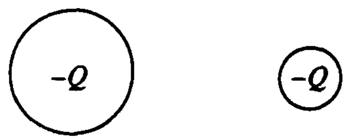


13. Two large parallel conducting plates P and Q are connected to a battery of emf $\mathcal{E}$, as shown above. A test charge is placed successively at points I, II, and III. If edge effects are negligible, the force on the charge when it is at point III is
(A) of equal magnitude and in the same direction as the force on the charge when it is at point I
(B) of equal magnitude and in the same direction as the force on the charge when it is at point II
(C) much greater in magnitude than the force on the charge when it is at point II, but in the same direction
(D) much less in magnitude than the force on the charge when it is at point II, but in the same direction



14. The diagram above shows an isolated, positive charge Q. Point (B) is twice as far away from Q as point A. The ratio of the electric field strength at point A to the electric field strength at point B is
(A) 8 to 1 (B) 4 to 1 (C) 2 to 1 (D) 1 to 2

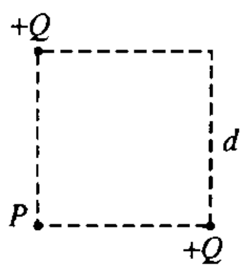
15. Which of the following is true about the net force on an uncharged conducting sphere in a uniform electric field?
(A) It is zero. (B) It is in the direction of the field. (C) It is in the direction opposite to the field.
(D) It causes the sphere to oscillate about an equilibrium position.



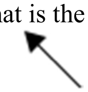
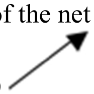
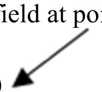
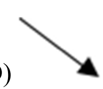
16. Two conducting spheres of different radii, as shown above, each have charge –Q. Which of the following occurs when the two spheres are connected with a conducting wire?
(A) No charge flows.
(B) Negative charge flows from the larger sphere to the smaller sphere until the electric potential of each sphere is the same.
(C) Negative charge flows from the smaller sphere to the larger sphere until the electric field at the surface of each sphere is the same.
(D) Negative charge flows from the smaller sphere to the larger sphere until the electric potential of each sphere is the same.

17. Two parallel conducting plates are connected to a constant voltage source. The magnitude of the electric field between the plates is 2,000 N/C. If the voltage is doubled and the distance between the plates is reduced to 1/5 the original distance, the magnitude of the new electric field is
(A) 800 N/C (B) 1,600 N/C (C) 2,400 N/C (D) 20,000 N/C

<u>Questions 18-19</u>

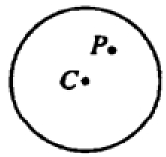


The figure above shows two particles, each with a charge of $+Q$, that are located at the opposite corners of a square of side d.

18. What is the direction of the net electric field at point P ?
(A)  (B)  (C)  (D) 

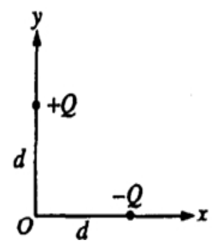
19. What is the potential energy of a particle of charge +q that is held at point P ?
(A) Zero (B) $\frac{\sqrt{2}}{4\pi\varepsilon_0}\frac{qQ}{d}$ (C) $\frac{2}{4\pi\varepsilon_0}\frac{qQ}{d}$ (D) $\frac{2\sqrt{2}}{4\pi\varepsilon_0}\frac{qQ}{d}$

20. Two parallel conducting plates, separated by a distance d, are connected to a battery of emf $\mathcal{E}$. Which of the following is correct if the plate separation is doubled while the battery remains connected?
(A) The electric charge on the plates is doubled.
(B) The electric charge on the plates is halved.
(C) The potential difference between the plates is doubled.
(E) The capacitance is unchanged.



21. The hollow metal sphere shown above is positively charged. Point C is the center of the sphere and point P is any other point within the sphere. Which of the following is true of the electric field at these points?
(A) It is zero at both points.
(B) It is zero at C, but at P it is not zero and is directed inward.
(C) It is zero at C, but at P it is not zero and is directed outward.
(D) It is not zero at either point.

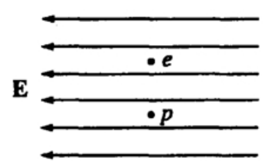
Questions 22-23



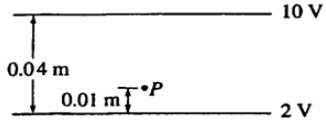
Charges $-Q$ and $+Q$ are located on the x– and y–axes, respectively, each at a distance d from the origin O, as shown above.

22. What is the direction of the electric field at the origin O ?

(A) → (B) ↖ (C) ↘ (D) ↙



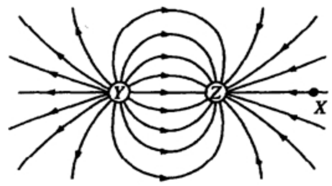
23. An electron e and a proton p are simultaneously released from rest in a uniform electric field E, as shown above. Assume that the particles are sufficiently far apart so that the only force acting on each particle after it is released is that due to the electric field. At a later time when the particles are still in the field, the electron and the proton will have the same
(A) direction of motion (B) speed (C) magnitude of acceleration
(D) magnitude of force acting on them



24. Two large, flat, parallel, conducting plates are 0.04 m apart, as shown above. The lower plate is at a potential of 2 V with respect to ground. The upper plate is at a potential of 10 V with respect to ground. Point P is located 0.01 m above the lower plate.The electric potential at point P is
(A) 10 V (B) 8 V (C) 6 V (D) 4 V

25. A particle of charge Q and mass m is accelerated from rest through a potential difference V, attaining a kinetic energy K. What is the kinetic energy of a particle of charge $2Q$ and mass $m/2$ that is accelerated from rest through the same potential difference?

(A) ½ K (B) K (C) $2K$ (D) $4K$

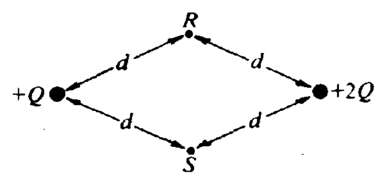


26. The diagram above shows electric field lines in an isolated region of space containing two small charged spheres, Y and Z. Which of the following statements is true?
(A) The charge on Y is negative and the charge on Z is positive.
(B) The strength of the electric field is the same everywhere.
(C) The electric field is strongest midway between Y and Z.
(D) A small negatively charged object placed at point X would tend to move toward the right.

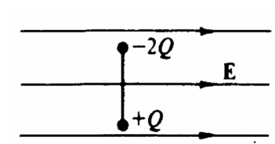
27. A parallel–plate capacitor has a capacitance C_o. A second parallel–plate capacitor has plates with twice the area and twice the separation. The capacitance of the second capacitor is most nearly

(A) ¼C_o (B) ½C_o (C) C_o (D) $2C_o$

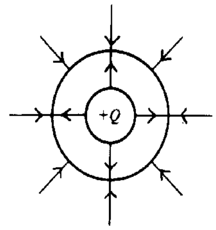
28. The electric field E just outside the surface of a charged conductor is
(A) directed perpendicular to the surface (B) directed parallel to the surface
(C) zero (D) infinite



29. 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) positive
(C) zero
(D) negative



30. A rigid insulated rod, with two unequal charges attached to its ends, is placed in a uniform electric field E as shown above. The rod experiences a
(A) net force to the left and a clockwise rotation
(B) net force to the left and a counterclockwise rotation
(C) net force to the right and a clockwise rotation
(D) net force to the right and a counterclockwise rotation



31. The electric field of two long coaxial cylinders is represented by lines of force as shown above. The charge on the inner cylinder is +Q. The charge on the outer cylinder is
(A) +3Q (B) +Q (C) – Q (D) –3 Q

32. An isolated capacitor with air between its plates has a potential difference V_o and a charge Q_o. After the space between the plates is filled with oil, the difference in potential is V and the charge is Q. Which of the following pairs of relationships is correct?
(A) $Q = Q_o$ and $V > V_o$ (B) $Q = Q_o$ and $V < V_o$ (C) $Q > Q_o$ and $V = V_o$ (D) $Q < Q_o$ and $V < V_o$

33. Two small spheres have equal charges q and are separated by a distance d. The force exerted on each sphere by the other has magnitude F. If the charge on each sphere is doubled and d is halved, the force on each sphere has magnitude
(A) F (B) 4F (C) 8F (D) 16F

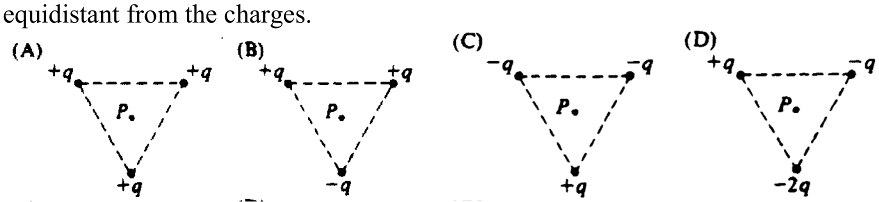
34. Which of the following statements about conductors under electrostatic conditions is true?
(A) Positive work is required to move a positive charge over the surface of a conductor.
(B) Charge that is placed on the surface of a conductor always spreads evenly over the surface.
(C) The electric potential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

35. A charged particle traveling with a velocity v in an electric field E experiences a force F that must be
(A) parallel to v (B) perpendicular to v (C) parallel to E (D) perpendicular to E

36. 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

Questions 37-38

The following configurations of electric charges are located at the vertices of an equilateral triangle. Point P is equidistant from the charges.



37. In which configuration is the electric field at P equal to zero?
(A) A (B) B (C) C (D) D

38. In which configuration is the electric field at P pointed at the midpoint between two of the charges?
(A) A (B) B (C) C (D) D

39. A sheet of mica is inserted between the plates of an isolated charged parallel–plate capacitor. Which of the following statements is true?
(A) The capacitance decreases.
(B) The potential difference across the capacitor decreases.
(C) The charge on the capacitor plates decreases
(D) The electric field between the capacitor plates increases.

40. 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 electrons be directed in the wire?
(A) From X to Y
(B) From Y to X
(C) There will be no flow of charge in the wire.
(D) It cannot be determined without knowing the magnitude of Q.

Questions 41-42
A sphere of radius R has positive charge Q uniformly distributed on its surface

41. 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 ?

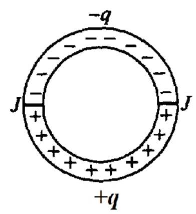
	E	V
(A)	0	kQ/R
(B)	0	kQ/r
(C)	kQ/r^2	0
(D)	kQ/R^2	0

42. 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 ?

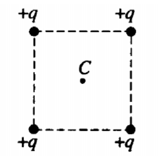
	E	V
(A)	kQ/R^2	kQ/R
(B)	kQ/R	kQ/r
(C)	kQ/r^2	kQ/r
(D)	kQ/r^2	kQ/r^2

43. From the electric field vector at a point, one can determine which of the following?
I. The direction of the electrostatic force on a test charge of known sign at that point
II. The magnitude of the electrostatic force exerted per unit charge on a test charge at that point
III. The electrostatic charge at that point
(A) I only (B) III only (C) I and II only (D) II and III only

44. A conducting sphere of radius R carries a charge Q. Another conducting sphere has a radius R/2, but carries the same charge. The spheres are far apart. The ratio of the electric field near the surface of the smaller sphere to the field near the surface of the larger sphere is most nearly
(A) 1/4 (B) 1/2 (C) 2 (D) 4

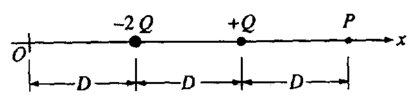


45. A circular ring made of an insulating material is cut in half. One half is given a charge –q uniformly distributed along its arc. The other half is given a charge + q also uniformly distributed along its arc. The two halves are then rejoined with insulation at the junctions J, as shown above. If there is no change in the charge distributions, what is the direction of the net electrostatic force on an electron located at the center of the circle?
(A) Toward the top of the page (B) Toward the bottom of the page (C) To the right D) To the left

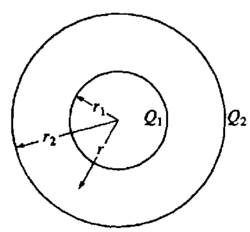


46. Four positive charges of magnitude q are arranged at the corners of a square, as shown above. At the center C of the square, the potential due to one charge alone is V_o and the electric field due to one charge alone has magnitude E_o. Which of the following correctly gives the electric potential 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)	$4 V_o$	Zero
(D)	$4 V_o$	$2E_o$

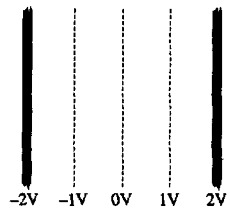


47. Two charges, –2Q and +Q, are located on the x–axis, as shown above. Point P, at a distance of 3D from the origin O, is one of two points on the positive x–axis at which the electric potential is zero. How far from the origin O is the other point?
(A) 2/3 D (B) 3/2 D (C) 5/3 D (D) 2D



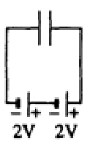
48. Two concentric, spherical conducting shells have radii r_1 and r_2 and charges Q_1 and Q_2, as shown above. Let r be the distance from the center of the spheres and consider the region $r_1 < r < r_2$. In this region the electric field is proportional to
(A) Q_1/r^2 (B) $(Q_1 + Q_2)/r^2$ (C) $(Q_1 + Q_2)/r$ (D) $Q_1/r + Q_2/r_2$

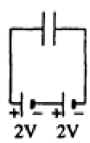
Questions 49-50

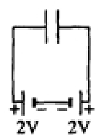


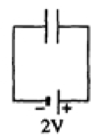
A battery or batteries connected to two parallel plates produce the equipotential lines between the plates shown above.

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

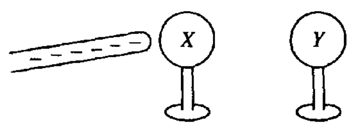
(A) 

(B) 

(C) 

(D) 

50. 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) to the right, but its magnitude cannot be determined without knowing the distance between the lines

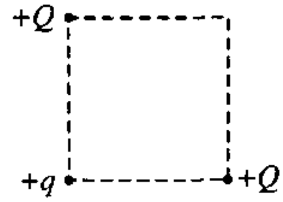


51. Two metal spheres that are initially uncharged are mounted on insulating stands, as shown above. A negatively charged rubber rod is brought close to, but does not make contact with, sphere X. Sphere Y is then brought close to X on the side opposite to the rubber rod. Y is allowed to touch X and then is removed some distance away. The rubber rod is then moved far away from X and Y. What are the final charges on the spheres?

	Sphere X	Sphere Y
A)	Zero	Zero
B)	Negative	Positive
C)	Positive	Negative
D)	Positive	Positive

52. Two initially uncharged conductors, 1 and 2, are mounted on insulating stands and are in contact, as shown above. A negatively charged rod is brought near but does not touch them. With the rod held in place, conductor 2 is moved to the right by pushing its stand, so that the conductors are separated. Which of the following is now true of conductor 2?
(A) It is uncharged. (B) It is positively charged. (C) It is negatively charged.
(D) It is charged, but its sign cannot be predicted.

Questions 53-54



53. As shown above, two particles, each of charge +Q, are fixed at opposite corners of a square that lies in the plane of the page. A positive test charge +q is placed at a third corner. What is the direction of the force on the test charge due to the two other charges?

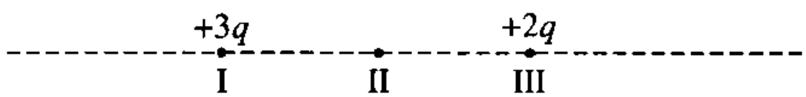
(A) ↘ (B) ↗ (C) ↓ (D) ↙

54. If F is the magnitude of the force on the test charge due to only one of the other charges, what is the magnitude of the net force acting on the test charge due to both of these charges?

(A) Zero (B) $\frac{F}{\sqrt{2}}$ (D) $\sqrt{2}F$ (E) 2

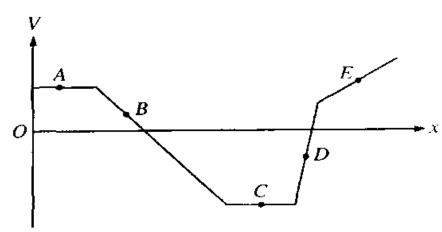
Questions 55-56

Two charges are 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.



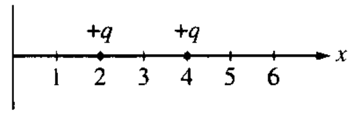
55. Other than at infinity, the electric field strength is zero at a point on the line in which of the following ranges?
(A) To the left of I (B) Between I and II (C) Between II and III (D) To the right of III

56. 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) None; this potential is never negative.

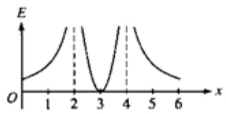
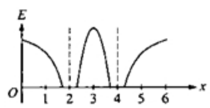
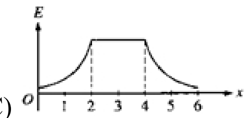
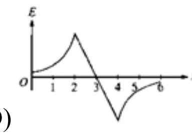


57. The graph above shows the electric potential V in a region of space as a function of position along the x–axis. At which point would a charged particle experience the force of greatest magnitude?
(A) A (B) B (C) D (D) E

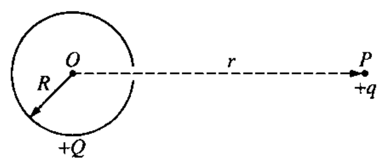
58. If the only force acting on an electron is due to a uniform electric field, the electron moves with constant
(A) acceleration in a direction opposite to that of the field
(B) acceleration in the direction of the field
(C) speed in a direction opposite to that of the field
(D) speed in the direction of the field



59. Two charged particles, each with a charge of +q, are located along the x–axis at x = 2 and x = 4, as shown above. Which of the following shows the graph of the magnitude of the electric field along the x–axis from the origin to x = 6?

(A) 
(B) 
(C) 
(D) 

60. 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

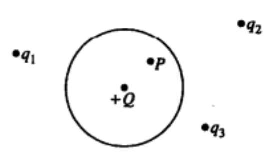


61. The nonconducting hollow sphere of radius R shown above carries a large charge +Q, which is uniformly distributed on its surface. There is a small hole in the sphere. A small charge +q is initially located at point P. a distance r from the center of the sphere. If $k = 1/4\pi\varepsilon_o$, what 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) kqQ/r (B) kqQ/R (C) kq(Q – q)/r (D) kqQ(1/R – 1/r)

<u>Questions 62-63</u>
A capacitor is constructed of two identical conducting plates parallel to each other and separated by a distance d. The capacitor is charged to a potential difference of V_0 by a battery, which is then disconnected.

62. If any edge effects are negligible, what is the magnitude of the electric field between the plates?
(A) V_0d (B) V_0/d (C) V_0/d^2 (D) V_0^2/d

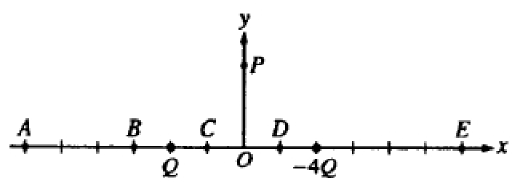
63. A sheet of insulating plastic material is inserted between the plates without otherwise disturbing the system. What effect does this have on the capacitance?
(A) It causes the capacitance to increase.
(B) It causes the capacitance to decrease.
(C) None; the capacitance does not change.
(E) Nothing can be said about the effect without knowing the thickness of the sheet.



64. A point charge +Q is inside an uncharged conducting spherical shell that in turn is near several isolated point charges, as shown above. The electric field at point P inside the shell depends on the magnitude of
(A) Q only
(B) the charge distribution on the sphere only
(C) Q and the charge distribution on the sphere
(D) all of the point charges

65. 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) $\frac{1}{\sqrt{V}}$ (B) $\sqrt{V}$ (C) V (D) V^2

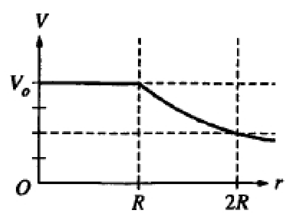
Questions 66-67



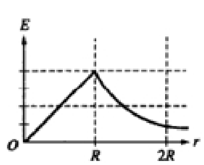
Particles of charge Q and –4Q are located on the x–axis as shown in the figure above. Assume the particles are isolated from all other charges.

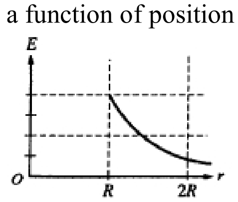
66. Which of the following describes the direction of the electric field at point P?
(A) +y (B)–y (C) Components in both the –x and +y directions
(D) Components in both the +x and –y directions

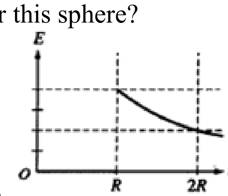
67. At which of the labeled points on the x–axis is the electric field zero?
(A) A (B) B (C) C (D) E

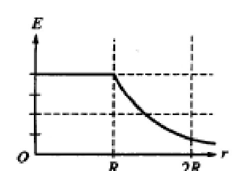


68. A solid metallic sphere of radius R has charge Q uniformly distributed on its outer surface. A graph of electric potential V as a function of position r is shown above. Which of the following graphs best represents the magnitude of the electric field E as a function of position r for this sphere?

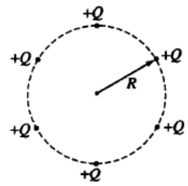
(A) 

(B) 

(C) 

(D) 

Questions 69-70



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.

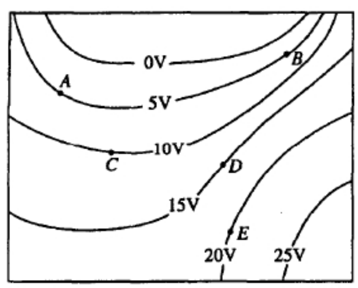
69. What is the magnitude of the resultant electric field at the center of the circle?

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

70. 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?

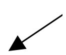
(A) 0 (B) $\frac{\sqrt{6}}{4\pi\varepsilon_0}\frac{Q}{R}$ (C) $\frac{3}{2\pi\varepsilon_0}\frac{Q^2}{R^2}$ (D) $\frac{3}{2\pi\varepsilon_0}\frac{Q^2}{R}$

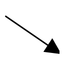
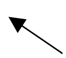
Questions 71-73



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

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

(A)  (B) 

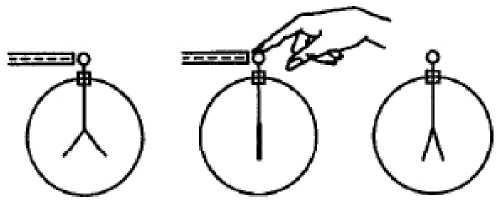
(C)  (D) 

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

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

74. 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 potential on the surface of the sphere is not constant
(C) electric potential in the center of the sphere is zero
(D) sphere is not made of metal

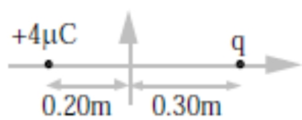
75. A uniform spherical charge distribution has radius *R*.. Which of the following is true of the electric field strength due to this charge distribution at a distance r from the center of the charge?
(A) It is greatest when $r = 0$.
(B) It is directly proportional to r when $r > R$.
(C) It is directly proportional to r when $r < R$.
(D) It is directly proportional to r^2.



76. When a negatively charged rod is brought near, but does not touch, the initially uncharged electroscope shown above, the leaves spring apart (I). When the electroscope is then touched with a finger, the leaves collapse (II). When next the finger and finally the rod are removed, the leaves spring apart a second time (III). The charge on the leaves is
(A) positive in both I and III
(B) negative in both I and III
(C) positive in I, negative in III
(D) negative in I, positive in III

77. A positively charged conductor attracts a second object. Which of the following statements *could* be true?
I. The second object is a conductor with negative net charge.
II. The second object is a conductor with zero net charge.
III. The second object is an insulator with zero net charge..
(A) I only (B) II only (C) III only (D) I, II & III

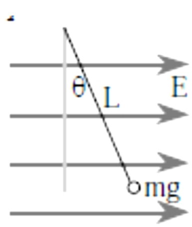
<u>Questions 78-79</u>



A point charge of +4.0 μC is placed on the negative x–axis 0.20 m to the left of the origin, as shown in the accompanying figure. A second point charge *q* is placed on the positive x–axis 0.30 m to the right of the origin.

78. If the net electric field at the origin is zero. What is q?
(A) +9.0 μC (B) +6.0 μC (C) –6.0 μC (D) –9.0 μC

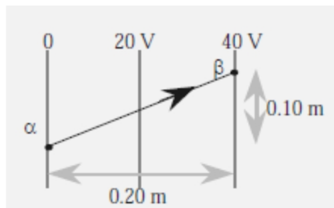
79. If the net electric potential at the origin is zero, what is q?
(A) +9.0 μC (B) +6.0 μC (C) –6.0 μC (D) –9.0 μC



80. A small object with charge q and weight mg is attached to one end of a string of length L. The other end is attached to a stationary support. The system is placed in a uniform horizontal electric field E, as shown in the accompanying figure. In the presence of the field, the string makes a constant angle q with the vertical. What is the sign and magnitude of q?

(A) positive with magnitude $\frac{mg}{E}$
(B) negative with magnitude $\frac{mg}{E}$
(C) positive with magnitude $\frac{mg}{E}\tan\theta$
(D) negative with magnitude $\frac{mg}{E}\tan\theta$

81. Two large parallel plates a distance d apart are charged by connecting them to a battery of potential difference V. The battery is disconnected, and the plates are slowly moved apart. As the distance between plates increases:
(A) the charge on the plates decreases.
(B) the electric field intensity between the plates increases.
(C) the potential difference between the plates decreases.
(D) the potential difference between the plates increases.



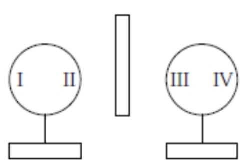
82. In the figure above, equipotential lines are drawn at 0, 20.0 V, and 40.0 V. The total work done in moving a point charge of + 3.00 mC from position a to position b is:
(A) 4.00 mJ (B) 8.00 mJ (C) 12.0 mJ (D) 120 mJ

83. Two positive point charges repel each other with force 0.36 N when their separation is 1.5 m. What force do they exert on each other when their separation is 1.0 m?
(A) 0.81 N (B) 0.54 N (C) 0.24 N (D) 0.16 N

84. Two isolated conducting spheres (S_1 of radius 0.030 m and initial charge + 6.0 nC and S_2 of radius 0.040 m and initial charge + 2.0 nC) are connected by a conducting wire. Charge will flow in the wire until:
(A) both spheres are equally charged.
(B) the force of repulsion between the two spheres becomes equal.
(C) both spheres have the same surface charge density.
(D) both spheres are at the same potential.

85. A point charge +q is placed midway between two point charges +3q and –q separated by a distance 2d. If Coulomb's constant is k, the magnitude of the force on the charge +q is:

(A) $2\frac{kq^2}{d^2}$ (B) $4\frac{kq^2}{d^2}$ (C) $6\frac{kq^2}{d^2}$ (D) $8\frac{kq^2}{d^2}$



86. A charged rod is placed between two insulated conducting spheres as shown. The spheres have no net charge. Region II has the same polarity as Region
(A) I only (B) III only (C) IV only (D) I & IV only

87. Two large oppositely charged insulated plates have a uniform electric field between them. The distance between the plates is increased. Which of the following statements is true?
I. The field strength decreases.
II. The field strength increases.
III. The potential difference between the plates increases.
(A) I only (B) II only (C) III only (D) I and III only

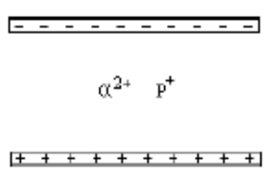
88. When two charged point–like objects are separated by a distance *R*, the force between them is *F*. If the distance between them is quadrupled, the force between them is
(A) 16 *F* (B) 4 *F* (C) *F*/4 (D) *F*/16

89. An electroscope is given a positive charge, causing its foil leaves to separate. When an object is brought near the top plate of the electroscope, the foils separate even further. We could conclude
(A) that the object is positively charged.
(B) that the object is negatively charged.
(C) only that the object is charged.
(D) only that the object is uncharged.

90. Four positive point charges are arranged as shown in the accompanying diagram. The force between charges 1 and 3 is 6.0 N; the force between charges 2 and 3 is 5.0 N; and the force between charges 3 and 4 is 3.0 N. The magnitude of the total force on charge 3 is most nearly
(A) 6.3 N (B) 8.0 N (C) 11 N (D) 14 N

91. Two isolated parallel plates are separated by a distance *d*. They carry opposite charges *Q* and each has surface area *A*. Which of the following would increase the strength of the electric field between the plates?
I. Increasing *Q*
II. Increasing *A*
III. Increasing *d*
(A) I only (B) II only (C) III only (D) II & III only

92. When a positive electrically charged glass rod is brought near a neutral hollow metal sphere suspended by an insulating string, the sphere will be attracted to the rod because:
(A) the rod removes electron from the sphere
(B) the electric charge produces a magnetic field to attract the sphere
(C) the charge on the rod causes a separation of charge in the sphere
(D) some of the protons from the rod have been given to the sphere



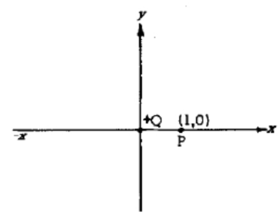
93. An alpha particle and a proton are placed equal distance between two large charged metal plates as shown. Which of the following would best describe the motion of the two particles if they were free to move?
(A) The alpha particle will travel upwards with twice the velocity of the proton.
(B) Both particles will travel upwards with the same velocity.
(C) Both particles will accelerate upwards with the same acceleration.
(D) The alpha particle will accelerate upwards with half the acceleration of the proton.

94. Two parallel metal plates carry opposite electrical charges each with a magnitude of Q. The plates are separated by a distance d and each plate has an area A. Consider the following:

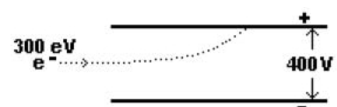
I. increasing Q
II. increasing d
III. increasing A

Which of the following would have the effect of reducing the potential difference between the plates?
(A) I only (B) II only (C) III only (D) II and III

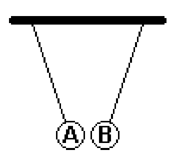
95. A positive point charge of $+q$ and a negative point charge of $-q$ are separated by a distance d. What would be the magnitude of the electric field midway between the two charges?
(A) $E = \frac{kq}{d^2}$ (B) $E = \frac{2kq}{d^2}$ (C) $E = \frac{4kq}{d}$ (D) $E = \frac{8kq}{d^2}$



96. A positive charge +Q located at the origin produces an electric field E_0 at point P (x = +1, y = 0). A negative charge –2Q is placed at such a point as to produce a net field of zero at point P. The second charge will be placed on the
(A) x-axis where x > 1 (B) x-axis where x < 0 (C) y-axis where y > 0 (D) y-axis where y < 0



97. A 300 eV electron is aimed midway between two parallel metal plates with a potential difference of 400 V. The electron is deflected upwards and strikes the upper plate as shown. What would be the kinetic energy of the electron just before striking the metal plate?
(A) 360 eV (B) 400 eV (C) 500 eV (D) 700 eV



98. Two small hollow metal spheres hung on insulating threads attract one another as shown. It is known that a positively charged rod will attract ball A.

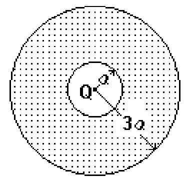
I. Ball A has a positive charge
II. Ball B has a negative charge
III. Ball A and Ball B have opposite charges

Which of the above can be correctly concluded about the charge on the balls?
(A) I only (B) II only (C) III only (D) none of these

99. A 5×10^{-6} coulomb electric charge is placed midway between two parallel metal plates connected to a 9–volt battery. If the electric charge experiences a force of 1.5×10^{-4} newtons, what is the separation of the metal plates?
(A) 6.75×10^{-9} m (B) 2.7×10^{-4} m (C) 3.7×10^{-3} m (D) 0.30 m

100. A parallel–plate capacitor is connected with wires of negligible resistance to a battery having emf $\mathcal{E}$ until the capacitor is fully charged. The battery is then disconnected from the circuit and the plates of the capacitor are moved to half of their original separation using insulated gloves. Let V_{new} be the potential difference across the capacitor plates when the plates are moved together. Let V_{old} be the potential difference across the capacitor plates when connected to the battery. $\frac{V_{new}}{V_{old}} =$

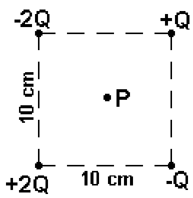
(A) ½ (B) 1 (C) 2 (D) 4



101. A solid, uncharged conducting sphere of radius $3a$ contains a hollowed spherical region of radius a. A point charge +Q is placed at the common center of the spheres. Taking V = 0 as r approaches infinity, the potential at position $r = 2a$ from the center of the spheres is:

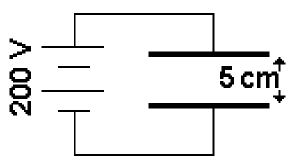
(A) 0 (B) $\frac{2kQ}{3a}$ (C) $\frac{kQ}{3a}$ (D) $\frac{kQ}{a}$

102. Two identical electrical point charges Q, separated by a distance d produce an electrical force of F on one another. If the distance is decreased to a distance of $0.40d$, what is the strength of the resulting force?
(A) $6.3F$ (B) $2.5F$ (C) $0.40F$ (D) $0.16F$

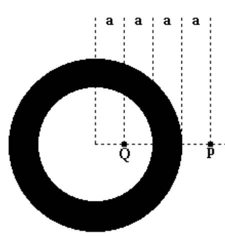


103. Four electrical charges are arranged on the corners of a 10 cm square as shown. What would be the direction of the resulting electric field at the center point P?

(A) → (B) ↑ (C) ↓ (D) ↗



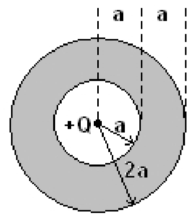
104. A proton is released between the two parallel plates of the fully charged capacitor shown above. What would be the resulting acceleration of the proton?
(A) 7.3×10^{13} m/s^2 (B) 9.6×10^{8} m/s^2 (C) 6.3×10^{19} m/s^2 (D) 3.8×10^{11} m/s^2



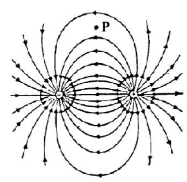
105. A solid uncharged conducting sphere has radius $3a$ contains a hollowed spherical region of radius $2a$. A point charge $+Q$ is placed at a position a distance a from the common center of the spheres. What is the magnitude of the electric field at the position $r = 4a$ from the center of the spheres as marked in the figure by P?

(A) 0 (B) $\frac{kQ}{16a^2}$ (C) $\frac{3kQ}{16a^2}$ (D) $\frac{kQ}{9a^2}$

106. A positively charged object is brought near but not in contact with the top of an uncharged gold leaf electroscope. The experimenter then briefly touches the electroscope with a finger. The finger is removed, followed by the removal of the positively charged object. What happens to the leaves of the electroscope when a negative charge is now brought near but not in contact with the top of the electroscope?
(A) they remain uncharged
(B) they move farther apart
(C) they move closer together
(D) they remain negatively charged but unmoved

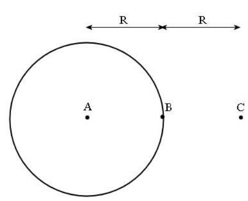


107. A solid spherical conducting shell has inner radius a and outer radius $2a$. At the center of the shell is located a point charge $+Q$. What must the excess charge of the shell be in order for the charge density on the inner and outer surfaces of the shell to be exactly equal?
(A) $-5Q$ (B) $+3Q$ (C) $-4Q$ (D) $+4Q$



108. A small positive test charge is placed at point P in the region near two charges. Which of the following arrows indicates the direction of the force on the positive test charge?

(A) → (B) ↓ (C) ← (D) ↘

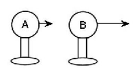


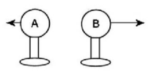
109. A spherical conducting shell has a net charge $+Q$ placed on it. Which of the following is the correct relationship for the electric potential at the points labeled A, B, and C? Point A is at the center of the sphere, point B is at the surface of the shell, a distance R from point A, and point C is a distance R from point B outside the sphere. As r goes to infinity, $V = 0$.
(A) $V_C < V_B < V_A$ (B) $V_A < V_B < V_C$ (C) $V_C = V_B = V_A$ (D) $V_C < V_B = V_A$

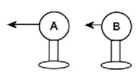
110. Which statement about a system of point charges that are fixed in space is necessarily true?
(A) If the potential energy of the system is negative, net positive work by an external agent is required to take the charges in the system back to infinity.
(B) If the potential energy of the system is positive, net positive work is required to bring any new charge not part of the system in from infinity to its final resting location.
(C) If the potential energy of the system is zero, no negative charges are in the configuration.
(D) If the potential energy of the system is negative, net positive work by an external agent was required to assemble the system of charges.

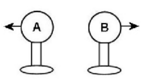
111. A positive point charge exerts a force of magnitude F on a negative point charge placed a distance x away. The negative point charge is replaced with a positive point charge and the distance between the two point charges is halved. What is the magnitude of the new force that the positive point charge exerts on the negative point charge?
(A) $4F$ (B) $2F$ (C) F (D) $F/2$

112. Two uniformly charged non–conducting spheres on insulating bases are placed on an air table. Sphere A has a charge $+3Q$ coulombs and sphere B has a charge $+Q$ coulombs. Which of the following correctly illustrates the magnitude and direction of the electrostatic force between the spheres when they are released?

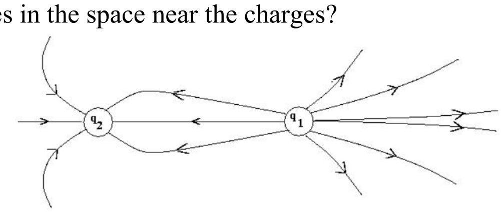
(A) 

(B) 

(C) 

(D) 

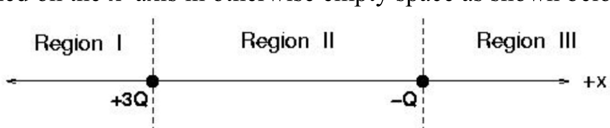
113. For the diagram shown below, what is the ratio of the charges q_2/q_1 where the diagram shown has a representation of the field lines in the space near the charges?



(A) – 3/2 (B) – 2/3 (C) 2/3 (D) 3/2

<u>Questions 114-115</u>

Two point charges are fixed on the x–axis in otherwise empty space as shown below.

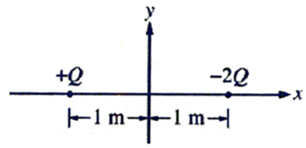


114. In which Region(s) is there a place on the x–axis (aside from infinity) at which the electric potential is equal to zero?
(A) Only in Region II (C) In both Regions I and III
(B) In both Regions I and II (D) In both Regions II and III

115. In which Region(s) is there a place on the x–axis (aside from infinity) at which the electric field is equal to zero?
(A) Only in Region I (C) Only in Region III
(B) In both Regions I and II (D) In both Regions II and III

116. A parallel–plate capacitor is connected to a battery. Without disconnecting the capacitor, a student pulls the capacitor's plates apart so that the plate separation doubles. As a result of this action, what happens to the voltage across the capacitor and the energy stored by the capacitor?
(A) the voltage doubles; the energy stays the same
(B) the voltage doubles; the energy halves
(C) the voltage stays the same; the energy halves
(D) the voltage stays the same; the energy doubles

117. A person rubs a neutral comb through their hair and the comb becomes negatively charged. Which of the following is the best explanation for this phenomenon?
(A) The hair gains protons from the comb.
(B) The hair gains protons from the comb while giving electrons to the comb.
(C) The hair loses electrons to the comb.
(D) The comb loses protons to the person's hand holding the comb.



118. A charge of $+Q$ is located on the x–axis at $x = -1$ meter and a charge of $-2Q$ is held at $x = +1$ meter, as shown in the diagram above. At what position on the x–axis will a test charge of $+q$ experience a zero net electrostatic force?
(A) $-(3+\sqrt{8})$ m (B) –1/3 m (C) 1/3 m (D) $(3+\sqrt{8})$ m

119. The two plates of a parallel-plate capacitor are a distance d apart and are mounted on insulating supports. A battery is connected across the capacitor to charge it and is then disconnected. The distance between the insulated plates is then increased to 2d. If fringing of the field is still negligible, which of the following quantities is doubled?
(A) The capacitance of the capacitor
(B) The surface density of the charge on the plates of the capacitor
(C) The energy stored in the capacitor
(D) The intensity of the electric field between the plates of the capacitor

120. Two point objects each carrying charge $10Q$ are separated by a distance d. The force between them is F. If half the charge on one object is transferred to the other object while at the same time the distance between them is doubled, what is the new force between the two objects?
(A) 0.19 F (B) 0.25 F (C) 0.75 F (D) 4.0 F

121. Two identical spheres carry identical electric charges. If the spheres are set a distance d apart they repel one another with a force F. A third sphere, identical to the other two but initially uncharged is then touched to one sphere and then to the other before being removed. What would be the resulting force between the original two spheres?
(A) ¾ F (B) 5/8 F (C) ½ F (D) 3/8 F

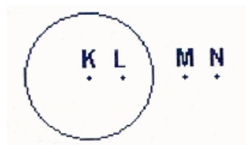
122 An alpha particle is accelerated to a velocity v in a particle accelerator by a potential difference of 1200 V. Which of the following potential differences would be needed to give the alpha particle twice the velocity?
(A) 4800 V (B) 4100 V (C) 2400 V (D) 1700 V

123. An electrical charge Q is placed at one vertex of an equilateral triangle. When an identical charge is placed at another vertex, each charge feels a force of 15 N. When a third charge identical to the first two, is placed at the third vertex, what would be the magnitude of the force on each charge?
(A) 15 N (B) 26 N (C) 30 N (D) 42 N

124. Two conducting spheres with the same charge Q are separated by an infinite distance. Sphere A has a radius of 10 cm while sphere B has a radius of 20 cm. At what distance from the centers of the spheres would the magnitude of the electric field be the same?
(A) 15 cm from A and 15 cm from B (C) 20 cm from A and 40 cm from B
(B) 30 cm from A and 40 cm from B (D) 40 cm from A and 40 cm from B

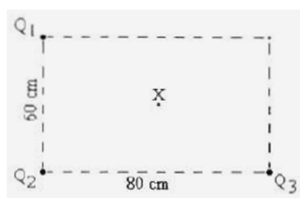
125. A large conducting sphere labeled X contains an electrical charge *Q*. Sphere X is connected by a metal wire to a small uncharged conducting sphere labeled Y. The wire is then removed. How does the electrical field (E_y) at the surface of sphere Y compare to the electrical field (E_x) at the surface of sphere X?
(A) $E_x = E_y = 0$ (B) $E_y = E_x \neq 0$ (C) $E_y < E_x$ (D) $E_y > E_x$

126. What voltage would be required across a 8.9 nF capacitor to accumulate 1.5×10^{12} excess electrons on one plate of the capacitor?
(A) 3.7 V (B) 5.9 V (C) 14 V (D) 27 V



127. A hollow metal sphere is uniformly charged with positive charge. Points K and L are inside the sphere and points M and N are outside the sphere as shown in the diagram. At which pair of points would the field be the smallest?
(A) points K and N (B) points L and M (C) points K and L (D) points M and N

<u>Questions 128-129</u>

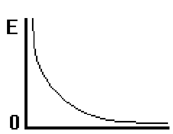


Three electric charges (Q_1, Q_2, and Q_3) are arranged at three corners of a rectangle as shown in the diagram and each has a charge of –40 nC.

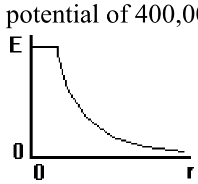
128. What is the magnitude of the net force on Q_2?
(A) 1.4×10^{-5} N (B) 1.7×10^{-5} N (C) 4.2×10^{-5} N (D) 4.6×10^{-5} N

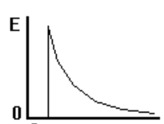
129. What would be the magnitude of the total electric field at center point X?
(A) 1440 N/C (B) 720 N/C (C) 360 N/C (D) 180 N/C

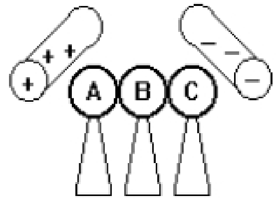
130. Which of the following graphs would best represent the electric field of a hollow sphere as a function of distance from its center when it is charged to a potential of 400,000 volts?

(A) 

(B) 

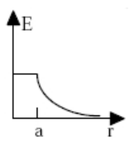
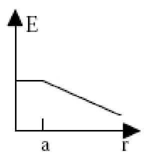
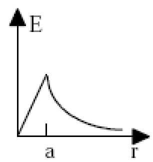
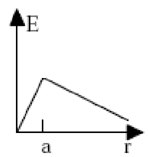
(C) 

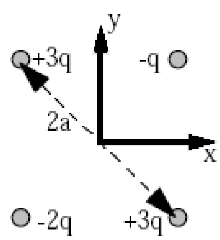
(D) 



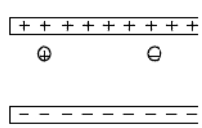
131. Three metal spheres A, B, and C are mounted on insulating stands. The spheres are touching one another, as shown in the diagram below. A strong positively charged object is brought near sphere A and a strong negative charge is brought near sphere C. While the charged objects remain near spheres A and C, sphere B is removed by means of its insulating stand. After the charged objects are removed, sphere B is first touched to sphere A and then to sphere C. The resulting charge on B would be of what relative amount and sign?
(A) the same sign but 1/2 the magnitude as originally on sphere A
(B) the opposite sign but 1/2 the magnitude as originally on sphere A
(C) the opposite sign but 1/4 the magnitude as originally on sphere A
(D) the same sign but 1/2 the magnitude as originally on sphere C

132. A charge is uniformly distributed through a volume of radius *a*. Which of the graphs below best represents the magnitude of the electric field as a function of distance from the center of the sphere?

(A)  (B)  (C)  (D) 



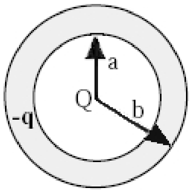
133. Four point charges are placed at the corners of a square with diagonal 2a as shown in the diagram. What is the total electric field at the center of the square?
(A) kq/a^2 at an angle 45° above the +x axis.
(B) kq/a^2 at an angle 45° below the –x axis.
(C) $3kq/a^2$ at an angle 45° above the –x axis.
(D) $3kq/a^2$ at an angle 45° below the +x axis.



134. A free electron and a free proton are placed between two oppositely charged parallel plates. Both are closer to the positive plate than the negative plate. See the diagram below. Which of the following statements is true?
I. The force on the proton is greater than the force on the electron.
II. The potential energy of the proton is greater than that of the electron.
III. The potential energy of the proton and the electron is the same.

(A) II only (B) III only (C) I & II only (D) I & III only

Questions 135-136



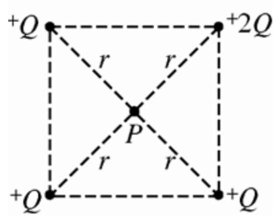
A spherical shell with an inner surface of radius a and an outer surface of radius b is made of conducting material. A charge +Q is placed at the center of the spherical shell and a total charge –q is placed on the shell.

135. How is the charge $-q$ distributed after it has reached equilibrium?
(A) $+Q$ on the inner surface, $-q-Q$ on the outer surface.
(B) The charge $-q$ is spread uniformly between the inner and outer surface.
(C) $-Q$ on the inner surface, $-q+Q$ on the outer surface.
(D) $-Q$ on the inner surface, $-q$ on the outer surface.

136. What is the electrostatic potential at a distance R from the center of the shell, where b < R < a?
(A) kQ/a (B) kQ/R (C) k(Q – q)/R (D) k(Q – q)/b

137. Conducting sphere X is initially uncharged. Conducting sphere Y has twice the diameter of sphere X and initially has charge q. If the spheres are connected by a long thin wire, which of the following is true once equilibrium has been reached?
(A) Sphere Y has half the potential of sphere X.
(B) Spheres X and Y have the same potential.
(C) Sphere Y has half the charge of sphere X.
(D) Spheres X and Y have the same charge.

Questions 138-139



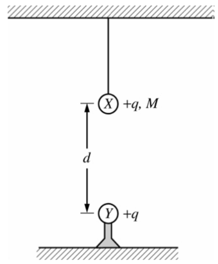
Four positive charges are fixed at the corners of a square, as shown above. Three of the charges have magnitude Q, and the fourth charge has a magnitude $2Q$. Point P is at the center of the square at a distance r from each charge.

138. What is the electric potential at point P?
(A) Zero (B) $2kQ/r$ (C) $4kQ/r$ (D) $5kQ/r$

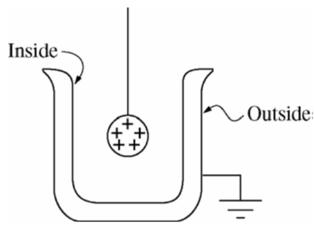
139. What is the magnitude of the electric field at point P ?
(A) kQ/r^2 (B) $2kQ/r^2$ (C) $4kQ/r^2$ (D) $5kQ/r^2$

140. The two charged metal spheres X and Y shown above are far apart, and each is isolated from all other charges. The radius of sphere X is greater than that of sphere Y, and the magnitudes of the electric fields just outside their surfaces are the same. How does the charge on sphere X compare with that on sphere Y?
(A) It is greater.
(B) It is less.
(C) It is the same.
(D It cannot be determined without knowing the actual value of the electric field just outside the spheres.

141. Two negative point charges are a distance x apart and have potential energy U. If the distance between the point charges increases to $3x$, what is their new potential energy?
(A) $9U$ (B) $3U$ (C) $1/3\ U$ (D) $1/9\ U$

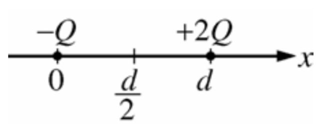


142. Sphere X of mass M and charge $+q$ hangs from a string as shown above. Sphere Y has an equal charge $+q$ and is fixed in place a distance d directly below sphere X. If sphere X is in equilibrium, the tension in the string is most nearly
(A) $Mg + kq/d$ (B) $Mg – kq/d$ (C) $Mg + kq^2/d^2$ (D) $Mg – kq^2/d^2$



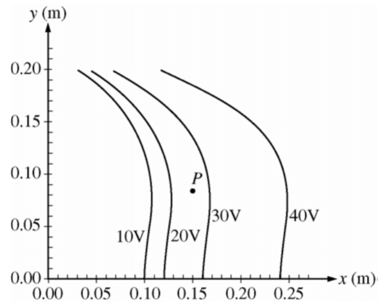
143. A small positively charged sphere is lowered by a nonconducting thread into a grounded metal cup without touching the inside surface of the cup, as shown above. The grounding wire attached to the outside surface is disconnected and the charged sphere is then removed from the cup. Which of the following best describes the subsequent distribution of excess charge on the surface of the cup?
(A) Negative charge resides on the inside surface, and no charge resides on the outside surface.
(B) Negative charge resides on the outside surface, and no charge resides on the inside surface.
(C) Positive charge resides on the inside surface, and no charge resides on the outside surface.
(D) Positive charge resides on the outside surface, and no charge resides on the inside surface.

144. A helium nucleus (charge $+2q$ and mass $4m$) and a lithium nucleus (charge $+3q$ and mass $7m$) are accelerated through the same electric potential difference, V_0. What is the ratio of their resultant kinetic energies, $\frac{K_{lithium}}{K_{Helium}}$?
(A) 2/3 (B) 6/7 (C) 7/6 (D) 3/2



145. A point charge $-Q$ is located at the origin, while a second point charge $+2Q$ is located at $x = d$ on the x-axis, as shown above. A point on the x-axis where the net electric field is zero is located in which of the following regions?
(A) $-\infty < x < 0$ (B) $0 < x < d/2$ (C) $d/2 < x < d$ (D) $d < x < \infty$

Questions 146-147

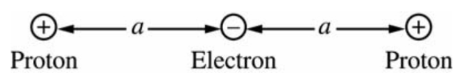


A fixed charge distribution produces the equipotential lines shown in the figure above.

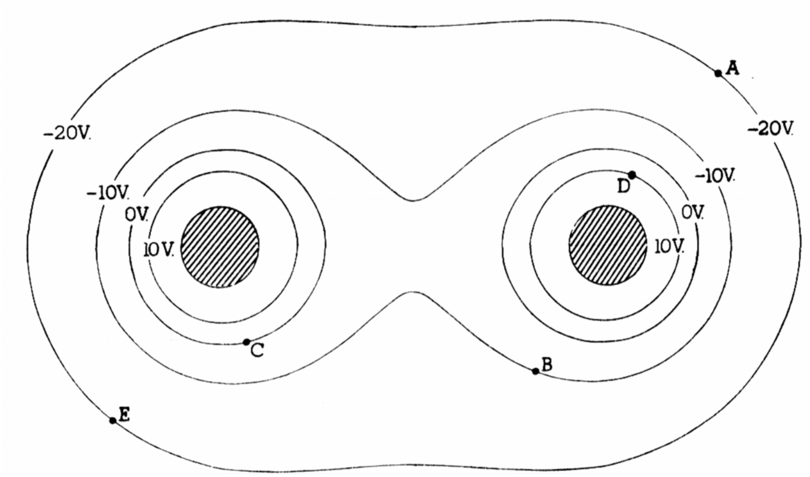
146. Which of the following expressions best represents the magnitude of the electric field at point *P* ?
(A) 10 V/0.14 m (B) 10 V/0.04 m (C) 25 V/0.14 m (D) 25 V/0.04 m

147. The direction of the electric field at point *P* is most nearly
(A) toward the left
(B) toward the right
(C) toward the bottom of the page
(D) toward the top of the page

148. A cloud contains spherical drops of water of radius *R* and charge *Q*. Assume the drops are far apart.
If two droplets happen to combine into a single larger droplet, the new potential *V* at the surface of the larger droplet is most nearly equal to
(A) $2V_0$ (B) $\frac{2}{\sqrt[3]{2}}V_0$ (C) $\sqrt[3]{2}V_0$ (D) V_0

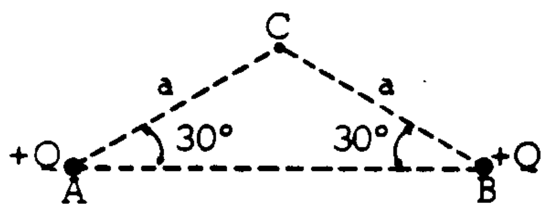


149. Two protons and an electron are assembled along a line, as shown above. The distance between the electron and each proton is *a*. What is the work done by an external force in assembling this configuration of charges?
(A) $-2ke^2/a$ (B) $-3ke^2/2a$ (C) $ke^2/2a$ (D) $3ke^2/a$



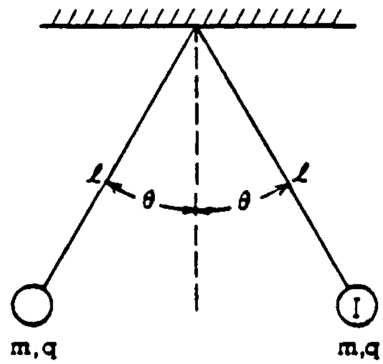
1974B5. The diagram above shows some of the equipotentials in a plane perpendicular to two parallel charged metal cylinders. The potential of each line is labeled.

a. The left cylinder is charged positively. What is the sign of the charge on the other cylinder?
b. On the diagram above, sketch lines to describe the electric field produced by the charged cylinders.
c. Determine the potential difference, $V_A - V_B$, between points A and B.
d. How much work is done by the field if a charge of 0.50 coulomb is moved along a path from point A to point E and then to point D?



1975B2. Two identical electric charges +Q are located at two corners A and B of an isosceles triangle as shown above.

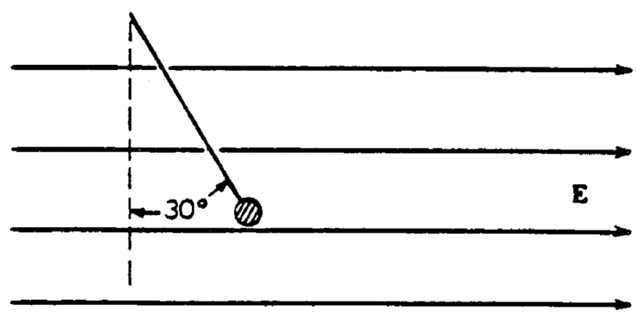
a. How much work does the electric field do on a small test charge +q as the charge moves from point C to infinity,
b. In terms of the given quantities, determine where a third charge +2Q should be placed so that the electric field at point C is zero. Indicate the location of this charge on the diagram above.



1979B7. Two small spheres, each of mass m and positive charge q, hang from light threads of lengths l. Each thread makes an angle θ with the vertical as shown above.

a. On the diagram draw and label all forces on sphere I.

b. Develop an expression for the charge q in terms of m, l, θ, g, and the Coulomb's law constant.

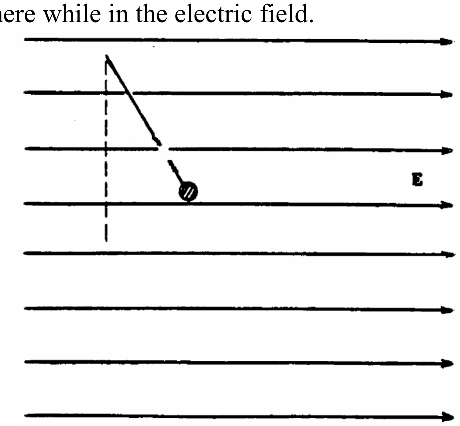


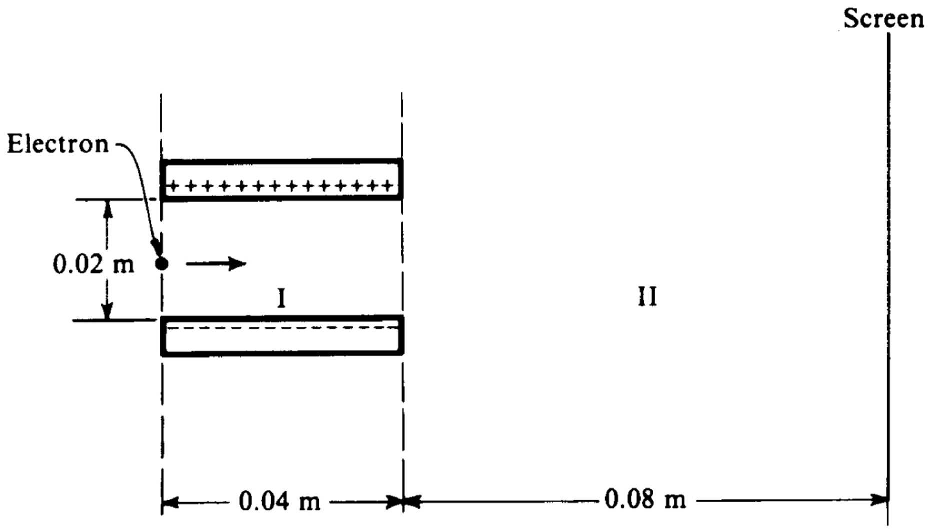
1981B3. A small conducting sphere of mass 5×10^{-3} kilogram, attached to a string of length 0.2 meter, is at rest in a uniform electric field E, directed horizontally to the right as shown above. There is a charge of 5×10^{-6} coulomb on the sphere. The string makes an angle of 30° with the vertical. Assume g = 10 meters per second squared.

a. In the space below, draw and label all the forces acting on the sphere.

b. Calculate the tension in the string and the magnitude of the electric field.

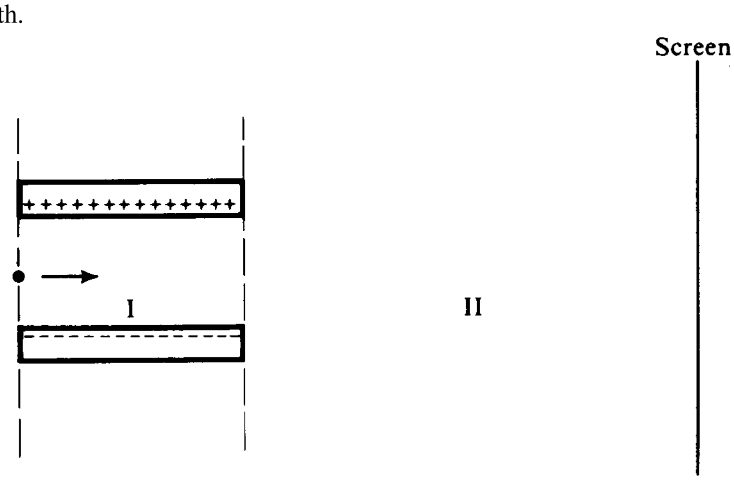
c. The string now breaks. Describe the subsequent motion of the sphere and sketch on the following diagram the path of the sphere while in the electric field.

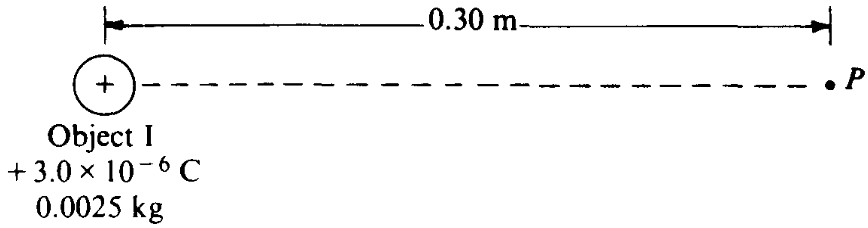




1985B3. An electron initially moves in a horizontal direction and has a kinetic energy of 2.0×10^3 electron–volts when it is in the position shown above. It passes through a uniform electric field between two oppositely charged horizontal plates (region I) and a field–free region (region II) before eventually striking a screen at a distance of 0.08 meter from the edge of the plates. The plates are 0.04 meter long and are separated from each other by a distance of 0.02 meter. The potential difference across the plates is 250 volts. Gravity is negligible.

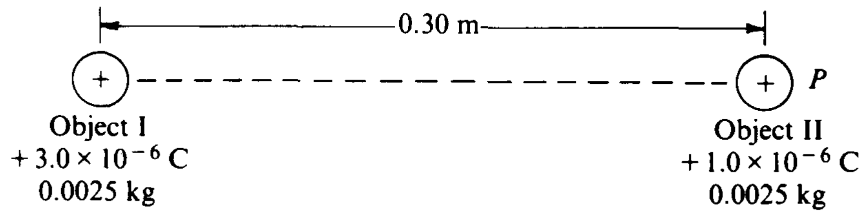
a. Calculate the initial speed of the electron as it enters region I.
b. Calculate the magnitude of the electric field E between the plates, and indicate its direction on the diagram above.
c. Calculate the magnitude of the electric force F acting on the electron while it is in region I.
d. On the diagram below, sketch the path of the electron in regions I and II. For each region describe the shape of the path.





1987B2. Object I, shown above, has a charge of + 3 x 10^{-6} coulomb and a mass of 0.0025 kilogram.

a. What is the electric potential at point P, 0.30 meter from object I?



Object II, of the same mass as object I, but having a charge of + 1 x 10^{-6} coulomb, is brought from infinity to point P, as shown above.

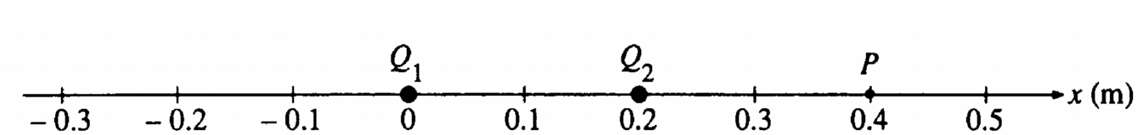
b. How much work must be done to bring the object II from infinity to point P?

c. What is the magnitude of the electric force between the two objects when they are 0.30 meter apart?

d. What are the magnitude and direction of the electric field at the point midway between the two objects?

The two objects are then released simultaneously and move apart due to the electric force between them. No other forces act on the objects.

e. What is the speed of object I when the objects are very far apart?



1989B2. Two point charges, Q_1 and Q_2, are located a distance 0.20 meter apart, as shown above. Charge $Q_1 = +8.0\mu C$. The net electric field is zero at point P, located 0.40 meter from Q_1 and 0.20 meter from Q_2.

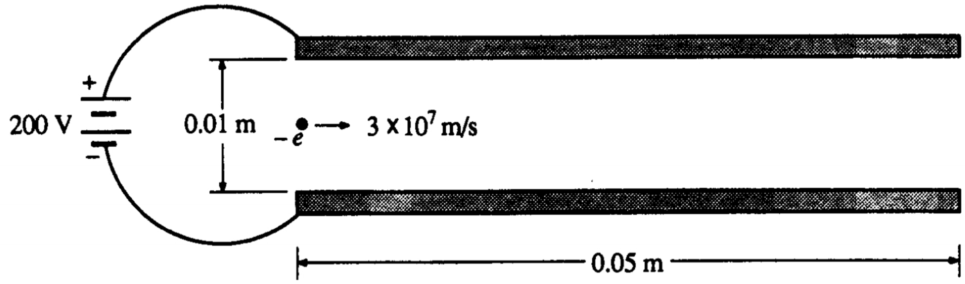
a. Determine the magnitude and sign of charge Q_2.

b. Determine the magnitude and direction of the net force on charge Q_1

c. Calculate the electrostatic potential energy of the system.

d. Determine the coordinate of the point R on the x–axis between the two charges at which the electric potential is zero.

e. How much work is needed to bring an electron from infinity to point R. which was determined in the previous part?



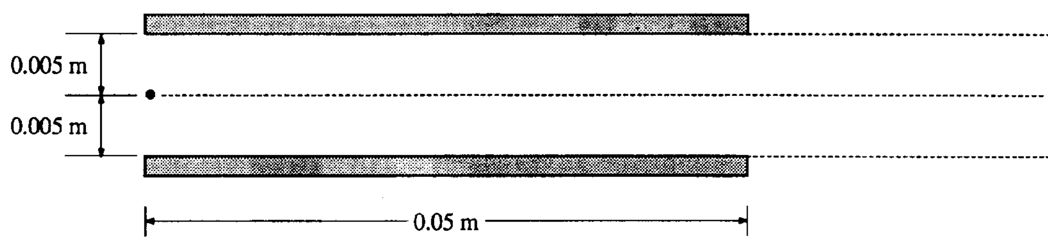
1990B2 (modified) A pair of square parallel conducting plates, having sides of length 0.05 meter, are 0.01 meter apart and are connected to a 200–volt power supply, as shown above. An electron is moving horizontally with a speed of 3×10^7 meters per second when it enters the region between the plates. Neglect gravitation and the distortion of the electric field around the edges of the plates.

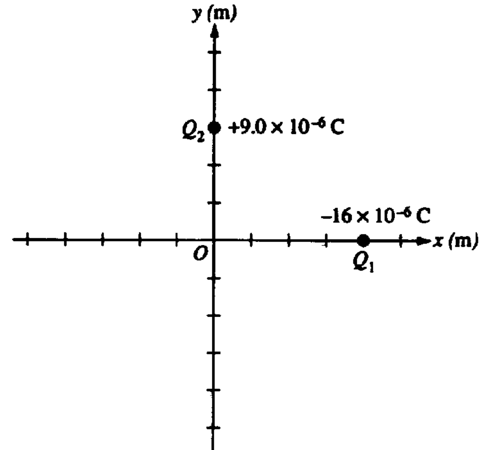
a. Determine the magnitude of the electric field in the region between the plates and indicate its direction on the figure above.

b. Determine the magnitude and direction of the acceleration of the electron in the region between the plates.

c. Determine the magnitude of the vertical displacement of the electron for the time interval during which it moves through the region between the plates.

d. On the diagram below, sketch the path of the electron as it moves through and after it emerges from the region between the plates. The dashed lines in the diagram have been added for reference only.



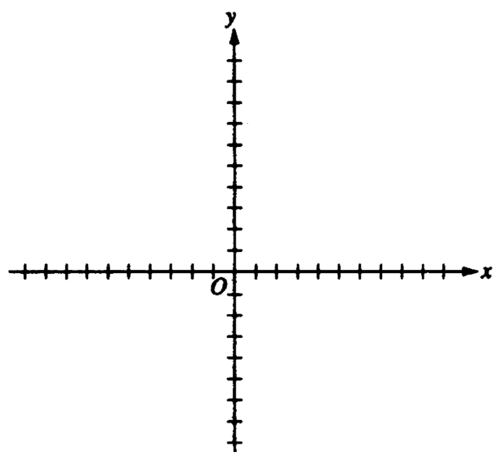


1993B2. A charge $Q_1 = -1.6 \times 10^{-6}$ coulomb is fixed on the x–axis at +4.0 meters, and a charge $Q_2 = +9 \times 10^{-6}$ coulomb is fixed on the y–axis at +3.0 meters, as shown on the diagram above.

a. i. Calculate the magnitude of the electric field E_1 at the origin O due to charge Q_1

ii. Calculate the magnitude of the electric field E_2 at the origin O due to charge Q_2.

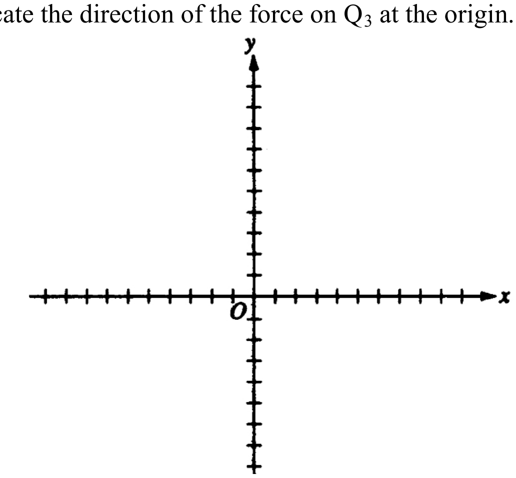
iii. On the axes below, draw and label vectors to show the electric fields E_1 and E_2 due to each charge, and also indicate the resultant electric field E at the origin.



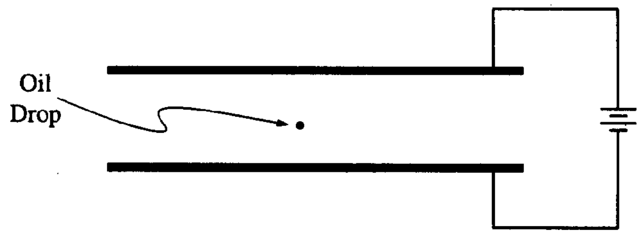
b. Calculate the electric potential V at the origin.

A charge $Q_3 = -4 \times 10^{-6}$ coulomb is brought from a very distant point by an external force and placed at the origin.

c. On the axes below, indicate the direction of the force on Q_3 at the origin.

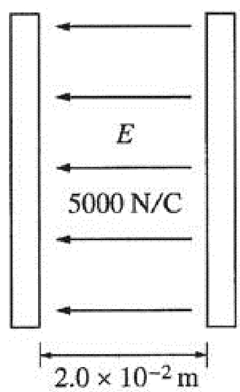


d. Calculate the work that had to be done by the external force to bring Q_3 to the origin from the distant point.



1996B6 Robert Millikan received a Nobel Prize for determining the charge on the electron. To do this, he set up a potential difference between two horizontal parallel metal plates. He then sprayed drops of oil between the plates and adjusted the potential difference until drops of a certain size remained suspended at rest between the plates, as shown above. Suppose that when the potential difference between the plates is adjusted until the electric field is 10,000 N/C downward, a certain drop with a mass of 3.27×10^{-16} kg remains suspended.

a. What is the magnitude of the charge on this drop?
b. The electric field is downward, but the electric force on the drop is upward. Explain why.
c. If the distance between the plates is 0.01 m, what is the potential difference between the plates?
d. The oil in the drop slowly evaporates while the drop is being observed, but the charge on the drop remains the same. Indicate whether the drop remains at rest, moves upward, or moves downward. Explain briefly.



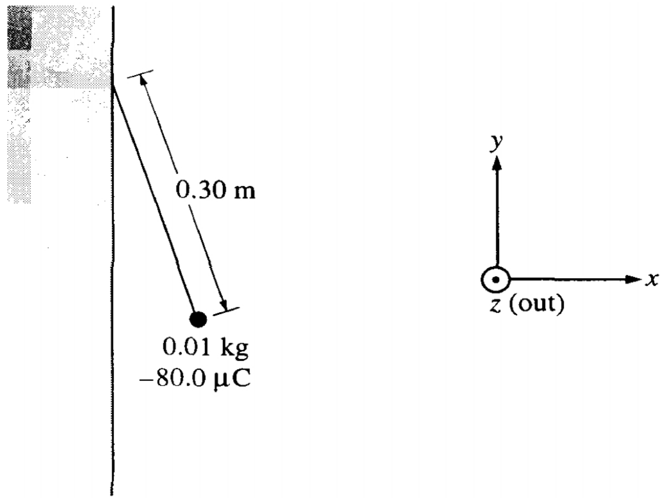
Note: Figure not drawn to scale.

2002B5B. Two parallel conducting plates, each of area 0.30 m^2, are separated by a distance of 2.0×10^{-2} m of air. One plate has charge +Q; the other has charge –Q. An electric field of 5000 N/C is directed to the left in the space between the plates, as shown in the diagram above.

a. Indicate on the diagram which plate is positive (+) and which is negative (–).
b. Determine the potential difference between the plates.
c. Determine the capacitance of this arrangement of plates.

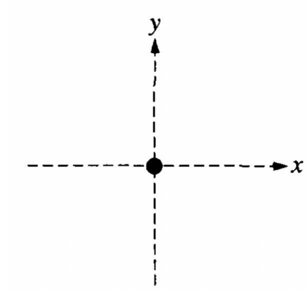
An electron is initially located at a point midway between the plates.

d. Determine the magnitude of the electrostatic force on the electron at this location and state its direction.
e. If the electron is released from rest at this location midway between the plates, determine its speed just before striking one of the plates. Assume that gravitational effects are negligible.



1998B2. A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

a. On the diagram below, draw and label the forces acting on the ball.



b. Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

c. Determine the perpendicular distance from the wall to the center of the ball.

d. The string is now cut.

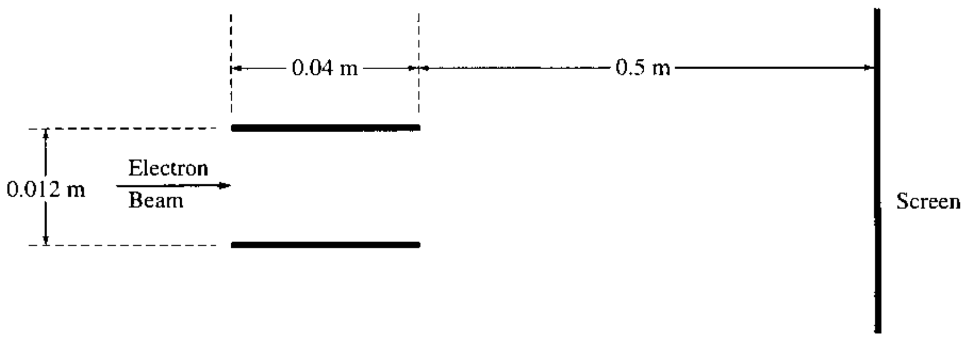
i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.

ii. Describe the resulting path of the ball.

1999B2. In a television set, electrons are first accelerated from rest through a potential difference in an electron gun. They then pass through deflecting plates before striking the screen.

a. Determine the potential difference through which the electrons must be accelerated in the electron gun in order to have a speed of 6.0×10^7 m/s when they enter the deflecting plates.

The pair of horizontal plates shown below is used to deflect electrons up or down in the television set by placing a potential difference across them. The plates have length 0.04 m and separation 0.012 m, and the right edge of the plates is 0.50 m from the screen. A potential difference of 200 V is applied across the plates, and the electrons are deflected toward the top of the screen. Assume that the electrons enter horizontally midway between the plates with a speed of 6.0×10^7 m/s and that fringing effects at the edges of the plates and gravity are negligible.



Note: Figure not drawn to scale.

b. Which plate in the pair must be at the higher potential for the electrons to be deflected upward? Check the appropriate box below.

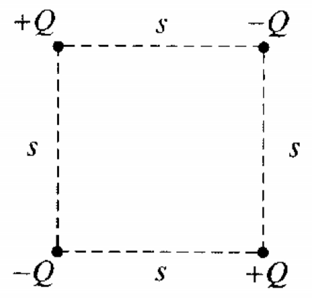
☐ Upper plate ☐ Lower plate

Justify your answer.

c. Considering only an electron's motion as it moves through the space between the plates, compute the following.
i. The time required for the electron to move through the plates
ii. The vertical displacement of the electron while it is between the plates

d. Show why it is a reasonable assumption to neglect gravity in part c.

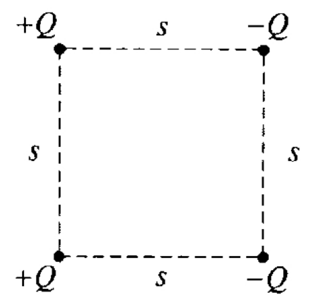
e. Still neglecting gravity, describe the path of the electrons from the time they leave the plates until they strike the screen. State a reason for your answer.



Arrangement 1

2001B3. Four charged particles are held fixed at the corners of a square of side s. All the charges have the same magnitude Q, but two are positive and two are negative. In Arrangement 1, shown above, charges of the same sign are at opposite corners. Express your answers to parts a. and b. in terms of the given quantities and fundamental constants.

a. For Arrangement 1, determine the following.
   i. The electrostatic potential at the center of the square
   ii. The magnitude of the electric field at the center of the square



Arrangement 2

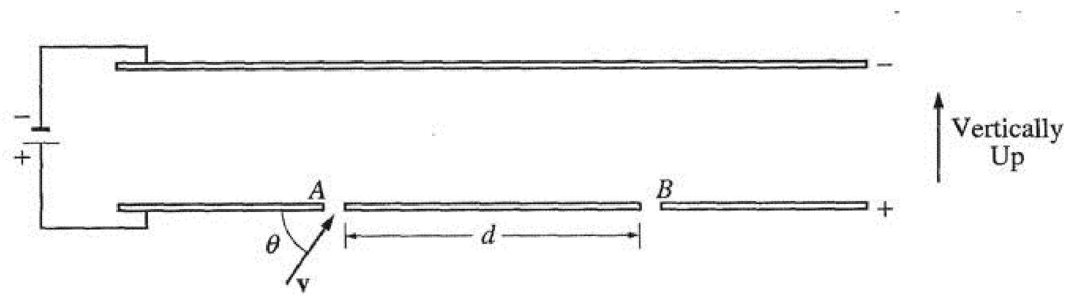
The bottom two charged particles are now switched to form Arrangement 2, shown above, in which the positively charged particles are on the left and the negatively charged particles are on the right.

b. For Arrangement 2, determine the following.
   i. The electrostatic potential at the center of the square
   ii. The magnitude of the electric field at the center of the square

c. In which of the two arrangements would more work be required to remove the particle at the upper right corner from its present position to a distance a long way away from the arrangement?

_________ Arrangement 1 ___________ Arrangement 2

Justify your answer

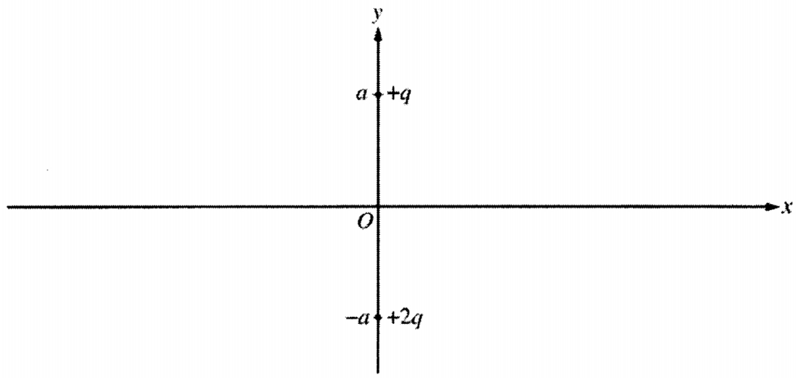


2003Bb4. An electric field E exists in the region between the two electrically charged parallel plates shown above. A beam of electrons of mass m, charge q, and velocity v enters the region through a small hole at position A. The electrons exit the region between the plates through a small hole at position B. Express your answers to the following questions in terms of the quantities m, q, E, θ, and v. Ignore the effects of gravity.

a. i. On the diagram of the parallel plates above, draw and label a vector to show the direction of the electric field E between the plates.
ii. On the following diagram, show the direction of the force(s) acting on an electron after it enters the region between the plates.

iii. On the diagram of the parallel plates above, show the trajectory of an electron that will exit through the small hole at position B.

b. Determine the magnitude of the acceleration of an electron after it has entered the region between the parallel plates.
c. Determine the total time that it takes the electrons to go from position A to position B.
d. Determine the distance d between positions A and B.
e. Now assume that the effects of gravity cannot be ignored in this problem. How would the distance where the electron exits the region between the plates change for an electron entering the region at A? Explain your reasoning.

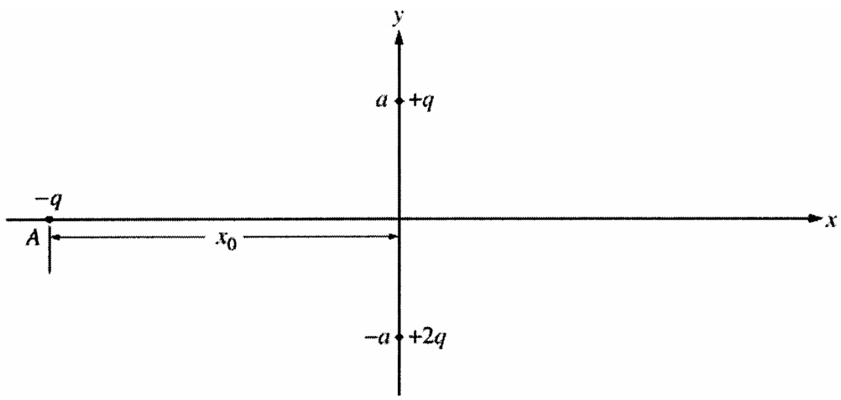


2005B3 Two point charges are fixed on the y–axis at the locations shown in the figure above. A charge of +q is located at y = +a and a charge of +2q is located at y = –a. Express your answers to parts a. and b. in terms of q, a, and fundamental constants.

a. Determine the magnitude and direction of the electric field at the origin.

b. Determine the electric potential at the origin.

A third charge of –q is first placed at an arbitrary point A (x = $-x_o$) on the x–axis as shown in the figure below.

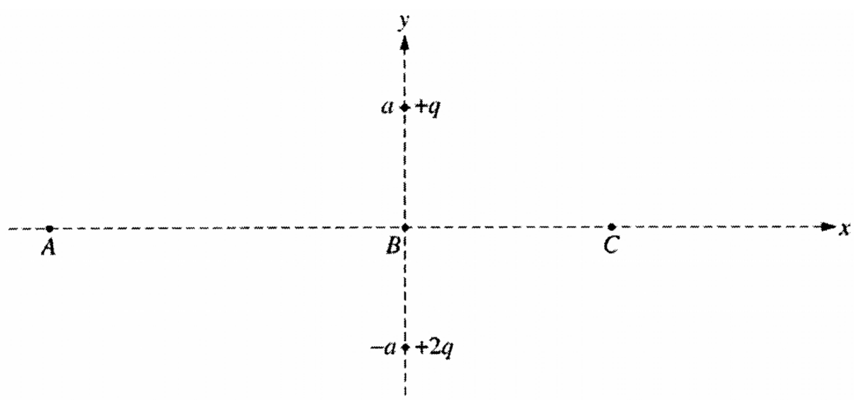


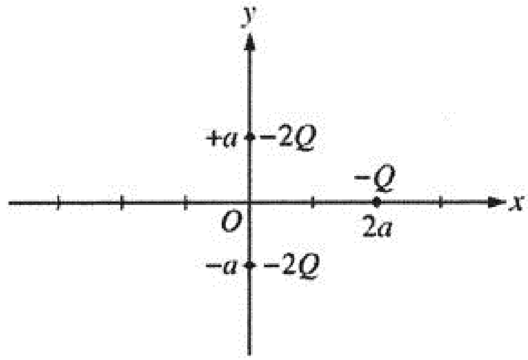
c. Write expressions in terms of q, a, x_0, and fundamental constants for the magnitudes of the forces on the –q charge at point A caused by each of the following.

i. The +q charge

ii. The +2q charge

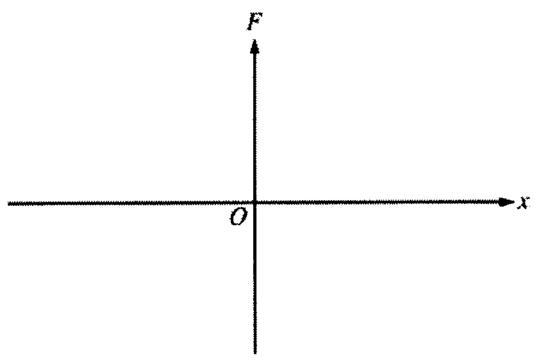
d. The –q charge can also be placed at other points on the x–axis. At each of the labeled points (A, B, and C) in the following diagram, draw a vector to represent the direction of the net force on the –q charge due to the other two charges when it is at those points.

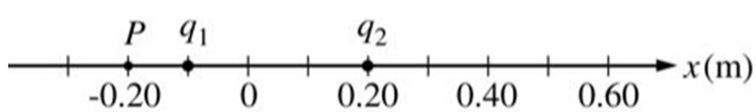




2005Bb3 The figure above shows two point charges, each of charge –2Q, fixed on the y–axis at y = +a and at y = –a. A third point charge of charge –Q is placed on the x–axis at x = 2a. Express all algebraic answers in terms of Q, a, and fundamental constants.

a. Derive an expression for the magnitude of the net force on the charge –Q due to the other two charges, and state its direction.
b. Derive an expression for the magnitude of the net electric field at the origin due to all three charges, and state its direction.
c. Derive an expression for the electrical potential at the origin due to all three charges.
d. On the axes below, sketch a graph of the force F on the –Q charge caused by the other two charges as it is moved along the x–axis from a large positive position to a large negative position. Let the force be positive when it acts to the right and negative when it acts to the left.





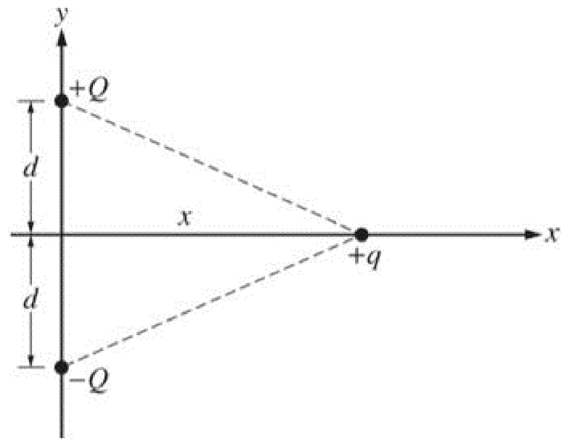
2006B3. Two point charges, q_1 and q_2, are placed 0.30 m apart on the x–axis, as shown in the figure above. Charge q_1 has a value of -3.0×10^{-9} C. The net electric field at point P is zero.

a. What is the sign of charge q_2?

____ Positive ____ Negative

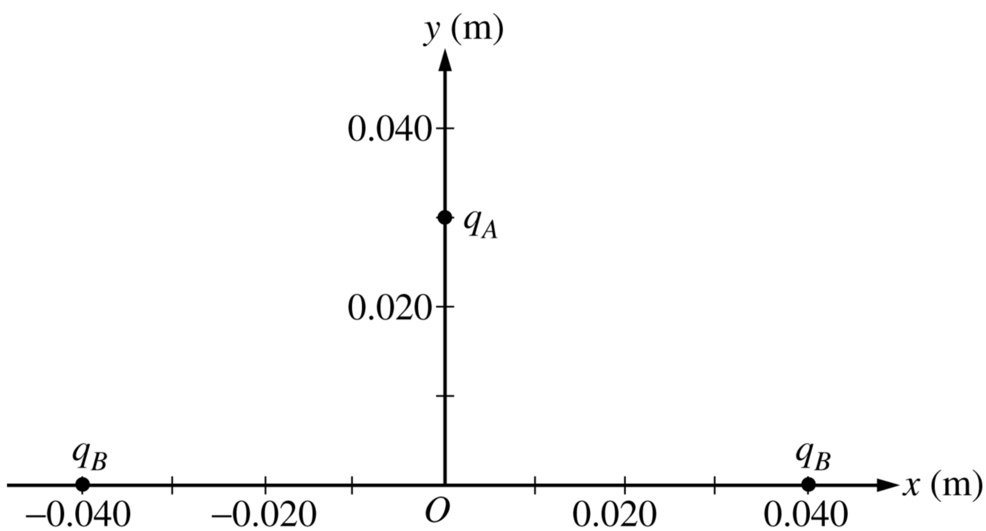
Justify your answer.

b. Calculate the magnitude of charge q_2.
c. Calculate the magnitude of the electric force on q_2 and indicate its direction.
d. Determine the x–coordinate of the point on the line between the two charges at which the electric potential is zero.
e. How much work must be done by an external force to bring an electron from infinity to the point at which the electric potential is zero? Explain your reasoning.



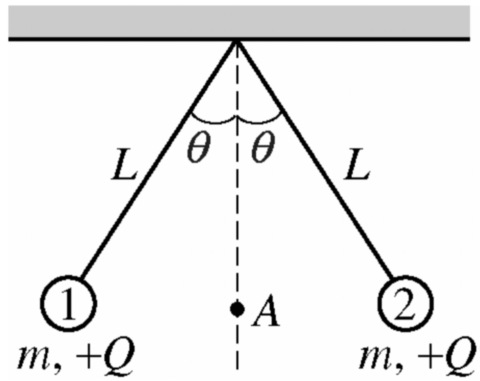
2006Bb3. Three electric charges are arranged on an x–y coordinate system, as shown above. Express all algebraic answers to the following parts in terms of Q, q, x, d, and fundamental constants.

a. On the diagram, draw vectors representing the forces F_1 and F_2 exerted on the +q charge by the +Q and –Q charges, respectively.
b. Determine the magnitude and direction of the total electric force on the +q charge.
c. Determine the electric field (magnitude and direction) at the position of the +q charge due to the other two charges.
d. Calculate the electric potential at the position of the +q charge due to the other two charges.
e. Charge +q is now moved along the positive x–axis to a very large distance from the other two charges. The magnitude of the force on the +q charge at this large distance now varies as $1/x^3$. Explain why this happens.



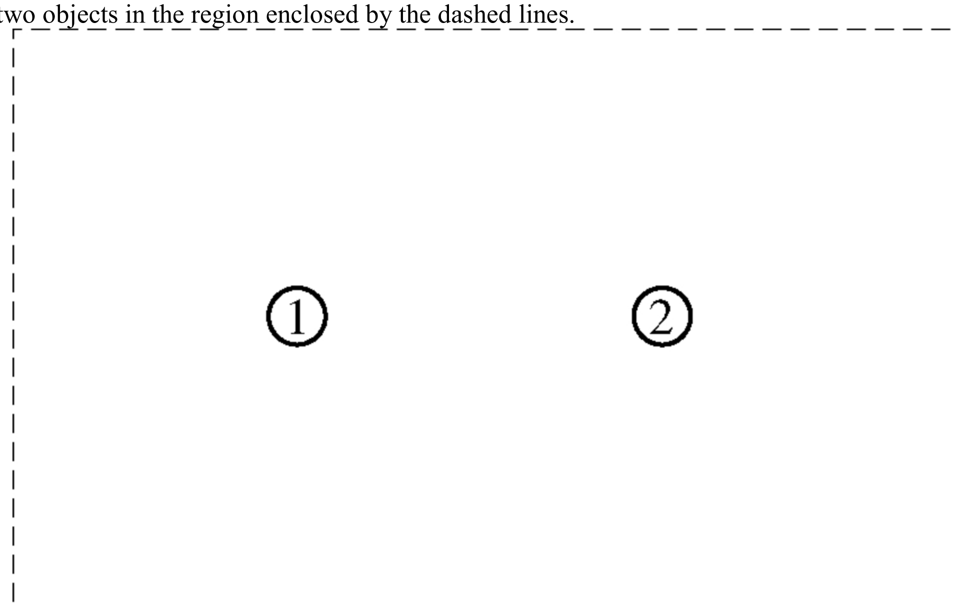
2009B2B.(modified) Three particles are arranged on coordinate axes as shown above. Particle A has charge q_A = –0.20 nC , and is initially on the y–axis at y = 0.030 m. The other two particles each have charge q_B = +0.30 nC and are held fixed on the x–axis at x = –0.040 m and x = +0.040 m, respectively.

a. Calculate the magnitude of the net electric force on particle A when it is at y = 0.030 m, and state its direction.
b. Particle A is then released from rest. Qualitatively describe its motion over a long time.



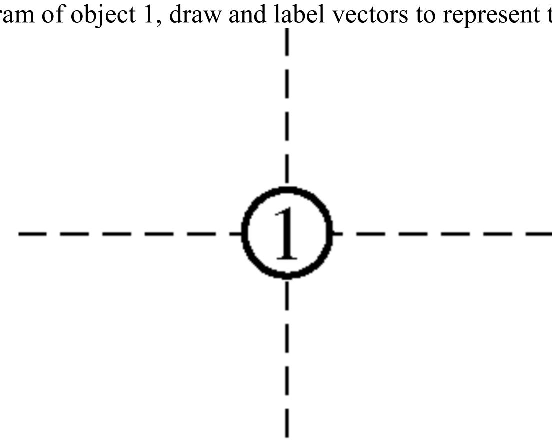
2009B2. Two small objects, labeled 1 and 2 in the diagram above, are suspended in equilibrium from strings of length L. Each object has mass m and charge +Q. Assume that the strings have negligible mass and are insulating and electrically neutral. Express all algebraic answers in terms of m, L, Q, q , and fundamental constants.

a. On the following diagram, sketch lines to illustrate a 2–dimensional view of the net electric field due to the two objects in the region enclosed by the dashed lines.

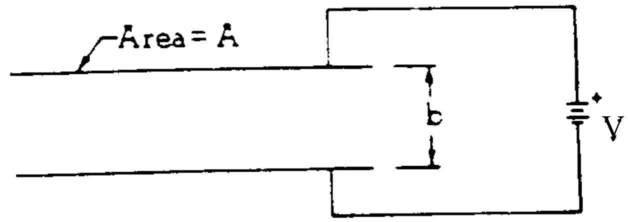


b. Derive an expression for the electric potential at point A, shown in the diagram at the top of the page, which is midway between the charged objects.

c. On the following diagram of object 1, draw and label vectors to represent the forces on the object.



d. Using the conditions of equilibrium, write—but do not solve—two equations that could, together, be solved for q and the tension T in the left–hand string.

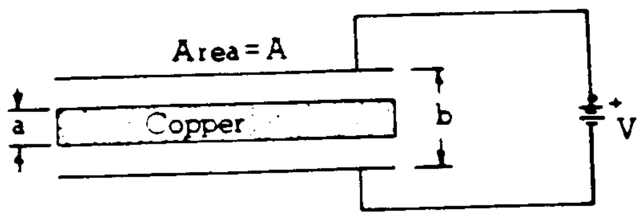


*1974E2. A parallel–plate capacitor with spacing b and area A is connected to a battery of voltage V as shown above. Initially the space between the plates is empty. Make the following determinations in terms of the given symbols.

a. Determine the electric field between the plates.

b. Determine the charge stored on each capacitor plate.

A copper slab of thickness a is now inserted midway between the plates as shown below.



c. Determine the electric field in the spaces above and below the slab.

d. Determine the ratio of capacitances $\frac{C_{with\ copper}}{C_{original}}$ when the slab is inserted

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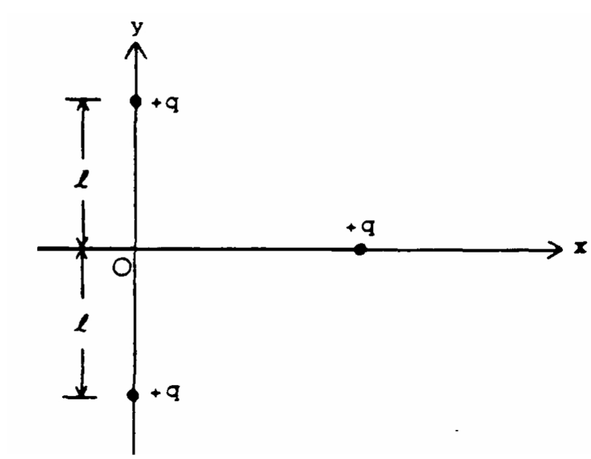
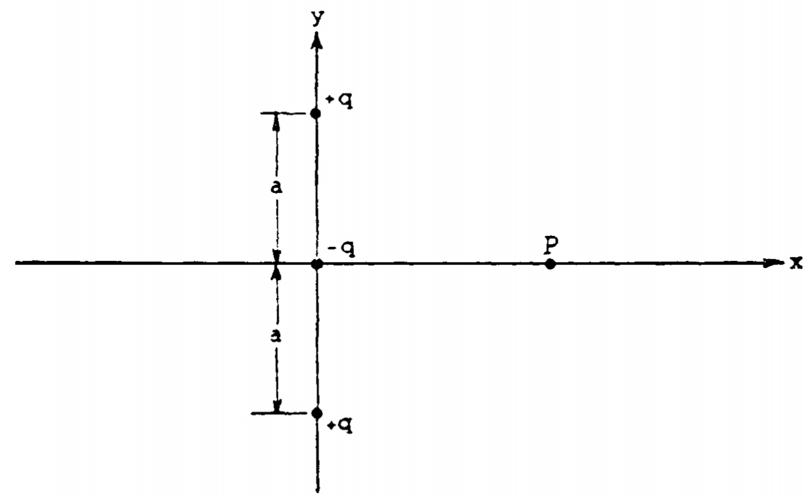


1975E1. Two stationary point charges +q are located on the y–axis as shown above. A third charge +q is brought in from infinity along the x–axis.

a. Express the potential energy of the movable charge as a function of its position on the x–axis.

b. Determine the magnitude and direction of the force acting on the movable charge when it is located at the position x = *l*

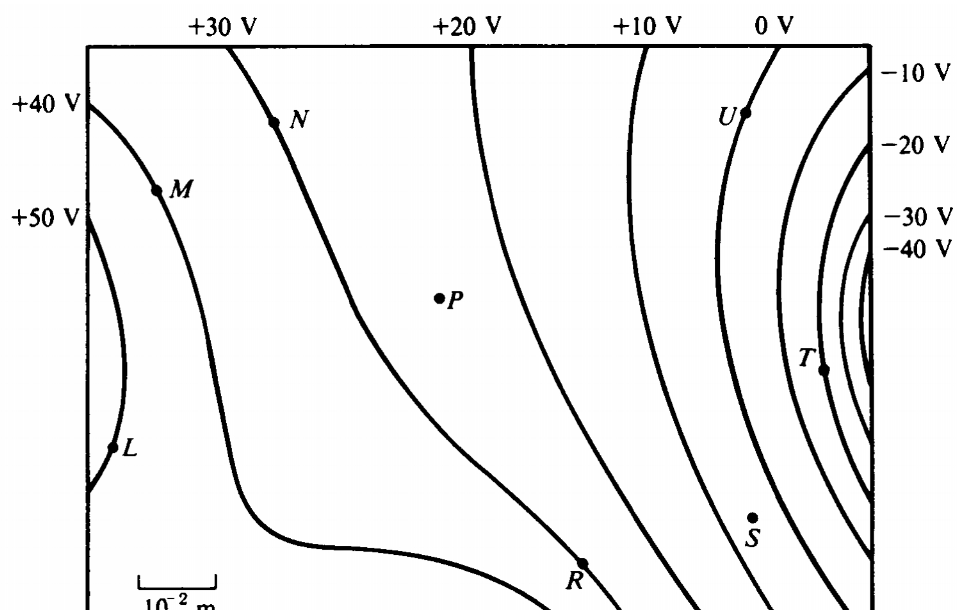
c. Determine the work done <u>by the electric field</u> as the charge moves from infinity to the origin.



1982E1 (modified) Three point charges are arranged on the y–axis as shown above. The charges are +q at (0, a), –q at (0, 0), and +q at (0, –a). Any other charge or material is infinitely far away.

a. Determine the point(s) on the x–axis where the electric potential due to this system of charges is zero.

b. Determine the x and y components of the electric field at a point P on the x–axis at a distance x from the origin.



*1986E1. Three point charges produce the electric equipotential lines shown on the diagram above.

a. Draw arrows at points L, N. and U on the diagram to indicate the direction of the electric field at these points.

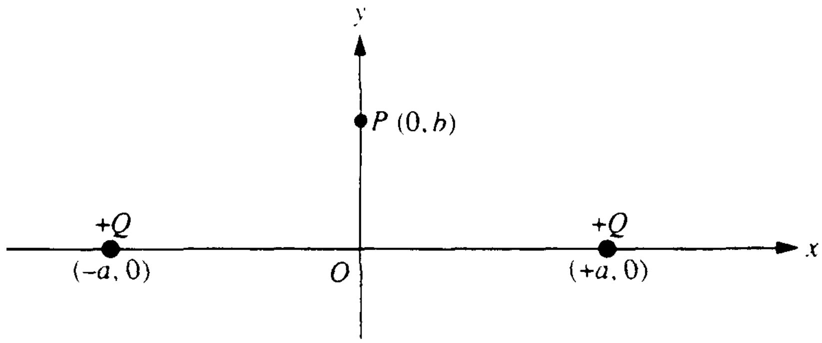
b. At which of the lettered points is the electric field E greatest in magnitude? Explain your reasoning.

c. Compute an approximate value for the magnitude of the electric field E at point P.

d. Compute an approximate value for the potential difference, $V_M - V_S$, between points M and S.

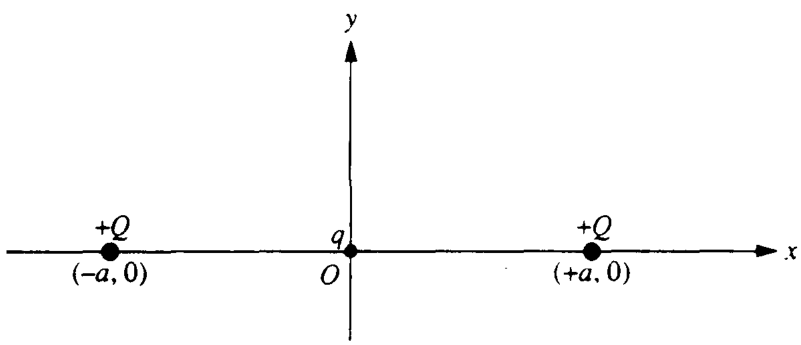
e. Determine the work done by the field if a charge of $+5 \times 10^{-12}$ coulomb is moved from point M to point R.

f. If the charge of $+5 \times 10^{-12}$ coulomb were moved from point M first to point S, and then to point R, would the answer to e. be different, and if so, how?



1991E1. Two equal positive charges Q are fixed on the x–axis. one at +a and the other at –a, as shown above. Point P is a point on the y–axis with coordinates (0, b). Determine each of the following in terms of the given quantities and fundamental constants.

a. The electric field E at the origin *O*.
b. The electric potential V at the origin *O*.
c. The magnitude of the electric field E at point *P*.



A small particle of charge q (q << Q) and mass m is placed at the origin, displaced slightly, and then released. Assume that the only subsequent forces acting are the electric forces from the two fixed charges Q. at x = +a and x = –a. and that the particle moves only in the xy –plane. In each of the following cases, describe briefly the motion of the charged particle after it is released. Write an expression for its speed when far away if the resulting force pushes it away from the origin.

d. q is positive and is displaced in the +x direction.
e. q is positive and is displaced in the +y direction.
f. q is negative and is displaced in the +y direction.

2000E2 (modified) Three particles, A, B, and C, have equal positive charges Q and are held in place at the vertices of an equilateral triangle with sides of length l, as shown in the figures below. The dotted lines represent the bisectors for each side. The base of the triangle lies on the x–axis, and the altitude of the triangle lies on the y–axis.

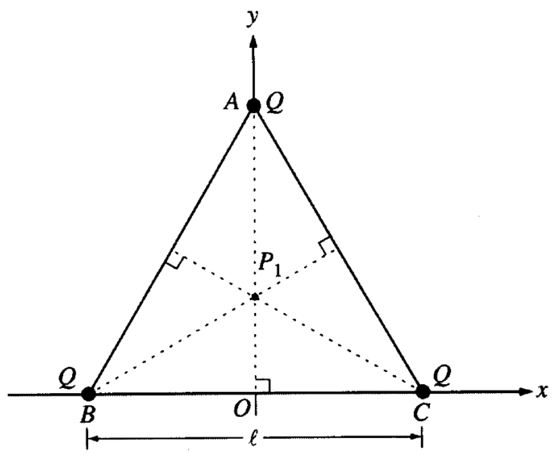


Figure 1

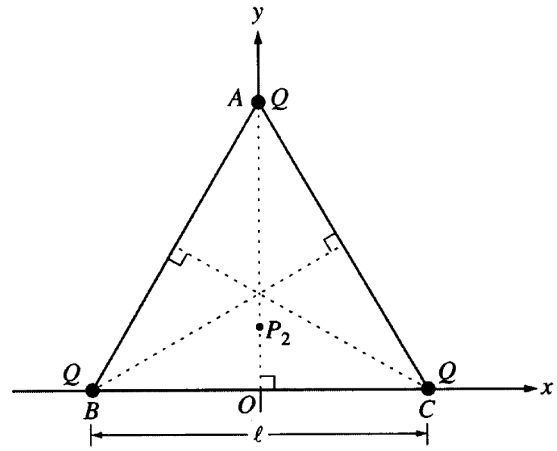


Figure 2

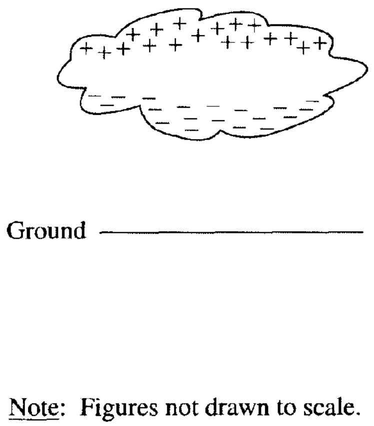
a. i. Point P_1, the intersection of the three bisectors, locates the geometric center of the triangle and is one point where the electric field is zero. On Figure 1 above, draw the electric field vectors E_A, E_B, and E_C at P, due to each of the three charges. Be sure your arrows are drawn to reflect the relative magnitude of the fields.

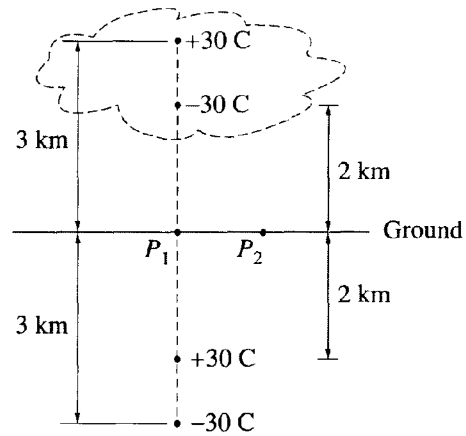
ii. Another point where the electric field is zero is point P_2 at $(0, y_2)$. On Figure 2 above, draw electric field vectors E_A, E_B, and E_C at P_2 due to each of the three point charges. Indicate below whether the magnitude of each of these vectors is greater than, less than, or the same as for point P_1.

	Greater than at P_1	Less than at P_1	The same as at P_1
E_A			
E_B			
E_C			

b. Explain why the x–component of the total electric field is zero at any point on the y–axis.

c. Write a general expression for the electric potential V at any point on the y–axis inside the triangle in terms of Q, l, and y.





2001E1. A thundercloud has the charge distribution illustrated above left. Treat this distribution as two point charges, a negative charge of –30 C at a height of 2 km above ground and a positive charge of +30 C at a height of 3 km. The presence of these charges induces charges on the ground. Assuming the ground is a conductor, it can be shown that the induced charges can be treated as a charge of +30 C at a depth of 2 km below ground and a charge of –30 C at a depth of 3 km, as shown above right. Consider point P_1, which is just above the ground directly below the thundercloud, and point P_2, which is 1 km horizontally away from P_1.

a. Determine the direction and magnitude of the electric field at point P_1.

b. i. On the diagram, clearly indicate the direction of the electric field at point P_2

ii. How does the magnitude of the field at this point compare with the magnitude at point P_1? Justify your answer:

____ Greater ____Equal ____ Less

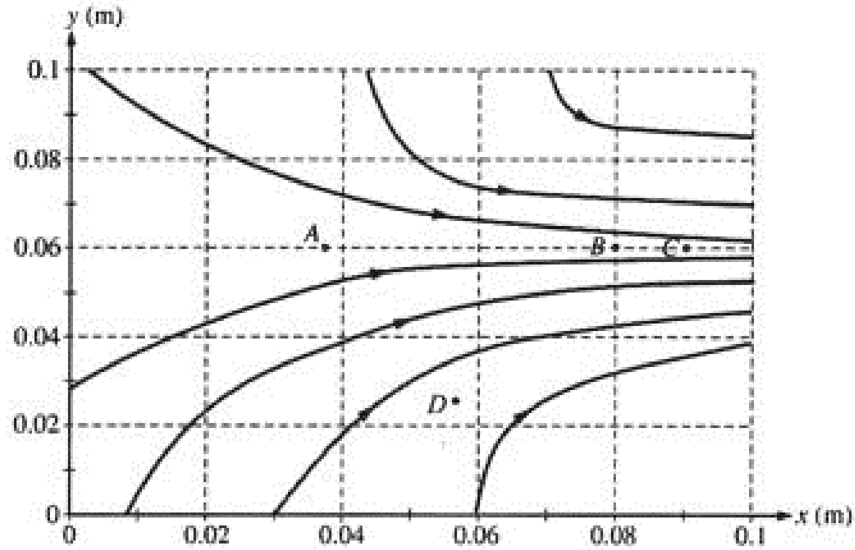
c. Letting the zero of potential be at infinity, determine the potential at these points.

i. Point P_1

ii. Point P_2

d. Determine the electric potential at an altitude of 1 km directly above point P_1.

e. Determine the total electric potential energy of this arrangement of charges.



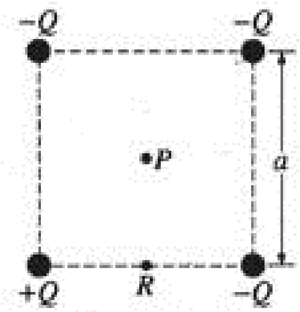
*2005E1. Consider the electric field diagram above.

a. Points A, B, and C are all located at y = 0.06 m .
   i. At which of these three points is the magnitude of the electric field the greatest? Justify your answer.
   ii. At which of these three points is the electric potential the greatest? Justify your answer.

b. An electron is released from rest at point B.
   i. Qualitatively describe the electron's motion in terms of direction, speed, and acceleration.
   ii. Calculate the electron's speed after it has moved through a potential difference of 10 V.

c. Points B and C are separated by a potential difference of 20 V. Estimate the magnitude of the electric field midway between them and state any assumptions that you make.

d. On the diagram, draw an equipotential line that passes through point D and intersects at least three electric field lines.



2006E1. The square of side a above contains a positive point charge +Q fixed at the lower left corner and negative point charges –Q fixed at the other three corners of the square. Point P is located at the center of the square.

a. On the diagram, indicate with an arrow the direction of the net electric field at point P.

b. Derive expressions for each of the following in terms of the given quantities and fundamental constants.

i. The magnitude of the electric field at point P

ii. The electric potential at point P

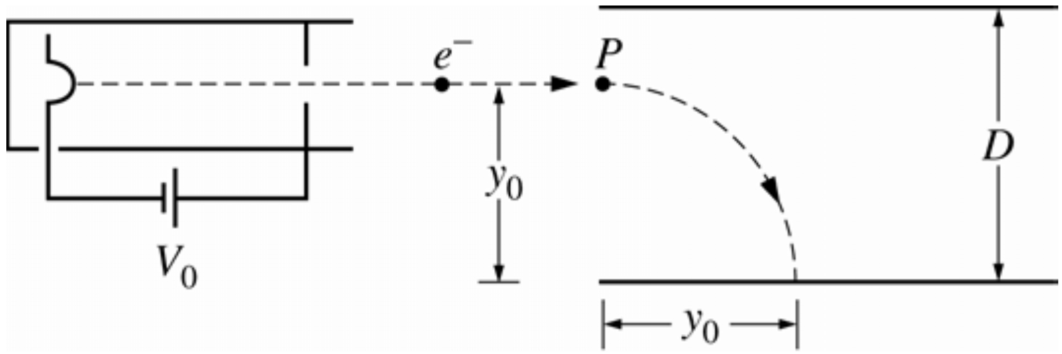
c. A positive charge is placed at point P. It is then moved from point P to point R, which is at the midpoint of the bottom side of the square. As the charge is moved, is the work done on it by the electric field positive, negative, or zero?

____Positive ____Negative ____Zero

Explain your reasoning.

d. i: Describe one way to replace a single charge in this configuration that would make the electric field at the center of the square equal to zero. Justify your answer.

ii. Describe one way to replace a single charge in this configuration such that the electric potential at the center of the square is zero but the electric field is not zero. Justify your answer.



2009E2 (modified) Electrons created at the filament at the left end of the tube represented above are accelerated through a voltage V_0 and exit the tube. The electrons then move with constant speed to the right, as shown, before entering a region in which there is a uniform electric field between two parallel plates separated by a distance D. The electrons enter the field at point P, which is a distance y_0 from the bottom plate, and are deflected toward that plate. Express your answers to the following in terms of V_0, D, y_0, and fundamental constants.

a. Calculate the speed of the electrons as they exit the tube.

b. i. Calculate the magnitude of the electric field required to cause the electrons to land the distance y_0 from the edge of the plate.
ii. Indicate the direction of the electric field.

____ To the left	____ To the right
____ Toward the top of the page	____ Toward the bottom of the page
____ Into the page	____ Out of the page

Justify your answer.

c. Calculate the potential difference between the two plates required to produce the electric field determined in part b.

ANSWERS - AP Physics Multiple Choice Practice – Electrostatics

	Solution	Answer
1.	Since charge is free to move around on/in a conductor, excess charges will repel each other to the outer surface	D
2.	When the battery is disconnected, Q remains constant. Since C decreases when d increases and Q = CV, V will increase	D
3.	W = qV	B
4.	Since both charges are positive, the electric field vectors point in opposite directions at points between the two. At point A, the magnitudes of the electric field vectors are equal and therefore cancel out, making E = 0 at point A	A
5.	$V = \Sigma kQ/r$ and since both charges are positive, the largest potential is at the closest point to the two charges (it is more mathematically complex than that, but this reasoning works for the choices given)	A
6.	$C = \varepsilon_0 A/d$; if A × 2, C × 2 and if d × 2, C ÷ 2 so the net effect is C is unchanged	B
7.	The net charge on the two spheres is +Q so when they touch and separate, the charge on each sphere (divided equally) is ½ Q. $F \propto Q_1Q_2$ so before contact $F \propto (2Q)(Q) = 2Q^2$ and after contact $F \propto (½ Q)(½ Q) = ¼ Q^2$ or 1/8 of the original force	D
8.	$C = \varepsilon_0 A/d$ and changing Q or V has no effect on the capacitance	C
9.	Inside the metal sphere E = 0. Once outside the sphere E decreases as you move away so the strongest field will be the closest point to the *outside* of the sphere	B
10.	Newton's third law	C
11.	Where E is zero must be closer to the smaller charge to make up for the weaker field. The vectors point in opposite directions when outside the two opposite charges. These two criteria eliminate 4 of the choices.	A
12.	Charges flow when there is a difference in potential. Analyzing the other choices: A is wrong because the charge resides on the surface. For B, E = 0 in a charged conducting sphere. $E = kQ/r^2$ eliminates choice C. And for D, charge separation will occur, but the object will not acquire any charge.	D
13.	E is uniform between charged parallel plates therefore the force on a charge is also uniform between the plates	B
14.	$E \propto 1/r^2$ so if r × 2, E ÷ 4	B
15.	While the charges may separate, the forces on the opposite charges are in opposite directions, canceling out	A
16.	V = kQ/r so the smaller sphere is at the lower potential (more negative = lower) Negative charge flows from low to high potential so the charge will flow from the smaller sphere to the larger. The flow of charge ceases when there is no difference in potential.	D
17.	E = V/d so if V × 2, E × 2 and if d ÷ 5, E × 5 so the net effect is E × 10	D
18.	The electric field vectors from the two charges point down and to the left (away from the charges) so the resultant field points down and left	C
19.	The potential energy of a particle at a location is the potential at that location times the charge. In this case, the potential is kQ/d + kQ/d = (2kQ/d)	C

20.	If the battery remains connected, the potential remains constant. C decreases as the separation increases soothe charge $Q = CV$ will also decrease	B
21.	In metals under electrostatic conditions, the electric field is zero everywhere inside.	A
22.	The electric field vector from the +Q charge points down and from the –Q charge points to the right so the resultant field points down and right	C
23.	The two vectors, each of magnitude $E = kQ/d^2$, point at right angles to each other so the resultant field is $\sqrt{2}E$	D
24.	The electric field between charged parallel plates is uniform, which means the potential changes uniformly with distance. For a change of 8 V over 4 cm means the change of potential with position (and the electric field strength) is 2 V/cm, which gives the potential 1 cm away from the 2 V plate as 4 V	D
25.	$W = \Delta K = QV$ (mass doesn't have an effect on the kinetic energy, just on the speed in this case)	C
26.	The field lines point away from Y and toward Z making Y positive and Z negative.	D
27.	$C = \varepsilon_0 A/d$; $\varepsilon_0(2A)/(2d) = \varepsilon_0 A/d$	C
28.	Charges arrange themselves on conductors so there is no electric field inside, and no electric field component along the surface	A
29.	By symmetry $V_R = V_S$ so $\Delta V_{RS} = 0$ and $W = q\Delta V$	C
30.	The force on the upper charge is to the left and twice the magnitude of the force on the bottom charge, which is to the right. This makes the net force to the left and the torque on the rod to be counterclockwise.	B
31.	Compared to the +Q charge at the center, the charge on the outer surface of the outer cylinder has twice the magnitude and is of opposite sign (so it is –2Q). There is also an equal and opposite charge induced on the inner surface of the outer cylinder making the total charge on the outer cylinder –2Q + –Q	D
32.	Since the capacitor is isolated, Q remains constant. Filling the place with oil (a dielectric) will increase the capacitance, causing the potential ($V = Q/C$) to decrease.	B
33.	$F_E \propto q_1q_2/r^2$; if q_1 and $q_2 \times 2$; $F \times 4$ and if $r \div 2$, $F \times 4$ making the net effect $F \times 4 \times 4$	D
34.	Since there is no component of the electric field along a conducting surface under electrostatic conditions, no work is done moving the charge around the surface, meaning no differences in potential	D
35.	Regardless of velocity, the force on a charge in an electric field is parallel to the field ($\mathbf{F} = q\mathbf{E}$)	C
36.	$W = Fd = qEd$	A
37.	E points away from + charges and toward – charges. Use symmetry.	A
38.	D is not symmetric so the field will not point at the midpoint of any side. The field in choice B points *at* the bottom charge.	C
39.	Since the capacitor is isolated, Q remains constant. Filling the place with oil (a dielectric) will increase the capacitance, causing the potential ($V = Q/C$) to decrease.	B
40.	$V = kQ/r$ so the smaller sphere (Y) is at the higher potential. Negative charge flows from low to high potential so the charge will flow from X to Y.	A
41.	Once inside a uniform sphere of charge, the electric field is zero. Since $E = 0$ the potential does not change within the sphere (meaning it is the same value as the surface)	A

42. Outside a uniform sphere of charge, it behaves as a point charge. C

43. **E** = **F**/q. The vector nature of the equation allows one to find the direction of F and the equation itself allows one to find the ratio F/q, but not q specifically C

44. Outside a uniform sphere of charge, it behaves as a point charge. $E = kQ/r^2$ D

45. By symmetry, the force on an electron at the center from the top half will be straight down and the force from the bottom half will also be straight down B

46. E is a vector so all the individual E field vectors from the four charges will cancel. V is a scalar and will add since they are all positive charges. C

47. The points where V = 0 must lie closer to the smaller charge. Unlike electric field vectors which also require the individual vectors point in opposite directions, there are a locus of points (in this case in a ring surrounding the +Q charge) where V = 0 as the two charges are opposite in sign and V is a scalar. So the other point on the x axis is between the two charges, but closer to the +Q charge. This must be a value between 1.5 D and 2 D C

48. When inside a uniform shell of charge, there is an electric field due to the shell. When outside a uniform shell of charge, the electric field is as if the shell was a point charge. A

49. The potential difference between the plates is 4 V and the right side is the positive plate. We need the batteries pointing in the same direction with the positive terminal on the right. A

50. The electron experiences a force toward the positive plate of magnitude F = Eq. E = V/d and cannot be calculated without knowing d. D

51. While spheres X and Y are in contact, electrons will repel away from the rod out of sphere X into sphere Y. C

52. While spheres 1 and 2 are in contact, electrons will repel away from the rod out of sphere 1 into sphere 2. C

53. The force vectors from the two +Q charges point down and to the left (away from the charges) so the resultant force points down and left D

54. The two vectors, each of magnitude F, point at right angles to each other so the resultant field is $\sqrt{2}F$ D

55. Where E is zero must be closer to the smaller charge to make up for the weaker field. The vectors point in opposite directions when between the two like charges. These two criteria eliminate 4 of the choices C

56. Since both charges are positive and V is a scalar equal to ΣkQ/r, the potential will never be zero in the vicinity of these two charges. D

57. The electric field (and hence, the electric force on a charge) is greatest where the potential changes most rapidly with position (the greatest gradient) since E = V/d. On this graph, this would be the point where the slope is the greatest C

58. If F is constant and F = ma, the acceleration is also constant. Negative charges experience forces opposite in direction to electric field lines. A

59. By symmetry, E = 0 at the midpoint and goes to infinity near each charge ($E = kQ/r^2$) A

60. If no work is done by the field and there is a field present, the motion must be perpendicular to the field, along an equipotential line, making the force perpendicular to the displacement of the charge (a requirement for zero work). Along an equipotential line, ΔV = 0 and W = qΔV. D

61. Inside the sphere, E = 0 which means the potential does not change with position and is the same value as the surface, which is kQ/R. At point P, the potential is kQ/r. W = qΔV = q(kQ/R – kQ/r) D

62. $E = V/d$ B

63. If the battery is disconnected, Q remains constant. If a dielectric is inserted between the plates, the capacitance increases and since $Q = CV$, the potential difference decreases. A

64. Conductors under electrostatic conditions will arrange their changes so no electric field exists inside (other than those created by charges placed inside the empty cavity). Fields from external charges will not penetrate into conducting enclosures. A

65. $W = K = q\Delta V$ and $K = ½ mv^2$ B

66. At point P, the field due to charge Q points up and to the right and the field due to charge –4Q is larger in magnitude and points down and to the right. Due to the asymmetry, no components will cancel. D

67. Where E is zero must be closer to the smaller charge to make up for the weaker field. The vectors point in opposite directions outside the two opposite charges. These two criteria eliminate 3 of the choices. For the magnitudes of the electric fields to be zero the ratios Q/r^2 must be equal giving (in units along the x axis) $Q/r^2 = 4Q/(r + 4 \text{ units})^2$ giving r = 4 units A

68. Since $E = \Delta V/d$, E represents the slope of the line on the graph which could be choice C or D. since $V \propto 1/r$ the slope is proportional to $\Delta V/r = (1/r)/r = 1/r^2$ which is choice C B

69. By symmetry, all the vectors cancel A

70. $W = q\Delta V = +Q(V_{center} – V_\infty) = +QV_{center}$ where $V_{center} = \Sigma V = \Sigma kQ/r = 6kQ/R$ D

71. E points from high potential to low potential, perpendicular to equipotential lines (the direction of the force on a positive charge) A

72. E is greatest in magnitude where V changes most rapidly with position (the largest gradient) which is where the lines are closest together. B

73. $\Delta V_{CE} = V_E – V_C = 10$ V. The amount of work, $W = q\Delta V = 1\ \mu C \times 10\ V = 10\ \mu C$. Since the external force must push against the negative charge to keep it from accelerating and bring it to rest at point E, the work done by the external force must be negative. B

74. For charge to be distributed *throughout* a material, it must be non-conducting D

75. Like gravity inside a uniform sphere of mass, the field is directly proportional to r when inside the sphere (and proportional to $1/r^2$ when outside) C

76. In I, charge separation occurs (negative charges repel to the leaves). The whole process describes charging by induction, where the electrons leave the electroscope to ground (the finger) and once contact with ground is broken, the electroscope is left with a positive charge (III) B

77. Charged objects attract object with an opposite charge, but also neutral objects by separation of charges. D

78. If E = 0, the field vectors point in opposite directions, making q positive. In magnitude we can find q by $(+4\ \mu C)/(0.2\ m)^2 = q/(0.3\ m)^2$ A

79. If V = 0 and $V = \Sigma kQ/r$ then q must be negative and $(+4\ \mu C)/(0.2\ m) = q/(0.3\ m)$ C

80. Since the electrostatic force pushes the charge to the right, with the field line, it is a positive charge. $\Sigma F_y = 0$ gives $T \cos\theta = mg$ and $\Sigma F_x = 0$ gives $T \sin\theta = F_E = qE$. Divide the two expressions to eliminate T. C

81. If the battery is disconnected, the charge on the plates remains constant. If the separation increases, C decreases ($C = \varepsilon_0 A/d$). Since $Q = CV$, V must increase. D

82. $W = q\Delta V$ (motion along an equipotential line requires no work so only ΔV matters, not the path) D

83. $F \propto 1/r^2$ A

84. Charges flow when there is a difference in potential. D

85. The distance between the +q charge and each charge is d. The force on the +q charge from each charge is in the same direction, making the net force $kq^2/d^2 + k(3q^2)/d^2$ B

86. The rod will attract the same charge from each sphere to the side closer to the rod. B

87. Since the plates are insulated, the charge remains constant. If the distance is increased, the capacitance will decrease ($C \propto A/d$) and since Q = CV, the potential difference must increase by the same factor that the distance increases. This means E = V/d remains the same. C

88. $F \propto 1/r^2$; if r × 4, F ÷ 16 D

89. If the leaves are positive, further separation means they are becoming more positive, which implies electrons are leaving the leaves, attracted to the top plate of the electroscope. This will occur if the object is positively charged. A

90. Vector addition. Since all the charges are positive, the forces due to charges 2 and 4 point in opposite directions, making the magnitude of the net force along the x axis 2 N. Combine this with a net force along the y axis of 6 N using the Pythagorean theorem A

91. Q = CV and V = Ed and using $C = \varepsilon_0 A/d$ gives $E = Q/\varepsilon_0 A$ A

92. Charged objects attract neutral objects by separating the charges within the neutral object. C

93. An alpha particle has twice the charge and four times the mass of a proton. Twice the charge means twice the electric force. This, combined with four times the mass gives half the acceleration. D

94. Q = CV and $C = \varepsilon_0 A/d$ which gives $V = Qd/\varepsilon_0 A$ C

95. At a point midway between the charges $E = kq/(d/2)^2$ from each charge. Since they are opposite charges, the field vectors between the charges point in the same direction. D

96. For the E field vectors to point in opposite directions, point P must lie outside the two charges. For the magnitudes of E due to each charge to cancel, Point P must be closer to the smaller charge. B

97. The extra kinetic energy gained by the electron is $W = K = q\Delta V$, where ΔV is the potential difference between the midway line and the upper plate, which is 200 V. This makes the additional kinetic energy 200 eV. Kinetic energy is a scalar so the total KE of the electron is now 300 eV + 200 eV C

98. If a positive rod attracts ball A, it is either negative or neutral. For ball B to also attract ball A means ball B can be charged positive or negative (if ball A is neutral) or neutral (if ball A is positive) D

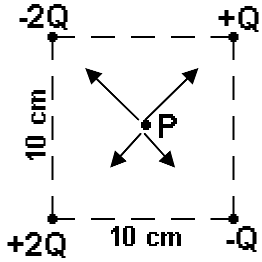
99. F = Eq and E = V/d giving d = qV/F D

100. Since the battery is removed, the charge remains constant. If the distance is decreased, the capacitance will increase ($C \propto A/d$) and since Q = CV, the potential difference must decrease by the same factor that the distance decreases. A

101. Since the spherical shell is conducting, a charge of –Q is induced on the inner surface. This gives a charge of +Q on the outer surface since the spherical shell is neutral. As E = 0 inside the conducting shell, the potential inside is constant and the same as on the surface, which is kQ/r C

102. $F \propto 1/r^2$; if r × 0.4 then $F \div 0.4^2$ A

103. The force vectors from each charge and their relative magnitude are drawn below B



104. Using F = ma = qE and E = V/d gives a = qV/md D

105. Since the spherical shell is conducting, a charge of –Q is induced on the inner surface. This gives a charge of +Q on the outer surface since the spherical shell is neutral and the field outside the shell is as if the shell was a point charge. B

106. The process described is charging by induction which gives the electroscope in this case a net negative charge. Bringing a negative charge near the top of the electroscope will cause electrons to repel to the leaves. Since the leaves are already negative, this will cause them to separate further. B

107. The charge density is Q/area which is $Q/4\pi r^2$ so for the inner surface it is $Q_{inner}/4\pi a^2$ and for the outer surface it is $Q_{outer}/16\pi a^2$. For these to be equal Q_{outer} must be $4Q_{inner}$. Because of the +Q charge inside, there is a charge of –Q induced on the inner surface, which means the outer surface must have charge –4Q. Thus the *total* charge on the shell is –5Q A

108. The force on a positive charge is in the direction of the electric field at that location. C

109. Once inside a uniform sphere of charge, the electric field is zero. Since E = 0 the potential does not change within the sphere (meaning it is the same value as the surface). $V \propto 1/r$ outside the sphere. D

110. Negative potential energy means the system is bound. This means energy input is required to break the system apart. A

111. $F \propto 1/r^2$ A

112. Newton's third law requires the forces be equal and opposite. This eliminates choices A, B and C. Since they both positive, the force is repulsive. D

113. q_2/q_1 = lines on q_2/lines on q_1 and since the lines point toward q_2 and away from q_1 they are oppositely charged, making the ratio negative. B

114. The points where V = 0 must lie closer to the smaller charge. Unlike electric field vectors which also require the individual vectors point in opposite directions, there are a locus of points (in this case in a ring surrounding the –Q charge) where V = 0 as the two charges are opposite in sign and V is a scalar. D

115. For E to be zero, the electric field vectors from each charge must point in opposite directions and must therefore occur at a point outside the charges. For the electric field vectors from each charge to be equal in magnitude so they can cancel, it must also occur at a point closer to the smaller charge to make up for the weaker field. C

116. Since the battery remains connected, V remains constant. C decreases as d increases ($C \propto 1/d$) and $U_C = ½ CV^2$ C

117. Only electrons are transferred in static charging processes. C

118. Any charge will experience a net force of zero where the electric field is zero. This must be where the fields from each charge point in opposite directions and also closer to the smaller charge, which is to the left of the +Q charge (the answer will be to the left of –1 m). Let the distances to the +Q and the –2Q charge be x and (X + 2), respectively. This gives $E_1 = E_2$ and $kQ/x^2 = k(2Q)/(x + 2)^2$. Solve for x and add the extra 1 m to the origin. A

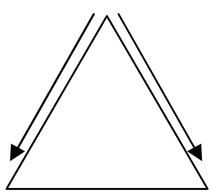
119. Since the battery is removed, the charge remains constant. If the distance is increased, the capacitance will decrease ($C \propto A/d$) and since Q = CV, the potential difference must increase by the same factor that the distance increases and $U_C = ½ QV$ C

120. $F \propto q_1q_2/r^2$; the original force $F \propto 100Q^2/d^2$. The new charges are 15Q and 5Q making the new force $F \propto 75Q^2/(2d)^2 = 19Q^2/d^2$ A

121. When one sphere is touched, the charged divides equally (½ Q each). When this sphere is then touched to the second sphere, the net charge (3/2 Q) is divided equally (¾ Q each). Since $F \propto q_1q_2$, the original force is proportional to Q^2 and the new force is then proportional to (½ Q)(¾ Q) = 3/8 Q^2 D

122. $W = K = q\Delta V$ so $\Delta V \propto v^2$ and for v to double, ΔV must increase by 4 A

123. Adding the force vectors shown (each 15 N) with x components that cancel and y components that equal 15 N cos 30º gives F = 2 × 15 N cos 30º = 26 N B



124. Once outside the spheres, they act as point charges and their difference in size is irrelevant D

125. When connected, the potentials become equal. This gives $kQ_X/r_X = kQ_Y/r_Y$ and since $E = kQ/r^2$, dividing the potentials by their respective radii gives $kQ_X/(r_X)^2 < kQ_Y/(r_Y)^2$ D

126. 1.5×10^{12} excess electrons is a charge of magnitude $(1.5 \times 10^{12}) \times (1.6 \times 10^{-19}) = 2.4 \times 10^{-7}$ C. Use Q = CV D

127. The field is zero everywhere inside a metal sphere. C

128. The force on Q_2 from Q_1 points downward and the force from Q_3 points at right angles to the left. Compute each force using $F = kq_1q_2/r^2$ and use the Pythagorean theorem. D

129. The field at the center due to Q_1 and Q_3 cancels. The only contribution to the field then is that due to Q_2. $E = kQ/r^2$ where $r^2 = 0.3^2 + 0.4^2$ A

130. E inside = 0 and outside $E \propto 1/r^2$ D

131. Initially, when B is removed, A and C are equally and oppositely charged and B is neutral. Touching B to A gives B ½ the charge of A (split equally). The charge on B is then ½ that of C and oppositely charged. When B and C touch, the total charge between them is ½ the charge of C and the same sign as C. Each sphere then has ¼ of the charge of C after contact is made. This makes the end result that the charge on sphere B is ¼ the original charge of A and the same sign as sphere C, which is opposite that of A C

132. Advanced question (not exactly in the B curriculum, but interesting). Like gravity inside a uniform sphere of mass, the field is directly proportional to r when inside the sphere (and proportional to $1/r^2$ when outside) C

133. The field due to the two +3q charges cancel. The –q in the upper right counters –q from the lower left, leaving the net contribution to the field a –q from the lower left. B

134. With equal charge, the forces are the same. The potential energy of the charges is equal in magnitude, but positive for the proton and negative for the electron. For scalars, positive numbers are higher than negative numbers. A

135. The charge Q in the middle will induce a charge –Q on the inner surface of the shell. For the net charge of the shell to be –q, the outer surface must have the rest of the charge such that $q_{outer} + q_{inner} = -q$ so $q_{outer} = -q - q_{inner} = -q - (-Q) = Q - q$ C

136. The potential inside the shell is the same as the potential at the surface of the shell since E = 0 inside the shell. $V = kq_{outer}/b$ D

137. Charges flow when there is a difference in potential. B

138. $V = \Sigma kQ/r$ D

139. The electric field cancels from symmetry all but +Q remaining in the upper right corner and $E = kQ/r^2$ A

140. If the E fields are the same, that means $kQ_X/r_X^2 = kQ_Y/r_Y^2$, or $Q_X/Q_Y = r_X^2/r_Y^2$ A

141. $U_E \propto 1/r$ C

142. $\Sigma F = 0$ so we have $T + k(q)(q)/d^2 - Mg = 0$ giving $T = Mg - kq^2/d^2$ D

143. When lowered inside, the charged sphere induces a negative charge on the inner surface of the cup. The outer surface remains neutral since it is grounded. When the grounding wire is removed, the cup has a net negative charge, which when the sphere is removed, will move to the outer surface of the cup. B

144. $K = q\Delta V$ so $K_1/K_2 = q_1/q_2$ D

145. The field is zero where the fields from each charge point in opposite directions and also closer to the smaller charge, which is to the left of the –Q charge A

146. $E = \Delta V/d$ B

147. E fields point from high potential to low potential, perpendicular to the equipotential lines. A

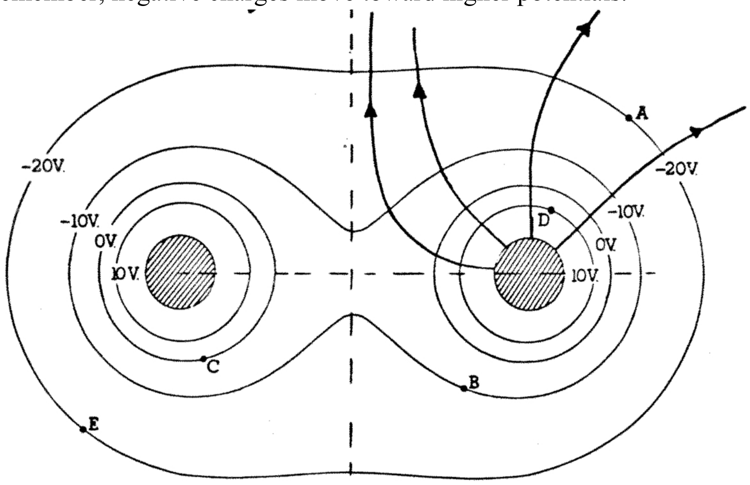
148. Combining two droplets doubles the charge. The volume is doubled, which means the radius is multiplied by $\sqrt[3]{2}$. This gives $V = kQ/r = k(2Q)/(\sqrt[3]{2}r)$ B

149. The work to assemble the charges is the potential energy of the system, which is the sum of the potential energies of each pair of charges $U_E = -ke^2/a - ke^2/a + ke^2/2a$ B

1974B5

a. Since the potential increases as you near the cylinder on the right, it must also have a positive charge. Remember, negative charges move toward higher potentials.

b.



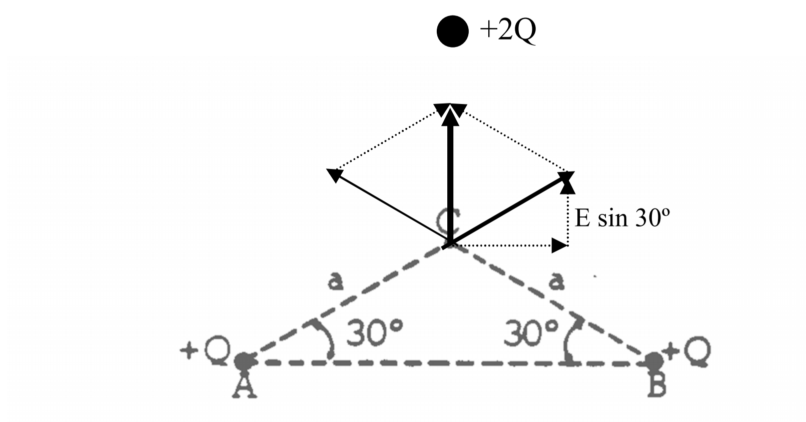
c. $V_A - V_B = (-20\text{ V}) - (-10\text{ V}) = -10\text{ V}$

d. $W_{AED} = W_{AD} = -q\Delta V = -(0.5\text{ C})(30\text{ V}) = -15\text{ J}$

1975B2

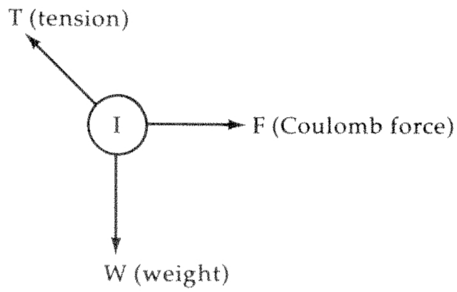
a. $V_C = kQ/a + kQ/a = 2kQ/a$; $W = -q\Delta V = -(+q)(V_\infty - V_C) = -q(0 - 2kQ/a) = 2kQq/a$

b. Looking at the diagram below, the fields due to the two point charges cancel their x components and add their y components, each of which has a value $(kQ/a^2)\sin 30° = \frac{1}{2} kQ/a^2$ making the net E field (shown by the arrow pointing upward) $2 \times \frac{1}{2} kQ/a^2 = kQ/a^2$. For this field to be cancelled, we need a field of the same magnitude pointing downward. This means the positive charge +2Q must be placed directly above point C at a distance calculated by $k(2Q)/d^2 = kQ/a^2$ giving $d = \sqrt{2}a$



1979B7

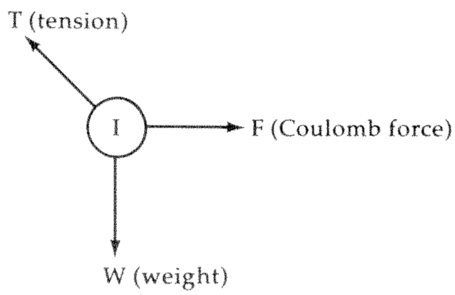
a.



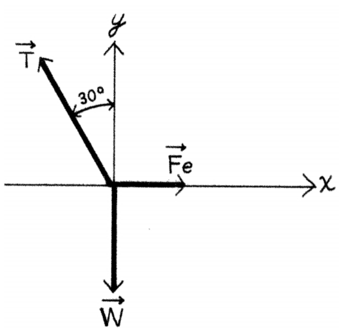
b. Resolving the tension into components we have T cos θ = W and T sin θ = F
where W = mg and $F = kq^2/r^2$ and $r = 2l \sin\theta$ giving $F = kq^2/(4l^2 \sin^2\theta)$
Dividing the two expressions we get $\tan\theta = F/mg = kq^2/(4l^2 \sin^2\theta\ mg)$
solving yields $q^2 = 4mgl^2 (\sin^2\theta)(\tan\theta)/k$

1981 B3

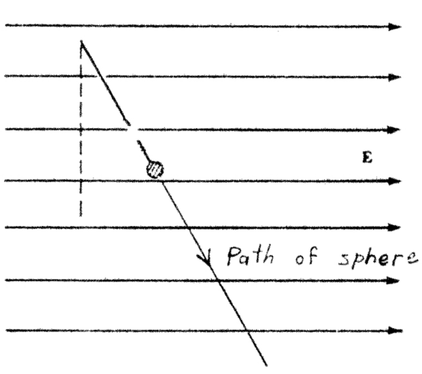
a.



b.



T cos 30° = mg so T = 0.058 N
$T \sin\theta = F_E = Eq$ gives $E = 5.8 \times 10^3$ N/C

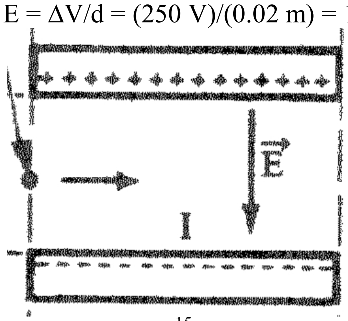


c. After the string is cut, the only forces are gravity, which acts down, and the electrical force which acts to the right. The resultant of these two forces causes a constant acceleration along the line of the string. The path is therefore down and to the right, along the direction of the string as shown above.

1985B3

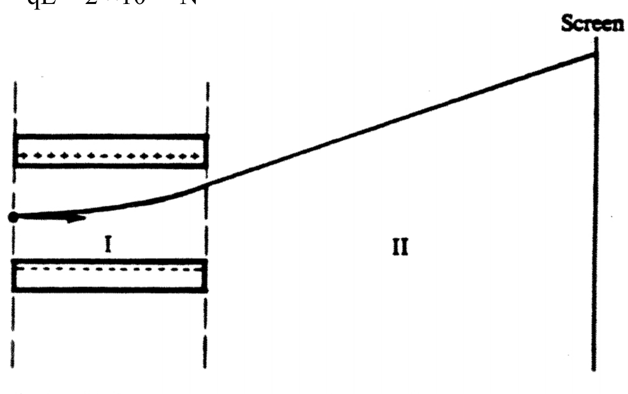
a. $K = (2 \times 10^3 \text{ eV})(1.6 \times 10^{-19} \text{ J/eV}) = 3.2 \times 10^{16}$ J
$K = \frac{1}{2} mv^2$ gives $v = 2.7 \times 10^7$ m/s

b. $E = \Delta V/d = (250 \text{ V})/(0.02 \text{ m}) = 1.25 \times 10^4$ V/m



c. $F = qE = 2 \times 10^{-15}$ N

d.



Path curves parabolically toward the upper plate in region I and moves in a straight line in region II.

1987B2

a. $V = kQ/r = 9 \times 10^4$ V

b. $W = q\Delta V$ (where V at infinity is zero) = 0.09 J

c. $F = kqQ/r^2 = 0.3$ N

d. Between the two charges, the fields from each charge point in opposite directions, making the resultant field the difference between the magnitudes of the individual fields.
$E = kQ/r^2$ gives $E_I = 1.2 \times 10^6$ N/C to the right and $E_{II} = 0.4 \times 10^6$ N/C to the left
The resultant field is therefore $E = E_I - E_{II} = 8 \times 10^5$ N/C to the right

e. From conservation of momentum $m_I v_I = m_{II} v_{II}$ and since the masses are equal we have $v_I = v_{II}$.
Conservation of energy gives $U = K = 2(\frac{1}{2} mv^2) = 0.09$ J giving v = 6 m/s

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1989B2

a. $E = kQ/r^2$ and since the field is zero $E_1 + E_2 = 0$ giving $k(Q_1/r_1^2 + Q_2/r_2^2) = 0$
This gives the magnitude of $Q_2 = Q_1(r_2^2/r_1^2) = 2\mu C$ and since the fields must point inopposite directions from each charge at point P, Q_2 must be negative.

b. $F = kQ_1Q_2/r^2 = 3.6$ N to the right (they attract)

c. $U = kQ_1Q_2/r = -0.72$ J

d. between the charges we have a distance from Q_1 of x and from Q_2 of (0.2 m – x)
$V = kQ_1.x + kQ_2/(0.2 \text{ m} - x) = 0$, solving for x gives x = 0.16 m

e. $W = q\Delta V$ where $\Delta V = V_\infty - V_R = 0$ so W = 0

1990B2

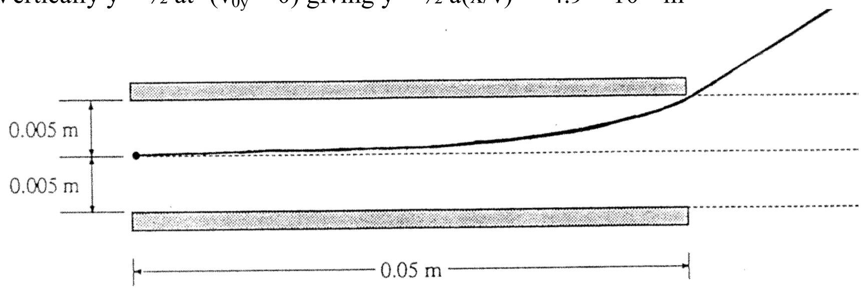
a. $E = V/d = 2 \times 10^4$ V/m

b. $F = Eq = ma$ gives $a = qE/m = 3.5 \times 10^{15}$ m/s^2

c. Horizontally: $x = vt$ giving $t = x/v$

Vertically $y = \frac{1}{2} at^2$ ($v_{0y} = 0$) giving $y = \frac{1}{2} a(x/v)^2 = 4.9 \times 10^{-3}$ m

d.

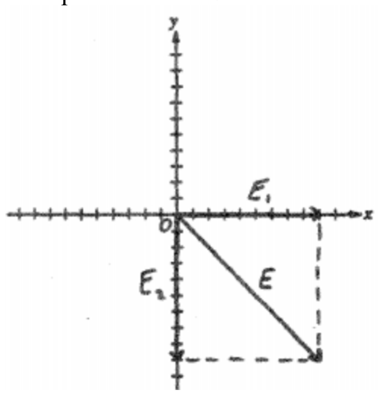


1993B2

a. i. $E = kq/r^2 = 9000$ N/C

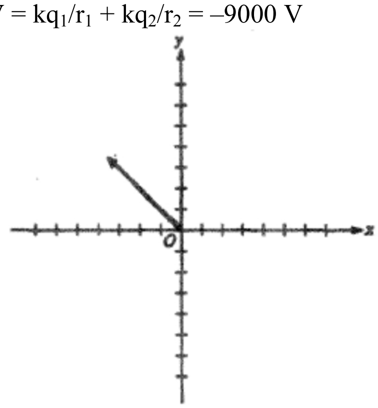
ii. $E = kq/r^2 = 9000$ N/C

iii.



b. $V = kq_1/r_1 + kq_2/r_2 = -9000$ V

c.



Since the charge is negative, the force acts opposite the direction of the net E field.

d. $W = q\Delta V = 0.036$ J

1996B6

a. $\Sigma F = 0$ gives $qE = mg$ and $q = mg/E = 3.27 \times 10^{-19}$ C

b. The drop must have a net negative charge. The electric force on a negative charge acts opposite the direction of the electric field.

c. $V = Ed = 100$ V

d. The drop moves upward. The reduced mass decreases the downward force of gravity on the drop while if the charge remains the same, the upward electric force is unchanged.

2002B5B

a. Electric field lines point away from positive charges and toward negative charges. The plate on the left is negative and the plate on the right is positive.

b. $V = Ed = 100$ V

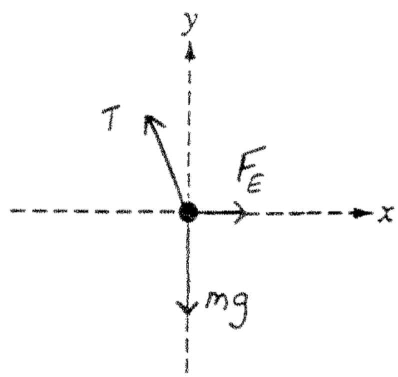
c. $C = \varepsilon_0 A/d = 1.3 \times 10^{-10}$ F

d. $F = qE = 8 \times 10^{-16}$ N to the right (opposite the direction of the electric field)

e. The potential difference between the center and one of the plates is 50 V.
$W = qV = ½ mv^2$ gives $v = 4.2 \times 10^6$ m/s

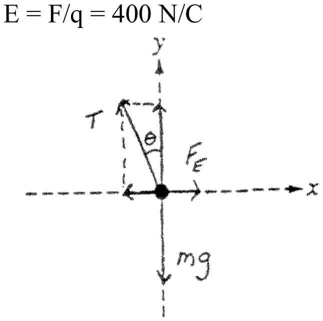
1998B2

a.



b. $E = F/q = 400$ N/C

c.



$T \sin\theta = F_E$ and $T \cos\theta = mg$. Dividing gives $\tan\theta = F/mg$ and $\theta = 18°$.
From the diagram $\sin\theta = x/(0.30 \text{ m})$ giving $x = 0.09$ m

d. i. $a_x = F/m = 3.2$ m/s^2; $a_y = 9.8$ m/s^2
$a = \sqrt{a_x^2 + a_y^2} = 10.3$ m/s^2; $\tan\theta = (9.8 \text{ m/s}^2)/(3.2 \text{ m/s}^2) = 72°$ below the x axis
(or 18° to the right of the y axis, the same as the angle of the string)
ii. The ball moves in a straight line down and to the right

1999B2

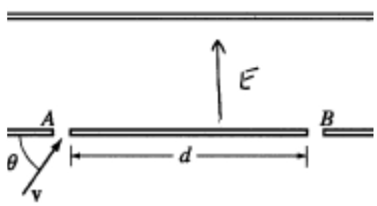
a. $W = qV = ½ mv^2$ gives $V = mv^2/2q = 1.0 \times 10^4$ V
b. Electrons travel toward higher potential making the upper plate at the higher potential.
c. i. $x = v_x t$ gives $t = 6.7 \times 10^{-10}$ s
   ii. $F = ma = qE$ and $E = V/d$ gives $a = qV/md$ and $y = ½ at^2$ ($v_{0y} = 0$) gives $y = qVt^2/2md = 6.5 \times 10^{-4}$ m
d. F_g is on the order of 10^{-30} N (mg) and $F_E = qE = qV/d$ is around 10^{-14} N so $F_E \gg F_g$
e. Since there is no more electric force, the path is a straight line.

2001B3

a. i. $V = \Sigma kQ/r = k(-Q/r + -Q/r + Q/r + Q/r) = 0$
   ii. The fields from the charges on opposing corners cancels which gives E = 0
b. i. $V = \Sigma kQ/r = k(-Q/r + -Q/r + Q/r + Q/r) = 0$
   ii. The field from each individual charge points along a diagonal, with an *x*-component to the right. The vertical components cancel in pairs, and the *x*-components are equal in magnitude. Each x component being $E = kQ/r^2 \cos 45°$ and the distance from a corner to the center of $r^2 = s^2/2$ gives
   $E = 4E_x = 4\frac{kQ}{s^2/_2}\frac{\sqrt{2}}{2} = 4\sqrt{2}kQ/s^2$
c. Arrangement 1. The force of attraction on the upper right charge is greater in arrangement 1 because the two closest charges are both positive, whereas in arrangement 2 one is positive and one is negative.

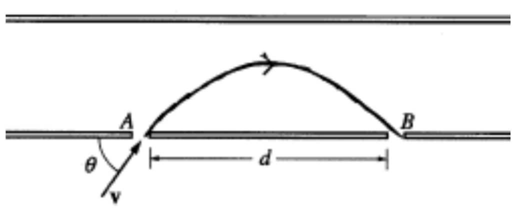
2003B4B

a. i.



   ii.

   iii.



b. $F = ma = qE$ gives $a = qE/m$
c. The acceleration is downward and at the top of the path, $v_y = v_{0y} - at = 0$ and $v_{0y} = v \sin\theta$ which gives $t_{top} = v \sin\theta/a$ or $t_{total} = 2t_{top} = 2v \sin\theta/a$ and substituting a from part b gives $t = (2mv \sin\theta)/qE$
d. $d = x_x t$ where $v_x = v \cos\theta$ giving $d = (2mv^2 \sin\theta \cos\theta)/qE$
e. The distance would be less because gravity, acting downward, will increase the electron's downward acceleration, decreasing the time spent in the field.

2005B3

a. $E = kq/r^2$ and the field from each charge points in opposite directions, with the larger field contribution pointing upward. $E_O = k(2q)/a^2 – kq/a^2 = kq/a^2$ upward (+y)

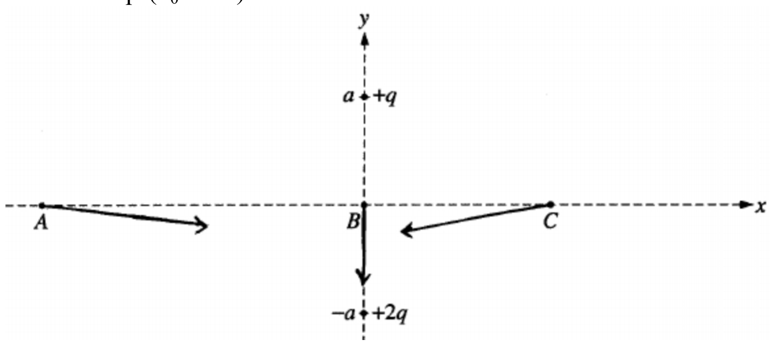
b. $V_O = \Sigma kq/r = k(2q)/a + kq/a = 3kq/a$

c. $F = kq_1q_2/r^2$ where in this case $r^2 = x_0^2 + a^2$

   i. $F = kq^2/(x_0^2 + a^2)$

   ii. $F = 2kq^2/(x_0^2 + a^2)$

d.



2005B3B

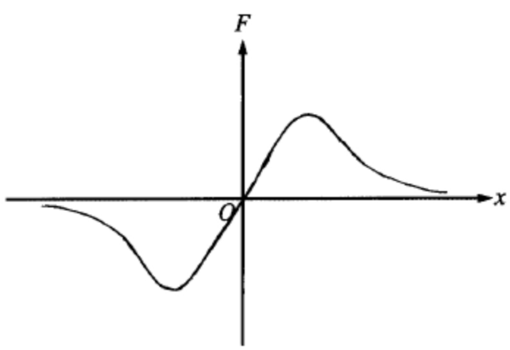
a. The distance between the charges is $r = \sqrt{a^2 + (2a)^2} = \sqrt{5}a$ The y components of the forces due to the two –2Q charges cancel so the magnitude of the net force equals the sum of the x components, where $F_x = F \cos \theta$ and $\cos \theta = 2a/r = 2/\sqrt{5}$

   Putting this all together gives $F_x = 2 \times (kQ(2Q)/r^2) \cos \theta = 8kQ^2/5\sqrt{5}a^2$ to the right (+x)

b. The contribution to the field from the –2Q charges cancel. This gives $E = kQ/(2a)^2 = kQ/4a^2$ to the right (+x)

c. $V = \Sigma kQ/r = k(–2Q)/a + k(–2Q)/a + k(–Q)/2a = –9kQ/2a$

d. At the origin the force is zero (they cancel). As the charge moves away from the origin, the force first increases as the x components grow, then decrease as the distance grows larger.



2006B3

a. Positive. The electric field due to q_1 points to the right since q_1 is negative. For the electric field to be zero at point P, the field form q_2 must point to the left, away from q_2 making q_2 positive.

b. $\mathbf{E}_1 + \mathbf{E}_2 = 0$ so setting the fields from each charge equal in magnitude gives $kq_1/d_1^2 = kq_2/d_2^2$, or $q_2 = q_1(d_2^2/d_1^2) = 4.8 \times 10^{-8}$ C

c. $F = kq_1q_2/r^2 = 1.4 \times 10^{-5}$ N to the left

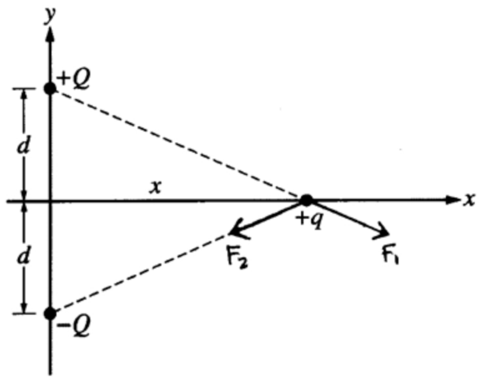
d. $V_1 + V_2 = 0 = kq_1/r_1 + kq_2/r_2$ and let $r_2 = d$ and $r_1 = (0.3 \text{ m} – d)$

   solving yields d = 0.28 m to the left of q_2 which is at x = 0.20 m – 0.28 m = –0.08 m

e. $W = q\Delta V$ and since $\Delta V = 0$, $W = 0$

2006B3B

a.



b. The x components of the forces cancel so the net force is the sum of the y components, which are equal in magnitude and direction. $F_{net} = 2 \times F \cos\theta$ where θ is the angle between the y axis and the dashed line in the diagram above. $\cos\theta = d/r = d/\sqrt{x^2 + d^2}$
This gives $F_{net} = 2 \times kqQ/r^2 \times \cos\theta = 2kqQd/(x^2 + d^2)^{3/2}$

c. $E = F/q$ at the point where q_1 lies. $E = 2kQd/(x^2 + d^2)^{3/2}$

d. Since the charges Q and –Q are equidistant from the point and $V = \Sigma kQ/r$, the potential $V = 0$

e. As x gets large, the distance to the charges r and the value of x become similar, that is $\sqrt{x^2 + d^2} \approx x$.
Substituting this into the answer to b. yields $F = 2kqQd/x^3$

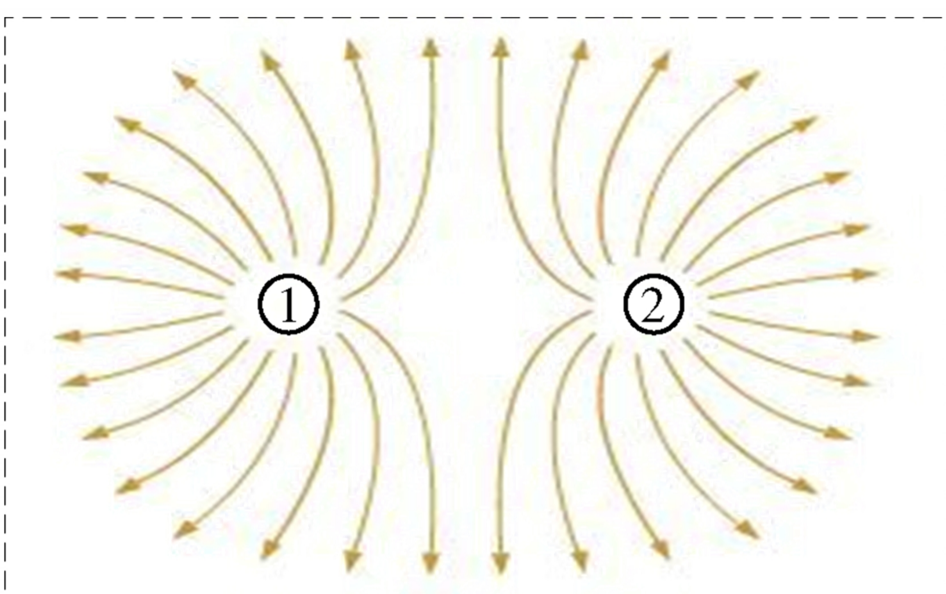
2009B2B

a. The x components of the forces due to the charges q_B cancel making the net force equal to the sum of the y components which are equal in magnitude and both point downward. The distance between q_A and either q_B is found by the Pythagorean theorem to be 0.05 m. $F_y = F \sin\theta$ where θ is the angle between the line joining q_A and q_B and the x axis, giving $\sin\theta = 3/5$.
This gives $F_{net} = 2 \times F_y = 2\,(kq_Aq_B/r^2) \times \sin\theta = 2.6 \times 10^{-7}$ N down (–y)

b. Particle A will accelerate downward, but as the particle approaches the origin, the force and the acceleration will decrease to zero at the origin. It will then pass through the origin, with a net force now pointing upward, where it will eventually slow down and reverse direction, repeating the process. The short answer is the particle will oscillate vertically about the origin.

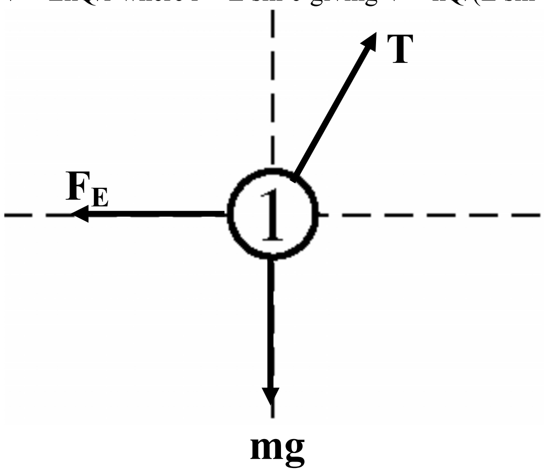
2009B2

a.



b. $V = \Sigma kQ/r$ where $r = L \sin \theta$ giving $V = kQ/(L \sin \theta) + kQ/(L \sin \theta) = 2kQ/(L \sin \theta)$

c.



d. $\Sigma F_y = 0$; $T \cos \theta = mg$
$\Sigma F_x = 0$; $T \sin \theta = F_E = kQ^2/(2L \sin \theta)^2$

1974E2

a. $E = V/d = V/b$

b. $C = \varepsilon_0 A/d = \varepsilon_0 A/b$; $Q = CV = \varepsilon_0 AV/b$

c. This arrangement acts as two capacitors in series, which each have a potential difference ½ V. Using $E = V/d$ where $d = ½(b – a)$ for each of the spaces above and below. This gives $E = V/d = (½ V)/½(b – a) = V/(b – a)$

d. With the copper inserted, we have two capacitors in series, each with a spacing ½(b – a). The capacitance of each is then $\varepsilon_0 A/(½(b – a))$ and in series, two equal capacitors have an equivalent capacitance of ½ C makinf the total capacitance with the copper inserted $½\varepsilon_0 A/(½(b – a)) = \varepsilon_0 A/(b – a)$ making the ratio $b/(b – a)$. Notice the final capacitance is effectively a new single capacitor with an air gap of (b – a). Imagine sliding the copper slab up to touch the top plate, this is the same result. This is why adding capacitors in series decreases the capacitance as if the gap between the plates was increased.

1975E1

a. To find V along the x axis we use $V = \Sigma kq/r$ where $r = \sqrt{l^2 + x^2}$ giving $V = 2kq/\sqrt{l^2 + x^2}$ and $U_E = qV$ so as a function of x we have $U_E = 2kq^2/\sqrt{l^2 + x^2}$

b. Along the x axis, the y components of the forces cancel and the net force is then the sum of the x components of the forces. Since x = l in this case, the forces make an angle of 45º to the x axis and we have $F = 2 \times F_x = 2 \times F \times \cos 45º = 2 \times kq^2/(\sqrt{l^2 + l^2})^2 \times \cos 45º = kq^2/\sqrt{2}l^2$

c. At the origin, the potential is $V = kq/l + kq/l = 2kq/l$ and with $V_\infty = 0$ we have $W = –q\Delta V = –2kq^2/l$

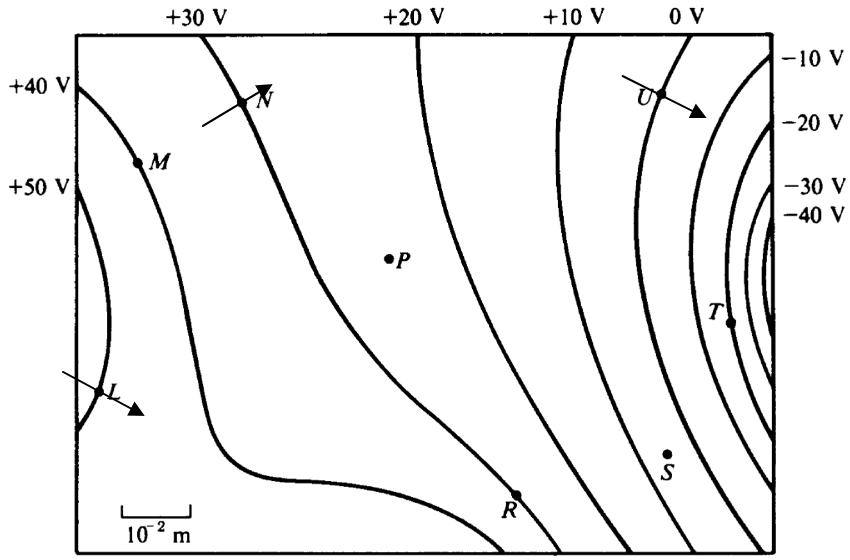
1982E1

a. $V = \Sigma kq/r = –kq/x + 2kq/\sqrt{a^2 + x^2} = 0$ which gives $1/x = 2/\sqrt{a^2 + x^2}$ cross multiplying and squaring gives $4x^2 = a^2 + x^2$ yielding $x = \pm a/\sqrt{3}$

b. $E = kq/r^2$ and by symmetry, the y components cancel. The x components of the electric field from the positive charges points to the right and has magnitude $(kq/r^2) \cos \theta$ where $\cos \theta = x/r = x/\sqrt{x^2 + a^2}$ and the x component of the electric field from the –q charge points to the left with magnitude kq/x^2 making the net field
$E = 2kqx/(x^2 + a^2)^{3/2} – kq/x^2$

<u>1986E1</u>

a.



The field lines point perpendicular to the equipotential lines from high to low potential.

b. The magnitude of the field is greatest at point T because the equipotential lines are closest together, meaning ΔV has the largest gradient, which is related to the strength of the electric field.

c. $E = \Delta V/d = (10\ V)/(0.02\ m) = 500\ V/m$

d. $V_M - V_S = 40\ V - 5\ V = 35\ V$

e. $W = -q\Delta V$ and $\Delta V = -10\ V$ which gives $W = 5 \times 10^{-11}\ J$

f. The work done is independent of the path so the answer would be the same.

<u>1991E1</u>

a. $E = kQ/a^2$ for each charge, but each vector points in the opposite direction so $E = 0$

b. $V = kQ/a + kQ/a = 2kQ/a$

c. the distance to point P from either charge is $r = \sqrt{a^2 + b^2}$ and the magnitude of E is $kQ/r^2 = kQ/(a^2 + b^2)$
The x components cancel so we have only the y components which are $E \sin \theta$ where $\sin \theta = b/\sqrt{a^2 + b^2}$ and adding the 2 y components from the two charges gives $E_{net} = 2kQb/(a^2 + b^2)^{3/2}$

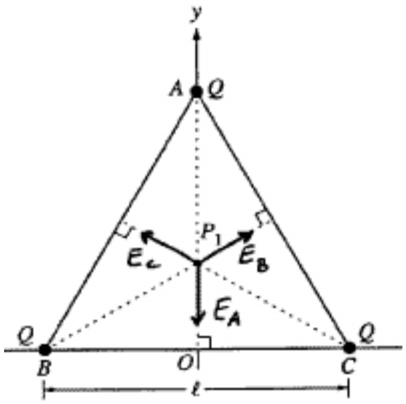
d. The particle will be pushed back toward the origin and oscillate left and right about the origin.

e. The particle will accelerate away from the origin.
The potential of at the center is $2kQ/a$ and far away $V_\infty = 0$. To find the speed when far away we use $W = q\Delta V = K = \frac{1}{2} mv^2$ which gives $v = 2\sqrt{\frac{kQq}{ma}}$

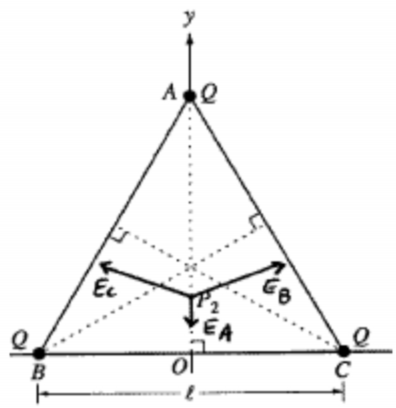
f. The particle will be pulled back toward the origin and oscillate up and down around the origin.

2000E2

a. i.



ii.



	Greater than at P_1	Less than at P_1	The same as at P_1
E_A		✓	
E_B	✓		
E_C	✓		

b. The x components cancel due to the symmetry about the y axis.

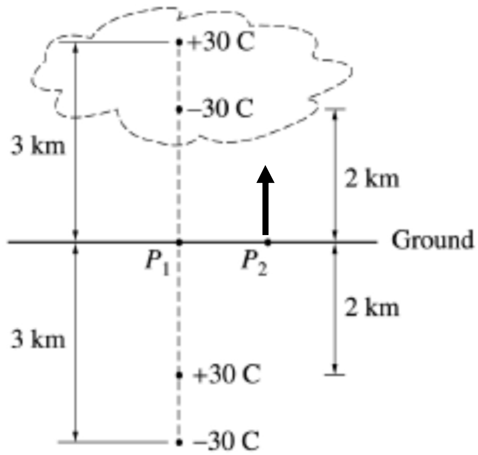
c. $V = \Sigma kQ/r = kQ_A/r_A + kQ_B/r_B + kQ_C/r_C$ where the terms for B and C are equal so we have $V = kQ_A/r_A + 2Q/r_B$

and using the proper geometry for the distances gives $V = k\left|\frac{Q}{\frac{\sqrt{3}l}{2}-y} + \frac{2Q}{\sqrt{\frac{l^2}{4}+y^2}}\right|$

2001E1

a. E is the vector sum of kQ/r^2. Let fields directed upward be positive and fields directed downward be negative. This gives $E = k[-30\ C/(3000\ m)^2 + 30\ C/(2000\ m)^2 + 30\ C/(2000\ m)^2 - 30\ C/(3000\ m)^2] = 75{,}000$ N/C upward

b. i.



ii. Because it is a larger distance from the charges, the magnitude is less.

c. i. By symmetry, the potentials cancel and V = 0

ii. By symmetry, the potentials cancel and V = 0

d. $V = \Sigma kQ/r = k[30\ C/(2000\ m) - 30\ C/(1000\ m) + 30\ C/(3000\ m) - 30\ C/(4000\ m)] = -1.12 \times 10^8$ V

e. $U = kq_1q_2/r$ for *each pair* of charges

$= k[(30)(-30)/1000 + (30)(30)/5000 + (30)(-30)/6000 + -30(30)/4000 + -30(-30)/5000 + 30(-30)/1000] =$

-1.6×10^{10} J

2005E1

a. i. The magnitude of the field is greatest at point C because this is where the field lines are closest together.

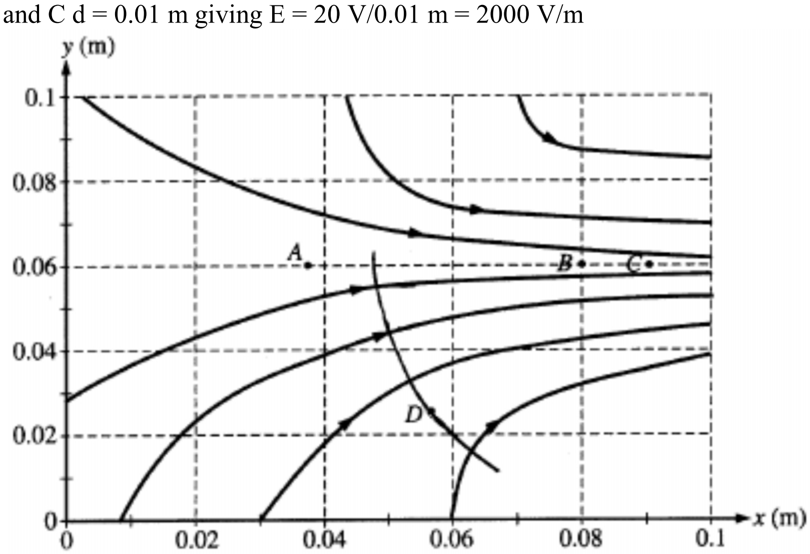
ii. The potential is greatest at point A. Electric field lines point from high to low potential.

b. i. The electron moves to the left, against the field lines. As the field gets weaker the electron's acceleration to the left decreases in magnitude, all the while gaining speed to the left.

ii. $W = q\Delta V = ½\ mv^2$ gives $v = 1.9 \times 10^6$ m/s

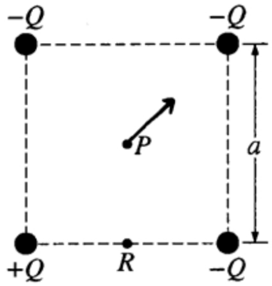
c. If we assume the field is nearly uniform between B and C we can use $E = \Delta V/d$ where the distance between B and C d = 0.01 m giving E = 20 V/0.01 m = 2000 V/m

d.



2006E1

a.



b. i. The fields at point P due to the upper left and lower right negative charges are equal in magnitude and opposite in direction so they sum to zero. The fields at point P due to the other two charges are equal in magnitude and in the same direction so they add.
Using $r^2 = a^2/2$ we have $E = 2 \times kQ/r^2 = 4kQ/a^2$
ii. $V = \Sigma kQ/r = k(-Q - Q - Q + Q)/r = -2kQ/r$ with $r = a/\sqrt{2}$ giving $V = -2\sqrt{2}kQ/a$

c. Negative. The field is directed generally from R to P and the charge moves in the opposite direction. Thus, the field does negative work on the charge.

d. i. Replace the top right negative charge with a positive charge OR replace the bottom left positive charge with a negative charge. The vector fields/forces all cancel from oppositely located same charge pairs.
ii. Replace the top left negative charge with a positive charge OR replace the bottom right negative charge with a positive charge. The scalar potentials all cancel from equidistant located opposite charge pairs. The field vectors in these cases will not cancel.

2009E2

a. $W = qV_0 = \frac{1}{2} mv^2$ giving $v = \sqrt{\frac{2eV_0}{m}}$

b. i. The time to travel horizontally a distance y_0 is found from $v = d/t$ giving $t = d/v = y_0/\sqrt{\frac{2eV_0}{m}}$
The downward acceleration of the electron is found from $F = qE = ma$ giving $a = eE/m$ and using $y = \frac{1}{2} at^2$ and substituting the values found earlier we have $y = y_0 = \frac{1}{2} (eE/m)(y_0^2)/(2eV_0/m)$ which yields $E = 4V_0/y_0$
ii. For the electron to accelerate downward requires the electric field to point upward, toward the top of the page since negative charges experience forces opposite electric field lines.

c. $\Delta V = ED = (4D/y_0)V_0$