CHAPTER 29

ELECTRIC FIELD AND POTENTIAL

29.1 WHAT IS ELECTRIC CHARGE ?

Matter is made of certain elementary particles. With the advancement in technology, we have discovered hundreds of elementary particles. Many of them are rare and of no concern to us in the present course. The three most common elementary particles are electrons, protons and neutrons having masses $m_e = 9{\cdot}10940 \times 10^{-31}$ kg, $m_p = 1{\cdot}67262 \times 10^{-27}$ kg and $m_n = 1{\cdot}67493 \times 10^{-27}$ kg. Because of their mass these particles attract each other by gravitational forces. Thus, an electron attracts another electron, placed 1 cm away, with a gravitational force

$$F = \frac{G m_1 m_2}{r^2}$$

$$= \frac{(6{\cdot}67 \times 10^{-11}\ \text{N-m}^2/\text{kg}^2) \times (9{\cdot}1 \times 10^{-31}\ \text{kg})^2}{(10^{-2}\ \text{m})^2}$$

$$= 5{\cdot}5 \times 10^{-67}\ \text{N}.$$

However, an electron is found to repel another electron at 1 cm with a force of $2{\cdot}3 \times 10^{-24}$ N. This extra force is called the *electric force*. The electric force is very large as compared to the gravitational force. The electrons must have some additional property, apart from their mass, which is responsible for the electric force. We call this property *charge*. Just as masses are responsible for the gravitational force, charges are responsible for the electric force. Two protons placed at a distance of 1 cm also repel each other with a force of $2{\cdot}3 \times 10^{-24}$ N. Thus, protons also have charge. Two neutrons placed at a distance of 1 cm attract each other with a force of $1{\cdot}9 \times 10^{-60}$ N which is equal to $\frac{G m_1 m_2}{r^2}$. Thus, neutrons exert only gravitational force on each other and experience no electric force. The neutrons have mass but no charge.

Two Kinds of Charges

As mentioned above, the electric force between two electrons is the same as the electric force between two protons placed at the same separation. We may guess that the amount of charge on an electron is the same as that on a proton. However, if a proton and an electron are placed 1 cm apart, they attract each other with a force of $2{\cdot}3 \times 10^{-24}$ N. Certainly this force is electric, but it is attractive and not repulsive. The charge on an electron repels the charge on another electron but attracts the charge on a proton. Thus, although the charge on an electron and that on a proton have the same strength, they are of two different nature. Also, if we pack a proton and an electron together in a small volume, the combination does not attract or repel another electron or proton placed at a distance. The net charge on the proton–electron system seems to be zero. It is, therefore, convenient to define one charge as positive and the other as negative. We arbitrarily call the charge on a proton as positive and that on an electron as negative. This assignment of positive and negative signs to the proton charge and the electron charge is purely a convention. It does not mean that the charge on an electron is "less" than the charge on a proton.

Unit of Charge

The above discussion suggests that charge is a basic property associated with the elementary particles and its definition is as difficult as the definition of mass or time or length. We can measure the charge on a system by comparing it with the charge on a standard body but we do not know what exactly it is that we intend to measure. The SI unit of charge is coulomb abbreviated as C. 1 coulomb is the charge flowing through a wire in 1 *s* if the electric current in it is 1 A. The charge on a proton is

$$e = 1{\cdot}60218 \times 10^{-19}\ \text{C}.$$

The charge on an electron is the negative of this value.

Charge is Quantized

If protons and electrons are the only charge carriers in the universe, all observable charges must

$$|\tau| = |\vec{p} \times \vec{E}|$$

$$= qlE \sin\theta.$$

This torque will tend to rotate the dipole back towards the electric field. Also, for small angular displacement $\sin\theta \approx \theta$ so that

$$\tau = -qlE\theta.$$

The moment of inertia of the system about the axis of rotation is

$$I = 2 \times m\left(\frac{l}{2}\right)^2 = \frac{ml^2}{2}.$$

Thus, the angular acceleration is

$$\alpha = \frac{\tau}{I} = -\frac{2qE}{ml}\theta = -\omega^2\theta$$

where $\omega^2 = \frac{2qE}{ml}$.

Thus, the motion is angular simple harmonic and the time period is $T = 2\pi\sqrt{\frac{ml}{2qE}}$.

□

QUESTIONS FOR SHORT ANSWER

1. The charge on a proton is $+1.6 \times 10^{-19}$ C and that on an electron is -1.6×10^{-19} C. Does it mean that the electron has a charge 3.2×10^{-19} C less than the charge of a proton?
2. Is there any lower limit to the electric force between two particles placed at a separation of 1 cm?
3. Consider two particles A and B having equal charges and placed at some distance. The particle A is slightly displaced towards B. Does the force on B increase as soon as the particle A is displaced? Does the force on the particle A increase as soon as it is displaced?
4. Can a gravitational field be added vectorially to an electric field to get a total field?
5. Why does a phonograph-record attract dust particles just after it is cleaned?
6. Does the force on a charge due to another charge depend on the charges present nearby?
7. In some old texts it is mentioned that 4π lines of force originate from each unit positive charge. Comment on the statement in view of the fact that 4π is not an integer.
8. Can two equipotential surfaces cut each other?
9. If a charge is placed at rest in an electric field, will its path be along a line of force? Discuss the situation when the lines of force are straight and when they are curved.
10. Consider the situation shown in figure (29-Q1). What are the signs of q_1 and q_2? If the lines are drawn in proportion to the charge, what is the ratio q_1/q_2?

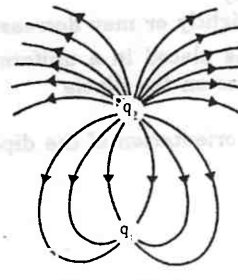


Figure 29-Q1

11. A point charge is taken from a point A to a point B in an electric field. Does the work done by the electric field depend on the path of the charge?
12. It is said that the separation between the two charges forming an electric dipole should be small. Small compared to what?
13. The number of electrons in an insulator is of the same order as the number of electrons in a conductor. What is then the basic difference between a conductor and an insulator?
14. When a charged comb is brought near a small piece of paper, it attracts the piece. Does the paper become charged when the comb is brought near it?

OBJECTIVE I

1. Figure (29-Q2) shows some of the electric field lines corresponding to an electric field. The figure suggests that

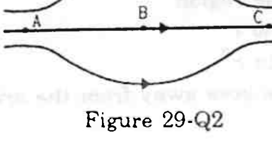


Figure 29-Q2

(a) $E_A > E_B > E_C$ (b) $E_A = E_B = E_C$
(c) $E_A = E_C > E_B$ (d) $E_A = E_C < E_B$.

2. When the separation between two charges is increased, the electric potential energy of the charges
(a) increases (b) decreases
(c) remains the same (d) may increase or decrease.

3. If a positive charge is shifted from a low-potential region to a high-potential region, the electric potential energy

(a) increases (b) decreases
(c) remains the same (d) may increase or decrease.

4. Two equal positive charges are kept at points A and B. The electric potential at the points between A and B (excluding these points) is studied while moving from A to B. The potential
(a) continuously increases
(b) continuously decreases
(c) increases then decreases
(d) decreases then increases.

5. The electric field at the origin is along the positive X-axis. A small circle is drawn with the centre at the origin cutting the axes at points A, B, C and D having coordinates $(a, 0)$, $(0, a)$, $(-a, 0)$, $(0, -a)$ respectively. Out of the points on the periphery of the circle, the potential is minimum at
(a) A (b) B (c) C (d) D.

6. If a body is charged by rubbing it, its weight
(a) remains precisely constant
(b) increases slightly
(c) decreases slightly
(d) may increase slightly or may decrease slightly.

7. An electric dipole is placed in a uniform electric field. The net electric force on the dipole
(a) is always zero
(b) depends on the orientation of the dipole
(c) can never be zero
(d) depends on the strength of the dipole.

8. Consider the situation of figure (29-Q3). The work done in taking a point charge from P to A is W_A, from P to B is W_B and from P to C is W_C.
(a) $W_A < W_B < W_C$. (b) $W_A > W_B > W_C$.
(c) $W_A = W_B = W_C$. (d) None of these.

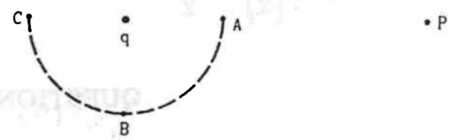


Figure 29-Q3

9. A point charge q is rotated along a circle in the electric field generated by another point charge Q. The work done by the electric field on the rotating charge in one complete revolution is
(a) zero (b) positive (c) negative
(d) zero if the charge Q is at the centre and nonzero otherwise.

OBJECTIVE II

1. Mark out the correct options.
(a) The total charge of the universe is constant.
(b) The total positive charge of the universe is constant.
(c) The total negative charge of the universe is constant.
(d) The total number of charged particles in the universe is constant.

2. A point charge is brought in an electric field. The electric field at a nearby point
(a) will increase if the charge is positive
(b) will decrease if the charge is negative
(c) may increase if the charge is positive
(d) may decrease if the charge is negative.

3. The electric field and the electric potential at a point are E and V respectively.
(a) If $E = 0$, V must be zero.
(b) If $V = 0$, E must be zero.
(c) If $E \neq 0$, V cannot be zero.
(d) If $V \neq 0$, E cannot be zero.

4. The electric potential decreases uniformly from 120 V to 80 V as one moves on the X-axis from $x = -1$ cm to $x = +1$ cm. The electric field at the origin
(a) must be equal to 20 V/cm
(b) may be equal to 20 V/cm
(c) may be greater than 20 V/cm
(d) may be less than 20 V/cm.

5. Which of the following quantities do not depend on the choice of zero potential or zero potential energy ?
(a) potential at a point
(b) potential difference between two points
(c) potential energy of a two-charge system
(d) change in potential energy of a two-charge system.

6. An electric dipole is placed in an electric field generated by a point charge.
(a) The net electric force on the dipole must be zero.
(b) The net electric force on the dipole may be zero.
(c) The torque on the dipole due to the field must be zero.
(d) The torque on the dipole due to the field may be zero.

7. A proton and an electron are placed in a uniform electric field.
(a) The electric forces acting on them will be equal.
(b) The magnitudes of the forces will be equal.
(c) Their accelerations will be equal.
(d) The magnitudes of their accelerations will be equal.

8. The electric field in a region is directed outward and is proportional to the distance r from the origin. Taking the electric potential at the origin to be zero,
(a) it is uniform in the region
(b) it is proportional to r
(c) it is proportional to r^2
(d) it increases as one goes away from the origin.

EXERCISES

1. Find the dimensional formula of ε_0.
2. A charge of 1·0 C is placed at the top of the your college building and another equal charge at the top of your house. Take the separation between the two charges to be 2·0 km. Find the force exerted by the charges on each other. How many times of your weight is this force ?
3. At what separation should two equal charges, 1·0 C each, be placed so that the force between them equals the weight of a 50 kg person ?
4. Two equal charges are placed at a separation of 1·0 m. What should be the magnitude of the charges so that the force between them equals the weight of a 50 kg person ?
5. Find the electric force between two protons separated by a distance of 1 fermi (1 fermi = 10^{-15} m). The protons in a nucleus remain at a separation of this order.
6. Two charges $2{\cdot}0 \times 10^{-6}$ C and $1{\cdot}0 \times 10^{-6}$ C are placed at a separation of 10 cm. Where should a third charge be placed such that it experiences no net force due to these charges ?
7. Suppose the second charge in the previous problem is $-1{\cdot}0 \times 10^{-6}$ C. Locate the position where a third charge will not experience a net force.
8. Two charged particles are placed at a distance 1·0 cm apart. What is the minimum possible magnitude of the electric force acting on each charge ?
9. Estimate the number of electrons in 100 g of water. How much is the total negative charge on these electrons ?
10. Suppose all the electrons of 100 g water are lumped together to form a negatively charged particle and all the nuclei are lumped together to form a positively charged particle. If these two particles are placed 10·0 cm away from each other, find the force of attraction between them. Compare it with your weight.
11. Consider a gold nucleus to be a sphere of radius 6·9 fermi in which protons and neutrons are distributed. Find the force of repulsion between two protons situated at largest separation. Why do these protons not fly apart under this repulsion ?
12. Two insulating small spheres are rubbed against each other and placed 1 cm apart. If they attract each other with a force of 0·1 N, how many electrons were transferred from one sphere to the other during rubbing ?
13. NaCl molecule is bound due to the electric force between the sodium and the chlorine ions when one electron of sodium is transferred to chlorine. Taking the separation between the ions to be $2{\cdot}75 \times 10^{-8}$ cm, find the force of attraction between them. State the assumptions (if any) that you have made.
14. Find the ratio of the electric and gravitational forces between two protons.
15. Suppose an attractive nuclear force acts between two protons which may be written as $F = Ce^{-kr}/r^2$. (a) Write down the dimensional formulae and appropriate SI units of C and k. (b) Suppose that $k = 1$ fermi^{-1} and that the repulsive electric force between the protons is just balanced by the attractive nuclear force when the separation is 5 fermi. Find the value of C.
16. Three equal charges, $2{\cdot}0 \times 10^{-6}$ C each, are held fixed at the three corners of an equilateral triangle of side 5 cm. Find the Coulomb force experienced by one of the charges due to the rest two.
17. Four equal charges $2{\cdot}0 \times 10^{-6}$ C each are fixed at the four corners of a square of side 5 cm. Find the Coulomb force experienced by one of the charges due to the rest three.
18. A hydrogen atom contains one proton and one electron. It may be assumed that the electron revolves in a circle of radius 0·53 angstrom (1 angstrom = 10^{-10} m and is abbreviated as Å) with the proton at the centre. The hydrogen atom is said to be in the ground state in this case. Find the magnitude of the electric force between the proton and the electron of a hydrogen atom in its ground state.
19. Find the speed of the electron in the ground state of a hydrogen atom. The description of ground state is given in the previous problem.
20. Ten positively charged particles are kept fixed on the X-axis at points $x = 10$ cm, 20 cm, 30 cm, ..., 100 cm. The first particle has a charge $1{\cdot}0 \times 10^{-8}$ C, the second 8×10^{-8} C, the third 27×10^{-8} C and so on. The tenth particle has a charge 1000×10^{-8} C. Find the magnitude of the electric force acting on a 1 C charge placed at the origin.
21. Two charged particles having charge $2{\cdot}0 \times 10^{-8}$ C each are joined by an insulating string of length 1 m and the system is kept on a smooth horizontal table. Find the tension in the string.
22. Two identical balls, each having a charge of $2{\cdot}00 \times 10^{-7}$ C and a mass of 100 g, are suspended from a common point by two insulating strings each 50 cm long. The balls are held at a separation 5·0 cm apart and then released. Find (a) the electric force on one of the charged balls (b) the components of the resultant force on it along and perpendicular to the string (c) the tension in the string (d) the acceleration of one of the balls. Answers are to be obtained only for the instant just after the release.
23. Two identical pith balls are charged by rubbing against each other. They are suspended from a horizontal rod through two strings of length 20 cm each, the separation between the suspension points being 5 cm. In equilibrium, the separation between the balls is 3 cm. Find the mass of each ball and the tension in the strings. The charge on each ball has a magnitude $2{\cdot}0 \times 10^{-8}$ C.
24. Two small spheres, each having a mass of 20 g, are suspended from a common point by two insulating strings of length 40 cm each. The spheres are identically charged and the separation between the balls at

equilibrium is found to be 4 cm. Find the charge on each sphere.

25. Two identical pith balls, each carrying a charge q, are suspended from a common point by two strings of equal length l. Find the mass of each ball if the angle between the strings is 2θ in equilibrium.

26. A particle having a charge of $2{\cdot}0 \times 10^{-4}$ C is placed directly below and at a separation of 10 cm from the bob of a simple pendulum at rest. The mass of the bob is 100 g. What charge should the bob be given so that the string becomes loose.

27. Two particles A and B having charges q and $2q$ respectively are placed on a smooth table with a separation d. A third particle C is to be clamped on the table in such a way that the particles A and B remain at rest on the table under electrical forces. What should be the charge on C and where should it be clamped?

28. Two identically charged particles are fastened to the two ends of a spring of spring constant 100 N/m and natural length 10 cm. The system rests on a smooth horizontal table. If the charge on each particle is $2{\cdot}0 \times 10^{-8}$ C, find the extension in the length of the spring. Assume that the extension is small as compared to the natural length. Justify this assmuption after you solve the problem.

29. A particle A having a charge of $2{\cdot}0 \times 10^{-6}$ C is held fixed on a horizontal table. A second charged particle of mass 80 g stays in equilibrium on the table at a distance of 10 cm from the first charge. The coefficient of friction between the table and this second particle is $\mu = 0{\cdot}2$. Find the range within which the charge of this second particle may lie.

30. A particle A having a charge of $2{\cdot}0 \times 10^{-6}$ C and a mass of 100 g is placed at the bottom of a smooth inclined plane of inclination 30°. Where should another particle B, having same charge and mass, be placed on the incline so that it may remain in equilibrium?

31. Two particles A and B, each having a charge Q, are placed a distance d apart. Where should a particle of charge q be placed on the perpendicular bisector of AB so that it experiences maximum force? What is the magnitude of this maximum force?

32. Two particles A and B, each carrying a charge Q, are held fixed with a separation d between them. A particle C having mass m and charge q is kept at the middle point of the line AB. (a) If it is displaced through a distance x perpendicular to AB, what would be the electric force experienced by it. (b) Assuming $x << d$, show that this force is proportional to x. (c) Under what conditions will the particle C execute simple harmonic motion if it is released after such a small displacement? Find the time period of the oscillations if these conditions are satisfied.

33. Repeat the previous problem if the particle C is displaced through a distance x along the line AB.

34. The electric force experienced by a charge of $1{\cdot}0 \times 10^{-8}$ C is $1{\cdot}5 \times 10^{-3}$ N. Find the magnitude of the electric field at the position of the charge.

35. Two particles A and B having charges of $+ 2{\cdot}00 \times 10^{-6}$ C and of $- 4{\cdot}00 \times 10^{-6}$ C respectively are held fixed at a separation of 20·0 cm. Locate the point(s) on the line AB where (a) the electric field is zero (b) the electric potential is zero.

36. A point charge produces an electric field of magnitude 5·0 N/C at a distance of 40 cm from it. What is the magnitude of the charge?

37. A water particle of mass 10·0 mg and having a charge of $1{\cdot}50 \times 10^{-6}$ C stays suspended in a room. What is the magnitude of electric field in the room? What is its direction?

38. Three identical charges, each having a value $1{\cdot}0 \times 10^{-8}$ C, are placed at the corners of an equilateral triangle of side 20 cm. Find the electric field and potential at the centre of the triangle.

39. Positive charge Q is distributed uniformly over a circular ring of radius R. A particle having a mass m and a negative charge q, is placed on its axis at a distance x from the centre. Find the force on the particle. Assuming $x << R$, find the time period of oscillation of the particle if it is released from there.

40. A rod of length L has a total charge Q distributed uniformly along its length. It is bent in the shape of a semicircle. Find the magnitude of the electric field at the centre of curvature of the semicircle.

41. A 10 cm long rod carries a charge of + 50 μC distributed uniformly along its length. Find the magnitude of the electric field at a point 10 cm from both the ends of the rod.

42. Consider a uniformly charged ring of radius R. Find the point on the axis where the electric field is maximum.

43. A wire is bent in the form of a regular hexagon and a total charge q is distributed uniformly on it. What is the electric field at the centre? You may answer this part without making any numerical calculations.

44. A circular wire-loop of radius a carries a total charge Q distributed uniformly over its length. A small length dL of the wire is cut off. Find the electric field at the centre due to the remaining wire.

45. A positive charge q is placed in front of a conducting solid cube at a distance d from its centre. Find the electric field at the centre of the cube due to the charges appearing on its surface.

46. A pendulum bob of mass 80 mg and carrying a charge of 2×10^{-8} C is at rest in a uniform, horizontal electric field of 20 kV/m. Find the tension in the thread.

47. A particle of mass m and charge q is thrown at a speed u against a uniform electric field E. How much distance will it travel before coming to momentary rest?

48. A particle of mass 1 g and charge $2{\cdot}5 \times 10^{-4}$ C is released from rest in an electric field of $1{\cdot}2 \times 10^{4}$ N/C. (a) Find the electric force and the force of gravity acting on this particle. Can one of these forces be neglected in comparison with the other for approximate analysis? (b) How long will it take for the particle to travel a distance of 40 cm? (c) What will be the speed of the particle after travelling this distance? (d) How much is the work done by the electric force on the particle during this period?

49. A ball of mass 100 g and having a charge of $4{\cdot}9 \times 10^{-5}$ C is released from rest in a region where a horizontal electric field of $2{\cdot}0 \times 10^{4}$ N/C exists. (a) Find the resultant force acting on the ball. (b) What will be the path of the ball ? (c) Where will the ball be at the end of 2 s ?

50. The bob of a simple pendulum has a mass of 40 g and a positive charge of $4{\cdot}0 \times 10^{-6}$ C. It makes 20 oscillations in 45 s. A vertical electric field pointing upward and of magnitude $2{\cdot}5 \times 10^{4}$ N/C is switched on. How much time will it now take to complete 20 oscillations ?

51. A block of mass m and having a charge q is placed on a smooth horizontal table and is connected to a wall through an unstressed spring of spring constant k as shown in figure (29-E1). A horizontal electric field E parallel to the spring is switched on. Find the amplitude of the resulting SHM of the block.

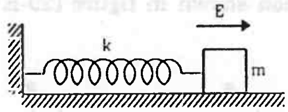


Figure 29-E1

52. A block of mass m containing a net positive charge q is placed on a smooth horizontal table which terminates in a vertical wall as shown in figure (29-E2). The distance of the block from the wall is d. A horizontal electric field E towards right is switched on. Assuming elastic collisions (if any) find the time period of the resulting oscillatory motion. Is it a simple harmonic motion ?

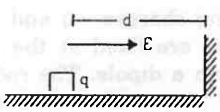


Figure 29-E2

53. A uniform electric field of 10 N/C exists in the vertically downward direction. Find the increase in the electric potential as one goes up through a height of 50 cm.

54. 12 J of work has to be done against an existing electric field to take a charge of 0·01 C from A to B. How much is the potential difference $V_B - V_A$?

55. Two equal charges, $2{\cdot}0 \times 10^{-7}$ C each, are held fixed at a separation of 20 cm. A third charge of equal magnitude is placed midway between the two charges. It is now moved to a point 20 cm from both the charges. How much work is done by the electric field during the process ?

56. An electric field of 20 N/C exists along the X-axis in space. Calculate the potential difference $V_B - V_A$ where the points A and B are given by,
(a) A = (0, 0); B = (4 m, 2 m)
(b) A = (4 m, 2 m); B = (6 m, 5 m)
(c) A = (0, 0); B = (6 m, 5 m).
Do you find any relation between the answers of parts (a), (b) and (c) ?

57. Consider the situation of the previous problem. A charge of $-2{\cdot}0 \times 10^{-4}$ C is moved from the point A to the point B. Find the change in electrical potential energy $U_B - U_A$ for the cases (a), (b) and (c).

58. An electric field $\vec{E} = (\vec{i}\,20 + \vec{j}\,30)$ N/C exists in the space. If the potential at the origin is taken to be zero, find the potential at (2 m, 2 m).

59. An electric field $\vec{E} = \vec{i}\,Ax$ exists in the space, where $A = 10$ V/m^2. Take the potential at (10 m, 20 m) to be zero. Find the potential at the origin.

60. The electric potential existing in space is $V(x, y, z) = A(xy + yz + zx)$. (a) Write the dimensional formula of A. (b) Find the expression for the electric field. (c) If A is 10 SI units, find the magnitude of the electric field at (1 m, 1 m, 1 m).

61. Two charged particles, having equal charges of $2{\cdot}0 \times 10^{-5}$ C each, are brought from infinity to within a separation of 10 cm. Find the increase in the electric potential energy during the process.

62. Some equipotential surfaces are shown in figure (29-E3). What can you say about the magnitude and the direction of the electric field ?

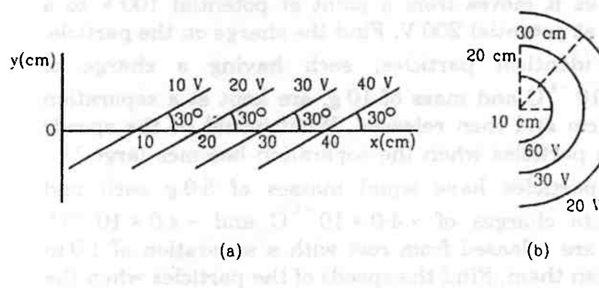


Figure 29-E3

63. Consider a circular ring of radius r, uniformly charged with linear charge density λ. Find the electric potential at a point on the axis at a distance x from the centre of the ring. Using this expression for the potential, find the electric field at this point.

64. An electric field of magnitude 1000 N/C is produced between two parallel plates having a separation of 2·0 cm as shown in figure (29-E4). (a) What is the potential difference between the plates ? (b) With what minimum speed should an electron be projected from the lower plate in the direction of the field so that it may reach the upper plate ? (c) Suppose the electron is projected from the lower plate with the speed calculated in part (b). The direction of projection makes an angle of 60° with the field. Find the maximum height reached by the electron.

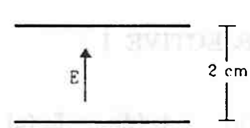


Figure 29-E4

65. A uniform field of 2·0 N/C exists in space in x-direction. (a) Taking the potential at the origin to be zero, write an expression for the potential at a general point (x, y, z). (b) At which points, the potential is 25 V ? (c) If the potential at the origin is taken to be 100 V, what will be the expression for the potential at a general point ? (d) What will be the potential at the origin if the potential at infinity is taken to be zero ? Is it practical to choose the potential at infinity to be zero ?

66. How much work has to be done in assembling three charged particles at the vertices of an equilateral triangle as shown in figure (29-E5) ?

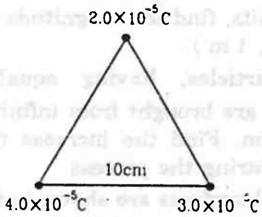


Figure 29-E5

67. The kinetic energy of a charged particle decreases by 10 J as it moves from a point at potential 100 V to a point at potential 200 V. Find the charge on the particle.

68. Two identical particles, each having a charge of $2{\cdot}0 \times 10^{-4}$ C and mass of 10 g, are kept at a separation of 10 cm and then released. What would be the speeds of the particles when the separation becomes large ?

69. Two particles have equal masses of 5·0 g each and opposite charges of $+4{\cdot}0 \times 10^{-5}$ C and $-4{\cdot}0 \times 10^{-5}$ C. They are released from rest with a separation of 1·0 m between them. Find the speeds of the particles when the separation is reduced to 50 cm.

70. A sample of HCl gas is placed in an electric field of $2{\cdot}5 \times 10^{4}$ N/C. The dipole moment of each HCl molecule is $3{\cdot}4 \times 10^{-30}$ C–m. Find the maximum torque that can act on a molecule.

71. Two particles A and B, having opposite charges $2{\cdot}0 \times 10^{-6}$ C and $-2{\cdot}0 \times 10^{-6}$ C, are placed at a separation of 1·0 cm. (a) Write down the electric dipole moment of this pair. (b) Calculate the electric field at a point on the axis of the dipole 1·0 cm away from the centre. (c) Calculate the electric field at a point on the perpendicular bisector of the dipole and 1·0 m away from the centre.

72. Three charges are arranged on the vertices of an equilateral triangle as shown in figure (29-E6). Find the dipole moment of the combination.

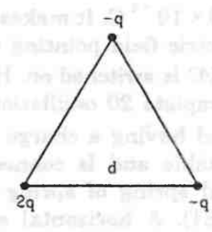


Figure 29-E6

73. Find the magnitude of the electric field at the point P in the configuration shown in figure (29-E7) for $d >> a$. Take $2qa = p$.

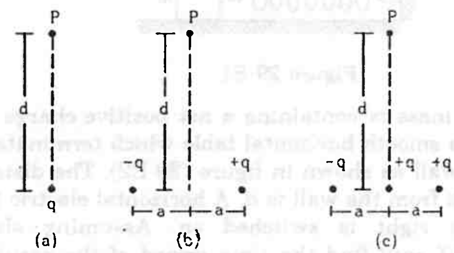


Figure 29-E7

74. Two particles, carrying charges $-q$ and $+q$ and having equal masses m each, are fixed at the ends of a light rod of length a to form a dipole. The rod is clamped at an end and is placed in a uniform electric field E with the axis of the dipole along the electric field. The rod is slightly tilted and then released. Neglecting gravity find the time period of small oscillations.

75. Assume that each atom in a copper wire contributes one free electron. Estimate the number of free electrons in a copper wire having a mass of 6·4 g (take the atomic weight of copper to be 64 g/mol).

□

ANSWERS

OBJECTIVE I

1. (c)	2. (d)	3. (a)	4. (d)	5. (a)	6. (d)
7. (a)	8. (c)	9. (a)			

OBJECTIVE II

1. (a)	2. (c), (d)	3. none
4. (b), (c)	5. (b), (d)	6. (d)
7. (b)	8. (c)	

EXERCISES

1. $I^2M^{-1}L^{-3}T^4$
2. $2{\cdot}25 \times 10^3$ N
3. $4{\cdot}3 \times 10^3$ m
4. $2{\cdot}3 \times 10^{-4}$ C
5. 230 N
6. 5·9 cm from the larger charge in between the two charges
7. 34·1 cm from the larger charge on the line joining the charge in the side of the smaller charge
8. $2{\cdot}3 \times 10^{-24}$ N
9. $3{\cdot}35 \times 10^{25}$, $5{\cdot}35 \times 10^6$ C
10. $2{\cdot}56 \times 10^{25}$ N
11. 1·2 N
12. 2×10^{11}
13. $3{\cdot}05 \times 10^{-9}$ N
14. $1{\cdot}23 \times 10^{36}$
15. (a) ML^3T^{-2}, L^{-1}, N-m^2, m^{-1} (b) $3{\cdot}4 \times 10^{-26}$ N-m^2
16. 24·9 N at 30° with the extended sides from the charge under consideration
17. 27·5 N at 45° with the extended sides of the square from the charge under consideration
18. $8{\cdot}2 \times 10^{-8}$ N
19. $2{\cdot}18 \times 10^6$ m/s
20. $4{\cdot}95 \times 10^5$ N
21. $3{\cdot}6 \times 10^{-6}$ N
22. (a) 0·144 N
 (b) zero, 0·095 N away from the other charge
 (c) 0·986 N and (d) 0·95 m/s^2 perpendicular to the string and going away from the other charge
23. 8·2 g, $8{\cdot}2 \times 10^{-2}$ N
24. $4{\cdot}17 \times 10^{-8}$ C
25. $\dfrac{q^2 \cot\theta}{16\pi\varepsilon_0 g l^2 \sin^2\theta}$
26. $5{\cdot}4 \times 10^{-9}$ C
27. $-(6 - 4\sqrt{2})\, q$, between q and $2q$ at a distance of $(\sqrt{2} - 1)\, d$ from q
28. $3{\cdot}6 \times 10^{-6}$ m
29. between $\pm 8{\cdot}71 \times 10^{-8}$ C
30. 27 cm from the bottom
31. $d/2\sqrt{2}$, $3{\cdot}08 \dfrac{Qq}{4\pi\varepsilon_0 d^2}$
32. (a) $\dfrac{Qqx}{2\pi\varepsilon_0 \left(x^2 + \dfrac{d^2}{4}\right)^{3/2}}$ (c) $\left[\dfrac{m\pi^3\varepsilon_0 d^3}{Qq}\right]^{\frac{1}{2}}$
33. time period $= \left[\dfrac{\pi^3\varepsilon_0 m d^3}{2Qq}\right]^{\frac{1}{2}}$
34. $1{\cdot}5 \times 10^3$ N/C
35. (a) 48·3 cm from A along BA
 (b) 20 cm from A along BA and $\dfrac{20}{3}$ cm from A along AB
36. $8{\cdot}9 \times 10^{-11}$ C
37. 65·3 N/C, upward
38. zero, $2{\cdot}3 \times 10^3$ V
39. $\left[\dfrac{16\pi^3\varepsilon_0 m R^3}{Qq}\right]^{1/2}$
40. $\dfrac{Q}{2\varepsilon_0 L^2}$
41. $5{\cdot}2 \times 10^7$ N/C
42. $R/\sqrt{2}$
43. zero
44. $\dfrac{QdL}{8\pi^2\varepsilon_0 a^3}$
45. $\dfrac{q}{4\pi\varepsilon_0 d^2}$ towards the charge q
46. $8{\cdot}8 \times 10^{-4}$ N
47. $\dfrac{mu^2}{2qE}$
48. (a) 3·0 N, $9{\cdot}8 \times 10^{-3}$ N, (b) $1{\cdot}63 \times 10^{-2}$ s
 (c) 49·0 m/s (d) 1·20 J
49. (a) 1·4 N making an angle of 45° with $\vec{g}$ and $\vec{E}$
 (b) straight line along the resultant force
 (c) 28 m from the starting point on the line of motion
50. 52 s
51. qE/k
52. $\sqrt{\dfrac{8\, md}{qE}}$
53. 5 V
54. 1200 volts
55. $3{\cdot}6 \times 10^{-3}$ J
56. (a) − 80 V (b) − 40 V (c) −120 V
57. 0·016 J, 0·008 J, 0·024 J
58. −100 V
59. 500 V
60. (a) $MT^{-3}I^{-1}$ (b) $-A\,\{\vec{i}\,(y + z) + \vec{j}\,(z + x) + \vec{k}\,(x + y)\}$
 (c) 35 N/C
61. 36 J
62. (a) 200 V/m making an angle 120° with the X-axis
 (b) radially outward, decreasing with distance as $E = \dfrac{6 \text{ V-m}}{r^2}$.
63. $\dfrac{r\lambda}{2\varepsilon_0 (r^2 + x^2)^{1/2}}$, $\dfrac{r\lambda x}{2\varepsilon_0 (r^2 + x^2)^{3/2}}$

64. (a) 20 V (b) 2.65×10^{6} m/s (c) 0.50 cm

65. (a) $-(2.0 \text{ V/m})\, x$
(b) points on the plane $x = -12.5$ m
(c) 100 V $-$ (2.0 V/m) x
(d) infinity

66. 234 J

67. 0.1 C

68. 600 m/s

69. 54 m/s for each particle

70. 8.5×10^{-22} N–m

71. (a) 2.0×10^{-8} C–m (b) 360 N/C (c) 180 N/C

72. $qd\sqrt{3}$, along the bisector of the angle at $2q$, away from the triangle

73. (a) $\dfrac{q}{4\pi\varepsilon_0 d^2}$ (b) $\dfrac{p}{4\pi\varepsilon_0 d^3}$ (c) $\dfrac{1}{4\pi\varepsilon_0 d^3}\sqrt{q^2 d^2 + p^2}$

74. $2\pi\sqrt{\dfrac{ma}{qE}}$

75. 6×10^{22}

CHAPTER – 29
ELECTRIC FIELD AND POTENTIAL
EXERCISES

1. $\varepsilon_0 = \dfrac{\text{Coulomb}^2}{\text{Newton m}^2} = I^1M^{-1}L^{-3}T^4$

$\therefore F = \dfrac{kq_1q_2}{r^2}$

2. $q_1 = q_2 = q = 1.0$ C distance between = 2 km = 1×10^3 m

so, force = $\dfrac{kq_1q_2}{r^2}$ $F = \dfrac{(9\times10^9)\times1\times1}{(2\times10^3)^2} = \dfrac{9\times10^9}{2^2\times10^6} = 2{,}25 \times 10^3$ N

The weight of body = mg = 40 × 10 N = 400 N

So, $\dfrac{\text{wt of body}}{\text{force between charges}} = \left(\dfrac{2.25\times10^3}{4\times10^2}\right)^{-1} = (5.6)^{-1} = \dfrac{1}{5.6}$

So, force between charges = 5.6 weight of body.

3. q = 1 C, Let the distance be χ

F = 50 × 9.8 = 490

$F = \dfrac{Kq^2}{\chi^2}$ $\Rightarrow 490 = \dfrac{9\times10^9\times1^2}{\chi^2}$ or $\chi^2 = \dfrac{9\times10^9}{490} = 18.36 \times 10^6$

$\Rightarrow \chi = 4.29 \times 10^3$ m

4. charges 'q' each, AB = 1 m

wt, of 50 kg person = 50 × g = 50 × 9.8 = 490 N

$F_C = \dfrac{kq_1q_2}{r^2}$ $\therefore \dfrac{kq^2}{r^2} = 490$ N

$\Rightarrow q^2 = \dfrac{490\times r^2}{9\times10^9} = \dfrac{490\times1\times1}{9\times10^9}$

$\Rightarrow q = \sqrt{54.4\times10^{-9}} = 23.323 \times 10^{-5}$ coulomb ≈ 2.3×10^{-4} coulomb

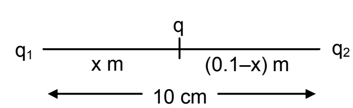
5. Charge on each proton = a= 1.6×10^{-19} coulomb

Distance between charges = 10×10^{-15} metre = r

Force = $\dfrac{kq^2}{r^2} = \dfrac{9\times10^9\times1.6\times1.6\times10^{-38}}{10^{-30}} = 9 \times 2.56 \times 10 = 230.4$ Newton

6. $q_1 = 2.0 \times 10^{-6}$ $q_2 = 1.0 \times 10^{-6}$ r = 10 cm = 0.1 m

Let the charge be at a distance x from q_1



$F_1 = \dfrac{Kq_1q}{\chi^2}$ $F_2 = \dfrac{kqq_2}{(0.1-\chi)^2}$

$= \dfrac{9.9\times2\times10^{-6}\times10^9\times q}{\chi^2}$

Now since the net force is zero on the charge q. $\Rightarrow f_1 = f_2$

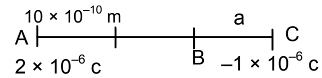
$\Rightarrow \dfrac{kq_1q}{\chi^2} = \dfrac{kqq_2}{(0.1-\chi)^2}$

$\Rightarrow 2(0.1-\chi)^2 = \chi^2$ $\Rightarrow \sqrt{2}\,(0.1-\chi) = \chi$

$\Rightarrow \chi = \dfrac{0.1\sqrt{2}}{1+\sqrt{2}} = 0.0586$ m = 5.86 cm ≈ 5.9 cm From larger charge

7. $q_1 = 2 \times 10^{-6}$ c $q_2 = -1 \times 10^{-6}$ c r = 10 cm = 10×10^{-2} m

Let the third charge be a so, $F_{-AC} = -F_{-BC}$



$\Rightarrow \frac{kQq_1}{r_1^2} = \frac{-KQq_2}{r_2^2}$ $\Rightarrow \frac{2 \times 10^{-6}}{(10+\chi)^2} = \frac{1 \times 10^{-6}}{\chi^2}$

$\Rightarrow 2\chi^2 = (10 + \chi)^2 \Rightarrow \sqrt{2}\,\chi = 10 + \chi \Rightarrow \chi(\sqrt{2} - 1) = 10 \Rightarrow \chi = \frac{-10}{1.414 - 1} = 24.14$ cm χ

So, distance = 24.14 + 10 = 34.14 cm from larger charge

8. Minimum charge of a body is the charge of an electron

Wo, q = 1.6×10^{-19} c χ = 1 cm = 1×10^{-2} cm

So, F = $\frac{kq_1q_2}{r^2} = \frac{9 \times 10^9 \times 1.6 \times 1.6 \times 10^{-19} \times 10^{-19}}{10^{-2} \times 10^{-2}} = 23.04 \times 10^{-38+9+2+2} = 23.04 \times 10^{-25} = 2.3 \times 10^{-24}$

9. No. of electrons of 100 g water = $\frac{10 \times 100}{18}$ = 55.5 Nos Total charge = 55.5

No. of electrons in 18 g of H_2O = $6.023 \times 10^{23} \times 10 = 6.023 \times 10^{24}$

No. of electrons in 100 g of H_2O = $\frac{6.023 \times 10^{24} \times 100}{18} = 0.334 \times 10^{26} = 3.334 \times 10^{25}$

Total charge = $3.34 \times 10^{25} \times 1.6 \times 10^{-19} = 5.34 \times 10^{6}$ c

10. Molecular weight of H_2O = 2 × 1 × 16 = 16

No. of electrons present in one molecule of H_2O = 10

18 gm of H_2O has 6.023×10^{23} molecule

18 gm of H_2O has $6.023 \times 10^{23} \times 10$ electrons

100 gm of H_2O has $\frac{6.023 \times 10^{24}}{18} \times 100$ electrons

So number of protons = $\frac{6.023 \times 10^{26}}{18}$ protons (since atom is electrically neutral)

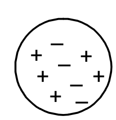
Charge of protons = $\frac{1.6 \times 10^{-19} \times 6.023 \times 10^{26}}{18}$ coulomb = $\frac{1.6 \times 6.023 \times 10^{7}}{18}$ coulomb

Charge of electrons = = $\frac{1.6 \times 6.023 \times 10^{7}}{18}$ coulomb

Hence Electrical force = $\frac{9 \times 10^9 \left(\frac{1.6 \times 6.023 \times 10^7}{18}\right) \times \left(\frac{1.6 \times 6.023 \times 10^7}{18}\right)}{(10 \times 10^{-2})^2}$

= $\frac{8 \times 6.023}{18} \times 1.6 \times 6.023 \times 10^{25} = 2.56 \times 10^{25}$ Newton

11. Let two protons be at a distance be 13.8 femi



F = $\frac{9 \times 10^9 \times 1.6 \times 10^{-38}}{(14.8)^2 \times 10^{-30}}$ = 1.2 N

12. F = 0.1 N

r = 1 cm = 10^{-2} (As they rubbed with each other. So the charge on each sphere are equal)

So, F = $\frac{kq_1q_2}{r^2} \Rightarrow 0.1 = \frac{kq^2}{(10^{-2})^2} \Rightarrow q^2 = \frac{0.1 \times 10^{-4}}{9 \times 10^9} \Rightarrow q^2 = \frac{1}{9} \times 10^{-14} \Rightarrow q = \frac{1}{3} \times 10^{-7}$

1.6×10^{-19} c Carries by 1 electron 1 c carried by $\frac{1}{1.6 \times 10^{-19}}$

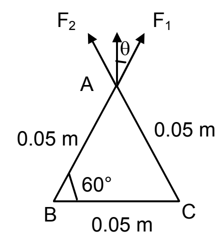
0.33×10^{-7} c carries by $\frac{1}{1.6 \times 10^{-19}} \times 0.33 \times 10^{-7} = 0.208 \times 10^{12} = 2.08 \times 10^{11}$

13. $F = \frac{kq_1q_2}{r^2} = \frac{9\times10^9\times1.6\times1.6\times10^{-19}\times10^{-19}}{(2.75\times10^{-10})^2} = \frac{23.04\times10^{-29}}{7.56\times10^{-20}} = 3.04 \times 10^{-9}$

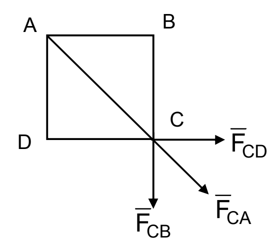
14. Given: mass of proton = 1.67×10^{-27} kg = M_p
$k = 9 \times 10^9$ Charge of proton = 1.6×10^{-19} c = C_p
$G = 6.67 \times 10^{-11}$ Let the separation be 'r'
$Fe = \frac{k(C_p)^2}{r^2}$, $fg = \frac{G(M_p)^2}{r^2}$
Now, $Fe : Fg = \frac{K(C_p)^2}{r^2}\times\frac{r^2}{G(M_p)^2} = \frac{9\times10^9\times(1.6\times1`0^{-19})^2}{6.67\times10^{-11}\times(1.67\times10^{-27})^2} = 9 \times 2.56 \times 10^{38} \approx 1,24 \times 10^{38}$

15. Expression of electrical force $F = C\times e^{\frac{-kr}{r^2}}$
Since e^{-kr} is a pure number. So, dimensional formulae of $F = \frac{\text{dim ensional formulae of C}}{\text{dim ensional formulae of } r^2}$
Or, $[MLT^{-2}][L^2]$ = dimensional formulae of C = $[ML^3T^{-2}]$
Unit of C = unit of force × unit of r^2 = Newton × m^2 = Newton–m^2
Since –kr is a number hence dimensional formulae of
$k = \frac{1}{\text{dim entional formulae of r}} = [L^{-1}]$ Unit of k = m^{-1}

16. Three charges are held at three corners of a equilateral trangle.
Let the charges be A, B and C. It is of length 5 cm or 0.05 m
Force exerted by B on A = F_1 force exerted by C on A = F_2
So, force exerted on A = resultant $F_1 = F_2$
$\Rightarrow F = \frac{kq_2}{r^2} = \frac{9\times10^9\times2\times2\times2\times10^{-12}}{5\times5\times10^{-4}} = \frac{36}{25}\times10 = 14.4$
Now, force on A = 2 × F cos 30° since it is equilateral Δ.
$\Rightarrow$ Force on A = 2 × 1.44 × $\sqrt{\frac{3}{2}}$ = 24.94 N.



17. $q_1 = q_2 = q_3 = q_4 = 2 \times 10^{-6}$ C
$v = 5$ cm = 5×10^{-2} m
so force on $\bar{c} = \bar{F}_{CA} + \bar{F}_{CB} + \bar{F}_{CD}$
so Force along × Component = $\bar{F}_{CD} + \bar{F}_{CA}\cos45° + 0$
$= \frac{k(2\times10^{-6})^2}{(5\times10^{-2})^2} + \frac{k(2\times10^{-6})^2}{(5\times10^{-2})^2}\frac{1}{2\sqrt{2}} = kq^2\left(\frac{1}{25\times10^{-4}} + \frac{1}{50\sqrt{2}\times10^{-4}}\right)$
$= \frac{9\times10^9\times4\times10^{-12}}{24\times10^{-4}}\left(1+\frac{1}{2\sqrt{2}}\right)$ = 1.44 (1.35) = 19.49 Force along % component = 19.49
So, Resultant $R = \sqrt{Fx^2+Fy^2} = 19.49\sqrt{2} = 27.56$



18. $R = 0.53$ A° = 0.53×10^{-10} m
$F = \frac{Kq_1q_2}{r^2} = \frac{9\times10^9\times1.6\times1.6\times10^{-38}}{0.53\times0.53\times10^{-10}\times10^{-10}} = 82.02 \times 10^{-9}$ N

19. Fe from previous problem No. 18 = 8.2×10^{-8} N Ve = ?
Now, $M_e = 9.12 \times 10^{-31}$ kg $r = 0.53 \times 10^{-10}$ m
Now, $Fe = \frac{M_ev^2}{r} \Rightarrow v^2 = \frac{Fe\times r}{m_e} = \frac{8.2\times10^{-8}\times0.53\times10^{-10}}{9.1\times10^{-31}} = 0.4775 \times 10^{13} = 4.775 \times 10^{12}$ m^2/s^2
$\Rightarrow v = 2.18 \times 10^6$ m/s

20. Electric force feeled by 1 c due to 1×10^{-8} c.

$F_1 = \dfrac{k \times 1 \times 10^{-8} \times 1}{(10 \times 10^{-2})^2} = k \times 10^{-6}$ N. electric force feeled by 1 c due to 8×10^{-8} c.

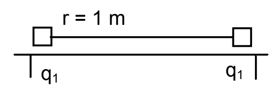
$F_2 = \dfrac{k \times 8 \times 10^{-8} \times 1}{(23 \times 10^{-2})^2} = \dfrac{k \times 8 \times \times 10^{-8} \times 10^2}{9} = \dfrac{28k \times 10^{-6}}{4} = 2k \times 10^{-6}$ N.

Similarly $F_3 = \dfrac{k \times 27 \times 10^{-8} \times 1}{(30 \times 10^{-2})^2} = 3k \times 10^{-6}$ N

So, $F = F_1 + F_2 + F_3 + \ldots\ldots + F_{10} = k \times 10^{-6} (1 + 2 + 3 + \ldots\ldots + 10)$ N

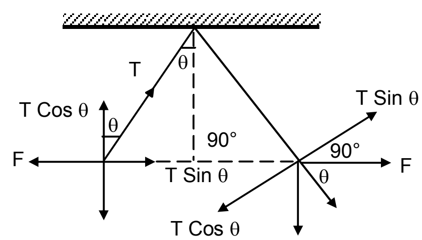
$= k \times 10^{-6} \times \dfrac{10 \times 11}{2} = 55k \times 10^{-6} = 55 \times 9 \times 10^9 \times 10^{-6}$ N $= 4.95 \times 10^3$ N

21. Force exerted $= \dfrac{kq_1^2}{r^2}$



$= \dfrac{9 \times 10^9 \times 2 \times 2 \times 10^{-16}}{1^2} = 3.6 \times 10^{-6}$ is the force exerted on the string

22. $q_1 = q_2 = 2 \times 10^{-7}$ c m = 100 g
l = 50 cm = 5×10^{-2} m d = 5×10^{-2} m



(a) Now Electric force

$F = K\dfrac{q^2}{r^2} = \dfrac{9 \times 10^9 \times 4 \times 10^{-14}}{25 \times 10^{-4}}$ N $= 14.4 \times 10^{-2}$ N = 0.144 N

(b) The components of Resultant force along it is zero, because mg balances T cos θ and so also.

F = mg = T sin θ

(c) Tension on the string

T sin θ = F T cos θ = mg

$\tan\theta = \dfrac{F}{mg} = \dfrac{0.144}{100 \times 10^{-3} \times 9.8} = 0.14693$

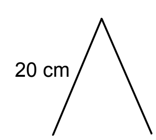
But $T\cos\theta = 10^2 \times 10^{-3} \times 10 = 1$ N

$\Rightarrow T = \dfrac{1}{\cos\theta} = \sec\theta$

$\Rightarrow T = \dfrac{F}{\sin\theta}$,

Sin θ = 0.145369 ; Cos θ = 0.989378;

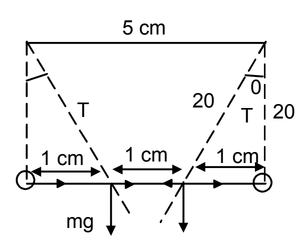
23. $q = 2.0 \times 10^{-8}$ c n= ? T = ? $\sin\theta = \dfrac{1}{20}$



Force between the charges

$F = \dfrac{Kq_1q_2}{r^2} = \dfrac{9 \times 10^9 \times 2 \times 10^{-8} \times 2 \times 10^{-8}}{(3 \times 10^{-2})^2} = 4 \times 10^{-3}$ N

$mg\sin\theta = F \Rightarrow m = \dfrac{F}{g\sin\theta} = \dfrac{4 \times 10^{-3}}{10 \times (1/20)} = 8 \times 10^{-3} = 8$ gm

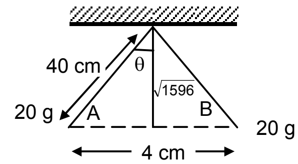


$\cos\theta = \sqrt{1 - \sin^2\theta} = \sqrt{1 - \dfrac{1}{400}} = \sqrt{\dfrac{400 - 1}{400}} = 0.99 \approx 1$

So, T = mg cos θ

Or $T = 8 \times 10^{-3}\ 10 \times 0.99 = 8 \times 10^{-2}$ M

24. T Cos θ = mg ...(1)
T Sin θ = Fe ...(2)



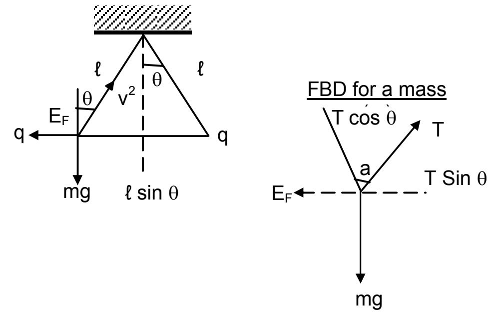
Solving, (2)/(1) we get, $\tan\theta = \frac{Fe}{mg} = \frac{kq^2}{r} \times \frac{1}{mg}$

$$\Rightarrow \frac{2}{\sqrt{1596}} = \frac{9\times10^9 \times q^2}{(0.04)^2 \times 0.02 \times 9.8}$$

$$\Rightarrow q^2 = \frac{(0.04)^2 \times 0.02 \times 9.8 \times 2}{9\times10^9 \times \sqrt{1596}} = \frac{6.27\times10^{-4}}{9\times10^9\times39.95} = 17 \times 10^{-16} c^2$$

$$\Rightarrow q = \sqrt{17\times10^{-16}} = 4.123 \times 10^{-8}\ c$$

25. Electric force = $\frac{kq^2}{(\ell\sin Q + \ell\sin Q)^2} = \frac{kq^2}{4\ell^2\sin^2}$



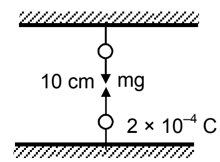
So, T Cos θ = ms (For equilibrium) T sin θ = Ef

Or $\tan\theta = \frac{Ef}{mg}$

$$\Rightarrow mg = Ef\cot\theta = \frac{kq^2}{4\ell^2\sin^2\theta}\cot\theta = \frac{q^2\cot\theta}{\ell^2\sin^2\theta 16\pi E_0}$$

or $m = \frac{q^2\cot\theta}{16\pi E_0\ell^2 Sin^2\theta g}$ unit.

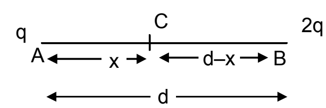
26. Mass of the bob = 100 g = 0.1 kg
So Tension in the string = 0.1 × 9.8 = 0.98 N.
For the Tension to be 0, the charge below should repel the first bob.



$\Rightarrow F = \frac{kq_1q_2}{r^2}$ T – mg + F = 0 $\Rightarrow$ T = mg – f T = mg

$$\Rightarrow 0.98 = \frac{9\times10^9\times2\times10^{-4}\times q_2}{(0.01)^2} \Rightarrow q_2 = \frac{0.98\times1\times10^{-2}}{9\times2\times10^5} = 0.054 \times 10^{-9}\ N$$

27. Let the charge on C = q
So, net force on c is equal to zero



So $\overline{F_{AC}} + \overline{F_{BA}} = 0$, But $F_{AC} = F_{BC} \Rightarrow \frac{kqQ}{x^2} = \frac{k2qQ}{(d-x)^2}$

$$\Rightarrow 2x^2 = (d-x)^2 \Rightarrow \sqrt{2}\,x = d - x$$

$$\Rightarrow x = \frac{d}{\sqrt{2}+1} = \frac{d}{(\sqrt{2}+1)} \times \frac{(\sqrt{2}-1)}{(\sqrt{2}-1)} = d(\sqrt{2}-1)$$

For the charge on rest, $F_{AC} + F_{AB} = 0$

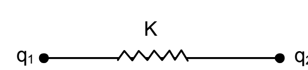
$$(2.414)^2\frac{kqQ}{d^2} + \frac{kq(2q)}{d^2} = 0 \Rightarrow \frac{kq}{d^2}[(2.414)^2Q + 2q] = 0$$

$$\Rightarrow 2q = -(2.414)^2\ Q$$

$$\Rightarrow Q = \frac{2}{-(\sqrt{2}+1)^2}q = -\left(\frac{2}{3+2\sqrt{2}}\right)q = -(0.343)\ q = -(6 - 4\sqrt{2})$$

28. K = 100 N/m ℓ = 10 cm = 10^{-1} m q = 2.0 × 10^{-8} c Find ℓ = ?

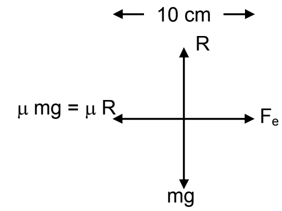
Force between them $F = \frac{kq_1q_2}{r^2} = \frac{9\times10^9 2\times10^{-8}\times2\times10^{-8}}{10^{-2}} = 36 \times 10^{-5}$ N



So, F = – kx or $x = \frac{F}{-K} = \frac{36\times10^{-5}}{100} = 36 \times 10^{-7}$ cm = 3.6 × 10^{-6} m

29. $q_A = 2 \times 10^{-6}$ C $\quad M_b = 80$ g $\quad \mu = 0.2$

Since B is at equilibrium, So, $Fe = \mu R$



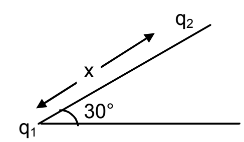
$\Rightarrow \dfrac{Kq_Aq_B}{r^2} = \mu R = \mu m \times g$

$\Rightarrow \dfrac{9\times10^9 \times 2\times10^{-6}\times q_B}{0.01} = 0.2 \times 0.08 \times 9.8$

$\Rightarrow q_B = \dfrac{0.2\times0.08\times9.8\times0.01}{9\times10^9\times2\times10^{-6}} = 8.7 \times 10^{-8}$ C $\qquad$ Range = $\pm 8.7 \times 10^{-8}$ C

30. $q_1 = 2 \times 10^{-6}$ c $\quad$ Let the distance be r unit

$\therefore F_{repulsion} = \dfrac{kq_1q_2}{r^2}$



For equilibrium $\dfrac{kq_1q_2}{r^2} = mg \sin\theta$

$\Rightarrow \dfrac{9\times10^9\times4\times10^{-12}}{r^2} = m \times 9.8 \times \dfrac{1}{2}$

$\Rightarrow r^2 = \dfrac{18\times4\times10^{-3}}{m\times9.8} = \dfrac{72\times10^{-3}}{9.8\times10^{-1}} = 7.34 \times 10^{-2}$ metre

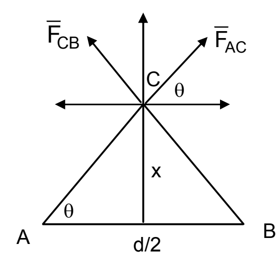
$\Rightarrow r = 2.70924 \times 10^{-1}$ metre from the bottom.

31. Force on the charge particle 'q' at 'c' is only the x component of 2 forces

So, $F_{on\ c} = F_{CB}\sin\theta + F_{AC}\sin\theta$ $\quad$ But $|\overline{F}_{CB}| = |\overline{F}_{AC}|$

$= 2F_{CB}\sin\theta = 2\dfrac{KQq}{x^2+(d/2)^2}\times\dfrac{x}{\left[x^2+d^2/4\right]^{1/2}} = \dfrac{2k\theta qx}{(x^2+d^2/4)^{3/2}} = \dfrac{16kQq}{(4x^2+d^2)^{3/2}}x$

For maximum force $\dfrac{dF}{dx} = 0$



$\dfrac{d}{dx}\left(\dfrac{16kQqx}{(4x^2+d^2)^{3/2}}\right) = 0 \Rightarrow K\left[\dfrac{(4x^2+d^2) - x\left[3/2\left[4x^2+d^2\right]^{1/2}8x\right]}{[4x^2+d^2]^3}\right] = 0$

$\Rightarrow \dfrac{K(4x^2+d^2)^{1/2}\left[(4x^2+d^2)^3 - 12x^2\right]}{(4x^2+d^2)^3} = 0 \Rightarrow (4x^2+d^2)^3 = 12x^2$

$\Rightarrow 16x^4 + d^4 + 8x^2d^2 = 12x^2$ $\qquad d^4 + 8x^2d^2 = 0$

$\Rightarrow d^2 = 0$ $\qquad d^2 + 8x^2 = 0$ $\qquad \Rightarrow d^2 = 8x^2 \Rightarrow d = \dfrac{d}{2\sqrt{2}}$

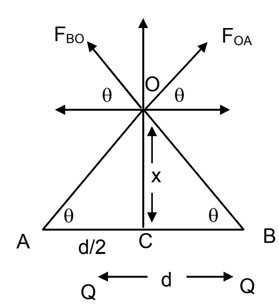
32. (a) Let Q = charge on A & B Separated by distance d

q = charge on c $\quad$ displaced $\perp$ to –AB

So, force on 0 = $\overline{F}_{AB} + \overline{F}_{BO}$

But $F_{AO}\cos\theta = F_{BO}\cos\theta$

So, force on '0' in due to vertical component.



$\overline{F} = F_{AO}\sin\theta + F_{BO}\sin\theta$ $\qquad |F_{AO}| = |F_{BO}|$

$= 2\dfrac{KQq}{(d/2^2+x^2)}\sin\theta$ $\qquad F = \dfrac{2KQq}{(d/2)^2+x^2}\sin\theta$

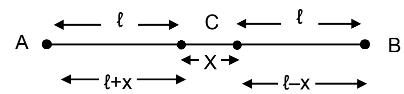
$= \dfrac{4\times2\times kQq}{(d^2+4x^2)}\times\dfrac{x}{[(d/2)^2+x^2]^{1/2}} = \dfrac{2kQq}{[(d/2)^2+x^2]^{3/2}}x$ = Electric force $\Rightarrow F \propto x$

(b) When x << d $F = \frac{2kQq}{[(d/2)^2 + x^2]^{3/2}} x$ x<<d

$\Rightarrow F = \frac{2kQq}{(d^2/4)^{3/2}} x \Rightarrow F \propto x$ $a = \frac{F}{m} = \frac{1}{m}\left[\frac{2kQqx}{[(d^2/4) + \ell^2]}\right]$

So time period $T = 2\pi\sqrt{\frac{\ell}{g}} = 2\pi\sqrt{\frac{\ell}{a}}$

33. $F_{AC} = \frac{KQq}{(\ell + x)^2}$ $F_{CA} = \frac{KQq}{(\ell - x)^2}$



Net force $= KQq\left[\frac{1}{(\ell - x)^2} - \frac{1}{(\ell + x)^2}\right]$

$= KQq\left[\frac{(\ell + x)^2 - (\ell - x)^2}{(\ell + x)^2(\ell - x)^2}\right] = KQq\left[\frac{4\ell x}{(\ell^2 - x^2)^2}\right]$

x<<< l = d/2 neglecting x w.r.t. ℓ We get

net $F = \frac{KQq4\ell x}{\ell^4} = \frac{KQq4x}{\ell^3}$ acceleration $= \frac{4KQqx}{m\ell^3}$

Time period $= 2\pi\sqrt{\frac{\text{displacement}}{\text{acceleration}}} = 2\pi\sqrt{\frac{xm\ell^3}{4KQqx}} = 2\pi\sqrt{\frac{m\ell^3}{4KQq}}$

$= \sqrt{\frac{4\pi^2 m\ell^3 4\pi\varepsilon_0}{4Qq}} = \sqrt{\frac{4\pi^3 m\ell^3 \varepsilon_0}{Qq}} = \sqrt{4\pi^3 md^3\varepsilon_0 8Qq} = \left[\frac{\pi^3 md^3\varepsilon_0}{2Qq}\right]^{1/2}$

34. $F_e = 1.5 \times 10^{-3}$ N, $q = 1 \times 10^{-6}$ C, $F_e = q \times E$

$\Rightarrow E = \frac{F_e}{q} = \frac{1.5 \times 10^{-3}}{1 \times 10^{-6}} = 1.5 \times 10^3$ N/C

35. $q_2 = 2 \times 10^{-6}$ C, $q_1^2 = -4 \times 10^{-6}$ C, r = 20 cm = 0.2 m

(E_1 = electric field due to q_1, E_2 = electric field due to q_2)

$\Rightarrow \frac{(r - x)^2}{x^2} = \frac{-q_2}{q_1} \Rightarrow \frac{(r - 1)^2}{x} = \frac{-q_2}{q_1} = \frac{4 \times 10^{-6}}{2 \times 10^{-6}} = \frac{1}{2}$

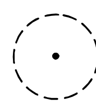
$\Rightarrow \left(\frac{r}{x} - 1\right) = \frac{1}{\sqrt{2}} = \frac{1}{1.414} \Rightarrow \frac{r}{x} = 1.414 + 1 = 2.414$

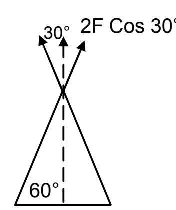
$\Rightarrow x = \frac{r}{2.414} = \frac{20}{2.414} = 8.285$ cm

36. $EF = \frac{KQ}{r^2}$

$5 \text{ N/C} = \frac{9 \times 10^9 \times Q}{4^2}$

$\Rightarrow \frac{4 \times 20 \times 10^{-2}}{9 \times 10^9} = Q \Rightarrow Q = 8.88 \times 10^{-11}$





37. m = 10, $mg = 10 \times 10^{-3}$ g $\times 10^{-3}$ kg, $q = 1.5 \times 10^{-6}$ C

But $qE = mg \Rightarrow (1.5 \times 10^{-6}) E = 10 \times 10^{-6} \times 10$

$\Rightarrow E = \frac{10 \times 10^{-4} \times 10}{1.5 \times 10^{-6}} = \frac{100}{1.5} = 66.6$ N/C

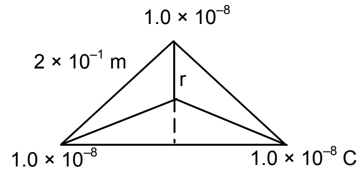
$= \frac{100 \times 10^3}{1.5} = \frac{10^{5+1}}{15} = 6.6 \times 10^3$

38. q = 1.0 × 10^{-8} C, ℓ = 20 cm

E = ? V = ?

Since it forms an equipotential surface.

So the electric field at the centre is <u>Zero</u>.

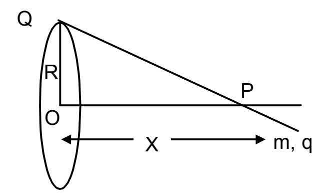


$$r = \frac{2}{3}\sqrt{(2\times10^{-1})^2-(10^{-1})^2} = \frac{2}{3}\sqrt{4\times10^{-2}-10^{-2}}$$

$$= \frac{2}{3}\sqrt{10^{-2}(4-1)} = \frac{2}{3}\times10^{-2}\times1.732 = 1.15\times10^{-1}$$

$$V = \frac{3\times9\times10^{9}1\times10^{-8}}{1\times10^{-1}} = 23\times10^{2} = 2.3\times10^{3}\ V$$

39. We know : Electric field 'E' at 'P' due to the charged ring



$$= \frac{KQx}{(R^2+x^2)^{3/2}} = \frac{KQx}{R^3}$$

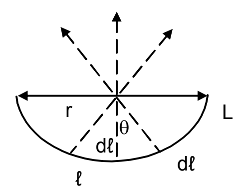
Force experienced 'F' = Q × E = $\frac{q\times K\times Qx}{R^3}$

Now, amplitude = x

$$\text{So, } T = 2\pi\sqrt{\frac{x}{KQqx/mR^3}} = 2\pi\sqrt{\frac{mR^3x}{KQqx}} = 2\pi\sqrt{\frac{4\pi\varepsilon_0 mR^3}{Qq}} = \sqrt{\frac{4\pi^2\times4\pi\varepsilon_0 mR^3}{qQ}}$$

$$\Rightarrow T = \left[\frac{16\pi^3\varepsilon_0 mR^3}{qQ}\right]^{1/2}$$

40. λ = Charge per unit length = $\frac{Q}{L}$



dq_1 for a length dl = λ × dl

Electric field at the centre due to charge = $k\times\frac{dq}{r^2}$

The horizontal Components of the Electric field balances each other. Only the vertical components remain.

∴ Net Electric field along vertical

$$d_E = 2\,E\cos\theta = \frac{Kdq\times\cos\theta}{r^2} = \frac{2kCos\theta}{r^2}\times\lambda\times dl \qquad \left[\text{but } d\theta = \frac{d\ell}{r} = d\ell = rd\theta\right]$$

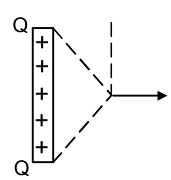
$$\Rightarrow \frac{2k\lambda}{r^2}Cos\theta\times rd\theta = \frac{2k\lambda}{r}Cos\theta\times d\theta$$

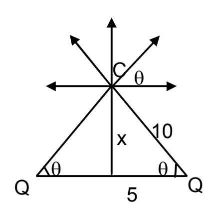
$$\text{or } E = \int_0^{\pi/2}\frac{2k\lambda}{r}Cos\theta\times d\theta = \int_0^{\pi/2}\frac{2k\lambda}{r}Sin\theta = \frac{2k\lambda l}{r} = \frac{2K\theta}{Lr}$$

but L = πR ⇒ r = $\frac{L}{\pi}$

$$\text{So } E = \frac{2k\theta}{L\times(L/\pi)} = \frac{2k\pi\theta}{L^2} = \frac{2}{4\pi\varepsilon_0}\times\frac{\pi\theta}{L^2} = \frac{\theta}{2\varepsilon_0 L^2}$$

41. G = 50 μC = 50 × 10^{-6} C



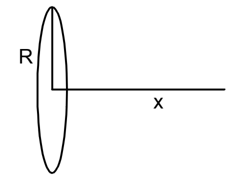


We have, E = $\frac{2KQ}{r}$ for a charged cylinder.

$$\Rightarrow E = \frac{2\times9\times10^{9}\times50\times10^{-6}}{5\sqrt{3}} = \frac{9\times10^{-5}}{5\sqrt{3}} = 1.03\times10^{-5}$$

42. Electric field at any point on the axis at a distance x from the center of the ring is

$$E = \frac{xQ}{4\pi\varepsilon_0(R^2+x^2)^{3/2}} = \frac{KxQ}{(R^2+x^2)^{3/2}}$$



Differentiating with respect to x

$$\frac{dE}{dx} = \frac{KQ(R^2+x^2)^{3/2} - KxQ(3/2)(R^2+x^2)^{11/2}2x}{(r^2+x^2)^3}$$

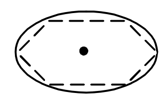
Since at a distance x, Electric field is maximum.

$$\frac{dE}{dx} = 0 \Rightarrow KQ\ (R^2+x^2)^{3/2} - Kx^2\ Q3(R^2+x^2)^{1/2} = 0$$

$$\Rightarrow KQ\ (R^2+x^2)^{3/2} = Kx^2\ Q3(R^2+x^2)^{1/2} \Rightarrow R^2 + x^2 = 3x^2$$

$$\Rightarrow 2x^2 = R^2 \Rightarrow x^2 = \frac{R^2}{2} \Rightarrow x = \frac{R}{\sqrt{2}}$$

43. Since it is a regular hexagon. So, it forms an equipotential surface. Hence the charge at each point is equal. Hence the net entire field at the centre is Zero.



44. Charge/Unit length = $\frac{Q}{2\pi a} = \lambda$; Charge of $d\ell = \frac{Qd\ell}{2\pi a}C$

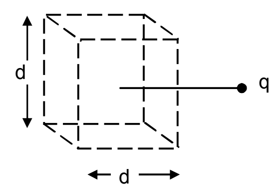
Initially the electric field was '0' at the centre. Since the element '$d\ell$' is removed so, net electric field must $\frac{K \times q}{a^2}$ Where q = charge of element $d\ell$

$$E = \frac{Kq}{a^2} = \frac{1}{4\pi\varepsilon_0} \times \frac{Qd\ell}{2\pi a} \times \frac{1}{a^2} = \frac{Qd\ell}{8\pi^2\varepsilon_0 a^3}$$

45. We know,

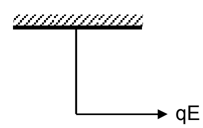
Electric field at a point due to a given charge

'E' = $\frac{Kq}{r^2}$ Where q = charge, r = Distance between the point and the charge



So, 'E' = $\frac{1}{4\pi\varepsilon_0} \times \frac{q}{d^2}$ [$\therefore$ r = 'd' here]

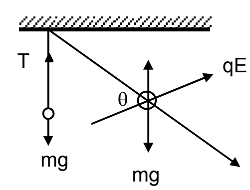
46. E = 20 kv/m = 20×10^3 v/m, m = 80×10^{-5} kg, c = 20×10^{-5} C



$$\tan\theta = \left(\frac{qE}{mg}\right)^{-1} \quad [\text{T Sin }\theta = mg,\ \text{T Cos }\theta = qe]$$

$$\tan\theta = \left(\frac{2\times10^{-8}\times20\times10^3}{80\times10^{-6}\times10}\right)^{-1} = \left(\frac{1}{2}\right)^{-1}$$

$$1 + \tan^2\theta = \frac{1}{4} + 1 = \frac{5}{4} \qquad [\text{Cos }\theta = \frac{1}{\sqrt{5}},\ \text{Sin }\theta = \frac{2}{\sqrt{5}}]$$



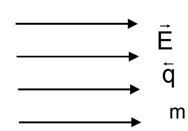
$$\text{T Sin }\theta = mg \Rightarrow T \times \frac{2}{\sqrt{5}} = 80 \times 10^{-6} \times 10$$

$$\Rightarrow T = \frac{8\times10^{-4}\times\sqrt{5}}{2} = 4\times\sqrt{5}\times10^{-4} = 8.9 \times 10^{-4}$$

47. Given

u = Velocity of projection, $\vec{E}$ = Electric field intensity

q = Charge; m = mass of particle



We know, Force experienced by a particle with charge 'q' in an electric field $\vec{E}$ = qE

$\therefore$ acceleration produced = $\frac{qE}{m}$

As the particle is projected against the electric field, hence deceleration = $\frac{qE}{m}$

So, let the distance covered be 's'

Then, $v^2 = u^2 + 2as$ [where a = acceleration, v = final velocity]

Here $0 = u^2 - 2 \times \frac{qE}{m} \times S \Rightarrow S = \frac{u^2 m}{2qE}$ units

48. $m = 1\ g = 10^{-3}$ kg, $u = 0$, $q = 2.5 \times 10^{-4}$ C ; $E = 1.2 \times 10^4$ N/c ; $S = 40$ cm $= 4 \times 10^{-1}$ m

a) $F = qE = 2.5 \times 10^{-4} \times 1.2 \times 10^4 = 3$ N

So, $a = \frac{F}{m} = \frac{3}{10^{-3}} = 3 \times 10^3$

$E_q = mg = 10^{-3} \times 9.8 = 9.8 \times 10^{-3}$ N

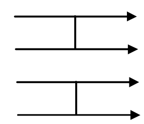
b) $S = \frac{1}{2}at^2$ or $t = \sqrt{\frac{2a}{g}} = \sqrt{\frac{2 \times 4 \times 10^{-1}}{3 \times 10^3}} = 1.63 \times 10^{-2}$ sec

$v^2 = u^2 + 2as = 0 + 2 \times 3 \times 10^3 \times 4 \times 10^{-1} = 24 \times 10^2 \Rightarrow v = \sqrt{24 \times 10^2} = 4.9 \times 10 = 49$ m/sec

work done by the electric force $w = F \to td = 3 \times 4 \times 10^{-1} = 12 \times 10^{-1} = 1.2$ J

49. $m = 100$ g, $q = 4.9 \times 10^{-5}$, $F_g = mg$, $F_e = qE$

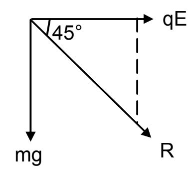
$\vec{E} = 2 \times 10^4$ N/C



So, the particle moves due to the et resultant R

$R = \sqrt{F_g^{\ 2} + F_e^{\ 2}} = \sqrt{(0.1 \times 9.8)^2 + (4.9 \times 10^{-5} \times 2 \times 10^4)^2}$

$= \sqrt{0.9604 + 96.04 \times 10^{-2}} = \sqrt{1.9208} = 1.3859$ N



$\tan\theta = \frac{F_g}{F_e} = \frac{mg}{qE} = 1$ So, $\theta = 45°$

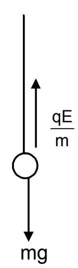
$\therefore$ Hence path is straight along resultant force at an angle 45° with horizontal

Disp. Vertical = (1/2) × 9.8 × 2 × 2 = 19.6 m

Disp. Horizontal = S = (1/2) $at^2 = \frac{1}{2} \times \frac{qE}{m} \times t^2 = \frac{1}{2} \times \frac{0.98}{0.1} \times 2 \times 2 = 19.6$ m

Net Dispt. $= \sqrt{(19.6)^2 + (19.6)^2} = \sqrt{768.32} = 27.7$ m

50. $m = 40$ g, $q = 4 \times 10^{-6}$ C



Time for 20 oscillations = 45 sec. Time for 1 oscillation = $\frac{45}{20}$ sec

When no electric field is applied, $T = 2\pi\sqrt{\frac{\ell}{g}} \Rightarrow \frac{45}{20} = 2\pi\sqrt{\frac{\ell}{10}}$

$\Rightarrow \frac{\ell}{10} = \left(\frac{45}{20}\right)^2 \times \frac{1}{4\pi^2} \Rightarrow \ell = \frac{(45)^2 \times 10}{(20)^2 \times 4\pi^2} = 1.2836$

When electric field is not applied,

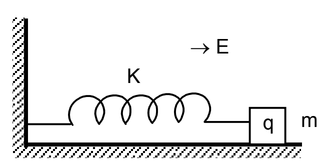
$T = 2\pi\sqrt{\frac{\ell}{g-a}}$ $\left[a = \frac{qE}{m} = 2.5\right] = 2\pi\sqrt{\frac{1.2836}{10-2.5}} = 2.598$

Time for 1 oscillation = 2.598

Time for 20 oscillation = 2.598 × 20 = 51.96 sec ≈ 52 sec.

51. $F = qE$, $F = -Kx$

Where x = amplitude

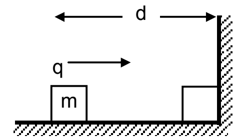


$qE = -Kx$ or $x = \frac{-qE}{K}$

52. The block does not undergo. SHM since here the acceleration is not proportional to displacement and not always opposite to displacement. When the block is going towards the wall the acceleration is along displacement and when going away from it the displacement is opposite to acceleration.

Time taken to go towards the wall is the time taken to goes away from it till velocity is

$d = ut + (1/2)\, at^2$



$\Rightarrow d = \frac{1}{2} \times \frac{qE}{m} \times t^2$

$\Rightarrow t^2 = \frac{2dm}{qE} \Rightarrow t = \sqrt{\frac{2md}{qE}}$

$\therefore$ Total time taken for to reach the wall and com back (Time period)

$= 2t = 2\sqrt{\frac{2md}{qE}} = \sqrt{\frac{8md}{qE}}$

53. E = 10 n/c, S = 50 cm = 0.1 m

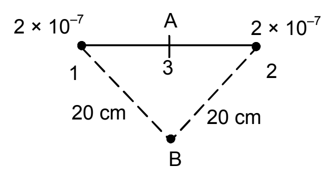
$E = \frac{dV}{dr}$ or, V = E × r = 10 × 0.5 = 5 cm

54. Now, $V_B - V_A$ = Potential diff = ? Charge = 0.01 C

Work done = 12 J Now, Work done = Pot. Diff × Charge

$\Rightarrow$ Pot. Diff $= \frac{12}{0.01}$ = 1200 Volt

55. When the charge is placed at A,



$E_1 = \frac{Kq_1q_2}{r} + \frac{Kq_3q_4}{r}$

$= \frac{9\times10^9(2\times10^{-7})^2}{0.1} + \frac{9\times10^9(2\times10^{-7})^2}{0.1}$

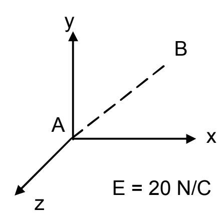
$= \frac{2\times9\times10^9\times4\times10^{-14}}{0.1} = 72 \times 10^{-4}$ J

When charge is placed at B,

$E_2 = \frac{Kq_1q_2}{r} + \frac{Kq_3q_4}{r} = \frac{2\times9\times10^9\times4\times10^{-14}}{0.2} = 36 \times 10^{-4}$ J

Work done = $E_1 - E_2 = (72 - 36) \times 10^{-4} = 36 \times 10^{-4}$ J $= 3.6 \times 10^{-3}$ J

56. (a) A = (0, 0) B = (4, 2)



$V_B - V_A = E \times d = 20 \times \sqrt{16} = 80$ V

(b) A(4m, 2m), B = (6m, 5m)

$\Rightarrow V_B - V_A = E \times d = 20 \times \sqrt{(6-4)^2} = 20 \times 2 = 40$ V

(c) A(0, 0) B = (6m, 5m)

$\Rightarrow V_B - V_A = E \times d = 20 \times \sqrt{(6-0)^2} = 20 \times 6 = 120$ V.

57. (a) The Electric field is along x-direction

Thus potential difference between (0, 0) and (4, 2) is,

$\delta V = -E \times \delta x = -20 \times (40) = -80$ V

Potential energy $(U_B - U_A)$ between the points = $\delta V \times q$

$= -80 \times (-2) \times 10^{-4} = 160 \times 10^{-4} = 0.016$ J.

(b) A = (4m, 2m) B = (6m, 5m)

$\delta V = -E \times \delta x = -20 \times 2 = -40$ V

Potential energy $(U_B - U_A)$ between the points = $\delta V \times q$

$= -40 \times (-2 \times 10^{-4}) = 80 \times 10^{-4} = 0.008$ J

(c) A = (0, 0) B = (6m, 5m)

$\delta V = -E \times \delta x = -20 \times 6 = -120$ V

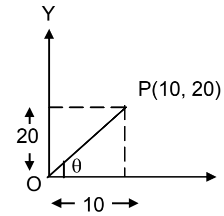
Potential energy $(U_B - U_A)$ between the points A and B

$= \delta V \times q = -120 \times (-2 \times 10^{-4}) = 240 \times 10^{-4} = 0.024$ J

58. E = $\left(\hat{i}20 + \hat{j}30\right)$ N/CV = at (2m, 2m) r = (2i + 2j)

So, V= $-\vec{E}\times\vec{r}$ = –(i20 + 30J) (2 $\hat{i}$ + 2j) = –(2 × 20 + 2× 30) = – 100 V

59. E = $\vec{i}$ × Ax = 100 $\vec{i}$



$\int_v^0 dv = -\int E\times d\ell$ V = $-\int_0^{10} 10x\times dx = -\int_0^{10}\frac{1}{2}\times 10\times x^2$

0 – V = $-\left[\frac{1}{2}\times 1000\right]$ = – 500 ⇒ V = 500 Volts

60. V(x, y, z) = A(xy + yz + zx)

(a) A = $\frac{\text{Volt}}{m^2} = \frac{ML^2T^{-2}}{ITL^2}$ = $[MT^{-3}I^{-1}]$

(b) E = $-\frac{\delta V\hat{i}}{\delta x} - \frac{\delta V\hat{j}}{\delta y} - \frac{\delta V\hat{k}}{\delta z} = -\left[\frac{\delta}{\delta x}[A(xy+yz+zx) + \frac{\delta}{\delta y}[A(xy+yz+zx) + \frac{\delta}{\delta z}[A(xy+yz+zx)\right]$

= $-\left[(Ay+Az)\hat{i} + (Ax+Az)\hat{j} + (Ay+Ax)\hat{k}\right] = -A(y+z)\hat{i} + A(x+z)\hat{j} + A(y+x)\hat{k}$

(c) A = 10 SI unit, r = (1m, 1m, 1m)

E = –10(2) $\hat{i}$ – 10(2) $\hat{j}$ – 10(2) $\hat{k}$ = – 20 $\hat{i}$ – 20 $\hat{j}$ – 20 $\hat{k}$ = $\sqrt{2o^2 + 20^2 + 20^2}$ = $\sqrt{1200}$ = 34.64 ≈ 35 N/C

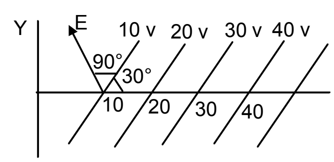
61. $q_1 = q_2 = 2 \times 10^{-5}$ C

Each are brought from infinity to 10 cm a part d = 10×10^{-2} m

So work done = negative of work done. (Potential E)

P.E = $\int_\infty^{10} F\times ds$ P.E. = $K\times\frac{q_1q_2}{r} = \frac{9\times 10^9\times 4\times 10^{-10}}{10\times 10^{-2}}$ = 36 J

62. (a) The angle between potential E dℓ = dv



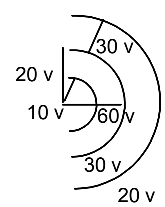
Change in potential = 10 V = dV

As E = ⊥r dV (As potential surface)

So, E dℓ = dV ⇒ E dℓ Cos(90° + 30°) = – dv

⇒ E(10× 10^{-2}) cos 120° = – dV

⇒ E = $\frac{-dV}{10\times 10^{-2}\text{Cos}120°} = -\frac{10}{10^{-1}\times(-1/2)}$ = 200 V/m making an angle 120° with y-axis



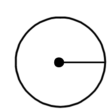
(b) As Electric field intensity is ⊥r to Potential surface

So, E = $\frac{kq}{r^2}r = \frac{kq}{r} \Rightarrow \frac{kq}{r}$ = 60 v q = $\frac{6}{K}$

So, E = $\frac{kq}{r^2} = \frac{6\times k}{k\times r^2}$ v.m = $\frac{6}{r^2}$ v.m

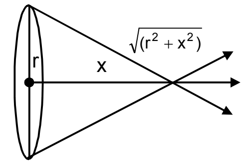
63. Radius = r So, 2πr = Circumference

Charge density = λ Total charge = 2πr × λ



Electric potential = $\frac{Kq}{r} = \frac{1}{4\pi\varepsilon_0}\times\frac{2\pi r\lambda}{(x^2+r^2)^{1/2}} = \frac{r\lambda}{2\varepsilon_0(x^2+r^2)^{1/2}}$

So, Electric field = $\frac{V}{r}\text{Cos}\theta$

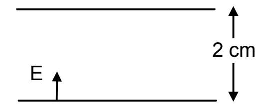


= $\frac{r\lambda}{2\varepsilon_0(x^2+r^2)^{1/2}}\times\frac{1}{(x^2+r^2)^{1/2}}$

= $\frac{r\lambda}{2\varepsilon_0(x^2+r^2)^{1/2}}\times\frac{x}{(x^2+r^2)^{1/2}} = \frac{r\lambda x}{2\varepsilon_0(x^2+r^2)^{3/2}}$

64. $\vec{E}$ = 1000 N/C

(a) $V = E \times d\ell = 1000 \times \frac{2}{100} = 20$ V



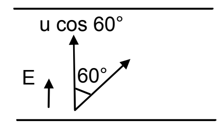
(b) u = ? $\vec{E}$ = 1000, = 2/100 m

$a = \frac{F}{m} = \frac{q \times E}{m} = \frac{1.6 \times 10^{-19} \times 1000}{9.1 \times 10^{-31}} = 1.75 \times 10^{14}$ m/s^2

$0 = u^2 - 2 \times 1.75 \times 10^{14} \times 0.02 \Rightarrow u^2 = 0.04 \times 1.75 \times 10^{14} \Rightarrow u = 2.64 \times 10^6$ m/s.

(c) Now, U = u Cos 60° V = 0, s = ?

$a = 1.75 \times 10^{14}$ m/s^2 $V^2 = u^2 - 2as$



$\Rightarrow s = \frac{(u\text{Cos}60°)^2}{2 \times a} = \frac{\left(2.64 \times 10^6 \times \frac{1}{2}\right)^2}{2 \times 1.75 \times 10^{14}} = \frac{1.75 \times 10^{12}}{3.5 \times 10^{14}} = 0.497 \times 10^{-2} \approx 0.005$ m ≈ 0.50 cm

65. E = 2 N/C in x-direction

(a) Potential aat the origin is O. $dV = -E_x\,dx - E_y\,dy - E_z\,dz$

$\Rightarrow V - 0 = -2x \Rightarrow V = -2x$

(b) $(25 - 0) = -2x \Rightarrow x = -12.5$ m

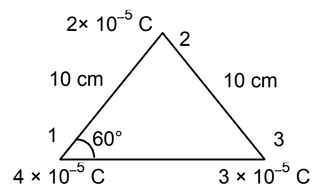
(c) If potential at origin is 100 v, $v - 100 = -2x \Rightarrow V = -2x + 100 = 100 - 2x$

(d) Potential at ∞ IS 0, $V - V' = -2x \Rightarrow V' = V + 2x = 0 + 2\infty \Rightarrow V' = \infty$

Potential at origin is ∞. No, it is not practical to take potential at ∞ to be zero.

66. Amount of work done is assembling the charges is equal to the net potential energy

So, P.E. = $U_{12} + U_{13} + U_{23}$



$= \frac{Kq_1q_2}{r_{12}} + \frac{Kq_1q_3}{r_{13}} + \frac{Kq_2q_3}{r_{23}} = \frac{K \times 10^{-10}}{r}[4 \times 2 + 4 \times 3 + 3 \times 2]$

$= \frac{9 \times 10^9 \times 10^{-10}}{10^{-1}}(8 + 12 + 6) = 9 \times 26 = 234$ J

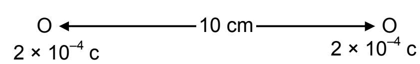
67. K.C. decreases by 10 J. Potential = 100 v to 200 v.

So, change in K.E = amount of work done

$\Rightarrow 10\text{J} = (200 - 100)\text{ v} \times q_0 \Rightarrow 100\,q_0 = 10$ v

$\Rightarrow q_0 = \frac{10}{100} = 0.1$ C

68. m = 10 g; $F = \frac{KQ}{r} = \frac{9 \times 10^9 \times 2 \times 10^{-4}}{10 \times 10^{-2}}$ $F = 1.8 \times 10^{-7}$



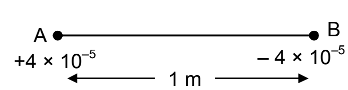
$F = m \times a \Rightarrow a = \frac{1.8 \times 10^{-7}}{10 \times 10^{-3}} = 1.8 \times 10^{-3}$ m/s^2

$V^2 - u^2 = 2as \Rightarrow V^2 = u^2 + 2as$

$V = \sqrt{0 + 2 \times 1.8 \times 10^{-3} \times 10 \times 10^{-2}} = \sqrt{3.6 \times 10^{-4}} = 0.6 \times 10^{-2} = 6 \times 10^{-3}$ m/s.

69. $q_1 = q_2 = 4 \times 10^{-5}$; s = 1m, m = 5 g = 0.005 kg

$F = K\frac{q^2}{r^2} = \frac{9 \times 10^9 \times (4 \times 10^{-5})^2}{1^2} = 14.4$ N



Acceleration 'a' = $\frac{F}{m} = \frac{14.4}{0.005} = 2880$ m/s^2

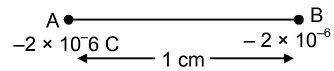
Now u = 0, s = 50 cm = 0.5 m, a = 2880 m/s^2, V =?

$V^2 = u^2 + 2as \Rightarrow V^2 = = 2 \times 2880 \times 0.5$

$\Rightarrow V = \sqrt{2880} = 53.66$ m/s ≈ 54 m/s for each particle

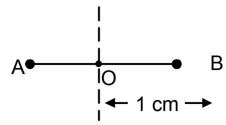
70. E = 2.5 × 104   P = 3.4×10^{-30} τ = PE sin θ
= P × E × 1 = $3.4 \times 10^{-30} \times 2.5 \times 10^{4} = 8.5 \times 10^{-26}$

71. (a) Dipolemoment = q × ℓ
(Where q = magnitude of charge   ℓ = Separation between the charges)
= $2 \times 10^{-6} \times 10^{-2}$ cm = 2×10^{-8} cm



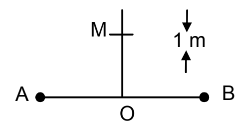
(b) We know, Electric field at an axial point of the dipole

$$= \frac{2KP}{r^3} = \frac{2 \times 9 \times 10^9 2 \times 10^{-8}}{(1 \times 10^{-2})^3} = 36 \times 10^7 \text{ N/C}$$

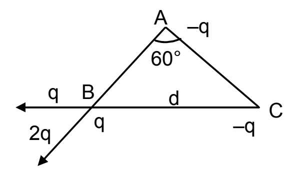


(c) We know, Electric field at a point on the perpendicular bisector about 1m away from centre of dipole.

$$= \frac{KP}{r^3} = \frac{9 \times 10^9 2 \times 10^{-8}}{1^3} = 180 \text{ N/C}$$



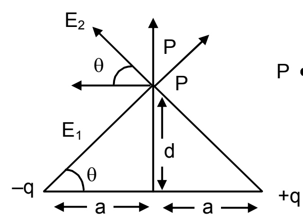
72. Let –q & –q are placed at A & C
Where 2q on B   So length of A = d
So the dipole moment = (q × d) = P
So, Resultant dipole moment
P= $[(qd)^2 + (qd)^2 + 2qd \times qd \text{ Cos } 60°]^{1/2} = [3\, q^2d^2]^{1/2} = \sqrt{3}\, qd = \sqrt{3}\, P$

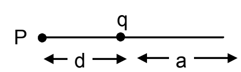


73. (a) P = 2qa
(b) E_1 Sin θ = E_2 sin θ Electric field intensity
= E_1 Cos θ + E_2 Cos θ = 2 E_1 Cos θ

$$E_1 = \frac{Kqp}{a^2 + d^2} \text{ so } E = \frac{2KPQ}{a^2 + d^2} \frac{a}{(a^2 + d^2)^{1/2}} = \frac{2Kq \times a}{(a^2 + d^2)^{3/2}}$$

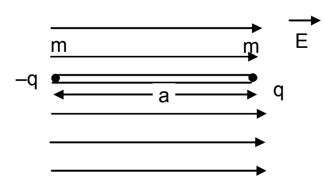
When a << d $= \frac{2Kqa}{(d^2)^{3/2}} = \frac{PK}{d^3} = \frac{1}{4\pi\varepsilon_0} \frac{P}{d^3}$





74. Consider the rod to be a simple pendulum.
For simple pendulum   T = $2\pi\sqrt{\ell / g}$ (ℓ = length, q = acceleration)
Now, force experienced by the charges
F = Eq   Now, acceleration = $\frac{F}{m} = \frac{Eq}{m}$

Hence length = a   so, Time period = $2\pi\sqrt{\frac{a}{(Eq/m)}} = 2\pi\sqrt{\frac{ma}{Eq}}$



75. 64 grams of copper have 1 mole   6.4 grams of copper have 0.1 mole
1 mole = No atoms   0.1 mole = (no × 0.1) atoms
= $6 \times 10^{23} \times 0.1$ atoms = 6×10^{22} atoms
1 atom contributes 1 electron 6×10^{22} atoms contributes 6×10^{22} electrons.

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