HINTS & SOLUTIONS

TOPIC : ELECTROSTATICS
EXERCISE : 1

SECTION (A)

2. Final charge on both spheres = 10 μC each. $\frac{F_1}{F_2} = \frac{(q_1 q_2)_i}{(q_1 q_2)_f} = \frac{800}{100}$ = 8 : 1

3. $0.144 = \frac{9\times10^9 q^2}{(0.05)^2}$ ⇒ $q^2 = \frac{0.144}{9\times10^9\times400}$

4. Coulomb's law follows Newtons third law.

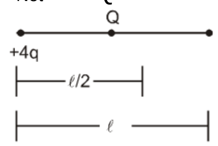
5. It will move in the direction of resultant force.

6. q = ne ⇒ $80 \times 10^{-6} = n \times 1.6 \times 10^{-19}$

8. According to principle of superposition force acting between the two charges does'nt depend on the presence of other.

9. $\vec{F} = \frac{K.q_1q_2\vec{r}}{|r|^3} = -\frac{1}{4\pi\epsilon_0}\times\frac{q_1.q_2(2\hat{i}-\hat{j}+3\hat{k})}{\left[\sqrt{2^2+(-1)^2+(3)^2}\right]}$

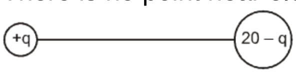
10. F_{Net} on Q = 0 ⇒ $K.\frac{Q.q}{(\ell/2)} + K.\frac{4Q.q}{\ell^2} = 0$ ⇒ Q = –q



11. $F = \frac{kq_1q_2}{r^2}$ ....(1)

$4F = \frac{kq_1q_2}{16R^2}$ ...(2) ⇒ $R = \frac{r}{8}$

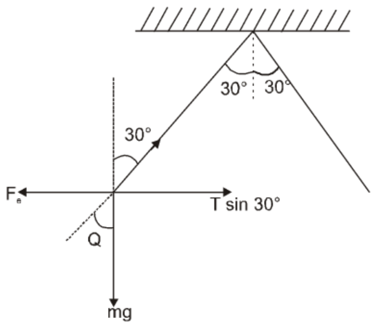
12. There is no point near electric dipole having E = 0.

13. 

Let the two charges are q & (20 – q) μC ∴ $F_e = \frac{K(q)(20-q)}{r^2}$

F_e will be max, when $\frac{dF_e}{dq} = 0$ or $\frac{dFe}{dq} = \frac{K}{r^2}(20-2q) = 0$ ⇒ ∴ q = 10 μC.

14. $F_e = \frac{9.0\times10^9\times(10^{-6}\times100\times10^{-6})}{1^2}$ ⇒ T sin 30 = $9.0 \times 10^9 \times 100\times10^{-12}$



T = 2 × 9.0 × 10^{-1} = 18 × 10^{-1} = 18 × 10^{-1} = 1.8 N. **Ans.** T =8N

15. The force between two charges q and – q is

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q\times -q}{r^2} = -\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}$$ where r = separation between the charges

$$\therefore F' = \frac{1}{4\pi\varepsilon_0}\frac{q\times -q}{r'^2} = -\frac{1}{4\pi\varepsilon_0}\times\frac{q}{(2r)^2} \quad (\because r' = 2r) \quad = \frac{1}{4}F$$

16. Dielectric constant is

$$K = \frac{E}{E'}$$

For an insulator E' < E. So, out of the given choice,
K = 5

17. Let the spherical conductors B and C have same charge as q. The electric force between them is

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}$$ r, being the distance between them.

When third uncharged conductor A is brought in contact with B, then charge on each conductor.

$$q_A = q_B = \frac{q_A + q_B}{2} = \frac{0+q}{2} = \frac{q}{2}$$

When this conductor A is now brought in contact with C, then charge on each conductor

$$q_A = q_C = \frac{q_A + q_C}{2} = \frac{(q/2)+q}{2} = \frac{3q}{4}$$

Hence, electric force acting between B and C us

$$F' = \frac{1}{4\pi\varepsilon_0}\frac{q_B q_C}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{(q/2)(q/4)}{r^2} = \frac{3}{8}\left[\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}\right] = \frac{3F}{8}$$

18.

$$\vec{F}_{12(x)} = \frac{q_1 q_2}{4\pi_0 b^2}(-\hat{i})$$

$$\vec{F}_{13\,(x)} = \frac{q_1 q_3}{4\pi\varepsilon_0 a^2}(-\sin\theta\,\hat{i})$$ $\therefore$ Net $\vec{F}_x = \frac{Kq_1q_2}{b^2}(-\hat{i}) + \frac{kq_1q_3}{a^2}\sin\theta(-\hat{i})$

or $F_x = -Kq_1\left[\frac{q_2}{b^2} + \frac{q_3}{a^2}\sin\theta\right]$ $\therefore$ $F_x \propto \frac{q_2}{b^2} + \frac{q_3}{a^2}\sin\theta$

19. Initially N : $\frac{kQ^2}{r^2} = F$

Finally : Charge on B = Q/2

and Charge on C = $\frac{3Q}{4}$ (By conduction) $\therefore$ $F' = \frac{k(Q/2)(3Q/4)}{r^2} = \frac{3kQ^2}{8r^2} = \frac{3F}{8}$

20. Torque about Q of charge –q is zero, so angular momentum charge –q is constant, but distance between charges is changing, so force is changing, so speed and velocity are changing.

21. When charge is given to a soap bubble then due to mutual repulsion between various pats of its two surface, increase in size of the soap bubble occurs.

SECTION (B)

1. Negative charge experiences force opposite to direction of electric field.

2. $E = \frac{F}{Q}$

3. Electric field due to one line charge at a distance r is $E = \frac{2k\lambda}{r}$

$F = qE = \frac{(\lambda \times 1)2k\lambda}{r} = \frac{2k\lambda^2}{r}$

5. $6 = \frac{q}{4\pi r^2}$ $\frac{\sigma_1}{\sigma_2} = \left(\frac{r_2}{r_1}\right)^2$

6. Maximum electric field will be at the surface

$E = \frac{kq}{r^2} = \frac{9 \times 10^9 \times 1 \times 10^{-6}}{(0.1)^2}$

7. mg = qE m = $\left(P.\frac{4}{3}\pi r^3\right)$
$q = 1.6 \times 10^{-19}C$

8. Resultant electric field between two charged plates is $E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$

$F = qE = \frac{e.\sigma}{a_0}$

9. Outside the plate Net electric field is zero

10. $E = \frac{\sigma}{2\mu_0} = \frac{e}{2\pi\omega_0} = \frac{2e}{4\pi\omega_0} = 2 \times 1.6 \times 10^{-19} \times 9 \times 10^9$

11. $W = Fr \cos\theta$ ⇒ $4 = 0.2 E 2 \cos 60^o$ ⇒ E = 20 N/C.

12. $T = 2\pi\sqrt{\frac{\ell}{g_{eff}}}$ where = $g_{eff} = \frac{\sqrt{m^2g^2 + q^2E^2}}{m} = \sqrt{g + \left(\frac{qE}{m}\right)^2}$

14. $E = \frac{kqx}{(R^2 + x^2)^{3/2}}$, for max E, $\frac{dE}{dx} = 0$ ⇒ $x = \pm\frac{R}{\sqrt{2}}$ ⇒ $E_{max} = \frac{2kq}{3\sqrt{3}R^2}$

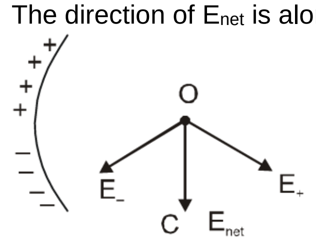
15. F = qE ⇒ $a = \frac{qE}{m}$ ⇒ $x = \frac{1}{2}at^2 = \frac{1}{2}\left(\frac{qE}{m}\right)t^2$

$k.E = W_E = qE\frac{1}{2}\left(\frac{qE}{m}\right)t^2 = \frac{E^2q^2t^2}{2m}$

16. $E = \frac{\sigma}{2\varepsilon_0}$ due to non-conducting sheet.

$\Delta E' = \frac{\sigma'}{\varepsilon_0}$ due to conducting sheet, but $\sigma^1 = \frac{\sigma}{2}$ ∴ Result is same i.e. E' = E

17. Given diagram shows :
The direction of E_{net} is along OC.



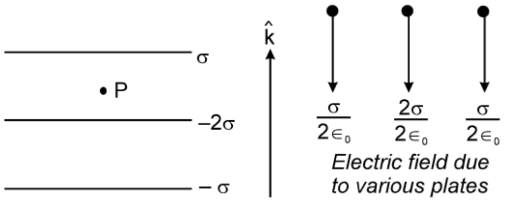
18. By definition.

19. $T = 2\pi\sqrt{\dfrac{\ell}{g_{eff}}}$;

where, $g_{eff} = \dfrac{mg - qE}{m} = g - \dfrac{qE}{m}$ ∴ Time period increases.

20. The electric field at the surface will be due to all charges, however net flux coming out of the surface will be = $\phi_{net} = \dfrac{q_{in}}{\varepsilon_0} = \dfrac{q_1 - q_1}{\varepsilon_0} = 0$.

21.



Electric field due to various plates

Resultant electric field = $\dfrac{\sigma}{2\epsilon_0} + \dfrac{2\sigma}{2\epsilon_0} + \dfrac{\sigma}{2\epsilon_0} = \dfrac{4\sigma}{2\epsilon_0} = \dfrac{2\sigma}{\epsilon_0} \downarrow = \dfrac{2\sigma}{\epsilon_0}(-\hat{k})$

23. $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$

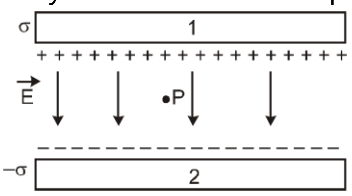
$q_{max} = E.\ 4\pi\varepsilon_0 r^2 = 3 \times 10^6 \times \dfrac{1}{9\times10^9} \times \left(\dfrac{5}{2}\right)^2 = 2 \times 10^{-3}$ C

24. Electric lines of force at any place represent the electric field intensity, so where the electric lines of force are close to each other, electric field in that region is very strong.

25. For equilibrium of charged drop, upward electric force = downward weight

$eE = mg$ ⇒ Electric field, $E = \dfrac{mg}{e}$

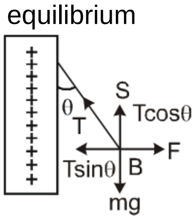
26. The situation is shown in the figure. Plate 1 has surface charge density σ and plate 2 has surface charge density σ. The electric field at point P due to charged plates add up, giving



$E = \dfrac{\sigma}{2\varepsilon_0} + \dfrac{\sigma}{2\varepsilon_0} = \dfrac{\sigma}{\varepsilon_0}$ Given, $\sigma = 2.64 \times 10^{-12}$ C/m^2,

$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/N-m^2 Hence, $E = \dfrac{26.4\times10^{-12}}{8.85\times10^{12}} \approx 3\,N/C$

27. In equilibrium



$T\cos\theta = mg$ .....(i) and $T\sin\theta = F\ Eq$

$T \sin\theta = \frac{\sigma}{2\varepsilon_0}.q$ ......(ii) $\therefore$ $\frac{T\sin\theta}{T\cos\theta} = \frac{\sigma q}{2\varepsilon_0 \times mg}$

$\tan\theta = \frac{\sigma q}{2\varepsilon_0 mg}$ or $\sigma \propto \tan\theta$

28. Search for the relations of electric potential and electric field at a particular point At any point, electric potential due to charge Q is

$V = \frac{1}{4\pi\varepsilon_0}.\frac{Q}{r}$ ....(i) where r is the distance of observation point from the charge.

At the same point electric field is

$E = \frac{1}{4\pi\varepsilon_0}.\frac{Q}{r^2}$ ....(ii) Combining Eqs. (i) and (ii), we have

$E = \frac{4\pi\varepsilon_0 V^2}{Q} = \frac{4\pi\varepsilon_0 \times (Q \times 10^{11})^2}{Q}$ $= 4\pi\varepsilon_0 Q \times 10^{22}$ V/m

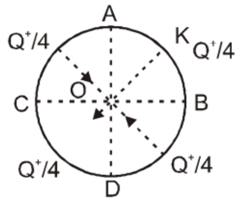
29. It is given that the ring is conducting. As the ring is conducting, so electric field at its centre is zero, ie,

$\vec{E}_{total} = 0$ or $\vec{E}_{AKB} + \vec{E}_{ACDB} = 0$ or $\vec{E}_{ACDB} = -\vec{E}_{AKB}$

or $\vec{E}_{ACDB} = -\vec{E}$ (along KO)

Therefore, the electric field at the centre due to the charge on the part ACDB of the ring is E along OK.

Alternative :



The fields at O due to AC and BD cancel each other.

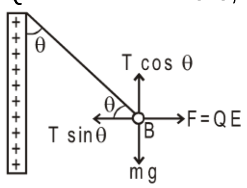
The field due to CD is acting in the direction OK and equal in magnitude to E due to AKB.

30. Electric field due to a charged conducting sheet of surface charge density σ is given by $E = \frac{\sigma}{2\varepsilon_0\varepsilon_r}$

Where, ε_0 = permittivity in vacuum and ε_r = relative permittivity of medium.

Here, electrostatic force on B

$QE = \frac{Q\sigma}{2\varepsilon_0\varepsilon_r}$ where, $T\cos\theta = mg$

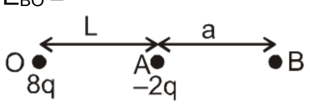


and $T\sin\theta = \frac{Q\sigma}{2\varepsilon_0\varepsilon_r}$

Thus, $\tan\theta = \frac{Q\sigma}{2\varepsilon_0\varepsilon_r mg}$ $\therefore$ $\tan\theta \propto \sigma$ or $\sigma \propto \tan\theta$

31. Suppose that at point B, where net electric field is zero due to charges 8q and 2q.

$E_{BO} = \frac{1}{4\pi\varepsilon_0}.\frac{8q}{(L+a)^2}$ $\Rightarrow$ $E_{BA} = \frac{1}{4\pi\varepsilon_0}.\frac{-2q}{(a)^2}$



According to condition $E_{BO} + E_{BA} = 0$ $\therefore$ $\frac{1}{4\pi\varepsilon_0}\frac{8q}{(a+L)^2} = \frac{1}{4\pi\varepsilon_0}\frac{2q}{(a)^2}$ $\Rightarrow$ $2 = \frac{a+L}{a}$

So, $a = L$

Thus, at distance 2L from origin, net electric field will be zero.

32. After connecting with conducting wire, let the charges on both spheres are q_1 & q_2.

$\therefore \frac{q_1}{q_2} = \frac{r_1}{r_2} = \frac{1}{2}$ $\therefore$ $\frac{E_1}{E_2} = \frac{q_1}{r_1^2} . \frac{r_2^2}{q_2} = 2 : 1$

33. Since, the electric field inside the shell is zero and outside, the electric field is given as $\frac{kQ}{r^2}$, where r = distance from centre. So, graph is as shown in option (4).

34. Density of electric field lines at a point i.e. no. of lines per unit area shows magnitude of electric field at that point.

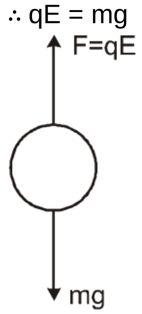
35. a & b can't be both +ve or both – ve otherwise field would have been zero at their mid point.
b can't be positive even, otherwise the field would have been in –ve direction to the right of mid point
answer is (A)

36. The frequency will be same $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

but due to the constant qE force, the equilibrium position gets shifted by $\frac{qE}{K}$ in forward direction. So Ans. will be (A)

37. **Key Idea** In steady state electric force on drop balances the weight of the drop.
In steady state, electric force on drop = weight of drop

$\therefore qE = mg \Rightarrow q = \frac{mg}{E} = \frac{9.9\times10^{-15}\times10}{3\times10^4} = 3.3 \times 10^{-18}$ C



38. Electric lines of force never form a closed loop. Therefore, options (A), (C) and (D) are wrong.

SECTION (C)

2. $E = \frac{v}{d}$, $E = \frac{10}{2}\times100 = 500$ N/C

8. Potential at origin is $v = \frac{-kq}{a} + \frac{kq}{a} = 0$

9. Potential at the centre is

$v = \left(\frac{kq}{a/\sqrt{2}}\right)\times4 = \frac{3\sqrt{3}kq}{a}$

$\Rightarrow \vec{E}_R = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$

11. $v = \frac{kq}{r}$

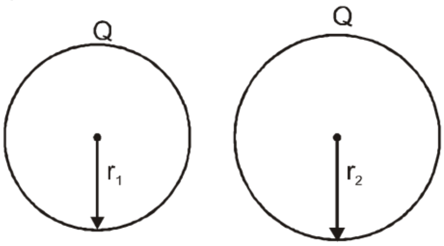
12. $E = \frac{v}{d}$, $v = 0.2 \times 5 = 1$ volt

13. Potential at origin is

$v = kq\left[1 - \frac{1}{2} + \frac{1}{4} - \frac{1}{8} ....\infty\right]$ $\Rightarrow$ $v = kq\left[\frac{1}{1+\frac{1}{2}}\right]$ $\Rightarrow$ $s_\infty = \left(\frac{a}{1-r}\right)$

15. $q_1 = \frac{2Qr_1}{r_1 + r_2}$

$q_2 = \frac{2Qr_2}{r_1 + r_2}$



After coming in contact

$v = \frac{kq}{r}$

16. Positive charge flows from higher potential to cover lower potential.

17. For isolated sphere $\frac{kQ_1}{r_1} = \frac{kQ_2}{r_2} \Rightarrow \frac{Q_1}{Q_2} = \frac{r_1}{r_2}$

18. $\frac{Q_1}{Q_2} = \frac{r_1}{r_2}$, $\frac{\sigma_1}{\sigma_2} = \frac{Q_1}{4\pi r_1^2}\frac{4\pi r_1^2}{Q_2} = \frac{r_1}{r_2}\left(\frac{r_2^2}{r_1^2}\right)$

19. Potential of single drop $v = \frac{kq}{r}$

Radius of bigger drop R = 4r

V' (potential of bigger drop) = $\frac{k64q}{4r} = \frac{16kq}{r}$

21. $V_{inside} = V_{surface} = \frac{kq}{R} = \frac{9 \times 10^9 \times 3.2 \times 10^{-19}}{0.1}$

22. V = Er $\quad$ $r = \frac{V}{E} = 6$m.

25. $V = \frac{9 \times 10^9 \times 1.5 \times 10^{-9}}{(.5)} = 27$ V.

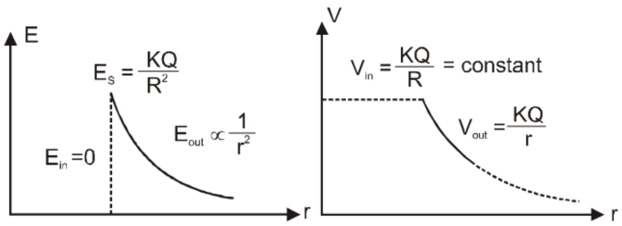
27. Since B and C are at same potential
$\Delta V_{AB} = \Delta V_{AC} = Eb$.

28. KE = VQ and momentum
$= \sqrt{2m(KE)} = \sqrt{2mVQ}$

29. Potential at 5cm = V = $\frac{kq}{(10cm)}$

Pontential at 15 cm $V^1 = \frac{kq}{15cm} = \frac{2}{3}$ V.

30. $v = \frac{K.Q}{R} = 0$ in side the sphrical shell the potential in eonstant = potential at the surface

31. 

32. Inside a dielectric sphere, electric field is zero.

33. Volume of bid drop = n × volume of a small drop

$\Rightarrow \frac{4}{3}\pi R^3 = n\frac{4}{3}\pi r^3$

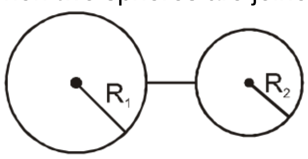
$\Rightarrow R = n^{1/3} r$ ...(i)

Potential of small drop V = $\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$\Rightarrow q = V \times 4\pi\varepsilon_0 r$ ...(ii)

So, potential of big drop = V' = $\frac{4\pi\varepsilon_0 \times V \times r}{4\pi\varepsilon_0 \times n^{1/3} r}$ $= n^{2/3}$ V

34. When two spheres are joined charge flows till it equalises. Hence electric potential is same.



$\therefore V_1 = V_2$

$\frac{1}{4\pi\varepsilon_0}\frac{q_1}{R_1} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{R_2}$

$\Rightarrow \frac{q_1}{R_2} = \frac{q_2}{R_2}$ ....(i)

Ratio of electric fields N $\frac{E_1}{E_2} = \frac{\frac{1}{4\pi\varepsilon_0}\frac{q_1}{R_1^2}}{\frac{1}{4\pi\varepsilon_0}\frac{q_2}{R_2^2}}$

$\Rightarrow \dfrac{E_1}{E_2} = \dfrac{q_1}{q_2}\left(\dfrac{R_2}{R_1}\right)^2$ ....(ii)

or $\dfrac{E_1}{E_2} = \dfrac{R_1}{R_2}\left(\dfrac{R_2}{R_1}\right)^2 = \dfrac{R_2}{R_1}$ [From Eq. (i)]

36. Charge will get equally distributed & now the force of repulsion will be maximum for given sum of charge.

37. $R = (27)^{1/3}\, r = 3r$

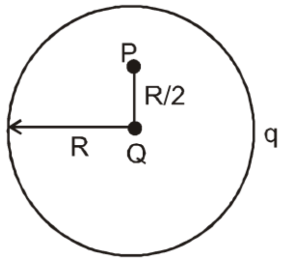
$\dfrac{kq}{r} = v \Rightarrow q = \dfrac{rv}{k}$

$V_f = K.$

38. At P, potential due to shell :

$V1 = \dfrac{q}{4\pi\varepsilon_o R}$

At P , potential due to Q :

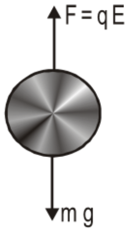


$V2 = \dfrac{Q}{4\pi\varepsilon_o \frac{R}{2}}$ $\therefore$ Net potential at P

$V = V1 + V2 = \dfrac{q}{4\pi\varepsilon_o R} + \dfrac{2Q}{4\pi\varepsilon_o R}$

39. In steady state,

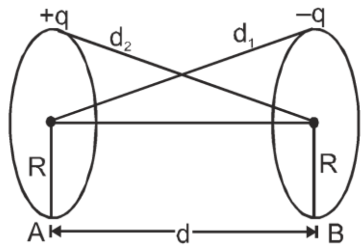
electric force on drop = weight of drop



$\therefore qE = mg \Rightarrow q = \dfrac{mg}{E} = \dfrac{9.9\times10^{-15}\times10}{3\times10^{4}} = 3.3\times10^{-18}$ C

40. V_A = (potential due to charge +q on ring A) + (potential due to charge – q on ring B) = $\dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{q}{R} - \dfrac{q}{d_1}\right)$

$d_1 = \sqrt{R^2 + d^2} = \dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{q}{R} - \dfrac{q}{\sqrt{R^2+d^2}}\right)$ .... (i)



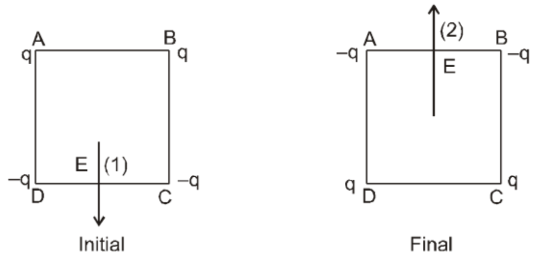
Similarly,

$V_B = \frac{1}{4\pi\varepsilon_0}\left(-\frac{q}{R}+\frac{q}{\sqrt{R^2+d^2}}\right)$

Potential difference $V_A - V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}+\frac{1}{4\pi\varepsilon_0}\frac{q}{R}-\frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{R^2+d^2}}-\frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{R^2+d^2}} = \frac{1}{2\pi\varepsilon_0}\left(\frac{q}{R}-\frac{q}{\sqrt{R^2+d^2}}\right)$

41. Since $V_A = 9 \times 10^9 \frac{10^{-9}}{\{2+2\}^{\frac{1}{2}}} = 4.5$ volt, $V_B = 9 \times 10^9 \frac{10^{-9}}{\{4+0\}^{\frac{1}{2}}}$ volt, $V_A - V_B = 0$

42. In initial case, E is along (1) whereas in final case E is along (2). Potential at centre remains same.



43. $\because V = \frac{kq}{r} - \frac{kq}{3r}$ $V = \frac{2kq}{3r}$

$\therefore$ Field intensity at distance 3r from centre

$= \frac{kq}{9r^2} = \frac{V}{6r}$

44. The whole volume of a uniformly charged spherical shell is equipotential.

SECTION (D)

1. $v = \frac{kq}{R} = \frac{9\times10^9\times50\times1.6\times10^{-19}}{10^{-12}}$

2. Electrostatic force is a conservative force. (work done by conservative force does not depend on path.)

3. $w = q(v_2 - v_1) = \frac{1}{2}mv^2 = \Delta K$

4. w = qV (v → Potential of diff.)

w = 0 Potential of all the points are same

5. Work done by external agent will be negative

6. PE = qV PE increases if q is +ve decreases if q is –ve.

7. $\therefore \frac{1}{2}mV_A^2 = qV$, $\frac{1}{2}mV_B^2 = 4\,qV$

$\therefore \frac{V_A^2}{V_B^2} = \frac{1}{4} \Rightarrow \frac{V_A}{V_B} = \frac{1}{2}$

8. $\frac{1}{2}mv^2 = eV \quad \therefore \quad v = \sqrt{\frac{2eV}{m}}$

9. $\frac{1}{2}mu^2 = eV \Rightarrow u = \sqrt{\frac{2eV}{m}} \quad \therefore \quad u \,\alpha\, V^{\frac{1}{2}}$

10. $ev = \frac{1}{2}mv^2$

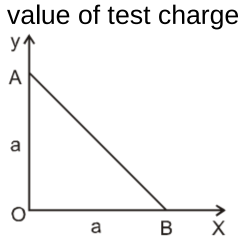
11. Both the points are at equitorial position. So, potential is zero at both the points.

12. When positive charge is shifted from a low potential to a high potential region, the electric potential energy increases.

13. If given voltage V, then energy of electron

$\frac{1}{2}mv^2 = eV \Rightarrow v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2\times1.6\times10^{-19}\times1000}{9.1\times10^{-31}}} = 1.875 \times 10^7 = 1.9 \times 10^7$ m/s

14. The work done in carrying a test charge consists in product of difference of potential at points A and B and value of test charge.



potential at A

$V_A = \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$; potential at B

$V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$

Thus, work done in carrying a test charge – Q from A to B ⇒ $w = (V_A - V_B)(-Q) = 0$

15. The change in potential energy of the system is $U_D - U_C$ as discussed under.
When charge q_3 is at C, then its potential energy is

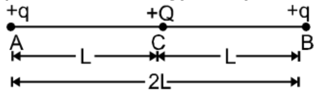
$U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.1}\right)$ When charge q_3 is at D, then

$U_D = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.1}\right)$ Hence, change in potential energy

$\Delta U = U_D - U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} + \frac{q_2 q_3}{0.5}\right)$ but $\Delta U = \frac{q_3}{4\pi\varepsilon_0}$ $k = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} + \frac{q_2 q_3}{0.5}\right)$

$\therefore \frac{q_3}{4\pi\varepsilon_0} = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} + \frac{q_2 q_3}{0.5}\right) \Rightarrow k = q_2(10 - 2) = 8q_2$

16. Work done is equal to change in potential energy. In Ist case, when charge + Q is situated at C. Electric potential energy of system in that case.



$U_1 = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)Q}{L} + \frac{1}{4\pi\varepsilon_0}.\frac{qQ}{L}$

In IInd case, when charge +Q is moved from C to D. Electric potential energy of system in that case

$U_2 = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}.\frac{qQ}{3L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)(Q)}{L}$ $\therefore$ Work done = $\Delta U = U_2 - U_1$

$= \left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{3L} - \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right) - \left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} - \frac{1}{4\pi\varepsilon_0}.\frac{qQ}{L} + \frac{1}{4\pi\varepsilon_0}.\frac{qQ}{L}\right)$

$= \frac{qQ}{4\pi\varepsilon_0}.\left[\frac{1}{3L} - \frac{1}{L}\right] = \frac{qQ}{4\pi\varepsilon_0}\frac{(1-3)}{3L}$ c $= \frac{-2qQ}{12\pi\varepsilon_0 L} = -\frac{qQ}{6\pi\varepsilon_0 L}$

17. By energy conservation:

Initially: $0 + \frac{1}{2}mv^2 = \frac{kQq}{r}$

Finally: $\frac{1}{2}$ m (2v)2 = $\frac{kQq}{r'}$ So , $\frac{4kQq}{r} = \frac{kQq}{r'}$ or $r' = \frac{r}{4}$

18. By work energy theorem :

$W_{\text{all forces}} = \Delta KE$

So, $q(\Delta V) = KE_{\text{final}} - KE_{\text{Initial}}$ or $1.6 \times 10^{-19} \times (20) = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 \therefore v = 2.65 \times 10^6$ m/s

19. By conservation of machenical energy

$\frac{1}{2}mv^2 = \frac{kq_1q_2}{r_1} - \frac{kq_1q_2}{r_2} \Rightarrow \frac{1}{2}(2\times10^{-3})\,v^2 = 9 \times 10^9 \times 10^{-6} \times 10^{-3}\left(\frac{1}{1} - \frac{1}{10}\right)$

or $v^2 = 9 \times 10^3 \times \frac{9}{10}$ or v = 90 m/sec

20. Potential difference between two points in a electric field is, $V_A - V_B = \frac{W}{q_0}$ where, W is work done by moving charge q_0 from point A to B. So, $V_A - V_B = \frac{2}{20}$ (Here: W = 2 J, q_0 = 20C) = 0.1 V

21. B & C are equipotential and field is conservative, therefore :

$\therefore W_{CA} = W_{BA} = -\int_{2a}^{a}\frac{\lambda}{2\pi\varepsilon_0 r}\,q\,dr. = \frac{q\lambda}{2\pi\varepsilon_0}\ln 2.$

22. By M.E. conservation between initial & final point :

$U_i + K_i = U_f + K_f$ $\therefore$ Answer is (4)

SECTION (E)

1. $\omega = \vec{F}\,.\,\vec{r}$

$\omega = 0$

Angle between force and disp. = 90° or workdone by conservative force round the trip will always be zero.

2. PE = $\frac{2Kq^2}{a^2} + \frac{2xkq^2}{a^2} + \frac{xkq^2}{a^2}$ = 0 where a is distance between charges.

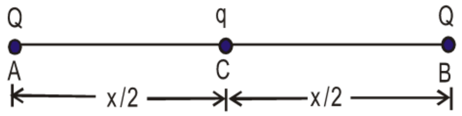
2 + 3x = 0 $\quad x = -\frac{2}{3}$

3. P.E. of system = $\frac{2Kq^2}{a} + \frac{2xkq^2}{a} + \frac{xkq^2}{a}$ = 0 where a is distance between charges.

or $\quad$ 2 + 3x = 0 $\quad \therefore \quad x = -\frac{2}{3}$

4. Let charge q is placed at mid point of line AB as shown below.

Also, $\quad$ AB = x $\quad$ (say) $\quad \therefore \quad$ AC = $\frac{x}{2}$, BC = $\frac{x}{2}$



For the system to be in equilibrium

$F_{Qq} + F_{QQ} = 0$

So, $\quad \frac{1}{4\pi\varepsilon_0}\frac{Qq}{(x/2)^2} + \frac{1}{4\pi\varepsilon_0}\frac{QQ}{x^2} = 0 \quad \Rightarrow \quad q = -\frac{Q}{4}$

SECTION (F)

1. Field near sphere = $\frac{V}{R} = \frac{800}{1\times10^{-2}}$ = 8 × 10^5 V/m

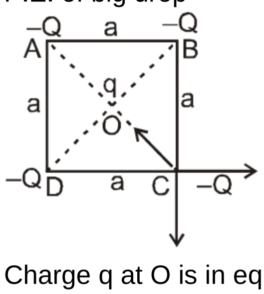
Energy density = $\frac{1}{2}\varepsilon_0 E^2 = \frac{4\pi\varepsilon_0}{8\pi}$ E^2 = $\frac{8\times8\times10^{10}}{8\pi\times9\times10^9} = \frac{80}{9\pi}$ = 2.83 J/m^3.

2. Let q is charge and a is racdius of single drop. U = $\frac{3kq^2}{5a}$ charge on big drop = nq.

Let Radius of big drop is R. ⇒ $\frac{4}{3}\pi R^3 = n.\frac{4}{3}\pi a^3$ $\quad \Rightarrow \quad$ R = $an^{1/3}$.

P.E. of big drop = $\frac{3}{5}\frac{k(qn)^2}{R} = \frac{3}{5}\frac{k.q^2n^2}{an^{1/3}} = Un^{\frac{5}{3}}$

3.



Charge q at O is in equilibrium. For –Q to be in equilibrium, we see charge at C. ∴ F_{net} on – Q (at C) = 0

or $\quad \frac{kQ^2}{(\sqrt{2}a)^2} + \frac{\sqrt{2}kQ^2}{a^2} - \frac{kQq}{(a/\sqrt{2})^2} = 0 \quad \therefore \quad q = \frac{Q}{4}(1+2\sqrt{2})$

SECTION (G)

1. Electric field is always perpendicular to equipotential surface. Opposite to electric field potential increases.

2. $E = \frac{10}{0.1\sin 30^\circ} = 200$ V/m

5. $E \propto r \Rightarrow -\int_0^v dV \propto \int_0^r r\,dr \Rightarrow V \propto (-\frac{r^2}{2}) \Rightarrow V \propto r^2$

6. Electric field $E \propto r^2$

7. Electric field due to a point charge

$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

Electric potential due to a point charge

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \Rightarrow \frac{E}{V} = \frac{1}{r} \Rightarrow r = \frac{V}{E} = \frac{3000}{500} = 6$ metre

8. Electric lines of force flow from higher potential to lower potential so,

$V_A = V_B > V_C$

9. $E = -\frac{dv}{dr} = 0$ at r = 3 cm

11. $v(x) = \frac{20}{x^2 - 4}$, $E = -\frac{dv}{dx} = -\frac{d}{dx}\left(\frac{20}{x^2-4}\right) = \frac{20}{(x^2-4)^2}$ (2x)

E at x = 4 μm, $\frac{(20)(2\times 4)}{144} = \frac{10}{9}$ volt/μm

Also as x increases, V decreases. So, E is along +ve x -axis.

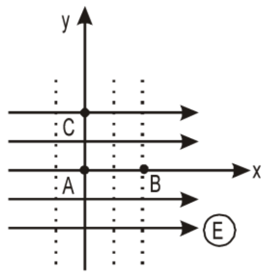
12. $E = -\frac{dV}{dx} = -10x - 10 \quad \therefore \quad E_{(x=1m)} - 10(1) - 10 = -20$ V/m

13. $\Delta V = -E\Delta x \Rightarrow V_x - 0 = -E_0x$.

or $V_x = -E_0x$.

14. Potential decreases in the direction of electric field. Dotted lines are equipotential lines.

$\therefore V_A = V_C$ and $V_A > V_B$



15. $\because E = \frac{F}{q} \quad \therefore \quad E = \frac{2000}{5} = 400$ N/C

Potential difference, $\Delta V = E.d = 400 \times \frac{2}{100} = 8V$.

16. Property of equipotential surface

SECTION (H)

2. $E \propto \frac{1}{r^3}$

5. $\dfrac{E_{axis} = \dfrac{k.2p}{r^3}}{E_{qui} = \dfrac{kp}{r^3}} = \dfrac{2}{1}$

6. Maximum torque = $\tau = |\bar{P} \times \bar{E}|$ = PE sin θ

τ_{max} = PE = 0 × 2 × 10^{-6} × 10^{-2} × 2 × 10^{5} = 12 × 10^{-3} NM

7. dipde moment

ρ = q × ℓ = e × ℓ = 1.6 × 10^{-10} × 10^{-10} = 1.6 × 10^{-29} c

8. Potential due to dipoleat its equitorial plane is zero.

9. $V = \dfrac{K.P\cos\theta}{r^2}$ = $V = \dfrac{90 \times 10^9 \times 2 \times 10^{-8} \times \frac{1}{2}}{(3)^2}$ = 10 volt

10. max PE ⇒ position of unstable equilibrium ⇒ θ = π .

11. Potential V = $\dfrac{p\cos\theta}{r^2}$ maximum

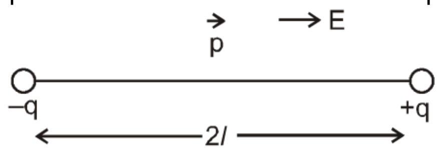
If θ = 0° then V_a = maximum

If θ = 180° then V_e = minimum

15. The electric potential of electric dipole on its axial position is

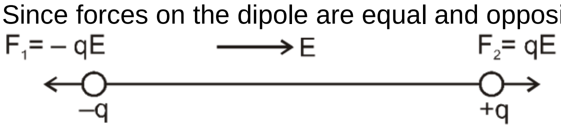
$v = \dfrac{p}{4\pi\varepsilon_0 r^2}$ where p = dipole moment or $V \propto \dfrac{1}{r^2}$ or $V \propto r^{-2}$

16. An electric dipole is an arrangement of two equal an opposite charges placed at a distance 2I. The dipole is placed in electric field as such its dipole moment is in direction of electric field as shown in figure.



Now force on the charge q is F_2 = qE along the direction of E and force on charge –q is F_1 = – qE in the direction opposite to E.

Since forces on the dipole are equal and opposite, so net force on the electric dipole is zero.



Now potential energy of the dipole.

U = – pE cos θ

Where θ is the angle between direction of electric field and direction of dipole moment.

∴ ∴ θ = 0° Hence, UJ = – pE cos 0° = – pE (minimum)

17. When an electric dipole is placed in an electric field $\vec{E}$, torque $\vec{\tau} = \vec{P} \cdot \vec{E}$ acts on it. This torque tries to rotate the dipole through an angle.

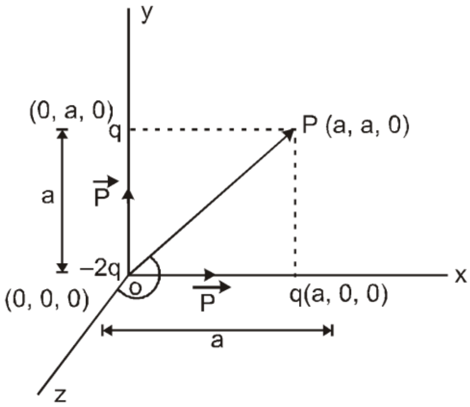
If the dipole is rotated from an angle θ_1 to θ_2. then work done by external force is given by

w = pE (cos θ_1 – cos θ_2) … (i) putting θ_1 = 0°, θ_2 = 90° in the Eq. (i), we get

w = pE (cos 0° – cos 90°) = pE (1 – 0) = pE

18. **Key Idea :** Electric dipole moment is a vector quantity directed from negative charge to the similar positive charge.

Choose the three coordinate axes as x, y and z and plot the charges with the given coordinates as shown. O is the origin at which –2q charge is placed. The system is equivalent to two dipoles along x and y-directions respectively. The dipole moments of two dipoles are shown in figure.



The resultant dipole moment will be directed along OP where P ≡ (a, a, 0). The magnitude of resultant dipole moment is

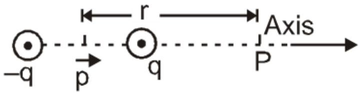
$p' = \sqrt{p^2 + p^2} = \sqrt{(qa)^2 + (qa)^2} = \sqrt{2}\ qa$

19. The dipole will have some distance along the electric field, so, option (1) is correct.

20. Since P & Q are axial & equatorial points, so electric fields are parallel to axis at both points.

21. τ_{max}= pE sin 90°
$= 10^{-6} \times 2 \times 10^{-2} \times 1 \times 10^{5}$ N – m $= 2 \times 10^{-3}$ N-m

22. $\tau_{max} = PE = 4 \times 10^{-8} \times 2 \times 10^{-4} \times 4 \times 10^{8} = 32 \times 10^{-4}$ N-m.
Work done W = $(P.E.)_f - (P.E.)_i$ = PE – (–PE) = 2PE $= 64 \times 10^{-4}$ N-m

23.


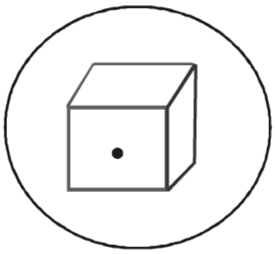
At a point 'P' on axis of dipole electric field $E = \frac{2kp}{r^3}$ and electric potential $V = \frac{kp}{r^2}$ both nonzero and electric field along dipole on the axis.

SECTION (I)

3. Flux emitted from the surface s_2

$\theta = \frac{q_2 + q_3}{E_0}$

5. $q_{in} = \Sigma q = (1–7–4+10+2–5–3+6)\ \mu c = (19–19)\ \mu 1 = 0$



Net flux = 0

6. $\theta_{in} = \theta_{out} \Rightarrow \theta_{Net} = 0$

7. Total flux through closed cubical vessel $= \frac{q}{\varepsilon_0}$ & Flux through one face $= \frac{1}{6}\left(\frac{q}{\varepsilon_0}\right)$

So, total flux passing through given cubical vessel is = $5\left(\frac{q}{6\varepsilon_0}\right)$; (as vessel has 5 faces)

8. $\lambda = \frac{\phi}{cm}$

$\phi = \frac{q_m}{E_0} = \frac{Q \times 100cm}{cm}$ ⇒ $\phi = \frac{100Q}{e_0}$

10. According to Gauss's theorem, total electric flux

$\phi = \frac{Q}{\varepsilon_0}$

11. The flux passing through the coil

$\Delta\ \phi = \vec{E} \cdot \Delta\vec{S} = E\ \Delta\ S \cos 60° = E \times (4 \times 4) \times \frac{1}{2} = 8\ E$

12. The total electric flux passing normally through a closed surface of any shape in an electric field is equal to $\frac{1}{\varepsilon_0}$ times the total charge present with in that surface i.e.,

$\phi = \frac{Q}{\varepsilon_0}$ since, charges are displaced ± 1.5 cm from centre of sphere so, there will be no change in flux passing through the sphere.

13. [From Gauss law, $\frac{\text{Charge enclosed}}{\varepsilon_0}$ = Flux leaving the surface]

$\frac{q}{\varepsilon_0} = \phi_2 - \phi_1$ ⇒ $q = (\phi_2 - \phi_1)\ \varepsilon_0$

14. Electric flux (ϕ_e) is a measure of the number of field linees crossing a surface. The number of field lines passsing through unit area (N/S) will be proportional to the electric field, or, $\frac{N}{S} \propto E \Rightarrow N \propto ES$
The quantity ES is the electric flux through surface S. As we have seen in the problem that, lines of force that enter the closed surface leave the surface immediately, so no electric flux is bound to the system. Hence, electric flux is zero.

15. $\Delta\phi = \frac{q}{\varepsilon_0}$ ⇒ $\phi 2 - \phi 1 = \frac{q}{\varepsilon_0}$
So, the electric charge inside the surface will be ⇒ $q = (\phi 2 - \phi 1)\varepsilon 0$

16. Since, dipole has net charge zero, so flux through sphere is zero with non-zero electric field at each point of sphere.

17. For the closed surface made by disc and hemisphere
$q_{in} = 0$ ∴ $\phi_{net} = 0$
$\phi_{disc} + \phi_{H.S} = 0$ ∴ $\phi_{HS} = -\phi_{disc} = -\phi$

18. According to Gauss's law, the electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

Since, q is the charge enclosed by the surface, thhen electric flux $\phi = \frac{q}{\varepsilon_0}$
If charge q is placed at a corner of cube, it will be divided into 8 such cubes. Thereofe, electric flux through the cube is

$\phi' = \frac{1}{8} \times \left(\frac{q}{\varepsilon_0}\right)$

19. According to Gauss's law, total electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the total charge enclosed by the surface. From key idea, the electric flux emerging from the cube is

$\phi = \frac{1}{\varepsilon_0} \times \text{charge enclosed} = \frac{1}{\varepsilon_0} \times q \times 10^{-6}$

Since, a cube has six faces, so electric flux throught each face is,

$\phi' = \frac{\phi}{6} = \frac{1}{6\varepsilon_0} \times q \times 10^{-6} = \frac{q \times 10^{-6}}{6\varepsilon_0}$

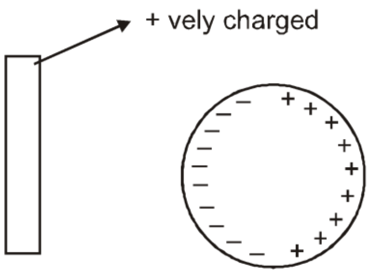
SECTION (J)

3. At the point B – Equipotential surface are very close to each the

$\text{sin} -\frac{\Delta v}{\Delta r} \quad E = -\frac{\Delta v}{\Delta r}$

⇒ Δ is smaller so E is greater at B

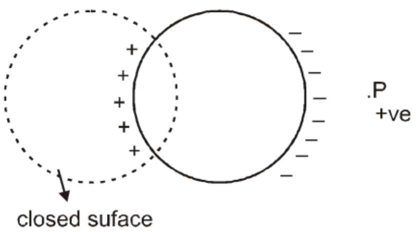
5. In a hollow metalic cavity if no chage in side the cavity ⇒ E_{in} - 0



6. Since distance between plate and –ve charge is less than that between plate and +ve charge. electric force acts on object towards plate.

8. Since field lines are always perpendicular to conductor surface field lines can not enter in to conductr only option C is correct.

10. Since electric field produced by charge is conservative.



11. enclosed charge = +ve
⇒flux through closed suface = +ve.

12. Inside the given sphere, there will not be any effect of external electric field. So net electric field will only be due to point charge 'q' at centre. ∴ Graph is (A)

13. On removing Q', no effect is there in previous situation as Q ' does not affect the electric field at inside point.

14. By definition

15. Distribution of charge in the volume of sphere depends on uniformity of material of sphere.

16. Since, no external electric field can enter into a conductor so force experienced by Q = 0

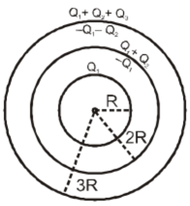
17. P.D, = $\int \vec{E}.\vec{dr}$ and E between spheres does not depend on charge on outer sphere.

18. Electric field is zero everywhere inside a metal (conductor). i.e., field lines do not enter in to metal also these are perpendicular to a metal surface (equipotential surface).

19. Sphere is electrically neutral therefore net charge will be zero. (by conservation of charge)

20. The charge distribution on the surfaces of the shells are given. As per the given condition.

$$\frac{Q_1}{4\pi R^2} = \frac{Q_1+Q_2}{4\pi(2R)^2} = \frac{Q_1+Q_2+Q_3}{4\pi(3R)^2} \Rightarrow \frac{Q_1}{1} = \frac{Q_2}{3} = \frac{Q_3}{5}.$$



21. Induction takes place on outer surface of sphere producing non-uniform charge distribution & since external electric field can not enter the sphere, so interior remains charge free.

22. Since A, B and C are at same potantial electric field inside C must be zero. for this final charge on A and B must be zero and final charge on C = Q + q_1 + q_2. (By conservation of charge)
∵ All charge comes out to the surface of C.

23. Since, no external electric field can enter into a conductor so force experienced by Q = 0

24. The surface and interior of a charged conductor is equipotential. Therefore, the potential is same throughout the charged conductor.

25. Electric field at given location is only due to inner solid metalic sphere.

26. Since potential on the surface of sphere will be same.

$$\frac{K.\sigma_A.4\pi a^2}{a} = \frac{K.\sigma_B.4\pi b^2}{b}$$

$$\sigma_A a = \sigma_B.b \quad ....(1)$$

$$E_A = \frac{K.\sigma_A \times 4\pi a^2}{a^2}, \quad E_B = \frac{K.\sigma_B.4\pi b^2}{b^2}$$

$$\frac{E_A}{E_B} = \frac{\sigma_A}{\sigma_B} = \frac{b}{a}$$

27. When inner cylinder is charged (outer cylinder may or maynot be charged) an electric field will be present in the gap between the cylinders which will produce a potential difference.

EXERCISE-2

1. In a conductor, potential is same everywhere

$\therefore$ Potential at A = potential at centre = $V_{\text{due to p}} + V_{\text{due to induced charges}} = \dfrac{kp}{(r\sec\phi)^2} + 0 = \dfrac{kp\cos^2\phi}{r^2}$

4. According to optioin (D) the electric field due to P and S and due to Q and T add to zero. While due to U and R will be added up. Hence the correct option is (4).

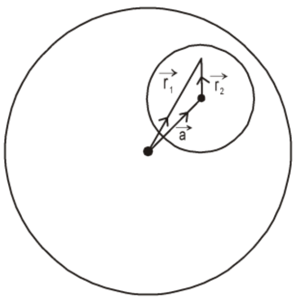
5. Electric dipole $= q \times 2\ell = L^1T^1A^1$

Electric flux $= \int E \cdot ds$ = (F/q) ds = $\dfrac{M^1L^1T^{-2}}{AT} \times L^2 = M^1 L^3 T^{-3} A^{-1}$

Electric field = $\dfrac{F}{q} = M^1L^1T^{-3}A^{-1}$

6. Electric field at P = $\vec{E}$ due to full sphere – $\vec{E}$ due to charge that would be present in cavity

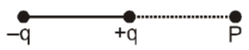
$= \dfrac{\rho\vec{r}_1}{3\varepsilon_0} - \dfrac{\rho\vec{r}_2}{3\varepsilon_0} = \dfrac{\rho}{3\varepsilon_0}(\vec{r}_1 - \vec{r}_2) = \dfrac{\rho}{3\varepsilon_0}\vec{a}$



It is uniform.

7. Statement-1 is true by information
Statement-2 is true by formula. But statement-2 is not the explanation of 1.
Ans. (B) B (Ans. of JEE was A)

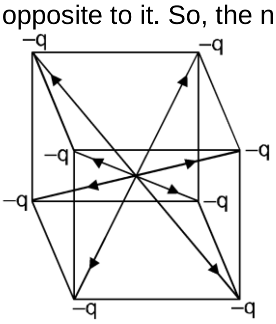
8. $\phi = \int E ds = \dfrac{Kq}{r^2} 4\pi r^2 = \dfrac{q}{\varepsilon_0}$



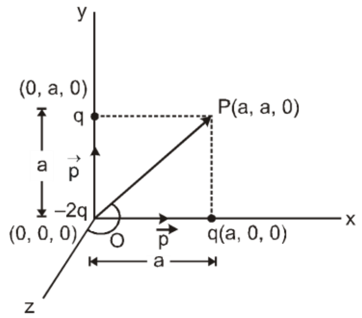
$W_{ext} = q(V_B - V_A)$
Comment : (D) is not correct answer because it is not given that charge is moving slowly.

10. When a glass rod is rubbed with silk, the amount of positive charge acquired by glass rod is equal to the negative charge acquired by silk.

11. Clearly, the electric-field of each point charge is equal and opposite to the electric-field of charge diagonally opposite to it. So, the net electric field at centre of the cube is zero.



12.

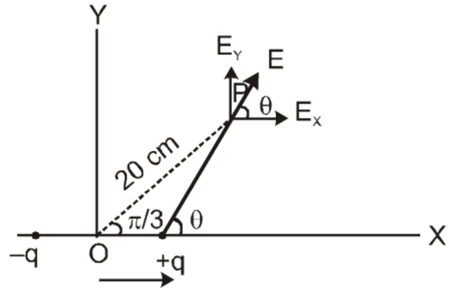


Electric dipole moment is a vector quantity directed from negative charge to the similar positive charge. Choose the three coordinate axes as x, y and z and plot the charges with the given coordinates as shown. O is the origin at which –2q charge is placed. The system is equivalent to two dipoles along x and y-directions respectively. The dipole moments of two dipoles are shown in figure.

The resultant dipole moment will be directed along OP where P ≡ (a, a, 0). The magnitude of resulant dipole moment is

$p' = \sqrt{p^2 + p^2} = \sqrt{(qa)^2 + (qa)^2} = \sqrt{2}qa$

13. Component of electric field at point P parallel to X-axis,

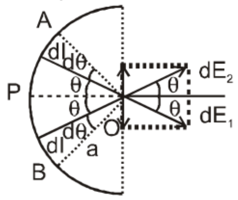


$E_X = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2(p\cos\pi/3)}{r^3} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^3}$

Component of electric field of point P perpendicular to y-axis,

$E_Y = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\pi \sin\pi/3}{r^3} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\sqrt{3}p}{2r^3}$ ∴ $\tan\theta = \frac{E_Y}{E_X} \frac{\sqrt{3}}{2}$ ∴ $\theta = \tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$

14. Considering symmetric elements each of length dl at A and B, we note that electric fields perpendicular to PO are cancelled and those along PO are added. The electric field due to an element of length dl (adθ) along PO.



$dE = \frac{1}{4\pi\varepsilon_0} \frac{dq}{a^2} \cos\theta$ (dl = adθ)

$= \frac{1}{4\pi\varepsilon_0} \frac{\lambda dl}{a^2} \cos\theta \quad \frac{1}{4\pi\varepsilon_0} \frac{\lambda(a\,d\theta)}{a^2} = \cos\theta$ Net electric field at O

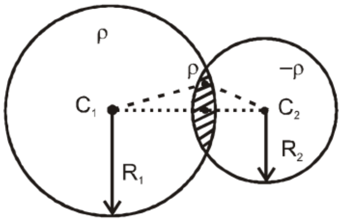
$E = \int_{-\pi/2}^{\pi/2} dE = 2\int_0^{\pi/2} \frac{1}{4\pi\varepsilon_0} \frac{\lambda a \cos\theta\, d\theta}{a^2} = 2. \frac{1}{4\pi\varepsilon_0} \frac{\lambda}{a} [\sin\theta]_0^{\pi/2} = 2. \frac{1}{4\pi\varepsilon_0} . \frac{\lambda}{a} .1 = \frac{\lambda}{2\pi\varepsilon_0 a}$

15. (None of the four choices) $\frac{1}{2}\epsilon_0 E^2$ is the expression of energy density (Energy per unit volume)

$\therefore \left[\frac{1}{2}\epsilon_0 \; E^2\right] = \left[\frac{ML^2T^{-2}}{L^3}\right]$ $[ML^{-1}\,T^{-2}]$

→ From this question, students can take a lesson that even in IIT-JEE, questions may be wrong or there may be no correct answer in the given choices. So don't waste time if you are confident.

16.



For electrostatic field,

$\vec{E}_P = \vec{E}_1 + \vec{E}_2 = \frac{\rho}{3\varepsilon_0}\overrightarrow{C_1P} + \frac{(-\rho)}{3\varepsilon_0}\overrightarrow{C_2P} = \frac{\rho}{3\varepsilon_0}(\overrightarrow{C_1P} + \overrightarrow{PC_2})$

$\vec{E}_P = \frac{\rho}{3\varepsilon_0}\overrightarrow{C_1C_2}$

For electrostatic potential, since electric field is non zero so it is not equipotential.

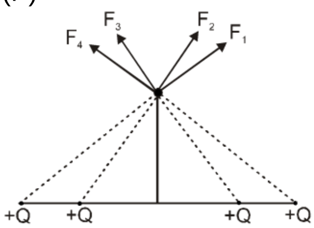
17. $E_1 = \frac{KQ}{R^2}$

$E_2 = \frac{k(2Q)}{R^2} \Rightarrow E_2 = \frac{2kQ}{R^2}$

$E_3 = \frac{k(4Q)R}{(2R)^3} \Rightarrow E_3 = \frac{kQ}{2R^2}$

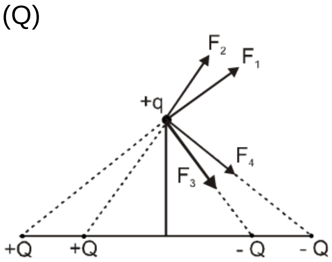
$E_3 < E_1 < E_2$

18. (P)



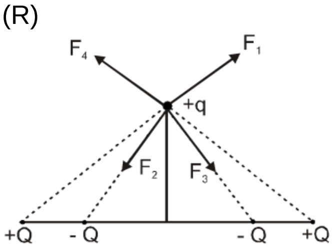
Component of forces along x-axis will vanish. Net force along +ve y-axis

(Q)



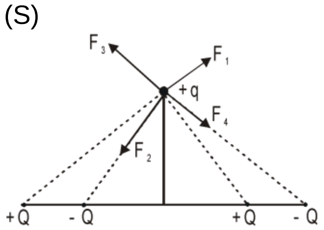
Component of forces along y-axis will vanish. Net force along +ve x-axis

(R)



Component of forces along x-axis will vanish. Net force along -ve y-axis.

(S)



Component of forces along y-axis will vanish. Net force along -ve x-axis.

Ans. **(A)** P—3, Q—1, R—4, S—2

EXERCISE # 3

PART-I

1. Eflectric field at a point is equal to the negative readient of he electrostatic potential at that point.

potential gradient relates with wlectric field according to the following relation E = $\frac{dv}{dr}$

$\vec{E} = -\frac{\partial v}{\partial r} = \left[-\frac{\partial v}{\partial x}\hat{i} - \frac{\partial v}{\partial y}\hat{j} - \frac{\partial v}{\partial x}\hat{k}\right]$ = [$\hat{i}$ (2xy + z^3) + $\hat{j}$ x^2 + $\hat{k}$ $3xz^2$]

2. Electric field insided charged conductor is always zero.

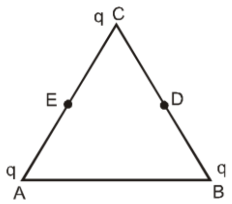
3. Total flux N = $\frac{\text{Net Charge enclosed}}{\epsilon_0}$. It depends only on net charge enclosed by the surface.

4. $V_A = \frac{kq}{L} \times 2 - 2\frac{kq}{L\sqrt{5}}$ (here, $k = \frac{1}{4\pi\epsilon_0}$) = $\frac{2kq}{L}\left(1 - \frac{1}{\sqrt{5}}\right)$

5. $\vec{E} = -\frac{dV}{dx}\hat{i}$ = $-8x\hat{i}$ volt/meter

$\vec{E}_{(1,0,2)} = -8\hat{i}$ V/m

6.



AC = BC

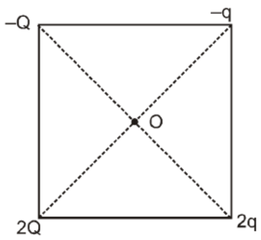
$V_D = V_E$

$W = Q(V_E - V_D)$

W = 0

7. τ = PE sin θ ⇒ U = – PE cos θ

8.



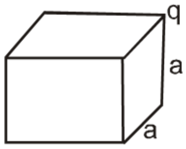
Let the side length of square be 'a' then potential at centre O is

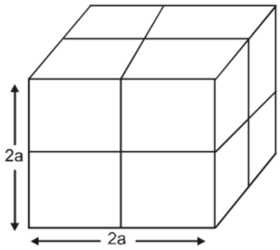
$$V = \frac{k(-Q)}{\left(\frac{a}{\sqrt{2}}\right)} + \frac{k(-q)}{\frac{a}{\sqrt{2}}} + \frac{k(2q)}{\frac{a}{\sqrt{2}}} + \frac{k(2Q)}{\frac{a}{\sqrt{2}}} = 0$$

$= -Q - q + 2q + 2Q = 0 = Q + q = 0 = Q = -q$

9. Eight identical cubes are required to arrange so that this charge is at centre of the cube formed so flux.

$$\phi = \frac{q}{8\varepsilon_o}$$





Ans. (2)

10. At equilibrium potential of both sphere becomes same if charge of sphere one x and other sphere Q – x then where $Q = 4 \times 10^{-2}$ C

$$\frac{kx}{1\text{ cm}} = \frac{k(Q-x)}{3\text{ cm}}$$

$3x = Q - x$

$4x = Q$

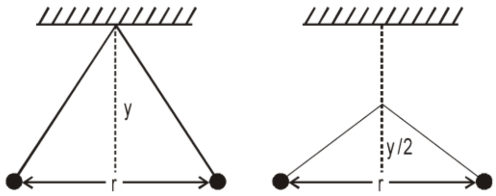
$x = \frac{Q}{4} = \frac{4\times10^{-2}}{4}C = 1 \times 10^{-2}$

$Q' = Q - x = 3 \times 10^{-2}$ C

11. V_B is maximum

$V_B > V_C > V_A$

In the direction of electric field potential decreases

12. 

$\tan\theta = \frac{F_e}{mg}$

$$\frac{r/2}{y} = \frac{\frac{kq^2}{r^2}}{mg}$$

$r^3 \propto y$

$r'^3 \propto \frac{y}{2} \Rightarrow \frac{r'}{r} = \frac{1}{2^{1/3}}$

13. For a conducting sphere electric fidld at centre = 0. Potential at centre = $\frac{KQ}{R} = \frac{Q}{4\pi\varepsilon_0 R}$

14. $V_{(x, y, z)} = 6x - 8xy - 6y + 6yz$

$E_x = -\frac{\partial V}{\partial x} = -6 + 8y \Rightarrow E_y = -\frac{\partial V}{\partial y} = 8x + 8 - 6z \Rightarrow E_z = -\frac{\partial V}{\partial z} = -6y$

$\vec{E} = (-6 + 8y),\ \hat{i} + (8x + 8 - 6z)\ \hat{j} - 6y\hat{k}$

$\vec{E}_{(1, 1, 1)} = 2\hat{i} + 10\hat{j} - 6\hat{k}$

$|\vec{E}| = 2\sqrt{35}$ NC^{-1}

$F = qE = 2 \times 2\sqrt{35} = 4\sqrt{35}$ N

15. Net flux emmited from a spherical surface of radius a is

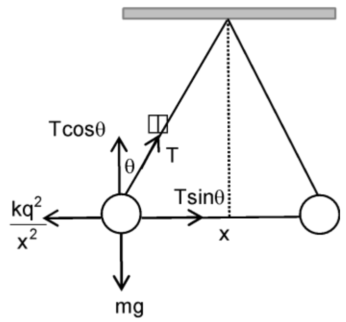
$\phi_{net} = \frac{q_{in}}{\varepsilon_0}$

$(Aa)(4\pi a^2) = \frac{q_{in}}{\varepsilon_0}$. So, $q_{in} = 4\pi\varepsilon_0 A a^3$

16. $V = 6xy - y + 24z$

$$\vec{E} = \left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right) \Rightarrow \vec{E} = \left[(6y)\hat{i} + (6x - 1 + 2z)\hat{j} + (2y)\hat{k}\right]$$

$\vec{E}_{(1,1,0)} = -(6\hat{i} + 5\hat{j} + 2\hat{k})$



17.

Tsinθ = $\frac{kq^2}{x^2}$

Tcosθ = mg

Dividing the equations

tanθ = $\frac{kq^2}{mgx^2}$ here tanθ ≈ sinθ = $\frac{x}{2\ell}$

$\Rightarrow \frac{x}{2\ell} = \frac{kq^2}{x^2}$ ⇒ $q \propto x^{3/2}$ ⇒ $\frac{dq}{dt} \propto \frac{3}{2}x^{1/2}\left(\frac{dx}{dt}\right)$ ⇒ $\frac{dx}{dt} \propto x^{-1/2}$

18. At closest approach

KE gets converted to PE

$\frac{1}{2}mV^2 = \frac{k(2e)(ze)}{r}$ ⇒ $m \alpha \frac{1}{r}$ or $r \alpha \frac{1}{m}$

19. τ = PE sinθ

$4 = P \times 2 \times 10^5 \times \frac{1}{2}$ ⇒ $P = 4 \times 10^{-5}$ cm = $q \times 2 \times 10^{-2}$ So, q = $\frac{4\times10^{-5}}{2\times10^{-2}}$ = 2×10^{-3} coulomb

20. Net Charge on one H-atom = –e + (e + Δe) = Δe

Net electrostatic force between two H-atoms = $\frac{k(\Delta e)(\Delta e)}{d^2}$ repulsive

Net gravitational force between two H-atoms = $\frac{G(m)(m)}{d^2}$

For equal magnitude $\frac{k(\Delta e)^2}{d^2} = \frac{Gm^2}{d^2}$

$\Delta e^2 = \frac{Gm^2}{k} = \frac{(6.67\times10^{-11})(1.67\times10^{-27})^2}{(9\times10^9)}$

Δe^2 is of the order of 10^{-74}

Δe is of the order of 10^{-37}

21. In all cases work done will be equal as

$W = q(V_f - V_i)$

22. F = qE ⇒ $a = \frac{qE}{m}$

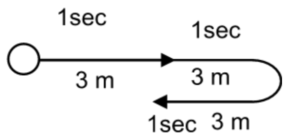
$s = at + \frac{1}{2}at^2$

$h = \frac{1}{2}\left(\frac{qE}{m}\right)t^2 \quad \Rightarrow \quad t = \sqrt{\frac{2hm}{qE}}$

$t \propto \sqrt{m}$

Since mass of electron is less, so time taken will also be smaller.

23. $s = \left(\frac{v+u}{2}\right)t = \left(\frac{6+0}{2}\right)(1) = 3m$



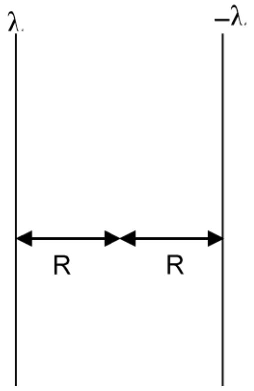
$<\vec{V}> = \frac{3\hat{i}}{3} = 1\ m/sec$

$<V> = \frac{3+3+3}{3} = 3m/sec$

24. $Q_1 = Q - \frac{Q}{4}, Q_2 = -Q + \frac{Q}{4}$

$F_1 = \frac{kQ^2}{r^2} \quad F_2 = \frac{k\left(\frac{3}{4}Q\right)\left(\frac{3}{4}Q\right)}{r^2} \quad \Rightarrow \quad \frac{F_2}{F_1} = \frac{9}{16}$

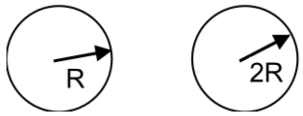
25. $\vec{E}$ due to infinite line charge = $\frac{2k\lambda}{R}$



λ = charge density

$\vec{E} = \vec{E}_1 + \vec{E}_2 = \frac{2k\lambda}{R} + \frac{2k\lambda}{R} = \frac{\lambda}{\pi\varepsilon_0 R} N/C$

26.



When $V_1 = V_2$ (potential same) charge flown is stopped

$\sigma = \frac{Q}{A}$

$Q = \sigma A$

$V = \frac{KQ}{R}$

$V_1 = \frac{K(\sigma_1 \times 4\pi R^2)}{R} = \frac{K(\sigma_2 \times 4\pi(2R^2))}{2R}$

$\sigma_1 = 2\sigma_2$

$\frac{\sigma_1}{\sigma_2} = 2$

Charge is conserved.

$\sigma A_1 + \sigma A_2 = \sigma_1 A_1 + \sigma_2 A_2$

$\sigma \times 4\pi R^2 + \sigma \times 4\pi (2R)^2 = \sigma_1 (4\pi R^2) + \sigma_2 (4\pi) (2R)^2$

$\sigma + 4\sigma = \sigma_1 + 4\sigma_2$

$5\sigma = \sigma_1 + 4\sigma_2$

$5\sigma = 6\sigma_2$

$\sigma_2 = \frac{5}{6}\sigma, \sigma_1 = \frac{5}{3}\sigma$

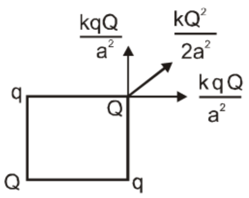
27. Total electric flux through the sphere $= \frac{q_{enclosed}}{\varepsilon_o} = \frac{+3\times10^6 - 3\times10^6}{\varepsilon_o} = \frac{0}{\varepsilon_o} = 0$

PART - II

1. $W_{P\to Q}|_{ext} = q\,(V_Q - V_P) = -1.6 \times 10^{-19} \times 100\,(-4 - 10) = 2.24 \times 10^{-16}$ J

2. Since, F_{net} on Q is zero, so :

$\frac{kqQ}{a^2}[\sqrt{2}] + \frac{kQ^2}{2a^2} = 0$



$\frac{Q}{q} = -2\sqrt{2}$

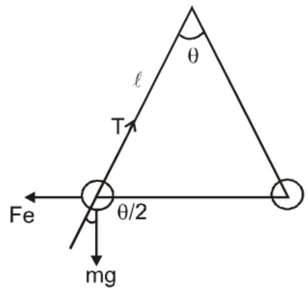
3. Statement–1 : Correct as the field is conservative. Statement –2 : Correct Explanation

4. $\vec{E} = \left(\frac{2k\lambda}{r}\right)(-\hat{j}) \Rightarrow \vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}(-\hat{j})$

$\lambda = \frac{q}{\pi r} \Rightarrow \vec{E} = \frac{q}{2\pi^2\varepsilon_0 r^2}(-\hat{j})$

5. At equilibrium

$\tan\theta/2 = \frac{F_e}{mg} = \frac{1}{4\pi\epsilon_0}\frac{q^2}{[\ell\sin(\theta/2)]^2}\cdot\frac{1}{mg}$



When suspended in liquid

$\tan\frac{\theta}{2} = \frac{1}{4\pi\epsilon_0 K}\frac{q^2}{[\ell\sin(\theta/2)]^2}\frac{1}{(mg - F_B)} = \frac{1}{4\pi\epsilon_0 K}\frac{q^2}{[\ell\sin(\theta/2)]^2}\cdot\frac{1}{\left(mg - \frac{m}{1.6}\times 0.8g\right)}$ on comparing the two equation we get $K\left(1-\frac{0.8}{1.6}\right) = 1 \Rightarrow K = 2.$

6. 

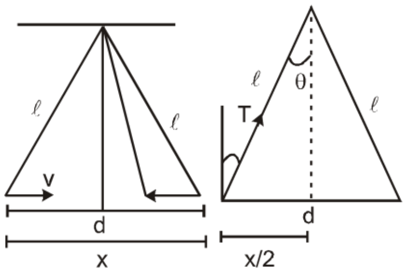
$\phi = ar^2 + b$

$E = -\frac{d\phi}{dt} = -2ar$

$\oint \vec{E}.d\vec{S} = \frac{q}{\varepsilon_0}$ $-2ar \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$

$q = -8\varepsilon_0 a\pi r^3$

$\rho = \frac{q}{\frac{4}{3}\pi r^3}$ $\rho = -6a\varepsilon_0$ **Ans.**

7. 

$\sin\theta = \frac{kq^2}{d^2}$

$\cos\theta = mg$

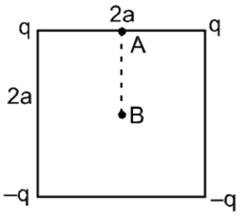
$\tan\theta = \frac{k}{mg}\cdot\frac{q^2}{x^2} \Rightarrow \frac{x}{2\ell} = \frac{k}{mg}\cdot\frac{q^2}{x^2} \Rightarrow x^3 = \frac{2k\ell}{mg} q^2$

$q^2 \propto x^3 \Rightarrow q \propto x^{3/2} \Rightarrow \frac{dq}{dt} \propto \frac{3}{2}x^{1/2}\frac{dx}{dt}$ (dq/dt is constant)

$c \propto x^{1/2} v \Rightarrow v \propto x^{-1/2}$.

8. Potential at point A,

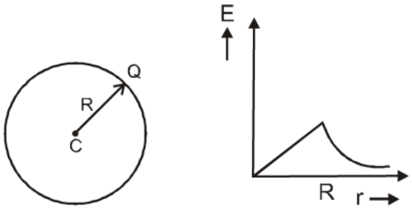
$V_A = \frac{2Kq}{a} - \frac{2Kq}{a\sqrt{5}}$

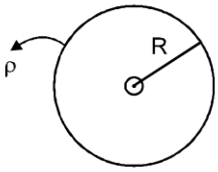


Potential at point B,

$V_B = 0$ $\therefore$ Using work energy theroem,

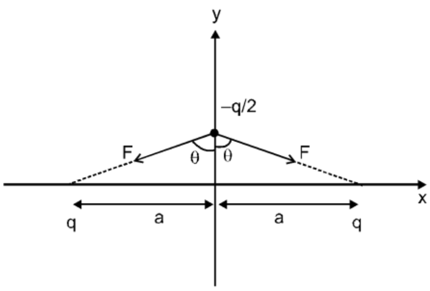
$W_{AB})_{electric} = Q(V_A - V_B)$ $= \frac{2KqQ}{a}\left[1-\frac{1}{\sqrt{5}}\right] = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2Qq}{a}\left[1-\frac{1}{\sqrt{5}}\right]$

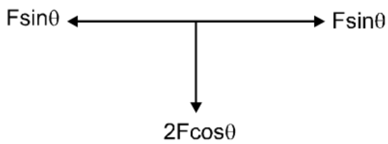
9. 

10. 

$U_c = \frac{3}{2}\frac{KQ}{R}q$

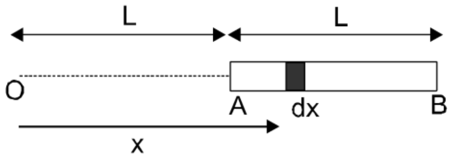
$U_S = \frac{KQ}{R}q$ $\therefore \Delta U = \frac{KQ}{2R}q = \frac{1}{4\pi\varepsilon_0}\cdot\frac{1}{2R}\rho\frac{4\pi R^3}{3}q = \frac{\rho R^2 q}{6\varepsilon_0}$

11. 



$\Rightarrow$ $F_{net} = 2F\cos\theta$

$F_{net} = \frac{2kq\left(\frac{q}{2}\right)}{\left(\sqrt{y^2+a^2}\right)^2}\cdot\frac{y}{\sqrt{y^2+a^2}}$ $\Rightarrow$ $F_{net} = \frac{2kq\left(\frac{q}{2}\right)y}{(y^2+a^2)^{3/2}}$ $\Rightarrow$ $\frac{kq^2y}{a^3} \propto y$

12. 

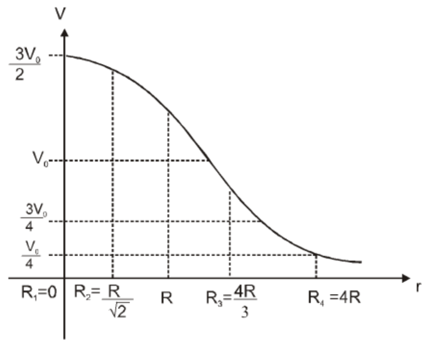
$V = \int_L^{2L}\frac{kdq}{x} = \int_L^{2L}\frac{1}{4\pi\varepsilon_0}\frac{\left(\frac{q}{L}\right)dx}{x} = \frac{q}{4\pi\varepsilon_0 L}\ell n(2)$

13. $V_A - V_0 = -\int_O^A E_x dx$

$V_A - V_0 = \int_0^2 30x^2 dx = -30\,\frac{2^3}{3} = -80V$

14. (2) and (3) is not possible since field lines should originate from positive and terminate to negative charge.
(4) is not possible since field lines must be smooth.
(1) satisfies all required condition.

15. $V_0 = \frac{KQ}{R}$



$V_{(r>R)} = \frac{KQ}{r}$

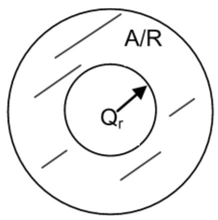
$V_{(r<R)} = \frac{KQ}{2R^3}(3R^2 - r^2)$

$V_{centre} = \frac{3}{2}\frac{KQ}{R} = \frac{3V_0}{2}$

V at R_2 = $\frac{5V_0}{4} = \frac{kQ}{2R^3}(3R^2 - R_2^2)$ $\Rightarrow$ $\frac{5}{2} = 3 - \frac{R_2^2}{R^2}$ $\Rightarrow$ $R_2 = \frac{R}{\sqrt{2}}$

V at R_3 = $\frac{3V_0}{4} = \frac{kQ}{R_3}$ $\Rightarrow R_3 = \frac{4}{3}R$

V at R_4 = $\frac{V_0}{4} = \frac{kQ}{R_4}$ $\Rightarrow R_4 = 4R$ $\therefore$ $R_4 - R_3 = 4R - \frac{4}{3}R = \frac{8R}{3} > R_2$

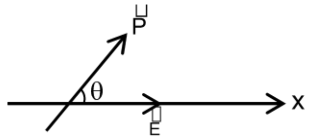


16.

$(E)(4\pi r^2) = \frac{Q + \int_a^r \frac{A}{r} 4\pi r^2 dr}{\varepsilon_0}$

$\Rightarrow$ $(E)\,4\pi r^2 = \frac{Q + \frac{4\pi A}{2}(r^2 - a^2)}{\varepsilon_0}$ $\Rightarrow$ $E = \frac{Q}{4\pi\varepsilon_0 r^2} + \frac{A}{\varepsilon_0 2r^2}(r^2 - a^2) = \frac{Q}{4\pi\varepsilon_0 r^2} + \frac{A}{2\varepsilon_0} - \frac{Aa^2}{2\varepsilon_0 r^2}$

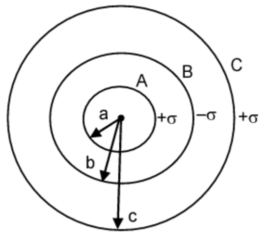
$\frac{Q}{4\pi\varepsilon_0} = \frac{Aa^2}{2\varepsilon_0}$ $\Rightarrow$ $A = \frac{Q}{2\pi a^2}$

17. 

PEsinθ = $P(\sqrt{3}E)$ sin(90° – θ)

tanθ = $\sqrt{3}$

θ = 60°

18. 

$V_B = \frac{1}{4\pi\varepsilon_0}\frac{4\pi a^2\sigma}{b} - \frac{1}{4\pi\varepsilon_0}\frac{4\pi b^2\sigma}{b} + \frac{1}{4\pi\varepsilon_0}\frac{4\pi c^2\sigma}{C} = \frac{\sigma}{\varepsilon_0}\left(\frac{a^2 - b^2}{b} + c\right)$

19. $\Rightarrow \frac{KQq}{d^2/4} + \frac{KQ^2}{d^2} = 0$ $\Rightarrow 4q + Q = 0$ $\Rightarrow q = -\frac{Q}{4}$

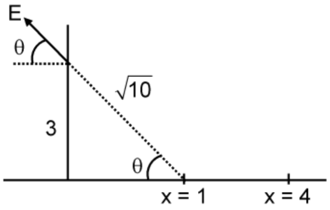
20. Electric field at a distance x on the axis of a ring from the centre is

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

$$\frac{dE}{dx} = K\left[\frac{(R^2+x^2)^{3/2} - x.\frac{3}{2}(R^2+x^2)^{1/2}2x}{(R^2+x^2)^3}\right] = 0$$

$R^2 + x^2 - 3x^2 = 0$

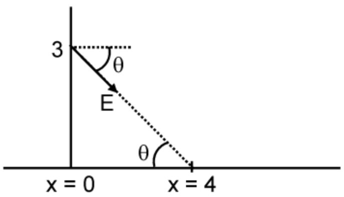
$x^2 = \frac{R^2}{2} \Rightarrow \quad x = \pm\frac{R}{\sqrt{2}}$



21.

Electric field due to charge $\sqrt{10}\mu C$

$\vec{E}_1 = \frac{9\times10^9\times\sqrt{10}\times10^{-6}}{10}\times\frac{1}{\sqrt{10}} - \hat{i} + \frac{9\times10^9\times\sqrt{10}\times10^{-6}}{10}\times\frac{3}{\sqrt{10}}$. Electric field due to charge $-25\mu C$



$\vec{E}_2 = E\cos\theta\hat{i} - E\sin\theta\hat{j}$

$= \frac{9\times10^9\times25\times10^{-6}}{25}\times\frac{4}{5}\hat{i} - \frac{9\times10^9\times25\times10^{-6}}{25}\times\frac{3}{5}\hat{j} = \left[\frac{36}{5}\hat{i} - \frac{27}{5}\hat{j}\right] \times 10^3$ N/C = $(72\hat{i} - 54\hat{j}) \times 10^2$ N/C

$\vec{E}_{net} = (63\hat{i} - 27\hat{j}) \times 10^2$ N/C

22.

$$\int_0^Q dq = 4\pi\int_0^R r^2 dr\rho(r)$$

$$Q = \int_0^R 4\pi r^2 \frac{A}{r^2} e^{-\frac{2r}{a}} dr$$

$$Q = -4\pi A\frac{a}{2}\left[e^{-\frac{2r}{a}}\right]_0^R$$

$$Q = -2\pi aA\left[e^{-\frac{2R}{a}} - 1\right]$$

$$\frac{Q}{2\pi aA} = 1 - e^{-\frac{2R}{a}}$$

$$e^{-\frac{2R}{a}} = 1 - \frac{Q}{2\pi aA}$$

$$-\frac{2R}{a} = \ell n\left[1 - \frac{Q}{2\pi aA}\right] \Rightarrow \quad \frac{2R}{a} = \ell n \frac{1}{1 - \frac{Q}{2\pi aA}}$$

$$R = \frac{a}{2}\ell n\left(\frac{1}{1 - \frac{Q}{2\pi aA}}\right)$$

23. $\frac{q_1}{a^2} = \frac{q_2}{b^2} = \frac{q_3}{c^2}$ = constant

$q_1 + q_2 + q_3 = Q$

$$q_1 = \frac{a^2(Q)}{a^2 + b^2 + c^2}$$

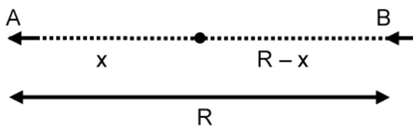
$$q_2 = \frac{b^2(Q)}{a^2 + b^2 + c^2}$$

$$q_3 = \frac{c^2(Q)}{a^2 + b^2 + c^2}$$

$$V = \frac{Kq_1}{a} + \frac{Kq_2}{b} + \frac{Kq_3}{c}$$

$$V = \frac{1}{4\pi\varepsilon_0}[Q]\left(\frac{a + b + c}{a^2 + b^2 + c^2}\right)$$

24.



$V_1 + V_2 = 0$

$$\frac{K4Qa}{x^2} - \frac{K2Qa}{(x - R)^2} = 0$$

$x^2 = 2(x - R)^2$

$$x = \left(\frac{\sqrt{2}R}{\sqrt{2} - 1}\right)$$

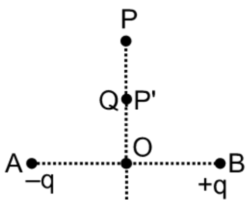
25. $W_{ele} = -\Delta U = U_i - U_f = 0 - \left[\frac{kQ^2}{2} + \frac{kQ^2}{2} + \frac{kQ^2}{2\sqrt{5}} + \frac{kQ^2}{2\sqrt{5}}\right]$

$W_{ele} = \Delta KE = 0$

$W_{ext} + W_{ele} = 0$

$W_{ext} = -W_{ele} = \left[kQ^2 + \frac{kQ^2}{\sqrt{5}}\right] \quad \Rightarrow \quad W_{ele} = \frac{Q^2}{4\pi\varepsilon_0}\left[1 + \frac{1}{\sqrt{5}}\right]$

26.



$F_A = E_A \times Q$

$F_A = \frac{KP}{y^3}Q = F \quad \Rightarrow \quad F_B = E_B \times Q$

$F_B = \frac{KP}{y^3} \cdot (3)^3 \cdot Q$
$= 27 \times F_A = 27F$

27. Theoritical

28. $\frac{1}{4\pi\varepsilon_0}\left(\frac{q^2}{a} + \frac{Q^2}{a} + \frac{Qq}{\sqrt{2}a}\right) = 0,$

Solving : $Q = -\frac{\sqrt{2}q}{(\sqrt{2}+1)}$

29. Work done by magnetic is = 0 work done by = [(2 × 1) + (3 × 1)]q = 5q

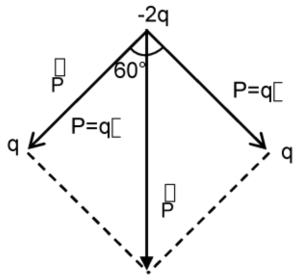
30. Electric potential energy of dipole is

$U = -pE\cos\theta$

$U = -10^{-29} \times 1000 \cos 45°$

$= -\frac{1}{\sqrt{2}} \times 10^{-26} = -5\sqrt{2} \times 10^{-27}$ J ≈ -7×10^{-27} J

31.



$|\vec{P}| = 2P\cos\frac{60°}{2} = 2q\ell\cos 30°$

$= \sqrt{3}q\ell$

$\vec{P} = -\sqrt{3}q\ell\hat{j}$

32. $U_i + K_i = U_f + K_f$

$\frac{KQ^2}{2r_0} + 0 = \frac{KQ^2}{2r} + \frac{1}{2}mv^2$

$v^2 = \frac{KQ^2}{m}\left(\frac{1}{r_0} - \frac{1}{r}\right)$

$v = \sqrt{\frac{KQ^2}{m}\left(\frac{1}{r_0} - \frac{1}{r}\right)}$