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www.askiitians.com
Email: info@askiitians.com
Tel: 1800-2000-838

Class: 12
Subject: Physics
Topic: Electric charges and fields
No. of Questions: 40

Q1. Explain the meaning of the statement 'electric charge of a body is quantized'.
Why can one ignore quantization of electric charge when dealing with macroscopic i.e. large scale charges?

Ans: Electric charge of a body is quantized. This means that only integral (1, 2, …… , n) number of electrons can be transferred from one body to the other. Charges are not transferred in fraction. Hence, a body possesses total charge only in integral multiples of electric charge.

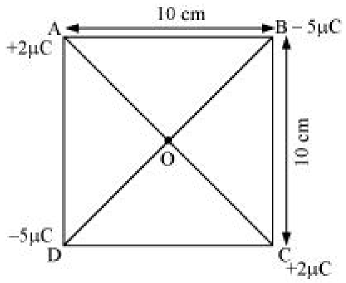
In macroscopic large scale charges, the charges used are huge as compared to the magnitude of electric charge. Hence, quantization of electric charge is of no use on macroscopic scale. Therefore, it is ignored and it is considered that electric charge is continuous.

Q2. When a glass rod is rubbed with a silk cloth, charges appear on both. A similar phenomenon is observed with many other of bodies. Explain how this observation is consistent with the law of conservation of charge.

Ans: Rubbing produces charges of equal magnitude but of opposite nature on the two bodies because charges are created in pairs. This phenomenon of charging is called charging by friction. The net charge on the system of two rubbed bodies is zero. This is because equal amount of opposite charges annihilate each other. When a glass rod is rubbed with a silk cloth, opposite natured charges appear on both the bodies. This phenomenon is in consistence with the law of conservation of energy. A similar phenomenon is observed with many other pairs of bodies.

Q3. Four point charges $q_A = 2\ _u C$, $q_B = -5\ _u C$ are located at the corners of a square ABCD of side 10 cm. What is the force on a charge of 1 $_u$C placed at the centre of the square?

Ans: The given figure shows a square of side 10 cm with four charges placed at its corners. O is the centre of the square.



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Where,
(Sides) AB = BC = CD = AD = 10 cm
(Diagonals) AC = BD = $10\sqrt{2}$ cm
AO = OC = DO = OB = $5\sqrt{5}$ cm
A charge of amount $1\mu C$ is placed at point O.
Force of repulsion between charges placed at corner A and centre O is equal in magnitude but opposite in direction relative to the force of repulsion between the charges placed at corner C and centre O. Hence, they will cancel each other. Similarly, force of attraction between charges placed at corner B and centre O is equal in magnitude but opposite in direction relative to the force of attraction between the charges placed at corner D and centre O. Hence, they will also cancel each other. Therefore, net force caused by the four charges placed at the corner of the square on $1\mu C$ charge at centre O is zero.

Q4. An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?

Ans: An electrostatic field line is a continuous curve because a charge experiences a continuous force when traced in an electrostatic field line cannot have sudden breaks because the charge moves continuously and does not jump from one point to the other.

Q5. Explain why two field line never cross each other at any point?

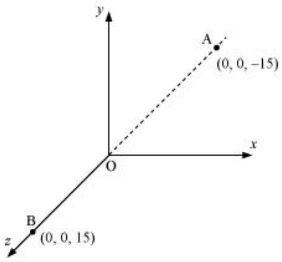
Ans: If two field lines cross each other at a point, then electric field intensity will show two directions at that point. This is not possible. Hence, two field lines never cross each other.

Q6. What is the relevance of large value of K (=81) for water?

Ans: It makes water a great solvent. This is because the binding force of attraction between oppositely charged ions of the substance in water becomes 1/81 of the force between these ions in air.

Q7. A system has two charges q_A= 2.5 × 10^{-7} C and q_B = -2.5×10^{-7} C located at points A: (0, 0, -15 cm) and B: (0, 0, + 15 cm), respectively. What are the total charge and electric dipole moment of the system?

Ans: Both the charges can be located in a coordinate frame of reference as shown in the given figure.



At A, amount of charge, $q_A = 2.5 \times 10^{-7}$ C

At B, amount of charge, $q_B = -2.5 \times 10^{-7}$ C

Total charge of the system,

$q = q_A + q_B$

$= 2.5 \times 10^{-7}\ C - 2.5 \times 10^{-7}\ C$

$= 0$

Distance between two charges at points A and B,

$$d = 15 + 15 = 30\ cm = 0.3\ m$$

Electric dipole moment of the system is given by,

$P = q_A \times d = q_B \times d$

$= 2.5 \times 10^{-7} \times 0.3$

$= 7.5 \times 10^{-8} C$ m along positive z-axis

Therefore, the electric dipole moment of the system is 7.5×10^{-8} C m along positive z-axis.

Q8. A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7} C.
Estimate the number of electrons transferred (from which to which?)
Is there a transfer of mass from wool to polythene?

Ans: When polythene is rubbed against wool, a number of electrons get transferred from wool to polythene. Hence, wool becomes positively charged and polythene becomes negatively charged.

Amount of charge on the polythene piece, $q = -3 \times 10^{-7}$ C

Amount of charge on an electron, $e = -1.6 \times 10^{-9}$ C

n can be calculated using the relation,

$q = ne$

$$n = \frac{q}{e}$$

$$= -3 \times \frac{10^{-7}}{-1.6 \times 10^{-19}}$$

$$= 1.87 \times 10^{12}$$

Therefore, the number of electrons transferred from wool to polythene is 1.87×10^{12}. Yes.

There is a transfer of mass taking place. This is because an electron has mass, $m_e = 9.1 \times 10^{-3}$ kg

Total mass transferred to polythene from wool,

$$m = m_e \times n$$
$$= 9.1 \times 10^{-31} \times 1.85 \times 10^{12}$$
$= 1.706 \times 10^{-18}$kg

Hence, a negligible amount of mass is transferred from wool to polythene.

Q9. Suppose the spheres A and B in Exercise 1.12 have identical sizes. A third sphere of the same size but uncharged is brought in contact with the first, then brought in contact with the second, and finally removed from both. What is the new force of repulsion between A and B?

Ans: Distance between the spheres, A and B, r = 0.5 cm

Initially, the charge on each sphere, q = 6.5 × 10^{-7} C

When sphere A is touched with an uncharged sphere C, $\frac{q}{2}$ amount of charge from A will transfer to sphere C. Hence, charge on each of the spheres, A and C, is $\frac{q}{2}$

When sphere C with charge $\frac{q}{2}$ is brought in contact with sphere B with charge q, total charges on the system will divide into two equal halves given as,

$$\frac{\frac{q}{2}+q}{2} = \frac{3q}{4}$$

Each sphere will each half. Hence, charge on each of the spheres, C and B, is $\frac{3q}{4}$.

Force of repulsion between sphere A having charge $\frac{q}{2}$and sphere B having charge $\frac{3q}{4}$

$$\frac{\frac{q}{2} \times \frac{3q}{4}}{4\pi \in_0 r^2} = \frac{3q^2}{8 \times 4\pi \in_0 r^2}$$
$$= 9 \times 10^9 \times \frac{3 \times (6.5 \times 10^{-7})^2}{8 \times (0.5)^2}$$
$= 5.703 \times 10^{-3}$ N

Therefore, the force of attraction between the two spheres is 5.703 ×10^{-3} N.

Q10. A hemispherical body is placed in uniform electric field E. What is the flux linked with the curved surface, if field is

(a) Parallel to the base
(b) Perpendicular to the base entering the plane surface

Ans: Considering the hemispherical body as a closed body with curved surface (CS) and plane surface (PS), the total flux linked with the body will be zero, as no charge is enclosed by the body.

Total flux = Flux_{CS} + Flux_{PS} = 0

So, When field is parallel to the base,

Flux_{PS} = 0 ; Angle between field and Plane surface is 90.

So, Flux_{CS} = 0

(a) When field is Perpendicular to the base,

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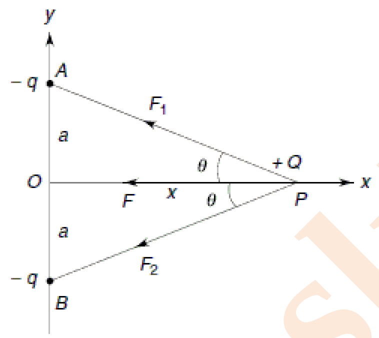
$Flux_{PS} = -E\,\pi r^2$; Angle between field and Plane surface is 180.
So, $Flux_{CS} = E\,\pi r^2$

Q11. Two equal negative charges – q are fixed at points (0, a) and (0, – a) on the y-axis. A positive charge Q is released from rest at a point (2a, 0) on the x-axis. The charge Q will

A. execute simple harmonic motion about the origin
B. move to the origin and remain at rest there
C. move to infinity
D. execute oscillatory but not simple harmonic motion

Right Answer Explanation:
Let the charge Q be at P, with OP = x. The resultant force F is along the x-axis directed towards the origin. The charge Q moves to O, and acquires kinetic energy. It will cross O and move to -ve x-axis until it comes to rest. It is again attracted towards O and cross it and this process continues. Therefore, charge Q executes periodic motion as shown in the figure.



Let $AP = BP = r$. Then

$$F_1 = F_2 = \frac{qQ}{4\pi\varepsilon_0 r^2}$$

The resultant force on Q is

$$F = F_1\cos\theta + F_2\cos\theta = \frac{2qQ}{4\pi\varepsilon_0 r^2}\cos\theta$$

$$F = \frac{2qQx}{4\pi\varepsilon_0 r^3} = \frac{2qQ}{4\pi\varepsilon_0}\,\frac{x}{\left(a^2+x^2\right)^{3/2}}$$

Thus, F is not of the form F = kx (where k = constant) and hence the motion is not simple harmonic. Hence, the correct choice is (4).

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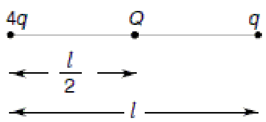
Q12. Three point charges 4q, Q and q are placed in a straight line of length l at points distant 0, l/2 and l respectively. The net force on charge q is zero. The value of Q is

A. q
B. 2q
C. $-\frac{1}{2}q$
D. 4q



The net force on q will be zero if

$$\frac{q \cdot 4q}{4\pi\varepsilon_0 l^2} + \frac{qQ}{4\pi\varepsilon_0 (l/2)^2} = 0$$

$$4q^2 + 4qQ = 0$$

or $$4q(q+Q) = 0$$

$\therefore$ $$Q = -q$$

Hence the correct choice is (1).

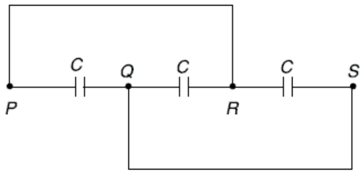
Q13. The work done in carrying a charge q, once round a circle of radius r with a charge Q at the centre is

A. $\frac{qQ}{4\pi\varepsilon_0 r}$
B. $\frac{qQ}{4\pi\varepsilon_0}\frac{1}{\pi r}$
C. $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{1}{2\pi r}\right)$
D. zero

Right Answer Explanation:

The work done in carrying a charge round a closed path is zero. Hence, the correct choice is (4).

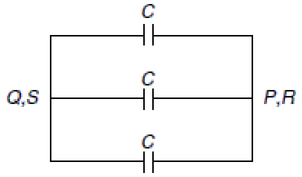
Q14. Three capacitors, each of capacitance C = 3 μF, are connected as shown in the figure. The equivalent capacitance between points P and S is



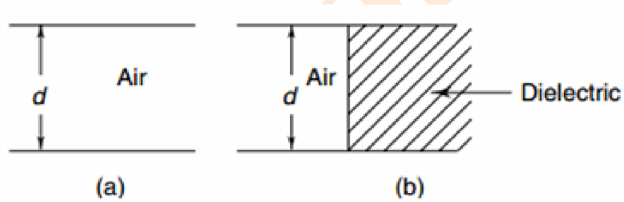
A. 1 μF
B. 3 μF
C. 6 μF
D. 9 μF

Right Answer Explanation:

The three capacitors can be rearranged as shown in figure. The capacitance between points P and S or between points Q and R = sum of the three capacitances = 3C = 9 . Hence the correct choice is (4).



Q15. A parallel plate air-filled capacitor has a capacitance of 2 μF. When it is half-filled with a dielectric of dielectric constant k = 3, its capacitance becomes



A. 4 μF
B. 3 μF
C. 1.5 μF
D. 0.5 μF

Right Answer Explanation:

$C_0 = \frac{\varepsilon_0 A}{d}$, where $C_0 = 2\ \mu F$ (given).

$$C_1 = \frac{\varepsilon_o A}{2d} = \frac{C_o}{2}$$

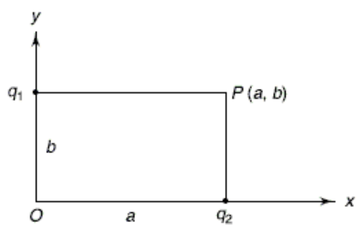
$$C_2 = \frac{k\varepsilon_0 A/2}{d} = \frac{k\varepsilon_0 A}{2d} = \frac{kC_0}{2}$$

$$C = C_1 + C_2 = \frac{C_0}{2} + \frac{kC_0}{2}$$

$$= \frac{C_0}{2}(1+k) = \frac{2\mu F}{2}(1+3) = 4\ \mu F$$

Correct Answer is A

Q16. Two point charges q1 = 2 μC and q2 = 1 μC are placed at distances b = 1 cm and a = 2 cm from the origin on the y and x axes as shown in figure. The electric field vector at point P (a, b) will subtend an angle q with the x-axis given by

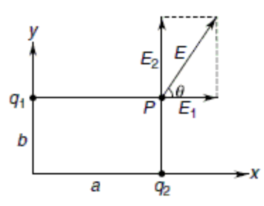


A. $\tan\theta = 1$
B. $\tan\theta = 2$
C. $\tan\theta = 3$
D. $\tan\theta = 4$

Right Answer Explanation:

The electric field E_1 at (a,b) due to q_1 has a magnitude

$$E_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{a^2}$$



And is directed along + x – axis. The electric field E_2 at (a, b) due to q_2 has a magnitude

$$E_2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_2}{b^2}$$

And is directed along + y – axis. The angle θ subtended by the resultant field E with the x – axis is given by

$$\tan\theta = \frac{E_2}{E_1} = \frac{q_2}{q_1}\cdot\frac{a^2}{b^2} = \frac{1}{2}\times\left(\frac{2}{1}\right)^2 = 2$$

Hence the correct choice is (2).

Q17. An electric dipole placed with its axis inclined at an angle to the direction of a uniform electric field experiences

A. a force but no torque
B. a torque but no force
C. a force as well as a torque
D. neither a force nor a torque

Right Answer Explanation:

The correct choice is (2). A torque acts on the dipole which tends to align it along field.

Q18. Four point charges + q, + q, – q and – q are placed respectively at the corners A, B, C and D of a square of side a. The electric potential at the centre O of the square is

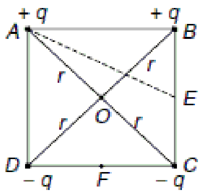
A. $\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a}$
B. $\frac{1}{4\pi\varepsilon_0}\cdot\frac{2q}{a}$
C. $\frac{1}{4\pi\varepsilon_0}\cdot\frac{4q}{a}$
D. zero

Right Answer Explanation:

Refer to the figure, potential at O is

$$V_0 = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r}+\frac{q}{r}-\frac{q}{r}-\frac{q}{r}\right) = 0$$

Hence, the correct choice is (4).

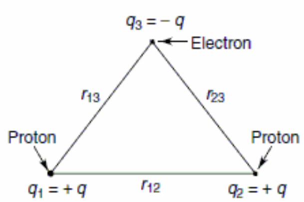


Q19. A neutral hydrogen molecule has two protons and two electrons. If one of the electrons is removed, we get a hydrogen molecular ion (H_2^+). In the ground state of H_2^+, the two protons are separated by roughly 1.5 Å and the electron is roughly 1 Å from each proton. What is the potential energy of the system?

A. 38.4 eV
B. 19.2 eV
C. 9.6 eV
D. Zero

Right Answer Explanation:

Refer to figure. The total potential energy of the arrangement of charges is the sum of the energies of each pair of charges. The potential energy of the system comprising the three charges q_1, q_2 and q_3 is



$$U = W_1 + W_2 + W_3$$
$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right) \quad \text{(i)}$$

Here $q_1 = q_2 = q = +1.6 \times 10^{-19}$ C (proton), $q_3 = -q = -1.6 \times 10^{-19}$ C (electron), $r_{12} = 1.5$ Å $= 1.5 \times 10^{-10}$ m, $r_{13} = r_{23} = 1$ Å $= 1 \times 10^{-10}$ m and $1/4\pi\varepsilon_0 = 9 \times 10^9$ Nm^{2}C^{-2}. Thus

$$U = -\frac{4}{3}\cdot\frac{q^2 \times 10^{10}}{4\pi\varepsilon_0} \text{ joule}$$
$$= -\frac{4}{3}\cdot\frac{q \times 10^{10}}{4\pi\varepsilon_0} \text{ eV}$$
$$= -\frac{4 \times 1.6 \times 10^{-19} \times 10^{10} \times 9 \times 10^9}{3}$$
$$= -19.2 \text{ eV}$$

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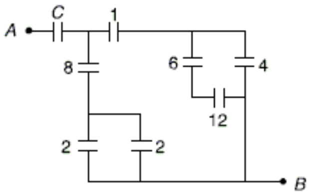
Q20. Figure shows a network of capacitors where the numbers indicate capacitances in microfarad. What must be the value of capacitance C, if the equivalent capacitance between points A and B is to be 1 μF?



A. $\frac{31}{23}\,\mu F$

B. $\frac{32}{23}\,\mu F$

C. $\frac{33}{23}\,\mu F$

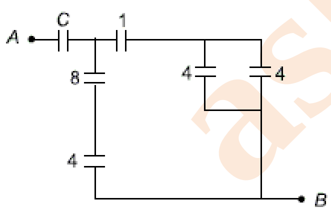
D. $\frac{34}{23}\,\mu F$

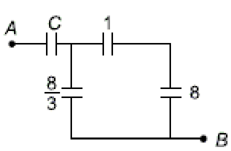
Right Answer Explanation:

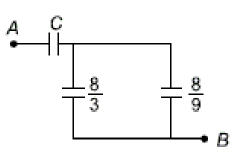
The series combination of 6 and 12 is equivalent to 4 and the parallel combination of 2 and 2 is also equivalent to 4. Therefore, the network can be simplified as shown in figure.

The parallel combination of 4 and 4 is equivalent to 8 and the series combination of 8 and 4 is equivalent to 8/3. Thus, the combination in figure reduces to that in figure.

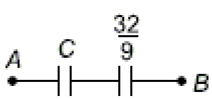
The series combination of 1 and 8 in figure yields 8/9 as shown in figure.







Now 8/3 and 8/9 are in parallel and their equivalent capacitance is 32/9. Therefore, the network finally reduces to that in figure. Since the total capacitance between A and B is to be (i.e. 1 μF), we have



$$1 = \frac{1}{C} + \frac{9}{32}$$

$\Rightarrow$ $C = \frac{32}{23}\ \mu F$. Hence, the correct choice is (2).

Q21. The magnitude of the electric field on the surface of a sphere of radius r having a uniform surface charge density σ is

A. $\frac{\sigma}{\varepsilon_0}$

B. $\frac{\sigma}{2\varepsilon_0}$

C. $\frac{\sigma}{\varepsilon_0 r}$

D. $\frac{\sigma}{2\varepsilon_0 r}$

Right Answer Explanation:

If q is charge on the sphere, the electric field on its surface is

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

But $\sigma = \frac{q}{4\pi r^2}$. Therefore $q = 4\pi r^2\sigma$. Hence

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

Thus the correct choice is (1).

Q22. The electric potential due to an extremely short dipole at a distance r from it, is proportional to

A. $\frac{1}{r}$

B. $\frac{1}{r^2}$

C. $\frac{1}{r^3}$

D. $\frac{1}{r^4}$

Right Answer Explanation:
The correct choice is (2).

Q23.If n drops, each of capacitance C, coalesce to form a single big drop, the capacitance of the big drop will be

A. n^3C
B. nC
C. $n^{1/2}C$
D. $n^{1/3}C$

Right Answer Explanation:

If ρ is the density of a small drop and r its radius, then the mass of each small drop is m = $\frac{4\pi}{3} r^3 \rho$.

If n such drops coalesce to form a big drop of radius R, then the mass of the big drop is nm = $\frac{4\pi}{3} R^3 \rho$.
Hence R = $n^{1/3}$ r. Now, the capacitance of a sphere is proportional to its radius.
Hence the capacitance of the drop will be C' = $n^{1/3}$ C. Hence the correct choice is (4).

Q24. A capacitor of capacitance C is fully charged by a 200 V supply. It is then discharged through a small coil of resistance wire embedded in a thermally insulated block of specific heat 2.5 $\times$ 10^2 J kg^{-1} K^{-1} and of mass 0.1 kg. If the temperature of the block rises by 0.4 K, what is the value of C?

A. 500 μF
B. 400 μF
C. 300 μF
D. 200 μF

Right Answer Explanation:
Energy stored in the capacitor is

$$\frac{1}{2}CV^2 = \frac{1}{2}\times C\times(200)^2 = 2\times10^4\times C \text{ joule}$$

Energy appearing as heat in the block is

$$m\,c\theta = 0.1\times2.5\times102\times0.4 = 10 \text{ J}$$

Therefore

$$2 \times 10^4 \times C = 10$$

or C = 5 $\times$ 10–4 F = 500 μF

Q25. Eight dipoles of charges of magnitude q are placed inside a cube. The total electric flux through the cube will be

A. $\frac{8q}{\varepsilon_0}$
B. $\frac{16q}{\varepsilon_0}$
C. $\frac{q}{\varepsilon_0}$
D. zero

Right Answer Explanation:

Since a dipole consists of two equal and opposite charges, the net charge of a dipole is zero. Hence the correct choice is (4).

Q26. The introduction of a metal plate between the plates of a parallel plate capacitor increases its capacitance by 4.5 times. If d is the separation of the two plates of the capacitor, then the thickness of the metal plate introduced is

A. $\frac{d}{3}$
B. $\frac{5d}{9}$
C. $\frac{7d}{9}$
D. d

Right Answer Explanation:

Initial capacitance $C = \frac{\varepsilon_0 A}{d}$. When a metal plate of thickness t is introduced, the capacitance becomes $C' = \frac{\varepsilon_0 A}{(d-t)}$. Given C' = 4.5 C

Thus, $\frac{\varepsilon_0 A}{d-t} = \frac{\varepsilon_0 A}{d} \times \frac{9}{2}$

which gives 9(d – t) = 2d or t = $\frac{7d}{9}$ which is choice (3).

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Q27. An electron of mass m_e, initially at rest, move through a certain distance in a uniform electric field in time t_1. A proton of mass m_p, also initially at rest, takes time t_2 to move through an equal distance in this uniform electric field. Neglecting the effect of gravity, the ratio t_2/t_1 is nearly equal to

A. 1

B. $\left(\frac{m_p}{m_e}\right)^{1/2}$

C. $\left(\frac{m_e}{m_p}\right)^{1/2}$

D. 1836

Right Answer Explanation:

Force $F = qE$. Therefore, acceleration $a = qE/m$.

Now distance moved in time t is

$$s = \frac{1}{2}at^2 = \frac{1}{2}\left(\frac{qE}{m}\right)t^2.$$

For electron: $s_e = \frac{1}{2}\left(\frac{qE}{m_e}\right)t_1^2$

For proton: $s_p = \frac{1}{2}\left(\frac{qE}{m_p}\right)t_2^2$

Given $s_e = s_p$. Therefore

$$\frac{t_1^2}{m_e} = \frac{t_2^2}{m_p} \text{ or } \frac{t_2}{t_1} = \left(\frac{m_p}{m_e}\right)^{1/2}$$

Hence the correct choice is (2).

Q28. A dielectric slab of thickness d is inserted in a parallel plate capacitor whose negative plate is at x 0 and positive plate is at x = 3d. The slab is equidistant from the plates. The capacitor is given some charge. As x goes from 0 to 3d,

A. the magnitude of the electric field remains the same
B. the direction of the electric field changes continuously
C. the electric potential increases continuously
D. the electric potential increases at first, then decreases and again increases

Right Answer Explanation:

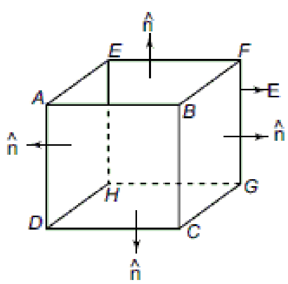
The insertion of the dielectric slab decreases the electric field without changing its direction. The electric potential increases as we go from the negative to the positive plate. Hence, the correct choice is (3).

Q29. The flux of electric field E = 200 $\hat{i}$ NC^{-1} through a cube of side 10 cm, oriented so that its faces are parallel to the co – ordinate axes is

A. zero
B. 2 NC^{-1} m^2
C. 6 NC^{-1} m^2
D. 12 NC^{-1} m^2

Right Answer Explanation:

Refer to figure. Let S be the surface area of each face of the cube. The flux through surfaces ABCD and EFGH is zero because these surfaces are parallel to the electric field E $(\theta = 90^\circ)$.



Flux through face BFGC is ϕ_1 = ES cos 0° ES. Flux through face AEHD is ϕ_2 = ES cos 180° = – ES. Total flux through the cube = $\phi_1 + \phi_2$ = ES – ES = 0.
Hence, the correct choice is (1).

30. The magnitude of electric field at a distance x from a charge q is E. An identical charge is placed at a distance 2x from it. The magnitude of the force experienced by it is

A. pE
B. 2 pE
C. $\frac{qE}{2}$
D. $\frac{qE}{4}$

Right Answer Explanation:

Given $E = \frac{q}{4\pi\varepsilon_0 x^2}$. Hence the magnitude of the electric field at a distance $2x$ from charge q is

$$E' = \frac{q}{4\pi\varepsilon_0 (2x)^2} = \frac{q}{4\pi\varepsilon_0 x^2} \times \frac{1}{4} = \frac{E}{4}$$

Therefore, the force experienced by a similar charge q at a distance $2x$ is

$$F = qE' = \frac{qE}{4}$$

Hence the correct choice is (4).

Q31. Three capacitors of capacitances 2 pF, 3 pF and 4 pF are connected in parallel.
What is the total capacitance of the combination?
Determine the charge on each capacitor if the combination is connected to a 100 V supply.

Sol. Capacitances of the give capacitors are

C_1 = 2 pF
C_2 = 3 pF
C_3 = 4 pF
For the parallel combination of the capacitors, equivalent capacitor C' is given by the algebraic sum,

$$C' = 2 + 3 + 4 = 9\,pF$$

Therefore, total capacitance of the combination is 9 p F.
Supply voltage, $V = 100\,V$
The voltage through all the three capacitors is same $= V = 100V$
Charge on a capacitor of capacitance C and potential difference V is given by the relation,

$$q = VC \ldots.(i)$$

For C = 2 pF,
Charge $= VC = 100 \times = 200\,pC = 2 \times 10^{-10}\,C$
For $C = 4\,pF$,
Charge $= VC = 100 \times 4 = 200\,pC = 4 \times 10^{-10}$ C

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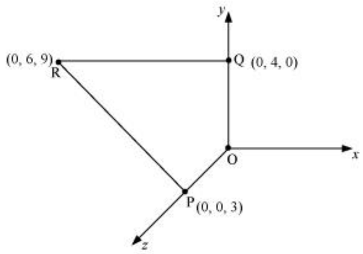
B -147, Sector -6 Noida, UP - 201301,
www.askiitians.com
Email: info@askiitians.com
Tel: 1800-2000-838

Q32. A charge of 8 mC is located at the origin. Calculate the work done in taking a small charge of -2×10^{-10} C from a point P (0, 0, 3 cm) to a point Q (0, 4 cm,) Via a point R (0, 6 cm, 9cm)

Sol. Charge located at the origin, $q = 8\,mC = 8 \times 10^{-3} C$

Magnitude of a small charge, which is taken from a point P to point R to point Q, $q_1 = -2$

All the points are represented in the given figure.



Point P is at a distance, d_1 = 3 cm, from the origin along z-axis.

Point Q is at a distance, d_2 = 4 cm, from the origin along y-axiz.

Potential at point P, $V = \frac{q}{4\pi \in_0 d_2}$

Work done (W) by the electrostatic force is independent of the path.

$\therefore$ W $= q_1[V_2 - V_1]$

$$= q_1\left[\frac{q}{4\pi \in_0 d_2} - \frac{q}{4\pi \in_0 d_1}\right]$$

$= \frac{qq_1}{4\pi\epsilon_0}\left[\frac{1}{d_2} - \frac{1}{d_1}\right]$ ......(i)

Where, $\frac{1}{4\pi\epsilon_0} = 9 \times N\, m^2 C^{-2}$

$\therefore$ W$= 9 \times 10^9 \times 8 \times 10^{-3} \times (-2 \times 10^{-9})\left[\frac{1}{0.04} - \frac{1}{0.03}\right]$

$$= -144 \times 10^{-3} \times \left(-\frac{25}{3}\right)$$

$$= 1.27\,J$$

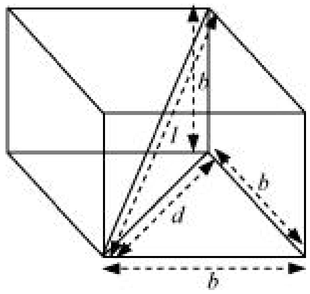
Therefore, work done during the process is 1.27 J.

Q33. A cube of side d has a charge q at each of its vertices. Determine the potential and electric field due to this charge array at the centre of the cube.

Sol. Length of the side of a cube $= b$

Charge at each of its vertices $= q$

A cube of side b is shown in the following figure.



$d =$ Diagonal of one of the six faces of the cube

$$d^2 = \sqrt{b^2 + b^2 = \sqrt{2b^2}}$$

$$d = b\sqrt{2}$$

l = Length of the diagonal of the cube

$l^2 = \sqrt{d^2 + b^2}$

$$= \sqrt{\left(\sqrt{2}b\right)^2 + b^2} = \sqrt{2b^2 + b^2 = \sqrt{3b^2}}$$

$$l = b\sqrt{3}$$

$r = \frac{1}{2} = \frac{b\sqrt{3}}{2}$ *is* the distance between the centre of the cube and one of the eight vertices

The electric potential (V) at the centre of the cube is due to the presence of eight charges at the vertices.

$$v = \frac{8q}{4\pi \in_0}$$

$$= \frac{8q}{4\pi \in_0 \left(b \frac{\sqrt{3}}{2}\right)}$$

$$= \frac{4q}{\sqrt{3\pi \ \in_0 b}}$$

Therefore, the potential at the centre of the cube is $\frac{4q}{\sqrt{3\pi}\in_0 b.}$

The electric field at the centre of the cube, due to the eight charges, gets cancelled. This is because the charges are distributed symmetrically with respect to the centre of the cube. Hence, the electric field is zero at the centre.

Q34. What is the area of the plates of a 2 F parallel plate capacitor, given that the separation between the plates is 0.5 cm? [You will realize from your answer why ordinary capacitors are in the range of μF or less. However, electrolytic capacitors do have a much large capacitance (0.1 F) because of very minute separation between the conductors.

Sol. Capacitance of a parallel capacitor, V = 2 F

Distance between the two plates, d = 0.5 cm = 0.5×10^{-2} m

Capacitance of a parallel plate capacitors is given by the relation,

$$C = \frac{\epsilon_0 A}{d}$$
$$A = \frac{Cd}{\epsilon_0}$$

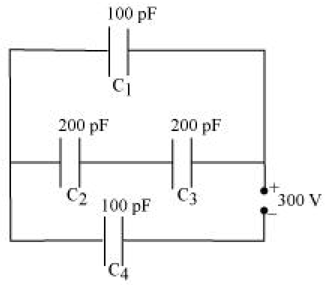
Where,

$$\epsilon_0 = Permittivity\ of\ free\ space = 8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$$

$\therefore A = \frac{2 \times 0.5 \times 10^{-2}}{8.85 \times 10^{-12}} = 1130\ km^2$

Hence, the area of the plates is too large. To avoid this situation, the capacitance is taken in the range of μF.

Q35. Obtain the equivalent capacitance of the network in Fig. 2.35. For a 300 V supply, determine the charge and voltage across each capacitor.



Sol. Capacitance of capacitor C_1 is 100 pF.

Capacitance of capacitor C_2 is 200 pF.

Capacitance of capacitor C_3 is 200 pF.

Capacitance of capacitor C_4 is 100 pF.

Capacitors C_2 and C_3 are connected in series. Let their equivalent capacitance be C'.

$\therefore \frac{1}{C'} = \frac{1}{200} + \frac{1}{200} = \frac{2}{200}$

C'=100 pF

Capacitors C_1 and C' are in parallel. Let their equivalent capacitance be C".

$\therefore$ C"=C'+C_1

=100+100=200 pF

C" and C_4 are connected in series. Let their equivalent capacitance be C.

$\therefore \frac{1}{C} = \frac{1}{C"} + \frac{1}{C_4}$

$= \frac{1}{200} + \frac{1}{100} = \frac{2+1}{200}$

$C = \frac{200}{3} pF$

Hence, the equivalent capacitance of the circuit is $\frac{200}{3}\ pF$

Potential difference across C” = V”

Potential difference across $C_4 = V_4$

$\therefore V" + V_4 = V = 300V$

Charge on C_4 is given by,

$Q_4 = CV$

$= \frac{200}{3} \times 10^{-12} \times 300$

$= 2 \times 10^{-8}$ C

$\therefore V_4 = \frac{Q_4}{C_4}$

$= \frac{2\times10^{-8}}{100\times10^{-12}} = 200$ V

$\therefore$ Voltage across C_1 is given by, $V_1 = V - V_4$

= 300 – 200 = 100 V

Hence, potential difference, V_1, across C_1 is 100 V.

Charge on C_1 is given by,

$Q_1 = C_1V_1$

$= 100 \times 10^{-12} \times 100$

$= 10^{-8}$ C

C_2 and C_3 having same capacitances have a potential difference of 100 V together. Since C_2 and C_3 are in series, the potential difference across C_2 and C_3 is given by,

$V_2 = V_3 = 50$ V

Therefore, charge on C_2 is given by,

$Q_2 = C_2V_2$

$= 200 \times 10^{-12} \times 50$

$= 10^{-8}$ C

And charge on C_3 is given by,

$Q_3 = C_3V_3$

$= 200 \times 10^{-12} \times 50$

$= 10^{-8}$ C

Hence, the equivalent capacitance of the given circuit is $\frac{200}{3}$ pF with,

$Q_1 = 10^{-8}$ C,	$V_1 = 100$ V
$Q_2 = 10^{-8}$ C,	$V_2 = 50$ V
$Q_3 = 10^{-8}$ C,	$V_3 = 50$ V
$Q_4 = 2 \times 10^{-8}$C,	$V_4 = 200$ V

Q36. Two large conducting spheres carrying charges Q_1 and Q_2 are brought close to each other.

Is the magnitude of electrostatic force between them exactly given by $Q_1Q_2/4\pi\epsilon_0 r^2$, where r is the distance between their centres?

A small test charge is released at rest at a point in an electrostatic field configuration. Will it travel along the field line passing through that point?

What is the work done by the field of a nucleus in a complete circular orbit of the electric potential also discontinuous there?

What meaning would you give to the capacitance of a single conductor?

Guess a possible reason why water has a much greater dielectric constant (=80) than say, mica (=60)

Sol. The force between two conducting spheres is not exactly given by the expression, $Q_1 Q_2/4\pi\epsilon_0 r^2$ because there is a non-uniform charge distribution on the spheres.

Yes,

Transweb Educational Services Pvt Ltd
B -147, Sector -6 Noida, UP - 201301,
www.askiitians.com
Email: info@askiitians.com
Tel: 1800-2000-838

If a small test charge is released at rest at a point in an electrostatic field configuration, then it will travel along the field lines passing through the point, only if the field lines are straight. This is because the field lines give the direction of acceleration and not of velocity.

Whenever the electron completes an orbit, either circular or elliptical, the work done by the field of a nucleus is zero.

No

Electric field is discontinuous across the surface of a charged conductor. However, electric potential is continuous.

The capacitance of a single conductor is considered as a parallel plate capacitor with one of its two plates at infinity.

Water has an unsymmetrical space as compared to mica. Since it has a permanent diploe moment, it has a great dielectric constant than mica.

Q37. If Coulomb's law involved $1/r^3$ dependence (instead of $1/r^2$), would Gauss's law be still true?

Sol. Gauss's law will not be true, if Coulomb's law involved $1/r^3$ dependence, instead of$1/r^2$, on r.

Q38. Describe schematically the equipotential surfaces corresponding to

A constant electric field in the z=direction,

A field that uniformly increases in magnitude but remains in a constant (say, z) direction,

A single positive charge at the origin, and

A uniform grid consisting of long equally spaced parallel charged wires in a plane.

Sol. Equidistant planes parallel to the x-y plane are the equipotential surfaces.

Planes parallel to the x-y plane are the equipotential surfaces with the exception that when

Concentric spheres centered are the equipotential surfaces with the exception that when Concentric spheres centered at the origin are equipotential surfaces.

A periodically varying shape near the given grid is the equipotential surface. This shape gradually reaches the shape of planes parallel to the grid at a larger distance.

Q39. In a Van de Graaff type generator a spherical metal shell is to be a 15×10^6 V electrode. The dielectric strength of the gas surrounding the electrode is 5×10^7 Vm^{-1}. What is the minimum radius of the spherical shell required? (You will learn from this exercise why one cannot build an electrostatic generator using a very small shell which requires a small

Sol. Potential difference, $V = 15 \times 10^6$ V

Dielectric strength of the surrounding gas $= 5 \times 10^7$V/m

Electric field intensity, E = Dielectric strength $= 5 \times 10^7$ V/m

Minimum radius of the spherical shell required for the purpose is given by,

$$r = \frac{V}{E}$$

$$= \frac{15\times10^6}{5\times10^7} = 0.3\ m = 30 \text{ cm}$$

Hence, the minimum radius of the spherical shell required is 30 cm.

Q40. A small sphere of radius $r_1$and charge q_1 is enclosed by a spherical shell of radius r_2 and charge q_2. Show that if q_1 is positive, charge will necessarily flow from the sphere to the shell (when the two are connected by a wire) no matter what the charge q_2 on the shell is.

Sol. According to Gauss' law the electric field between a sphere and a shell is determined by the charge q_1 on a small sphere. Hence, the potential difference, V, between the sphere and the shell is independent of charge q_2. For positive charge q_1, potential difference V is always positive.