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12

PHYSICS

Study material

Unit - 1

ELECTROSTATICS

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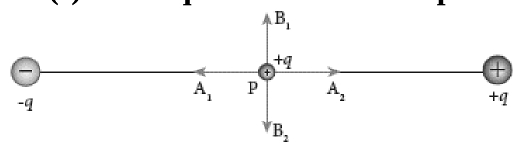
UNIT – I

ELECTROSTATICS

Multiple Choice Questions

1. Two identical point charges of magnitude -q are fixed as shown in the figure below. A third charge +q is placed midway between the two charges at the point P. Suppose this charge +q is displaced a small distance from the point P in the direction indicated by the arrows, in which direction(s) will +q be stable with respect to the displacement?

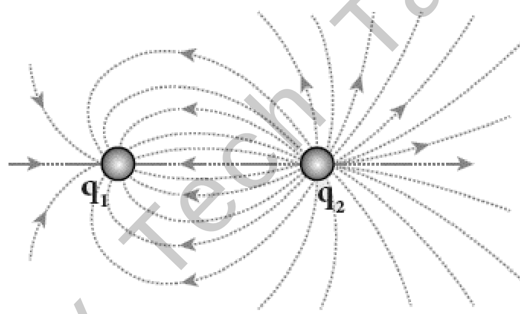


a) A_1 and A_2 **b) B_1 and B_2**   c) both directions   d) No stable

2. Which charge configuration produces a uniform electic field?

a) Point Charge   b) infinite uniform line charge
c) uniformly charged infinite plane   d) uniformly charged spherical shell

3. When is the ratio of the charges $\left|\frac{q_1}{q_2}\right|$ for the following electric field line pattern?

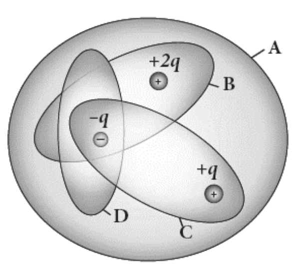


a) 1/5   b) 25/11   c) 5   **d) 11/25**

4. An electric dipole is placed at an alignment angle = 30^0 with an electric field of $2 \times 10^5 NC^{-1}$. It experiences a torque equal to 8 Nm. The charge on the dipole if the dipole length is 1 cm is

a) 4mC   **b) 8mC**   c) 5mC   d) 7 mC

5. Four Gaussian surfaces are given below with charges inside each Gaussian surface. Rank the electric flux through each Gaussian surface in increasing order.



a) D < C< B < A   b) A < B = C < D   c) C < A = B < D   d) D>C>B>A

6. The total electric flux for the following closed surface which is kept inside water.

a) $80q/\varepsilon_i$ **b) $q/40\varepsilon_i$** c) $q/ 80\varepsilon_i$ d) $q/160\ \varepsilon_i$

7. Two identical conducting balls having positive charges q_1 and q_2 are separated by a center to center distance r. if they are made to touch each other and then separated to the same distance, the force between them will be

a) less than before b) same as before **c) more than before** d) zero

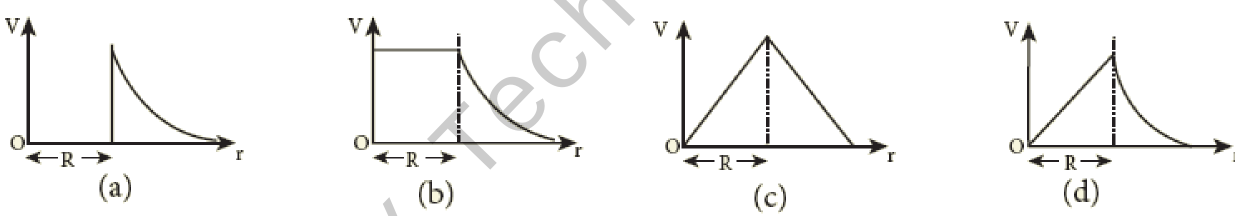
8. Rank the electrostatic potential energies for the given system of charges in increasing order

a) 1 = 4 < 2 < 3 b) 2= 4 < 3 < 1 c) 2 = 3 < 1 < 4 d) 3< 1 < 2 < 4

9. An electric field $\vec{E} = 10x\vec{i}$ exists in a certain region of space. Then the potential difference V = V_0 - V_A, Where V_0 is the potential at the origin and V_{BA} is the potential at x = 2 m is

a) 10V **b) -20 V** c) +20 V d) -10V

10. A thin conducting spherical shell of radius R has a charge Q which is uniformly distributed on its surface. The correct plot for electrostatic potential due to this spherical shell is



Ans: b

11. Two points A and B are maintained at a potential of 7v and -4v respectively. The work done in moving 50 electrons from A to B is

a) 8.80×10^{-17} J b) -8.80×10^{-17} J c) 4.40×10^{-17} J d) 5.80×10^{-17} J

12. If voltage applied on a capacitor is increased from V to 2V, Choose the correct conclusion.

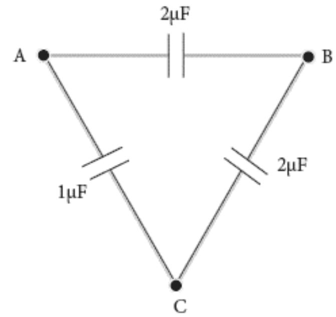
a) Q remains the same, C is doubled b) Q is doubled, C doubled

c) C remains same , Q doubled c) Both Q and C remain same

13. A parallel plate capacitor stores a charge Q at a voltage V. Suppose the area of the parallel plate capacitor and the distance between the plates are each doubled then which is the quantity that will change?

a) Capacitance b) Charge c) Voltage **d) Energy density**

14. Three capacitors are connected in triangle as shown in the figure. The equivalent capacitance between the points A and C is



a) 1μF **b) $2\ \mu F$** c) $3\ \mu F$ d) $\frac{1}{4}\mu F$

15. Two metallic spheres of radii 1 cm and 3 cm are given charges of $-1\times 10^{-2}C$ and $5\times 10^{-2}C$ respectively. If these are connected by a conducting wire, the final charge on the bigger sphere is

a) $3\times 10^{-2}C$ b) $4\times 10^{-2}C$ c) $1\times 10^{-2}C$ d) $2\times 10^{-2}C$

Solutions

1. For B_1 , $B_2 \rightarrow \theta = 90^0$

$V = \frac{1}{4\pi\varepsilon_0}\frac{P\cos\theta}{r^2}$

V = 0 ($\cos 90^0 = 0$)

W = V.q = 0

So, +q is stable along B_1 and B_2

4. $\theta = 30^0$, $E = 2\times 10^5 NC^{-1}$,

$\tau = 8Nm$, 2a = 1 $cm = 10^{-2}m$

$$\tau = qE2a\sin\theta$$

$$q = \frac{\tau}{E\ 2a\sin\theta}$$

$$q = \frac{8}{2\times 10^5\times 10^{-2}\times\sin 30^0}$$

$$q = \frac{8}{2\times 10^3\times\frac{1}{2}}$$

$$q = 8\times 10^{-3}C\ (or)\ q = 8mc$$

5. Net charge in

i) A = 2q

ii) B = q

iii) C = 0

iv) D = -q

According to Gauss theorem

$\phi = \frac{q}{\varepsilon_0}$; $\phi \propto q$

Electric flux ϕ increase. q also increase.

6. *[net charge Q = -q+2q+q = 2q]*

$\phi = \frac{Q}{\varepsilon} = \frac{Q}{\varepsilon_0\varepsilon_r} = \frac{2q}{80\ \varepsilon_0} = \frac{q}{40\ \varepsilon_0}$

7. *Before contact*

$F = K\frac{q_1 q_2}{r^2} = k\ \frac{24}{r^2}$ $[q_1 = 4C, q_2 = 6C]$

After contact

$F' = k\ \frac{25}{r^2}$ $F' > F$ $[q_1 = 5C, q_2 = 5C]$

$[\therefore \frac{q_1+q_2}{r^2} = \frac{4+6}{2} = 5C = q]$

8. 1) $u = K\ \frac{-Q^2}{r}$ 2) $u = K\ \frac{2Q^2}{r}$

3) $u = K\ \frac{Q^2}{r}$ 4) $u = K\ \frac{-2Q^2}{2r} = \frac{-Q^2}{r}$

9. $E = -\frac{dv}{dx}$

dv = -E dx

$\int_{V_0}^{v_A} dv = -\int_0^2 10x\ dx$

$v_{A-}\ v_0 = -10\left[\frac{x^2}{2}\right]_0^2 = -10\ (4/2) = -20V$

10. *V = Constant (Inside)*

$V \propto \frac{1}{r}$ *(outside)*

11. $V_{AB} = 7-(-4) = 11V,\ n = 50$

W = Vq

W = V(ne)

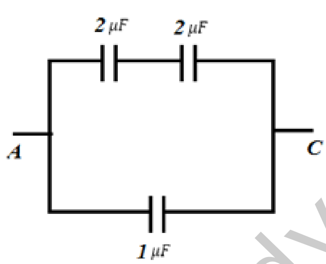
$W = 11\times 50\times 1.6\times 10^{-19}$

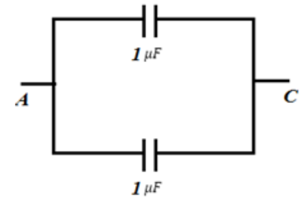
$W = 880\times 10^{-19} J (or) 8.80\ \times 10^{-17} J$

12. Q $\propto V$, $\therefore C = \frac{q}{v}$
If V to 2V then Q to 2Q
C remains same. Because $C = \frac{\varepsilon_0 A}{d}$

13. a) $C = \frac{\varepsilon_0 A}{d}$, $C' = \frac{\varepsilon_0 2A}{2d} = \frac{\varepsilon_0 A}{d}$
$C = C'$
b) Q $\propto V$, So V not change then Q not change
c) $V = \frac{Qd}{\varepsilon_0 A}$, $V' = \frac{Q2d}{2\varepsilon_0 A} = \frac{Qd}{\varepsilon_0 A}$
V' = V
d) $u_E = \frac{1}{2}\,\varepsilon_0(Ad)E^2$
$$u_E{}' = \frac{1}{2}\,\varepsilon_0(2A \times 2d)E^2$$
$$u_E{}' = 4 \times \frac{1}{2}\,\varepsilon_0(Ad)E^2$$
$$u_E' = 4u_E$$
So, Energy density change.

14.





Equal capacitors are connected in series,
$$(C_s = \frac{C}{n} = \frac{2\mu F}{2} = 1\mu F)$$
Equal capacitors are connected in parallel
$$(C_P = 1\mu F + 1\mu F = 2\,\mu F)$$

15. $r_1 = 10^{-2}m,\ r_2 = 3 \times 10^{-2}m,$
$q_1 = -1 \times 10^{-2}C, q_2 = 5 \times 10^{-2}C$
If these are connected by conducting wire, Q = $q_1 + q_2$;
$q_2 = Q - q_1 = Q - x$ [$\therefore\ q_1 = x$]
Q $= -1 \times 10^{-2} + 5 \times 10^{-2}$
Q = $4 \times 10^{-2}C$
Potential of both sphere become equal
$V_1 = V_2$
$$\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$$
(Here $q_1 = x, q_2 = Q - x$)
$$\frac{x}{1 \times 10^{-2}} = \frac{Q - x}{3 \times 10^{-2}}\ (or)$$
$$\frac{x}{1} = \frac{Q - x}{3}$$
3x = Q-x $\Rightarrow 4x = Q \Rightarrow x = \frac{Q}{4}$
$= \frac{4 \times 10^{-2}}{4} = 10^{-2}$
$x = q_1 = 1 \times 10^{-2}$
$q_2 = Q - x$
$q_2 = 4 \times 10^{-2} - 1 \times 10^{-2}$
$= 3 \times 10^{-2}$C

II Short Answer Questions

1. What is meant by quantisation of charges?

- The charge q on any object is equal to an integral multiple of this fundamental unit of charge e.

q = ne

- Here , n is any integer $(0, \pm1, \pm2, \pm3, \pm4, \ldots)$ and e = $1.6 \times 10^{-19}C$. This is called quantisation of charges.

2. Write down Coulomb's law in vector form and mention what each term represents.

$$\overrightarrow{F_{21}} = k\,\frac{q_1 q_2}{r^2}\,\widehat{r_{12}}$$

$\overrightarrow{F_{21}}$ - Force on the q_2 charge due to q_1. ; q_1, q_2 – charges

$\widehat{r_{12}}$ – the unit vector directed from charge q_1 to charge q_2 ; k - proportionality constant.

r - Distance between two charges.

An electric line of force is the path along which a unit positive charge will move inside the electric field, if it is free to

3. What are the differences between Coulomb force and gravitational force?

Coulomb force	Gravitational force
1. Coulomb force, also called electrostatic force or Coulomb interaction, attraction or repulsion of particles or objects because of their electric charge	1. The gravitational force is a force that attracts any two objects with mass.
2. Between two charges can be attractive and repulsive depending on the nature of charges	2. Between two masses always attractive.
3. Constant k = $9 \times 10^{9} Nm^2C^{-2}$	3. Constant G =$6.626 \times 10^{-11} Nm^2kg^{-2}$
4. Depends on nature of the medium	4. Independent of the medium
5. If the charges are in motion, yet another force (Lorentz force) comes into play in addition to coulomb force.	5. Force between two point masses are same whether two masses are at rest or in motion
6. $\overrightarrow{F_{21}} = k\,\frac{q_1 q_2}{r^2}\,\widehat{r_{12}}$	6. $\vec{F} = -\frac{GM_1M_2}{r^2}\,\hat{r}$

4. Write a short note on superposition principle.

- The superposition principle explains the interaction between multiple charges.
- According to this superposition principle, the total force acting on a given charge is equal to the vector sum of forces exerted on it by all the other charges.

$$\overrightarrow{F_1^{tot}} = \overrightarrow{F_{12}} + \overrightarrow{F_{13}} + \overrightarrow{F_{14}} + \ldots\ldots\ldots \overrightarrow{F_{1n}}$$

$$\overrightarrow{F_1^{tot}} = k\left\{\frac{q_1q_2}{r_{21}^2}\,\widehat{r_{21}} + \frac{q_1q_2}{r_{31}^2}\,\widehat{r_{31}} + \frac{q_1q_2}{r_{41}^2}\,\widehat{r_{41}} + \cdots . + \frac{q_1q_2}{r_{n1}^2}\,\widehat{r_{n1}}\right\}$$

5. Define 'Electric field'.

- The electric field at the point P at a distance r from the point charge q is the electrostatic force experienced by a unit charge due to point charge and is given by

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

- The electric field is a vector quantity and its SI unit is Newton per Coulomb (NC^{-1}).

6. What is mean by 'Electric field lines' or Electric line of force?

An electric field line is an imaginary line or curve drawn through a space so that the tangent at any point of it is in the direction of electric field vector at that point.

Electric field vectors are visualized by the concept of electric field lines are form a set of continuous lines which are the visual representation of the electric field in some region of space.

7. The electric field lines never intersect.Justify.

- No two electric field lines intersect each other. If two lines cross at a point, then there will be two different electric field vectors at the same point.
- As a consequence, if some charge is placed in the intersection point, then it has to move in two different directions at the same time, which is physically impossible.
- This can be proved by the method of contradiction.
- Hence, electric field lines do not intersect.

8. Define 'Electric dipole'

Two equal and opposite charges separated by a small distance constitute an electric dipole.

9. What is the general definition of electric dipole moment?

- The electric dipole moment is defined as $\vec{P} = q\vec{r_+} = \ q\vec{r_-}$
- Here. $\vec{r_+}$ is the position vector of +q from the origin and $\vec{r_-}$ is the position vector of -q from the origin
- The SI unit of dipole moment is coulomb meter (Cm).

10. Define "electrostatic potential".

The electrostatic potential at a point P is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point P in the region of the external electric field $\vec{E}$ without acceleration.

11. What is an equipotential surface?

An equipotential surface is a surface on which all the points are at the same potential.

12. What are the properties of an equipotential surface?

(i) The work done to move a charge q between any two points A and B, W = q ($V_B - V_A$). If the points A and B lie on the same equipotential surface, work done is zero because $V_A = V_B$.

(ii) The electric field is normal to an equipotential surface.

13. Give the relation between electric field and electric potential.

$$E = -\frac{dv}{dx}$$

$$\vec{E} = -\left(\frac{\partial V}{\partial x}\,\hat{\imath} + \frac{\partial V}{\partial x}\,\hat{\jmath} + \frac{\partial V}{\partial x}\,\hat{k}\right)$$

14. Define 'electrostatic potential energy'.

Electrostatic potential energy for system of charges is equal to the work done to arrange the charges in the given configuration.

15. Define 'electric flux' .

- The number of electric field lines crossing a given area kept normal to the electric field lines is called electric flux.
- Unit - Nm^2C^{-1} (Newton meter square per Coulomb)

16. What is meant by electrostatic energy density or electrostatic volume energy density?

The energy stored per unit volume of space is defined as electrostatic energy density.

17. Write a short note on 'electrostatic shielding'.

- A sensitive electrical instrument which is to be protected from external electrical disturbance is kept inside this cavity.
- The electric field inside the cavity is zero.

18. What is Polarisation?

Polarisation $\vec{P}$ is defined as the total dipole moment per unit volume of the dielectric.

19. What is dielectric strength?

The maximum electric field, the dielectric can withstand before its breakdown is called dielectric strength. Unit - Vm^{-1} (Volt per meter).

20. Define 'capacitance'. Give its unit.

- The capacitance C of a capacitor is defined as the ratio of the magnitude of charge on either of the conductor plates to the potential difference existing between the conductors.
- The SI unit of capacitance is coulomb per volt (CV^{-1}) or farad (F).

21. What is corona discharge?

- The leakage of electric charges from the sharp points on the charged conductor is known as 'action of points' or 'Corona discharge'.
- The electric field near this sharp edge is very high and it ionizes the surrounding air.
- The positive ions are repelled at the sharp edge and negative ions are attracted towards the sharp edge.
- This reduces the total charge of the conductor near the sharp edge.

NUMERICAL PROBLEMS

1. When two objects are rubbed with each other, approximately a charge of 50nC can be produced in each object. Calculate the number of electrons that must be transferred to produced this charge.

Given data: q = 50 nc (or) $q = 50 \times 10^{-9}C,\ e = 1.6\ \times 10^{-9}C$, n = ?

Connecting formula, $q = ne\ \Rightarrow n = \frac{q}{e}$

$$n = \frac{50 \times 10^{-9}}{1.6\ \times 10^{-19}} = 31.25\ \times 10^{10}\text{electrons} = 3.125\ \times 10^{11}\text{electrons}$$

2. The total number of electrons in the human body is typically in the order of 10^{28}. Suppose , due to some reason, you and your friend lost 1% of this number of electrons. Calculate the electrostatic force between you and your friend separated at a distance of 1m. Compare this with your weight. Assume mass of each person is 60 kg and use point charge approximation.

$q = 10^{28}$, $q' = \frac{1}{100} \times 10^{28} = 10^{26},\ r = 1m$

$F = \frac{1}{4\pi\varepsilon_0}\ \frac{q'q'}{r^2} = \frac{9 \times 10^9 \times 10^{26} \times 10^{26}}{(1)^2}$

$F = 9\ \times 10^{61}$ N

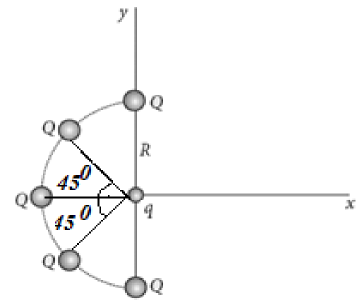
W = mg

W = 60 × 9.8 = 588 N

3. Five identical charges Q are placed equidistant on a semicircle as shown in the figure. Another point charge q is kept at the centre of the circle of radius R. calculate the electrostatic force experienced by the charge q.

$F_a = \vec{F}_{Q_{on\ X-axis}} + 2\vec{F}_{Q_{at\ 45^0}}$ [Net force is zero on the y - axis]

$F_a = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2} + 2\left(\frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}\cos45^0\right)$



$F_a = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}[1 + 2\cos45^0]$

$F_a = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}\left[1 + 2.\frac{1}{\sqrt{2}}\right]$

$F_a = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}\left[1 + \frac{\sqrt{2}\ \sqrt{2}}{\sqrt{2}}\right]$

$F_a = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}[1 + \sqrt{2}]N\hat{i}$ (along x axis).

4. Suppose a charge +q on Earth's surface and another +q charge is placed on the surface of the Moon. (a) Calculate the value of q requied to balance the gravitational attraction between Earth and Moon and Earth is halved, would the charge q change?

Given Data:

Gravitational Constant G = $6.67 \times 10^{-11}\ Nm^2kg^{-2}$

Mass of Earth $m_E = 5.9 \times 10^{24}kg$

Mass of moon $m_M = 7.9 \times 10^{22}$ kg

a) $\boldsymbol{F_e = F_G}$

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

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

$9 \times 10^9 . q^2 = 6.67 \times 10^{-11} \times 5.9 \times 10^{24} \times 7.9 \times 10^{22}$

$q^2 = \frac{6.67 \times 10^{-11} \times 5.9 \times 10^{24} \times 7.9 \times 10^{22}}{9 \times 10^9}$

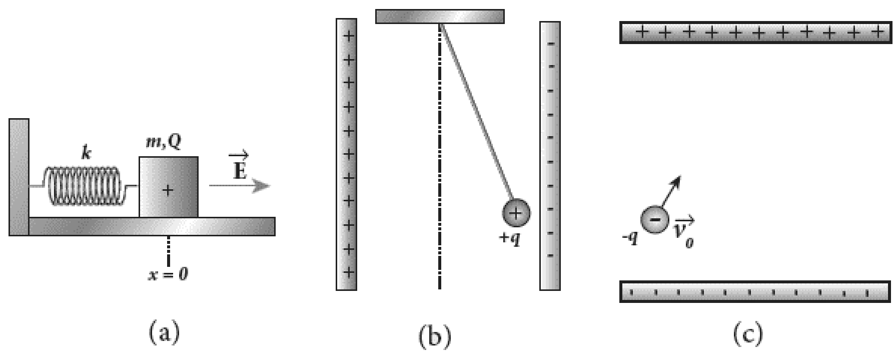
$q^2 = \frac{310.888}{9} \times 10^{26} = 5.87 \times 10^{13}C$

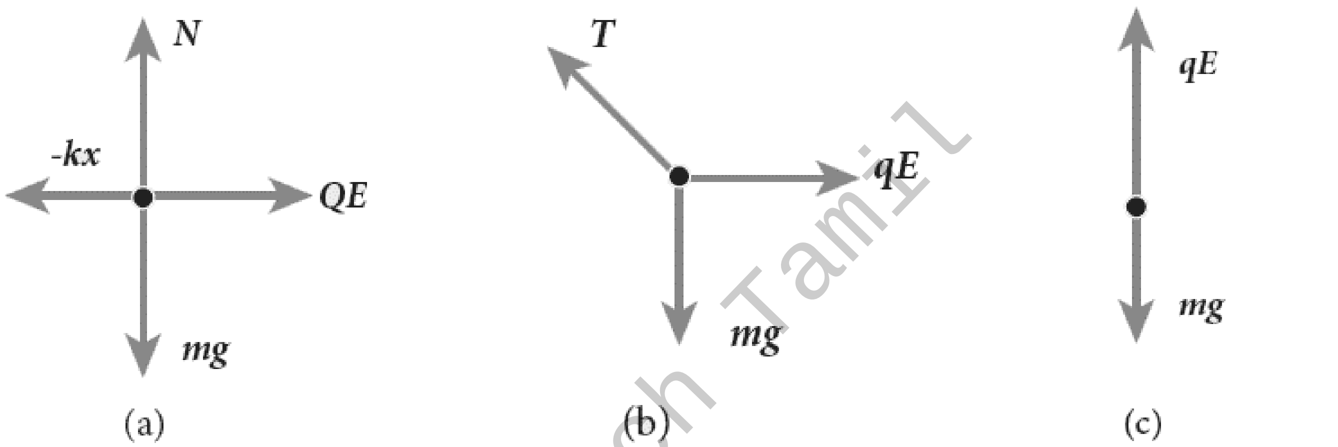
b) $\boldsymbol{q \propto m_Em_M}$

$\frac{1}{4\pi\varepsilon_0}q^2 = Gm_Em_M$ $\left[\therefore \text{Where } \frac{1}{4\pi\varepsilon_0} \text{ \&G are constants q is indpendent of distance}\right]$

so q is not change by change in distance.

5. Draw the free body diagram for the following charges as shown in the figure (a), (b), and (c).



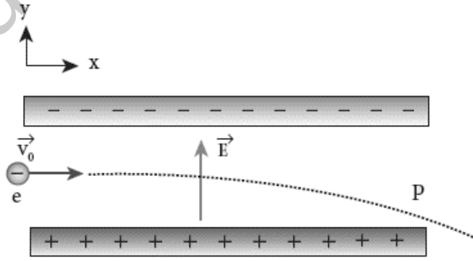


F = kx   k - Force constant
F - Force on a charge 'q' due to Electric field
N = Normal force (Reaction)

F = qE .

F = mg

6. Consider an electron travelling with a speed V_0 and entering into a uniform electric field $\vec{E}$ which is perpendicular to $\overrightarrow{V_0}$ as shown in the figure. Ignoring gravity, obtain the electron's acceleration, velocity and position as functions of time.



[F = ma ; F = eE ; ma = eE ; a = $\frac{eE}{m}$]

$$\vec{a} = \frac{eE}{m}(-\hat{j}) = -\frac{eE}{m}\hat{j}$$

$$\vec{v} = \vec{u} + \vec{a}t = v_o\hat{\imath} + \frac{eE}{m}t(-\hat{j}) = v_o\hat{\imath} - \frac{eE}{m}t(\hat{j})$$

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

$$\vec{r} = v_o t\hat{\imath} + \frac{1}{2}\frac{eE}{m}t^2(-\hat{j}) = v_o t\hat{\imath} - \frac{1}{2}\frac{eE}{m}t^2(\hat{j})$$

7. A closed triangular box is kept in an electric field of magnitude $E = 2 \times 10^3 NC^{-1}$ as shown in the figure. Calculate the electric flux through the (a) vertical rectangular surface (b) slanted surface and (c) entire surface.

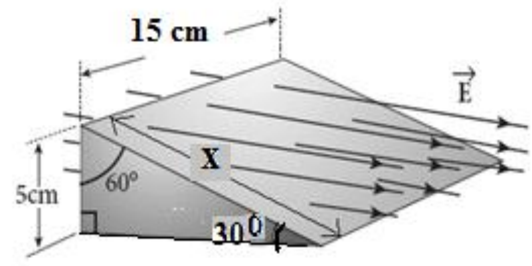
a) Vertical rectangular surface

$\phi_E = EA\cos\theta$; $\theta -$ angle between the electric field and the direction normal to the area.

$\phi_E = 2 \times 10^3 \times 15 \times 10^{-2} \times 5 \times 10^{-2} \times \cos 0^0$

$\phi_E = 150 \times 10^{-1}$ (or) $15\ Nm^2C^{-1}$

b) slanted surface



$\phi_E = EA\cos\theta$

$\phi_E = 2 \times 10^3 \times 15 \times 10^{-2} \times 10 \times 10^{-2} \times \cos 60^0$

$\phi_E = 300 \times 10^{-1} \times \frac{1}{2}$

$= 150 \times 10^{-1}$ (or) $15\ Nm^2C^{-1}$

$sin\ 30^0 = \frac{5cm}{x}$

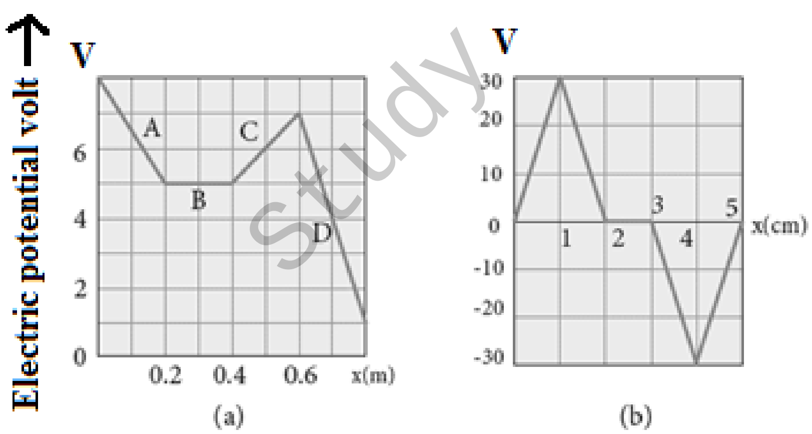
$x = \frac{5}{sin\ 30^0}$

$x = \frac{5}{\frac{1}{2}} = 10\ cm$

c) entire surface

Net flux is zero. (inward flux = outward flux)

8. The electrostatic potential is given as a function of x in figure (a) and (b). Calculate the corresponding electric fields in regions A,B,C and D. Plot the electric field as a function of x for the figure (b).



$E = -\frac{dV}{dx}$

I. (a) Region A:

$E = \frac{dV}{dx} = \frac{3}{0.2} = 15\ (negative\ slope)$

$E_x = +15\ vm^{-1}$

Region B:

$$E = \frac{dV}{dx} = \frac{0}{0.2} = 0$$

$$E_x = 0$$

Region C:

$$E = \frac{dV}{dx} = \frac{2}{0.2} = 10 \quad (positive\ slope)$$

E_x = - 10 vm^{-1}

Region D :

$$E = \frac{dV}{dx} = \frac{6}{0.2} = 30 \quad (negative\ slope)$$

E_x = +30 vm^{-1}

II. ***b.*** The electric field as a function of x for the figure. $E = -\frac{dV}{dx}$

i) $E = -\frac{dV}{dx} = \frac{-30}{1} = 30\ (negative\ slope)$

ii) $E = -\frac{dV}{dx} = -\frac{(-30)}{1} = 30\ (positive\ slope)$

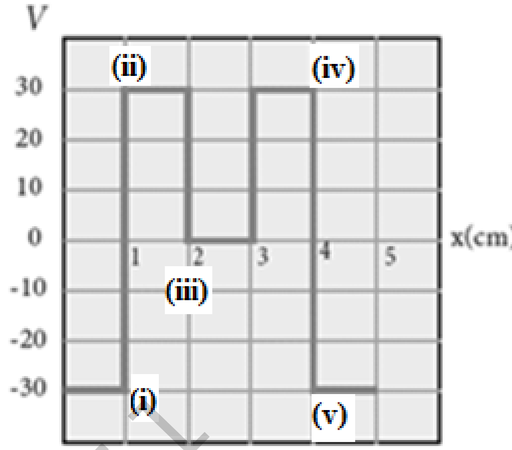
iii) $E = -\frac{dV}{dx} = \frac{0}{1} = 0$

iv) $E = -\frac{dV}{dx} = -\frac{(-30)}{1} = 30\ (positive\ slope)$

v) $E = -\frac{dV}{dx} = \frac{-30}{1} = 30\ (negative\ slope)$

Ans:

b)



9. A spark plug in a bike or a car is used to ignite the air-fuel mixture in the engine. It consists of two electrodes separated by a gap of around 0.6 mm gap as shown in the figure. To create the spark, an electric field of magnitude 3 × 10^6 Vm^{-1} is required. (a) What potential difference must be applied to produce the spark? (b) If the gap is increased, does the potential difference increase, decrease or remains the same? (c) find the potential difference if the gap is 1 mm?

Data: x = 0.6 mm (or) $6 \times 10^{-4} m$, $E = 3 \times 10^6 Vm^{-1}$

a) V = E .dx ; E = $\frac{dV}{dx}$

V = $3 \times 10^6 \times 6 \times 10^{-4}$ m = 1800V

b) V $\propto dx$

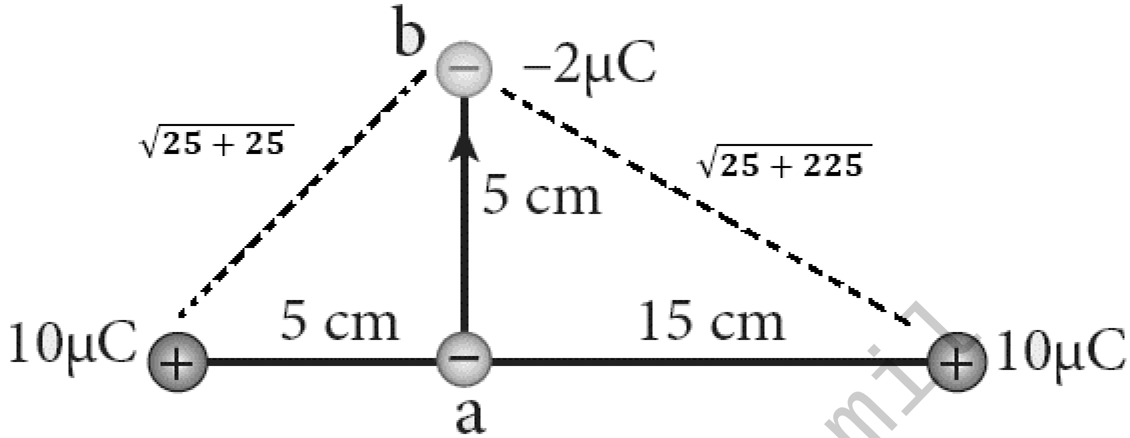
so, if gap increased , V also increased.

C) for x = 1 mm (or) 1×10^{-3} m

V = $3 \times 10^6 \times 10^{-3}$

V = 3000V

10. A point charge of +10 μc *is* placed at a distance of 20 cm from another identical point charge of +10 μc. A point charge of -2 μc is moved from point a to be as shown in figure. Calculate the change in potential energy of the system? Interpret your result.



V = $V_1 + V_2 = \frac{1}{4\pi\varepsilon_0}\left(\frac{10\times10^{-6}}{\sqrt{50}\times10^{-2}}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{10\times10^{-6}}{\sqrt{250}\times10^{-2}}\right)$

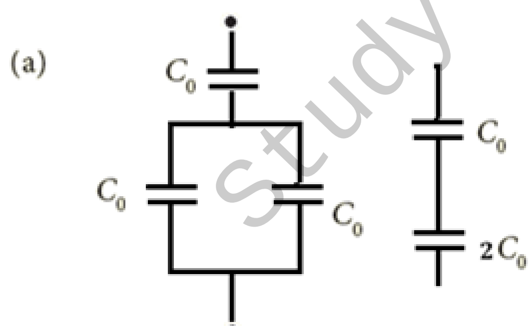
V = $\frac{1}{4\pi\varepsilon_0}\left[\frac{1}{\sqrt{50}} + \frac{1}{\sqrt{250}}\right] \times 10^{-3} = 9\times10^{9}\times10^{-3}\left[\frac{1}{\sqrt{50}} + \frac{1}{\sqrt{250}}\right] = 1.623\ \times 10^{6} V$

Change in potential energy of the system,

$$\Delta U = V \times q = 1.623\ \times 10^{6}\ \times (-2\times10^{-6}) = -3.246\, J$$

Negative sign implies that to move the charge -2 μc , no external work is required.
System spends its stored energy to move the charge from te point a to b.

11. Calculate the resultant capacitances for each of the following combinations of capacitors.



(i) Effective capacitance when two equal capacitors are in HCl

$$C_P = C_0 \times x = 2C_o$$

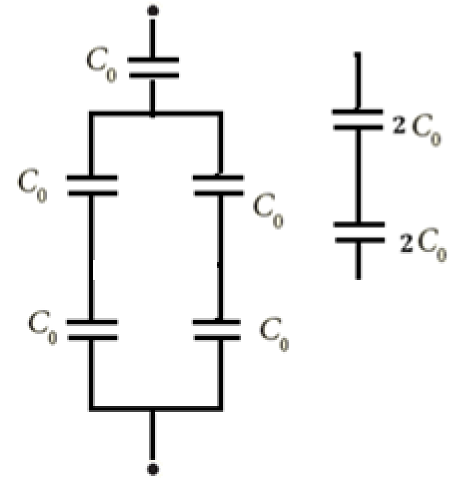
ii) In series different C_s

Then $\frac{1}{C_s} = \frac{1}{C_0} + \frac{1}{2}\times\left(\frac{1}{C_0}\right)$

$$\frac{1}{C_s} = \frac{3}{2}\times\left(\frac{1}{C_0}\right)$$

$$C_s = \frac{2C_0}{3}$$

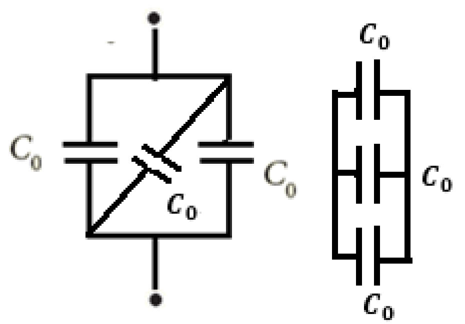
(b)



i) In parallel, equal capacitor, $C_P = x \times C = 2C_0$

ii) In series, equal capacitors , $C_s = \frac{C}{x} = \frac{2C_0}{x} = C_0$

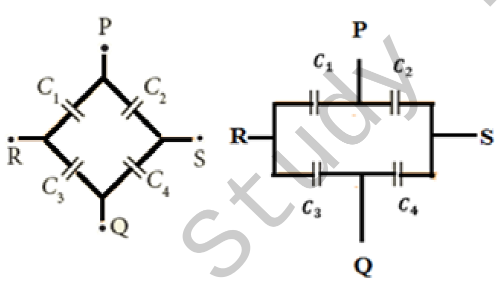
(c)



In equal capacitors which are parallel

$C_p = x \times C = 3C_0$

(d)



(i) across PQ

c_1, c_3 are in series

$$\frac{1}{C_{s1}} = \frac{1}{C_1} + \frac{1}{C_3} = \frac{C_3 + C_1}{C_1 C_3}$$

$$C_{s1} = \frac{C_1 C_3}{C_3 + C_1}$$

Similarly,

c_R and c_4 aare in series, $C_{SR} = \frac{C_2 C_4}{C_4 + C_2}$

Across PQ, C_{s1} and C_{SR} are parallel. So,

$C_p = C_{s1} + C_{SR} = \frac{C_1 C_3}{C_3 + C_1} + \frac{C_2 C_4}{C_4 + C_2}$

$= \frac{C_1 C_3 (C_4 + C_2) + C_2 C_4 (C_3 + C_1)}{(C_3 + C_1)\,(C_4 + C_2)} =$

$\frac{C_1 C_3 C_4 + C_1 C_3 C_2 + C_2 C_4 C_3 + C_2 C_4 C_1}{(C_3 + C_1)\,(C_4 + C_2)}$

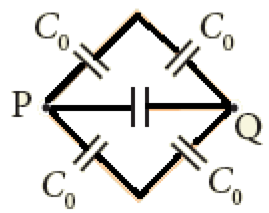
(ii) across RS: $C_1 C_2$ *are sereis* $C_{s1} = \frac{C_1 C_2}{C_1 + C_2}$

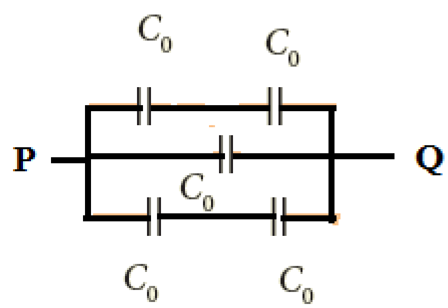
c_3 and c_4 are in parallel, $C_{SR} = \frac{C_3 C_4}{C_4 + C_3}$

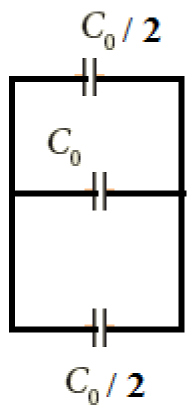
$C_P = C_{s1} + C_{SR} = \frac{C_1 C_2}{C_1 + C_2} + \frac{C_3 C_4}{C_4 + C_3}$

$$CP = \frac{C_1 C_2 (C_3 + C_4) + C_3 C_4 (C_1 + C_2)}{(C_2 + C_1)\,(C_4 + C_3)}$$

$$= \frac{C_1 C_2 C_3 + C_1 C_2 C_4 + C_1 C_3 C_4 + C_2 C_3 C_4}{(C_1 + C_2)\,(C_3 + C_4)}$$

(e) 



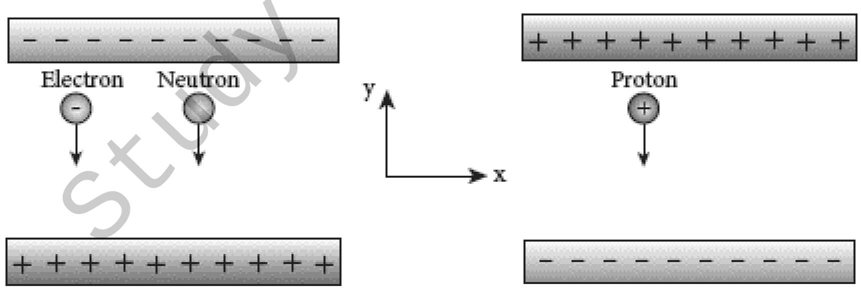


$$C_P = \frac{C_0}{2} + C_0 + \frac{C_0}{2}$$

$$C_P = 2C_0$$

Hint:
For identical Capacitor for Series $C_s = \frac{C_0}{n} = \frac{C_0}{2}$

12. An electron and a proton are allowed to fall through the separation between the plates of a parallel plate capacitor of voltage 5V and separation distance h = 1mm as shown in the figure. (a) Calculate the time of flight for both electron and proton (b) Suppose if a neutron is allowed to fall, what is the time of flight? (c) Among the three, which one will reach the bottom first? [Take $m_p = 1.6 \times 10^{-27\,kg}, m_e = 9.1 \times 10^{-31} kg\ , g = 10\ ms^{-2}$]



Vertical motion: Initial velocity u = o
From equation of motion
S = ut + $\frac{1}{2}at^2$
S = h; u = 0, h = $\frac{1}{2}at^2$
F = ma = eE
$a = \frac{eE}{m}$
$m_e = Mass\ of\ electron = 9.1 \times 10^{-31} kg$
$m_P = Mass\ of\ proton = 1.6 \times 10^{-27} kg$

u = 0 (fall), h = 1mm (or) 1×10^{-3} m

E = $\frac{V}{x} = \frac{5}{10^{-3}} = 5 \times 10^3 Vm^{-1}$

a) h = $\frac{1}{2}at^2 \Rightarrow t^2 = \frac{2h}{a} \Rightarrow t = \sqrt{\frac{2h}{a}}$

t = $\sqrt{\frac{2hm}{eE}}$

$$t_e = \sqrt{\frac{2 \times 10^{-3} \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 5 \times 10^3}}$$

$t_e = \sqrt{\frac{18.2}{8} \times 10^{-18}} = \sqrt{2.275 \times 10^{-18}} = 1.5 \times 10^{-9}s$ (or) 1.5 ns

$$t_p = \sqrt{\frac{2 \times 10^{-3} \times 1.6 \times 10^{-27}}{1.6 \times 10^{-19} \times 5 \times 10^3}}$$

$t_p = \sqrt{\frac{3.2}{8} \times 10^{-14}} = \sqrt{0.4 \times 10^{-14}} = 0.63 \times 10^{-7}s$ (or) $63 \times 10^{-9}s$ (or) 63 ns

b) neutron has no charge, so only 'g' act (g = 10 ms^{-2})

$t_n = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\times10^{-3}}{10}} = \sqrt{2 \times 10^{-4}} = 1.414 \times 10^{-2}s$ (or) $14.14 \times 10^{-3}s$ (or) 14.1 ms

c) $t_n > t_p > t_e$

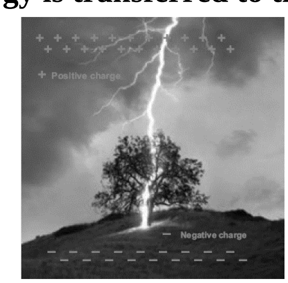
So, electron will reach first.

13. During a thunder storm, the movement of water molecules within the clouds creates friction, partially causing the bottom part of the clouds to become negatively charged. This implies that the bottom of the cloud and the ground act as a parallel plate capacitor. If the electric field between the clud and ground exceeds the dielectric breakdown of th air (3×10^6 Vm^{-1}) lightning will occur.

(a) if the bottom part of the cloud is 1000 m above the ground, determine the electric potential difference that exist between the cloud and ground.

b) In a typical lightning phenomeneon, around 25C of electrons are transferred from cloud to ground. How much electrostatic potential energy is transferred to the ground?

E = $3\times 10^6 Vm^{-1}$, d = 1000m, q = 25C



a) V = E × d

V = $3 \times 10^6 \times 10^3$

V = 3×10^9V

b) u = Vq

u = $3 \times 10^9 \times 25$

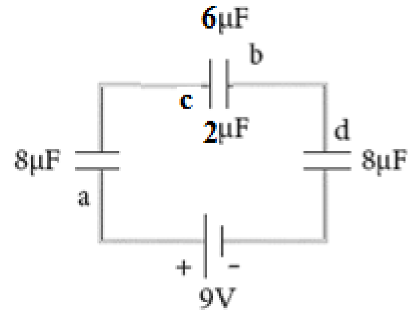
V = 75×10^9J

14. For the given capacitor configuration.

(a) Find the charges on each capacitor.

(b) Potential difference across them.

(c) Energy stored in each capacitor.



b,c are parallel

$C_P = C_b + C_c$

$C_P = 6\mu F + 2\ \mu F = 8\ \mu F$

$C_a = C_P = C_d$

Total capacitance(For identical) = $\frac{C}{n}$ (series connection)

Total capacitance $= \frac{8\ \mu F}{3}$

$C_s = 2.66\ \mu F$

Total charge Q = $C_s V = 2.66\ \mu F \times 9 = 23.94\ \mu C = 24\mu C$

Voltage for each capacitor (For identical) $= \frac{V}{n} = \frac{9}{3} = 3V$

b and c are parallel. So each will get 3V.

$Q_b = C_b V_b = 6\ \mu F \times 3V = 18\ \mu C$

$Q_c = C_c V_c = 2\ \mu F \times 3V = 6\ \mu C$

$Q_d = C_d V_d = 8\ \mu F \times 3V = 24\ \mu C$

$V_a = V_b = V_c = V_d = 3V$

$u_a = \frac{1}{2} C_a {V_a}^2$

$u_a = \frac{1}{2} \times 8\mu F \times 9V = 36\mu J$

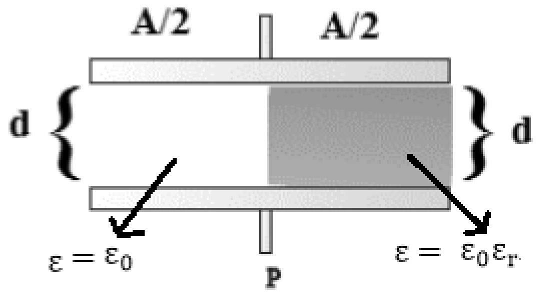
$u_b = \frac{1}{2} \times 6\mu F \times 9V = 27\mu J$

$u_c = \frac{1}{2} \times 2\mu F \times 9V = 9\mu J$

$u_d = \frac{1}{2} \times 8\mu F \times 9V = 36\mu J$

15. Capacitors P and Q have identical cross sectional areaas A and separation d. The space between the capacitors is filled with a dielectric of dielectric constant ε_r as shown in the figure. Calculate the capacitance of capacitors P and Q.

(i)



[For air $\varepsilon_r = 1$]

This is parallel connection

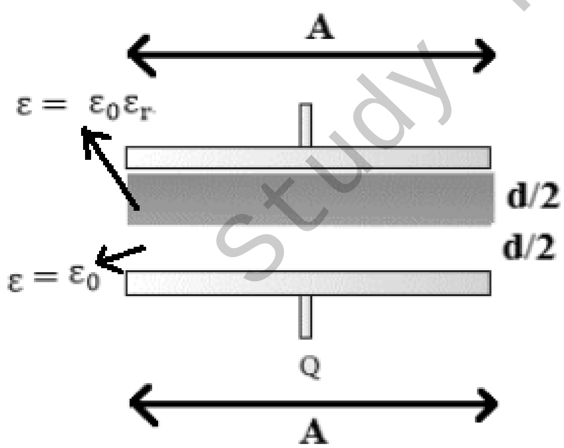
$$C_1 = \frac{\varepsilon_0 A}{2d}, \quad C_2 = \frac{\varepsilon_0 \varepsilon_r A}{2d}$$

$$\boxed{C_P = C_1 + C_2}$$

$$C_P = \frac{\varepsilon_0 A}{2d} + \frac{\varepsilon_0 \varepsilon_r A}{2d}$$

$$C_P = \frac{\varepsilon_0 A}{2d}(1 + \varepsilon_r)$$

(ii)



This is series connection

$$\frac{1}{C_Q} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_1 = \frac{2\varepsilon_0 \varepsilon_r A}{d}, \quad C_2 = \frac{2\varepsilon_0 A}{d}$$

$$\boxed{C_Q = \frac{C_1 C_2}{C_1 + C_2}}$$

$$C_Q = \frac{\frac{2\varepsilon_0 \varepsilon_r A}{d} \times \frac{2\varepsilon_0 A}{d}}{\frac{2\varepsilon_0 \varepsilon_r A}{d} + \frac{2\varepsilon_0 A}{d}}$$

$$C_Q = \frac{\frac{4\varepsilon_0^{2} \varepsilon_r A^2}{d^2}}{\frac{2\varepsilon_0 A + 2\varepsilon_0 \varepsilon_r A}{d}}$$

$$C_Q = \frac{\frac{4\varepsilon_0^{2} \varepsilon_r A^2}{d^2}}{\frac{2\varepsilon_0 A(1+\varepsilon_r)}{d}} = \frac{4\varepsilon_0^{2} \varepsilon_r A^2}{d^2} \times \frac{d}{2\varepsilon_0 A(1+\varepsilon_r)}$$

$$C_Q = \frac{2\varepsilon_0 A}{d}\left(\frac{\varepsilon_r}{1 + \varepsilon_r}\right)$$

Note:

Point charge q: (Charged particle or body)

If the size of the charged body is very small compared the distance from all other surrounding objects of interest, the charged body is said to be a point charge.

A point charge will never experience a force due to its own electric field.

Test charge q_0: Unit positive point charge is called as 'Test charge'. A test charge is a charge of small magnitude such that it does not disturb the configurataion of the charge distribution which produces the electric field.