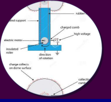
Physics for

Advanced Level

ELECTROSTATICS



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Physics

Advanced level

Electrostatics

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ACKNOLEDGEMENT

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ABOUT THE BOOK.

This text extracted to cover the whole electrostatics concepts for advanced level with reference to the ***first re-print Advanced level Physics syllabus of 2010***. Everything is extracted from different sources but are within syllabus. The book designed in such a way that every advanced level physics students can grasp the required knowledge of solving different questions, it is simplified and non-complicated. It consists of almost 500 questions including NECTA question. This book written to reduce some complexity in electrostatics for advanced leaner.

NB:
Further Remarks, advice and any other additional idea/knowledge for the readers are completely considered for further modification.

Send via +255 754 249 049

DEDICATION OF THE BOOK

IN THE MEMORY OF MY
mom & daddy
LUCIANA M.K & BENITHO C.E

Typing, drawing and all other system type setting was done by Mwl. Chambilo Edward

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CHAPTER ONE; INTRODUCTION TO ELECTROSTATICS

Electrostatics is the study of electric charge at rest. Electric charge is denoted by Q. The electricity developed on objects, when they are rubbed with each other, is called **frictional electricity.** The electric charge developed cannot move from part of object to another part, for this reason, frictional electricity is also known as **static electricity or electrostatic.**

Electrostatic is the study of forces, potentials and fields arising from static charges i.e charge at rest.

Electric Charge

Is the particle or substance carrying either positive or negative electricity. In nature electric charge occur in two forms

(a) Positive charge $(+q)$
(b) Negative charge $(-q)$

The SI – unit of electric charge is Coulomb (C). Other common use is micro coulomb (μC)

$$1\mu m = 10^{-6}C$$

Electric Charging

This is the process of either adding or removing electron from a body. **OR** is the process of transferring electron from a charged particle to uncharged substance.

The body whose charge is removed become positively charged and the body which receive electrons becomes negatively charged.

Additive Nature of Charge

Like mass, electric charge also possesses additive property.

$$such\ that\ q = q_1 + q_2 + q_3 \ldots\ldots$$

The total electric charge on an object is equal to algebraic sum of all the electric charges distributed on the different parts of the object.

Quantization of Charge

The magnitude of charge on a proton or electron ($e = 1.6 \times 10^{-19}C$) is called elementary charge. Since protons and electrons are the only charged particle constituting the matter, the charge on object must be integral multiple of $\pm e$.

- A charged possessed by an object cannot be fraction.
- Mathematically, the charge on any object must always be equal to $q = \pm ne$
- where n is any integer.

Hence charge can be decreased or increased in steps of e, because during the charging process an integral number of electrons, can be transferred from one body to another, this process is called quantization of charge. Or discrete nature of charge.

- Since all observable charges are always have some integral multiple of elementary charge $e = (\pm 1.6 \times 10^{-19}C)$ is known as quantization of charge, the number of elementary charges involved in become extremely large even when electric charge on an object is changed by very small amount.
- Example when a glass rod is rubbed with silk, a charge of order 10^{-6}C appear on the glass rod or silk. Since the elementary charge is equal to 1.6×10^{-19} C, then the number of elementary charges on the glass rod is given by

$$n = \frac{10^{-6}}{1.6 \times 10^{-19}}$$

$$n = 6.25 \times 10^{12}$$

Since it is very large number, the quantization of charge not observed.

Example: A polythene piece rubber with wool is found to have a negative charge of 3×10^{-7} C. Estimate the number of electrons transferred from the wool to polythene.

solution

$$q = -3 \times 10^{-7}C$$

$$e = 1.6 \times 10^{-19}C$$

$$from\ quantization\ of\ charge$$

$$q = ne$$

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

$$n = 1.875 \times 10^{12}$$

Properties of Electric Charge

(i). Like charge repel each other and unlike charge attract each other.
(ii). The magnitude of elementary negative or positive charge is the same and equal to 1.6×10^{-19}C.
(iii). Electric charge is additive in nature.
(iv). The charge is quantized i.e charge carried by a charged object is equal to $\pm ne$ n is integer.
(v). The electric charge of a system is always conserved.
(vi). Unlike mass, electric charge on an object is not affected by the motion of object.

Methods of Charging Body

A body can be charged by three different method as analyzed below.

(a) Charging by friction or rubbing.
(b) Charging by induction
(c) Charging by direct contact.

Charging By Friction or Rubbing

This method is suitable for charging insulator only. Insulator is the substance that is poor conductor of heat and electricity.

Example

- Glass
- Wool

- Cotton
- Fur
- Silk
- Polythene
- Ebonite
- Rubber

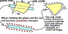
These substances do not conduct both heat and electricity because they contain no free electron. When two insulators are rubbed together they will acquire static charge.

This process of rubbing bodies together causes electrons to be turn off from one body and get deposited.

NB: When a charge is placed on insulator (by rubbing) it stay in the region in which it has been placed

- Rubbing an ebonite rod with fur produces negative charge on the rod and positive charge on the fur.
- When you rub one material to another, they are charged by friction. Material loosing electrons is positively charged and material gaining electrons is negatively charged. The amount of electrons gained is equal to each other

- Rubbing a glass rod with silk produces positive charge on the rod and negative charge on the silk.



Charging By Induction

Is the process of charging neutral body usually a conductor when charged body is brought near it. This is the method of charging the body without touching.

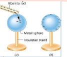
Charging by induction - Using a Negatively Charged Object

Diagram i.	Diagram ii.	Diagram iii.	Diagram iv.
Two metal spheres are mounted on insulating stands	The presence of a – charge induces e- to move from sphere A to B. the two-sphere system is polarized.	Sphere B is separated from sphere A using the insulating stand. The two spheres have opposite charges.	The excess charge distributes itself uniformly over the surface of the spheres.

Charges from x will be separated as shown due to the law of electrostatics. Upon earthing of y negative charges will be migrating the earth and body y will remain positive charged.

Charging By Contact Method

The process of giving one object a net electric charge by placing it in contact with another object that already charged is known as **charging by contact.**



This method is suitable for conductors. If A is made to touch another conductor B (uncharged) then the charges will spread over the surface of the uncharged conductor. This is the method of charging the body by touching each other.

Then the positive charge will be transferred to body y, and then after sometime they will be separated after the charge in x is equal charge.

Lightning Conductor

This is the simple device used to protect tall buildings from the lighting effects. When charged cloud comes near building, an opposite charge is induced on the pointed end of the conductor. Due to the discharge action points, an opposite charge is sprayed to the surrounding air which neutralizes the charge on the cloud. If the cloud discharges, through the conducting copper strip and the building is not **Lightning Conductor**

The Phenomenon of Lightning Conductor;

Explain the phenomenon of lightning conductor

Lightning is a gigantic electric spark discharge occurring between two charged clouds or between a cloud and the earth.

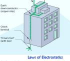
Lightning conductor is a long pointed iron rod with its lower end buried in the earth and the other above the highest part of the building which is used to protect the building from lightning damage.

The Structure and Mode of Action of Lightning Conductor

Describe the structure and mode of action of lightning conductor.
Structure of a lightning conductor
It consists of a long thick pointed copper rod with its lower end buried in the earth(earth plate) and the other end reaching above the highest part of the building and ending in several sharp spikes. -It is fixed to the side of the building. Mode of action of lightning conductor
When a negatively charged thunder-cloud passes overhead it acts inductively on the conductor, charging the points positively and the earth plate negatively.
The negative charge on the plate is, of course, immediately dissipated into the surrounding earth. At the same time point action occurs at the spikes. Negative ions are attracted to the spikes and becomes discharged by giving up their electrons. These electrons then pass down the conductor and escape to earth.
At the same time positive ions are repelled upwards from the spikes and spread out to form what is called a space charge. This positive space charge, however, has a negligible effect in neutralizing the negative charge on the cloud.

***Note:** Without the protection of a lightning conductor the lightning usually strikes the highest point, generally a chimney, and the current passes to earth through the path of* *least resistance. Considerable heat is generated by the passage of the current and sometimes it may set into fire.*

A Simple Lighting Conductor. Construct a simple lightning conductor. A simple lightning conductor damaged.



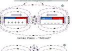
Laws of Electrostatics

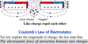
First law of electrostatic. These laws explain the relation between sign of charge when placed nearby to each other. It is also called fundamental law of electrostatics. The law state that;

"The like charge repel while unlike charge attract each other"

This law explains the effect of charge between two charge conductors or bodies.

Unlike charge attract each other





Like charge repel each other

Coulomb's Law of Electrostatics

This law explain the magnitude of charge; the law state that

"The electrostatic force of attraction between two charges is directly proportional to the product of the charges and inversely proportional to the square of distance between them"

Suppose two charges q_1 *and* q_2 are separated by a distance r between them so that the force of attraction between them is proportional the product of the two charges then it can be presented mathematically as shown below

$$mathematically$$

$$F \propto \frac{q_1 q_2}{r^2}$$

$$F = \frac{kq_1q_2}{r^2}$$

k is the constant of proportionality called electrostatic force constant

The value of K depends on the medium between the charges and its value is equal to $K = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$

When substituted to the above equation results into

$$\mathbf{F = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}}$$

This is valid iff when the two charges are placed free space since ε_0 is electric permittivity in free space and its numerical value is equal to

$$\varepsilon_0 = 8.854 \times 10^{-12}C^2N^{-1}m^{-2}$$

$$K = \frac{1}{4\pi\varepsilon_0} = \frac{1}{4\pi \times 8.854 \times 10^{-12}} = 9 \times 10^9$$

Suppose the two charges are placed in medium so that the value of ε_0 changed to ε_m then force of attraction between these charges will become.

$$\mathbf{F = \frac{q_1q_2}{4\pi\varepsilon_m r^2}}$$

NB: *The force F can either be repulsive or attractive depending upon nature whether the charge is like or unlike*

The force always acts along the line joining the centers of the two charges.

Limitation of Coulomb's Law

- Does not tell if the force is attractive or repulsive
- It provide only magnitude of force but not direction.
- It is applied only in a point charges or particle.

Relative Permittivity or Dielectric Constant of Medium in Material

Relative permittivity is the ratio between permittivity of medium and permittivity of free space. And it is denoted by ε_r.

$$\varepsilon_r = \frac{\varepsilon_m}{\varepsilon_o}$$

$$\varepsilon_m = \varepsilon_r \varepsilon_o$$

Since relative permittivity ε_r can be expressed in terms of electrostatic forces..

Consider the point electric charges q_1 and q_2 separated by a distance r in vacuum so that

$$\mathrm{F}_1 = \frac{q_1 q_2}{4\pi r^2 \varepsilon_o} - - - - (*)$$

If the two charges are separated by the same distance r in a medium of relative permittivity ε_r then the magnitude of electrostatic force between the charges is given by

$$\mathrm{F}_2 = \frac{q_1 q_2}{4\pi r^2 \varepsilon_m}$$

$$\textit{considering that} \quad \varepsilon_m = \varepsilon_r \varepsilon_o$$

$$\mathrm{F}_2 = \frac{q_1 q_2}{4\pi r^2 \varepsilon_r \varepsilon_o} - - - - (**)$$

dividing the two equations

$$\frac{F_1}{F_2} = \left(\frac{\frac{q_1 q_2}{4\pi r^2 \varepsilon_o}}{\frac{q_1 q_2}{4\pi r^2 \varepsilon_r \varepsilon_o}}\right)$$

simple mathematics

$$\frac{F_1}{F_2} = \frac{\varepsilon_r \varepsilon_o}{\varepsilon_o}$$

$$\varepsilon_r = \frac{F_1}{F_2}$$

Similarities Between Electrostatic Force And Graviatational Force

(a) Both obey Universe square law.
(b) Both can act in vacuum.
(c) **Differences Between Electrostatic Force And**

ELECTROSTATIC FORCE	GRAVITATIONAL FORCE
Can be attractive or repulsive	It is only attractive
Occur between charges	Occur between masses
It is greater than gravitational force	It is less than electrostatic force
It change with nature of medium	It is constant does not change.

Gravitational Force

NB:

1. The suspended charged ball will be just able to make complete revolution, if the necessary centripetal force required at the highest point of the vertical circular path is provided by the resultant of its weight and electrostatic repulsion between the two charged ball.

2 Each particle is under the action of three forces namely weight, tension in the string and the resultant electrostatic force on it due to the other two particles.

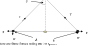
3. For the three particle to be in equilibrium, the net force on each particle should be zero

Worked Examples Set 01.

Example 01: Two identical charged sphere are suspended by strings of equal lengths. The string makes an angle of $30°$ with each other. When suspended in liquid of density $800\,kg/m^3$, the angle remains the same. Calculate the dielectric constant of the liquid given the density of the material of sphere is $1600\,kg/m^3$.

solution

Let the sphere be A and B each of weight W and charge q, when suspended by a string of equal length, so that the string make an angle $30°$ with each othe



There are three forces acting on the sphere

(a) Weight W acting vertically

(b) Tension T in the string along AS.

(c) Electrostatic force on one sphere due to the other.

Here density of the material $\rho = 1600\text{kgm}^{-3}$
if v is the volume of sphere then

$$w = Vpg = V \times 1600 \times 9..8N$$
$$w = 15680VN$$
but electrostatic force
$$F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{(AB)^2}$$
but electrostatic force
$$F = w \times \frac{OA}{OS}$$
$$F = w \times \tan 15°$$
since $w = 15680VN$
comparing
$$\frac{1}{4\pi\varepsilon_0} \times \frac{q^2}{AB^2} = 15680 \tan 15 V - - - (*)$$

When a spheres are suspended in a liquid, suppose the two spheres are suspended in a liquid of dielectric constant k then when suspended in a liquid the weight of sphere decrease and become W' this is due up thrust and electrostatic force between the sphere also decrease and become F'

Since the electrostatic force between the spheres after being suspended in water become
$$F' = \frac{q^2}{4\pi\varepsilon_0 AB^2 k}$$
the apparent weight of the sphere;
$$w' = w - \text{upthrust}$$
suppose σ is density of liquid
$$\text{then } w' = Vpg - V\sigma g$$
$$w' = V(\rho - \sigma)g$$
$$\text{but density of liquid } \sigma = 800 \text{ kg/m}^3$$
$$w' = V(1600 - 800) \times 9.8$$
$$w' = 800 \times 9.8 \times V$$
$$w' = 7840VN$$

As the sphere is in equilibrium, the three forces W', F' and T' can be represented respectively by the three sides **SO**, **OA**, and **AS** of the triangle **AOS** therefore

$$\frac{w'}{SO} = \frac{F'}{OA} = \frac{T'}{AS}$$

$$\text{the } F' = w' \times \frac{OA}{SO}$$

$$\frac{q^2}{4\pi\varepsilon_0 kAB^2} = 7840 \tan 15° V ----(**)$$

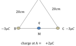
dividing uequation (*)and (**)

$$k = \frac{15680 \tan 15° V}{7840 \tan 15° V}$$

$$k = 2$$

Example 02:

Three point charges are kept at vertices A, B and C respectively of an equilateral triangle of sides 20 cm as shown below. What should be the sign and magnitude of the charge to be placed at the midpoint M of side BC, so that the charge at A remains in equilibrium.



$$\text{charge at A} = +2\mu C$$

$$q_B = q_A = -3\mu C = -3 \times 10^{-6} C$$

$$AB = AC = 20cm = 0.2m$$

let q be charge placed at M so that charge

$$= \frac{9 \times 10^9 \times 1 \times 100}{10^2}$$

$$= 9 \times 10^9 \mathrm{N}$$

force along AD

$$F_{AD} = \frac{q_A q_D}{4\pi\varepsilon_o AD^2}$$

$$= \frac{9 \times 10^9 \times 1 \times 75}{(10^2 - 5^2)}$$

$$= 9 \times 10^9 \mathrm{N}$$

force along x − component

$$F_x = F_{AB}\cos 60 + F_{AC}\cos 60$$

$$\text{since } F_{AB} = F_{AC}$$

$$F_x = 2F\cos 60$$

$$F_x = 2 \times 9 \times 10^9 \cos 60^\circ$$

$$F_x = 9 \times 10^9 \mathrm{N}$$

force along y − component

each force act in opposite direct

$$\text{hence} \quad F_y = F_{AB}\cos 60^\circ - F_{AC}\cos 60^\circ$$

since

$$F_{AB} = F_{AC} = F$$

$$F_y = F\cos 60^\circ - F\cos 60^\circ = 0$$

hence force along y − component cancel each other

force of charge q_A along Y direction

$$F_y = 9 \times 10^9 \mathrm{N}$$

since charge q_A along AD has no reaction with other charge consider the vertical component of the force

$$T\cos\theta = mg ----(1)$$

consider the horizontal component

$$T\sin\theta = k\frac{q_1 q_2}{r^2} ----(2)$$

dividing the two equations results

$$\tan\theta = k\frac{q_1 q_2}{mgr^2}$$

simple mathematics

$$q_2 = \frac{mgr^2\tan\theta}{kq_1}$$

$$= \frac{0.01 \times 9.8 \times (0.3)^2 \times \frac{30}{40}}{9 \times 10^9 \times 8 \times 8 \times 10^{-6}}$$

$$= 9.2 \times 10^{-8}C$$

$$\mathbf{q_2 = 9.2 \times 10^{-8}C}$$

Example 22;
Two similar balls of mass m are hang from silk threads of length l and carry a similar charges q. Assume that θ is so small that $\tan\theta$ can be approximated to $\sin\theta$. Using this approximation, show that

$$x = \left(\frac{q^2\ell}{2\pi\varepsilon_o mg}\right)^{\frac{1}{3}}$$

Where x is separation between the balls. If $\ell = 120$cm; m = 10g; and $x = 5$cm, calculate the value of q.

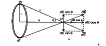
solution ;

consider the illustration below.

is given by the relation

$$dE = \frac{dq}{4\pi\varepsilon_o a^2}$$

Consider the illustration below.



horizontal component

$$dE = dEcos\,\theta$$

vertical components

$$dE = dEsin\,\theta$$

$$\mathbf{dE\ along\ y - component = 0}$$

This is because component $dEsin\theta$ of any charge element dl is cancelled by component $dEsin\theta$ due to charge element dl' on the opposite side of the ring.

Now:

The magnitude of E at P is calculated by

$$dE = dEcos\,\theta$$

$$integrating\ both\ sides$$

$$\int_0^E dE = \int dE\cos\theta$$

$$\int_0^E dE = \int_0^{2\pi r} dE\cos\theta$$

$$\textit{but from the diagram} \quad \cos\theta = \frac{x}{a}$$

$$[E]_0^E = \int_0^{2\pi r} \left(\frac{x}{a}\right) dE$$

$$\textit{but also} \quad dE = \frac{dq}{4\pi\varepsilon_o a^2} \textit{ then substitute to the eqn}$$

$$E = \int_0^{2\pi r} \frac{dq}{4\pi\varepsilon_o a^2} \cdot \left(\frac{x}{a}\right) ----(ii)$$

plugging eqn (i)into eqn (ii)results

$$E = \int_0^{2\pi r} \left(\frac{x}{4\pi\varepsilon_o a^3}\right) \cdot \frac{qdl}{2\pi r}$$

$$\textit{also} \quad a = \sqrt{x^2 + r^2}$$

$$E = \int_0^{2\pi r} \frac{xq}{4\pi\varepsilon_o\left(\sqrt{x^2 + r^2}\right)^3} \cdot \frac{dl}{2\pi r}$$

$$E = \int_0^{2\pi r} \frac{xq}{4\pi\varepsilon_o (x^2 + r^2)^{\frac{3}{2}}} \cdot \frac{dl}{2\pi r}$$

$$E = \frac{qx}{8\pi^2\varepsilon_o r(x^2 + r^2)^{\frac{3}{2}}} \int_0^{2\pi r} dl$$

$$E = \frac{qx}{8\pi^2\varepsilon_o r(x^2 + r^2)^{\frac{3}{2}}}[\,l\,]_0^{2\pi r}$$

$$E = \frac{2\pi rqx}{8\pi^2\varepsilon_o(x^2 + r^2)^{\frac{3}{2}}r}$$

since electric field at point P will be

$$E_p = \frac{qx}{4\pi\varepsilon_o(x^2 + r^2)^{\frac{3}{2}}} \quad along\ Px$$

Note:

(i)When point P lies at the centre of the ring x = 0

then

$$E = \frac{qx}{4\pi\varepsilon_o(x^2 + r^2)^{\frac{3}{2}}} \quad at\ \ x = 0$$

$$E = \frac{0}{4\pi\varepsilon_o(r^2)^{\frac{3}{2}}}$$

Electric field at the centre of ring is zero

(ii)When the point P lies far away from the ring

$$such\ that\quad x \ggg\ggg r$$

$$r\ \ is\ \ alomst\ \ negligible\ \ (r = 0)$$

then

$$E = \frac{qx}{4\pi\varepsilon_o(x^2 + 0^2)^{\frac{3}{2}}}$$

$$E = \frac{qx}{4\pi\varepsilon_o(x^2)^{\frac{3}{2}}}$$

$$F_g = mg = \frac{4}{3}\pi r^3 \rho g$$

$$= \frac{4}{3}\pi r^3 \times 1.26 \times 10^3 \times 9.81$$

$$F_g = 5.18 \times 10^4 r^3 N$$

the drop will be held stationary if and

$$only\ if \quad F_g = F_e$$

$$4.896 \times 10^{-14} = 5.18 \times 10^4 r^3$$

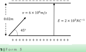
$$solving\ for\ r$$

$$r = \left(\frac{4.896 \times 10^{-14}}{5.18 \times 10^4}\right)^{\frac{1}{3}}$$

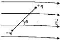
$$r = 9.82 \times 10^{-4} m$$

Example 4:

A uniform electric field of strength $2 \times 10^3 NC^{-1}$ is established between two parallel plates of length 0.1m held horizontally at a distance of 0.02m apart. An electrons is projected at a speed of 6×10^6m/s making an angle of 45° as shown below. The field is directed vertically upwards. Will electrons strike either of the plate? If it strikes the plates, where does it do so



minimum time required for the rod to become parallel to the filled after it set free.

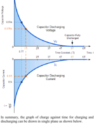


[**ans.** $\frac{\pi}{2}\sqrt{\frac{ml}{2qE}}$ refer to this book related solved example]

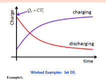
16. A small ball of mass 2×10^{-2}kg having a charge 1μC is suspended by a string of length 0.8m. another identical ball having the same charge is kept at the point of suspension. Determine the minimum horizontal velocity which should be imparted to the lower ball so that it can make complete revolution. **[ans. 5.8m/s]**

17. A pendulum bob of mass 80mg and carrying a charge of 2×10^{-8}C is at rest in a horizontal uniform electric field of 20000V/m. calculate the tension in the thread of the pendulum and the angle it makes with the vertical.
[ans. 8.8×10^{-4}N nearly 27°]

18. A particle having a charge of 1.6×10^{-19}C enters midway between the plates of a parallel plate condenser. The initial velocity of the particle is parallel to the plates. A potential difference of 300V is applied to the capacitor plates. If the length of the capacitor plate is 10 cm and the plates are separated by 2cm, calculate the greatest initial velocity for which a particle will not be able to come out of the plates. Given the mass of the particle is 12×10^{-24}kg.
[ans. 10^4m/s]



In summary, the graph of charge against time for charging and discharging can be drawn in single plane as shown below.



Worked Examples: Set 03.

Example1;

A 5μF capacitor is charged by a 12V supply voltage and is then discharged through a 2MΩ resistor. What is;

(a) The charge on the capacitor.
(b) The p.d across the capacitor.
(c) The current in the circuit at 5sec of the discharge.

solution

(a) the charge on the capacitor

$$q_o = CV = 5 \times 12$$
$$q_o = 60\mu F$$

then from the relation of discharge

$$q = q_o e^{-\frac{t}{CR}}$$
$$q = 60 \times 10^{-6} \times e^{-\left(\frac{5}{5 \times 12}\right)}$$
$$q = 36.4\mu C$$

(b) required p.d after 5seconds

$$from \quad V = \frac{q}{C} = \frac{36.4 \times 10^{-6}}{5 \times 10^{-6}}$$
$$V = 7.3V$$
$$Current\ after = 5sec$$

$$E = \sqrt{E_x^2 + E_y^2}$$

$$E = \sqrt{(2.55 \times 10^4)^2 + 0^2}$$

$$E = 2.55 \times 10^4 \, N/C$$

The electric field at the centre of square is 2.55×10^5 N/C

(i) electrical potential at the centre of square

$$V = V_A + V_B + V_C + V_D$$

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

$$V = k\left(\frac{q_A}{r} + \frac{q_B}{r} + \frac{q_C}{r} + \frac{q_D}{r}\right)$$

$$V = \frac{9 \times 10^9}{0.707}(5 + 5 - 5 - 5)$$

$$V = 0V$$

electrical potential at the centre is zero

Example 15:

Three point charges of $+8 \times 10^{-9}$ C, $+32 \times 10^{-9}$ C, $+24 \times 10^{-9}$ C are placed at corner A, B and C respectively having each side of 4cm. calculate electric field and electric potential at a corner.

final energy of the system

$$= \frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 + \frac{1}{4\pi\varepsilon_o} * \frac{Q.Q}{d}$$

$$= \frac{1}{4}mv^2 + \frac{1}{4\pi\varepsilon_o} * \frac{Q^2}{d} = \frac{1}{2}mv^2$$

$$\frac{1}{4\pi\varepsilon_o} * \frac{Q^2}{d} = \frac{1}{4}mv^2$$

$$solving\ for\ distance\ d$$

$$d = \frac{1}{\pi\varepsilon_o} * \frac{Q^2}{mv^2}$$

Example 17:

ABC is right angled triangle where AB and BC are 25cm and 60cm respectively. A metal sphere of 2 cm radius charged to a potential of 9×10^5V is placed at B. Find the amount of work done in carrying a positive charge of 1C from C to A.
Consider the illustration below.

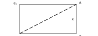
potential of a charged sphere is given by

$$V = 9 \times 10^9 \times \frac{q}{r}$$

$$q = \frac{V \times r}{9 \times 10^9}$$

$$q = \frac{9 \times 10^5 \times 0.02}{9 \times 10^9}$$

(d) Consider the diagram below.



Let V_A = potential of point A
V_B = potential of point B.

$$\textbf{potential due to point charge } V = \frac{Q}{4\pi\varepsilon_o r}$$

$$V_A = V \text{ due to } q_1 + V \text{ due to } q_2$$

$$V_A = \frac{q_1}{4\pi\varepsilon_o y} + \frac{q_2}{4\pi\varepsilon_o X} = \frac{1}{4\pi\varepsilon_o}\left(\frac{q_1}{y} + \frac{q_2}{X}\right)$$

$$V_A = \frac{1}{4\pi\varepsilon_o}\left(\frac{-5\times10^{-5}}{y} + \frac{2\times10^{-6}}{X}\right)$$

$$\text{similarly, } V_A = V \text{ due to } q_1 + V \text{ due to } q_2$$

$$V_B = \frac{1}{4\pi\varepsilon_o}\left(\frac{-5\times10^{-5}}{x} + \frac{2\times10^{-6}}{y}\right)$$

Potential difference between A and B given by p.d $V_A - V_B$, work done in moving a third charge between A and B is given by;

$$workdone = q_3 \times p.d$$

$$workdone = q_3(V_A - V_B)$$

$$workdone = 3\times10^{-6}(V_A - V_B)$$

$$w.d = \frac{3\times10^{-6}}{4\pi\varepsilon_o}\left(\frac{-5\times10^{-5}}{y} + \frac{2\times10^{-6}}{x} + \frac{5\times10^{-5}}{x} - \frac{2\times10^{-6}}{y}\right)$$

Since the dimension of rectangle are not provided since we cannot provide final conclusion in this question

9. (a) (i) define the term dielectric constant and give SI units
   (iii) Mention three uses of dielectric material in capacitors.
   (iv) The plates of a parallel plate air capacitor consisting of two circular plates, each of 10cm radius, placed 2mm apart are connected to the terminals of an electrostatic voltmeter scale. The space between the plates is then filled oil of dielectric constant 4.7 and the voltammeter reading falls to 2.5V. Determine the capacitance of the voltammeter (assume the voltage recorded by the voltammeter is proportional to the scale reading).

   (b) Prove that if two spherical shells of a spherical capacitor have their radii approximately equal, the device approximates a parallel plate capacitor.

Answers:

Dielectric constant of a dielectric material is the ratio of the capacitance of a capacitor with the dielectric between its plates to the capacitance of a same capacitor with air or vacuum between the plates.

Dielectric constant is the ratio of dimensionally equivalent quantities, hence it has no SI – unit

Uses of dielectric materials in capacitors.

- to increase the capacitance of the capacitor and hence the quantity of charge stored.
- To prevent short circuits.
- To transmit electric field across the plates.

solution

$$C = \frac{A\varepsilon_o}{d}; \text{ since } A = \pi r^2$$

$$C_o = \frac{\pi(0.1)^2\varepsilon_o}{2 \times 10^{-3}}$$

vertically upward. Will the electron strike the either plate? If it will strike where it will do so? **[ans. 2.71 cm **]**

33. A pendulum bob of mass 80mg and carrying a charge of $2\times10^{-8}C$ is at rest in a horizontal uniform electric field of $20000Vm^{-1}$. Find the tension in the in the threads of the pendulum and the angle it makes with the vertical. **[ans. 8.8×10^{-4} **]**

34. Two points charges of $2\times10^{-7}C$ and $1.0\times10^{-7}C$ are 1.0cm apart. What is the magnitude of the field produced by either charge at the site of the other? **[ans. 1.8×10^{7}N; 9×10^{6}N]**

35. Two points charges of $+5\times10^{-19}C$ and $+20\times10^{-19}C$ are separated by a distance 2m. Find the point on the line joining them at which electric field is zero.**[ans. $x = 2/3m$ **]**

36. Four points charges each having a charge of q are placed in four corners A, B,C and D of a regular pentagon ABCDE. Distance of each corner from the centre O is **a** .find the electric field at the centre of the pentagon.

[ans. $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a^2}$]

37. Four charges +4, -3, +2 and +3C are placed at the corners of a square of each side 1m. find the electric field at the centre of the square. **[ans. 1.125×10^{7}N/C **]**

38. An infinite number of charges, each equal to q are placed along X-axis at $x=1, x=2, x=4, x=8$ and so on. Find the electric field at the point x=0 due to this set of charges and what will be the electric field if in the above set up, the consecutive charges have opposite charges. **[ans. $\frac{q}{3\pi\varepsilon_0}$; $\frac{q}{5\pi\varepsilon_0}$]**

39. A particle of mass M is attached to one end of a mass less rigid non-conducting rod of length L . Another point particle of the same mass is attached to one end of the rod. The two particles carry charges +q and –q respectively. This arrangement is held in a uniform electric field E, such that the rod makes the small angle θ with the field direction. **[refer to notes]**

40. An inclined plane making an angle of 30^0 with the horizontal is placed in a uniform horizontal electric field of $100Vm^{-1}$. A particle of 1kg and charge 0.01C is allowed to slide down from rest from a height of 1m. If the coefficient of static friction is 0.2. Find the time it will take to reach the bottom. **[ans. 1.31s]**

41. Fig1.36 shows four points charges at the corners of the square of side 2cm. find the magnitude and direction of electric field at the centre O of the square if $Q = 0.02\mu C$

$< 10^5$ N/C]

42. ABC is a right-angled triangle, the right angle being at point B , charges of -10.24, +11.52, + 3.24μC are placed at points A, B and C respectively. If AB=4cm and BC= 3cm. Calculate the magnitude and direction of the resultant electric field at the foot D of the perpendicular drawn from B on the side AC. **[ans. $180\sqrt{2}$ N/C]**

43. A charged particle of mass 1g is suspended through a silk thread of length 40cm in a horizontal electric field of $4.0\times10^4\ Nc^{-1}$. If the particle stays at a distance of 24cm from the wall in equilibrium. Find the charge on the particle. **[ans. 1.838×10^{-7}C]**

44. What is the relationship between electric field and electric flux?
    (*i*) State Gauss' theorem and give the importance of the theorem
    (*ii*) What is Gauss' surface?
    (*iii*) What is electrostatic shielding?
    (*iv*) What is the principle of electrostatic shielding?
    (*v*) The safety way to safeguard from the lightening is to be inside a car. Why?
    A man inside an insulated metallic cage does not receive a shock, when a cage is highly charged. Why?

45. Deduce Coulomb's law from Gauss' theorem

46. Use Gauss' theorem to derive the electric field of the following

114. Two small balls are suspended by insulating threads from a common point. Each ball has a mass of 0.20g and suspension thread are 1m long. When the balls are given equal positive charge each suspension thread is found to make an angle of 7° with the vertical. What are the charges carried by the two balls? [ans. 3.99×10^{-8}C, necta 2004]

115. Positive charge is distributed over a solid spherical volume of radius R and the charge per unit volume is σ

116. Show that the electric field inside the volume at a distance r < R from the center is given by

(i) $E = \dfrac{\sigma\ r}{3\Sigma_0}$

(ii) What is the electric field at a point $r > R$ (i.e. outside the spherical volume)

NOTE:

Charge is anything that possessed by a material objects which make it possible for the charge to exert force and to respond to electrical force

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