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PHYSICS

Class 10th (KPK)

Unit # 13 Electrostatics

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UNIT #13

ELECTROSTATICS

COMPREHENSIVE QUESTION

Give an extended response to the following questions.

Q1. What is electric charge? How objects can be electrified? Describe with the help of experiments?

Ans: <u>Electric Charge:</u>

It is the property of a substance due to which it can attract or repel another substance.

OR

Electric charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field.

Unit:

The unit of charge is coulomb(C)

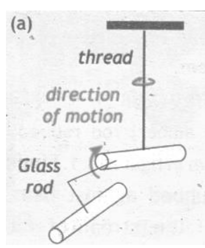
Kinds of charges:

There are two types of charges.

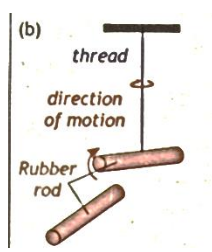
1. Positive charge
2. Negative charge

Experiments:

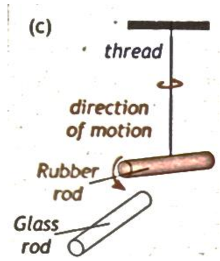
(a) Glass rod rubbed with silk cloth brought near another suspended glass rod rubbed with silk cloth repels each other.



(b) Rubber rod rubbed with fur brought near another suspended rubber rod rubbed with fur repels each other.



(c) Glass rod rubbed with silk cloth brought near a suspended rubber rod rubbed with fur attracts each other.



It is concluded that friction between two different materials produces two different kinds of charges that is positive and negative charge. Like charge always repel each other and unlike charges always attract each other.

Electrification:

Electric charge is not created in the process of charging objects; charges are only transferred between the objects. In electrification experiments in figure 3.2, it is seen that silk cloth/animal fur also attained charge. Thus, in those experiments, charge was not produced rather it was only transferred and we can say that objects can be charged by removal or addition of charges (specifically electrons) called electrification.

Since electrons can be transferred easily therefore if an object has a…..

- Positive (+) charge – means it has less electrons than normal.
- Negative (-) charge – means it has more electrons than normal.

Q2. What is electrostatic induction? Explain.

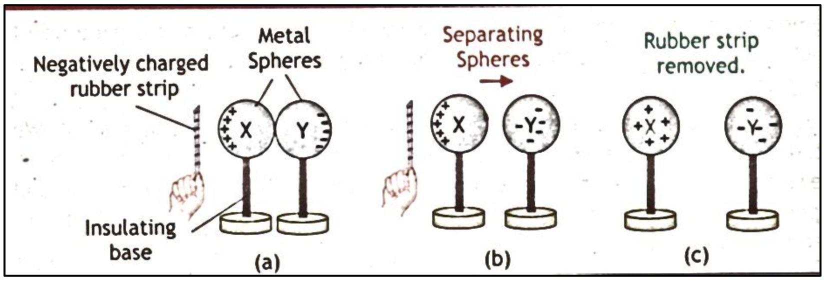
Electrostatic Induction:

A change in distribution of electrical charge in an object, caused by the influence of nearby charges is called electrostatic induction.

Explanation:

Electrostatic induction may be shown by bringing a negatively charged rubber strip near to an insulated metal sphere X which is touching a similar sphere Y (as shown in figure-a). Electrons in the spheres are repelled to the far side of Y.

If X and Y are separated, with the charged strip still in position, X is left with a positive charge (deficient of electrons) and Y with a negative charge (excess of electrons) as shown in Figure – b. In this way electrostatic induction can be used to charge objects as in Figure- c.



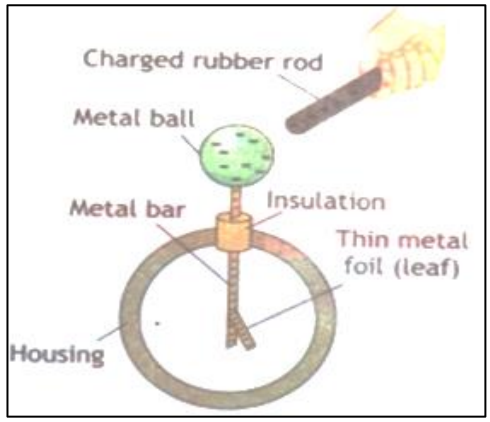
Q3. What is the function of electroscope? How can we use electroscope to find the presence and nature of charge on a body?

Ans. **Electroscope:**

Electroscope is a device used for detecting and testing the nature of charge on a body. It works on the principle that similar charges repel each other.

Construction:

A simple form of electroscope consists of a metal bar which has a metallic sphere (ball) at its upper end. Thin flexible metal leaf (made of gold, silver, copper or any other metal) is attached to the lower end of metal bar. The lower part is enclosed in an insulated housing as shown in the figure.



Working:

1. Presence of charge on a body:

In order to detect the presence of charge on a body, bring it near the metal ball of an uncharged electroscope. If the body is charged, the leaves of the electroscope diverge to a definite extent, otherwise they would remain in their normal position. The divergence between the leaves of the electroscope is due to the presence of a charged body or electrostatic induction.

If a negatively charged body is brought near the electroscope, due to induction positive charge will appear on the metal ball and negative charges on the leaves. As like charges repel each other, therefore, due to the force of repulsion between the negative charges on the two leaves, the leaves will more away from each other.

2. Testing the Nature of charge on a body:

To test for the nature of a charge on body, we need to charge the electroscope first. In order to charge the electroscope, touch its metal ball with either positively charged body or negatively charged body. In this process some of the charges present on the body is transferred to the metallic sphere (metal ball) and leaves of the electroscope. After charging electroscope bring the body under test near the metal ball (or disc) of the electroscope. If the divergence increases, the body has the same kind of charge as on the electroscope. On the other hand, if the divergence decreases, the charge on the body will be opposite to the charge present on the electroscope.

Q4. State and explain Coulomb's Law?

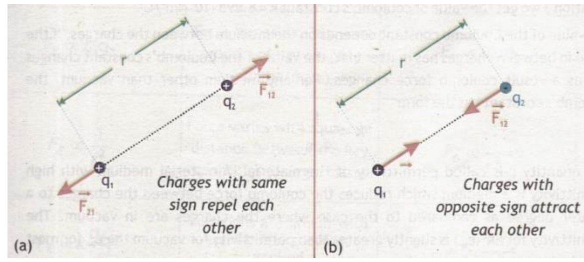
Ans. **Coulomb's law:**

Statement:

The electric force between two stationary point charges is

- directly proportional to the product of the charges;
- inversely proportional to the square of the distance between them and
- Is directed along the line joining these charges.

Consider two point charges q_1 and q_2 separated by distance r as shown in figure. By definition of Coulomb's Law



$F_E \propto q_1 q_2$ -----------(1)

And $F_E \propto \frac{1}{r^2}$------------(2)

Combining equation (1) and equation (2), we get

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

Changing the sign of proportionality into equality

$F_E = k\,\frac{q_1 q_2}{r^2}$-------(3)

Equation (3) gives Coulomb force, where k is a constant of proportionality and is called the Coulomb constant. Here the charges 'q_1' and 'q_2' are considered as point charges as distance 'r' is considered large as compared to their size.

COULOMB'S CONSTANT:

The Coulomb constant k for vacuum in SI units has the value **9×10^9 Nm^2/C^2**, this constant, is also written in the form

$k = \frac{1}{4\pi\varepsilon_0}$--------------- (3)

Where the constant ε_0(lowercase Greek epsilon) is known as the permittivity of free space (vacuum) and has the value 8.85×10^{-12} C^2/Nm^2. Putting this value in above equation (3) we get the value of coulomb's constant $k = 8.998\times 10^9$ Nm^2/C^2.

The value of the Coulomb constant depends on the medium between the charges. If the space in between the charges has matter in it, the value of the Coulomb's constant changes and as a result coulomb forces changes. For any medium other than vacuum, the coulomb's constant has the form

$$k = \frac{1}{4\pi\varepsilon}$$

The quantity ε is called permittivity of the material. A material medium with high permittivity is a medium which reduces the coulomb force between the charges to a greater degree as compared to the case where the charges are in vacuum. The permittivity for air (ε_{air}) is slightly greater than permittivity for vacuum the ε_0, for most practical purposes they are taken as equal.

Q5. What is meant by electric field and electric field intensity? How the field lines represent the electric field for isolated positive and negative point charges?

Ans: Electric field:

The region around a charge in which an electric test charge would experience an electric force is called electric field.

Explanation:

An electric field exists in the region of space around a charged object in three dimensions. When another charged object enters this electric field, an electric force acts on it even without any physical contact between the charges.

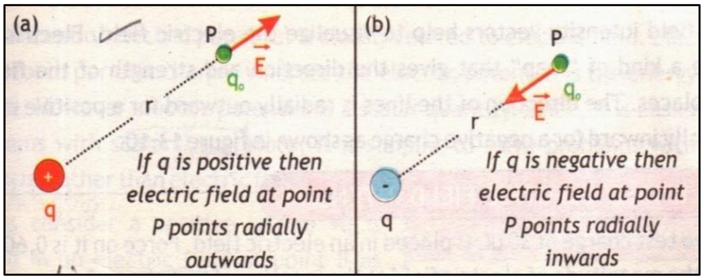
Electric Field Intensity:

The strength of the field (equal to the force experience by a (+ 1C) test charge) at any point is called electric field intensity.

OR

The electric force experienced by a unit test charge placed at a certain point in electric field is known as electric field intensity.

Explanation:



Consider a small positive test charge q_0 near the greater magnitude charge q as shown in figure. Now the electric field E at any point in space is defined as the force F_E acting on unit positive charge q_0, divided by the magnitude of test charge q_0, mathematically

$$E = \frac{F_E}{q_0}$$

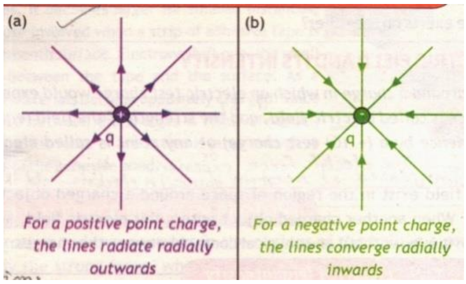
Unit:

The SI of electric field intensity is newton per coulomb (NC^{-1}). It is a vector quantity having direction in which a positive test charge would move under the influence of force.

Electric Field Lines:

An easy way to visualize an electric field is to draw lines that follow the same direction as the electric field intensity vector E at any point. These lines are called electric field lines.

Explanation:



Electric field intensity vectors help to visualize the electric field. Electric field lines are a kind of "map" that gives the direction and strength of the field at various places. The direction of the lines is radially outward for a positive charge and radially inward for a negative charge as shown in figure.

Q6. What is electric potential? In what units we measure electric potential?

Ans. Electric Potential:

The electric potential energy "U" per unit charge "q" in an electric field is called electric potential V.

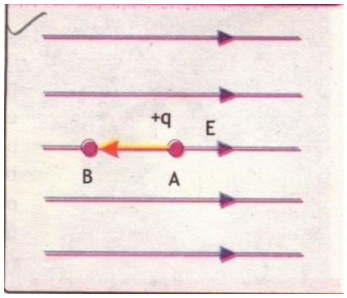
$$V = \frac{U}{q} = \frac{W}{q}$$

OR

The work-done in moving a unit positive charge from one point to another against electric field is known as electric potential.

Electric potential is a scalar quantity.

Explanation:



Let us consider a positive charge +q is placed in an electric field at point B as shown in the figure. If the charge is allowed to move freely, it will acquire kinetic energy and will move from B to A. Conversely, we can say that an external force is required to keep the charge at rest or to move with uniform velocity from A to B. Thus

$$V_B - V_A = \frac{W_{AB}}{q}$$

Often point A is taken to be at infinity, meaning a large distance from the charges that produce the electric field, and the electric potential at A is taken to be Zero. Note that the choice of zero potential at infinity is taken arbitrarily and for simplicity, such that

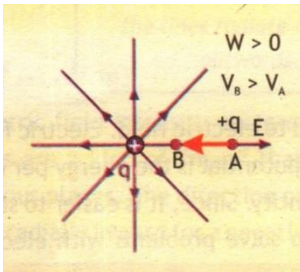
$$V = \frac{W}{q}$$

V (by definition) the work that must be done against the Electric Field to bring a test charge q from infinity to a specific location.

Positive and Negative Work Done:

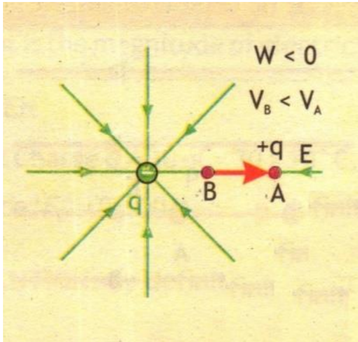
The work done W_{AB} in moving charge +q from point A to point B can be positive, negative or zero, thus the potential at point B can be higher, lower or equal to potential at point A.

i) **Positive Work Done:**



In order for a positive test charge to be brought closer to an isolated positive charge +q. The work must be done by an external agent, the work done in this case in positive. In this case, the electric potential at point B is higher than electric potential at point A. Alternately, we can observe that $V_B > V_A$ by nothing that the electric field would push a positive charge from B to A, which is always from high potential to low potential.

ii) **Negative Work Done:**



If the isolated charge is negative (-q), the positive test charge must be restrained from moving from point A to point B and the work done must be negative. In this case, the electric potential at point B is lower than electric potential at point A. Alternately, we can observe that $V_B < V_A$ by noting that the electric field would pull a positive charge from A to B, which is always from high potential (A) to low potential (B).

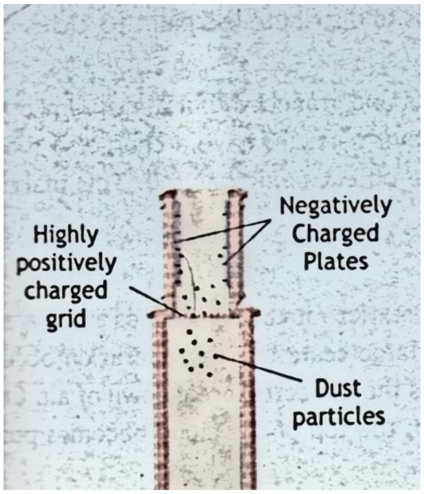
Q7. Give some practical applications in which electric field is useful.

Ans. **Practical Applications of Electrostatics:**

Electrostatic phenomena have wide applications in daily life.

A: Electrostatic precipitator and dust extraction:

Electrostatic phenomena can be used to separate dust from smoke particles. To reduce air pollution, modern day coal burning power stations extract dust from the smoke in chimneys before releasing it to the environment by a process called electrostatic precipitation.



For this purpose, chimneys have a highly positively charged grid (usually wire gauze) and negatively charged plates as shown in the figure. When smoke rising from chimney containing smoke and dust particles pass through the positively charged grid they acquire a positive charge. Theses charged particles are attracted by the negatively charged plate and are deposited on them. Thus, the smoke coming out of chimney is free from dust and other particles.

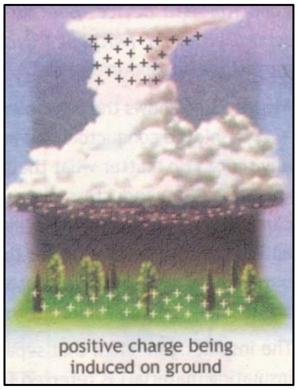
B. Electro painting:

Electrostatic spray painting is a method in which electrostatically charged paint is applied. This method reduces the paint usage and uneven coating that result from using a regular spray painter, both for powder and liquid paint.

On type of system applies a negative electric charge to the paint while it is in the container. Other systems apply the charge in the barrel of the spray painter gun. The paint is then pushed through the gun, rubbing against the side, and gaining a static electric charge as it moves. Since the paint particles all have the same charge, they repel each other. This helps to distribute the paint particles evenly and get uniform coverage.

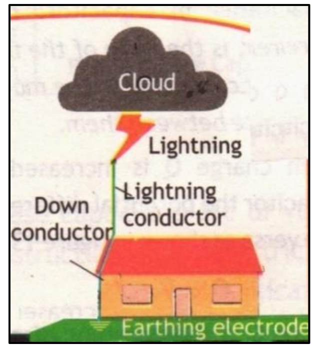
Usually the object being painted is metal and grounded, but almost any product can be finished electrostatically. The paint particles have a charge so they are attracted to the opposite charge of the object being painted. This makes the particles less likely to stay in the air.

Q8. How lighting occurs? How can we safeguard ourselves from lightning hazard?



Ans. Lightning is the result of large scale charge separation occurring within a thundercloud. Lighting involves the dielectric breakdown of air. Charge separation occurs within a thundercloud; the top of the cloud becomes positive and the lower part becomes negative.

The negative charge at the bottom of the thundercloud induces positive charge on the Earth just underneath the cloud as shown in figure. When the electric field between the cloud and the earth becomes large enough, the air undergoes dielectric breakdown, meaning it momentarily becomes a good conductor of electricity allowing the negative charge to jump from the cloud to the earth. A lightning channel is completed and electrons rush to the ground making the channel glow in the process. A total of about 20C to 25C of electronic charge is transferred from the thundercloud to the surface.



<u>How can we protect out self from lighting Hazard:</u>

We should stay indoors or in an automobile if possible. When caught in the open, we should keep low, stay away from any tall tree; if lightning strikes the tree, charge traveling down the tree and then along the surface will put us in danger.

If trapped in such situation we should try to go in a nearby ditch or low spot keeping our head low and feet as close together as possible.

Q9. What is capacitor? Define capacitance and its units.

Ans. <u>Capacitor:</u>

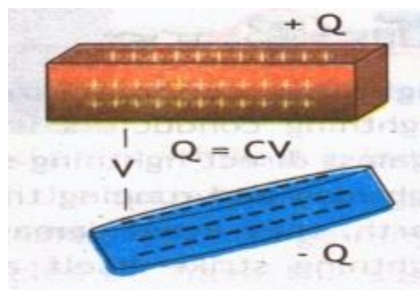
Capacitor is a device used for storing charge.

<u>Construction:</u>

It consists of two parallel metal plates, separated from each other by small distance, carrying charges of equal magnitude but opposite sign.

The insulating medium between the two plates is air or sheet of some insulating material. This medium is known as dielectric.

<u>Capacitance of capacitor:</u>



The capacitance C of a capacitor, is the ratio of the magnitude of the charge on either conductor to the magnitude of the potential difference between them.

When charge Q is increased on the plates of the capacitor the potential difference V also increases and vice versa as shown in figure, thus we can write

$Q \propto V$ or $Q=CV$

Where C is the constant of proportionality and is called the capacitance of a capacitor.

Therefore $C = \frac{Q}{V}$

The capacitance of a capacitor is the amount of charge the capacitor can store per unit of potential difference. The capacitance of a capacitor depends upon the size and shape of the plates. It also depends upon the separation and the nature of insulating material in between the plates.

<u>Units of capacitance:</u>

The SI unit of capacitance is coulombs per volt or the farad (F), named in honor of Michael Faraday, such that

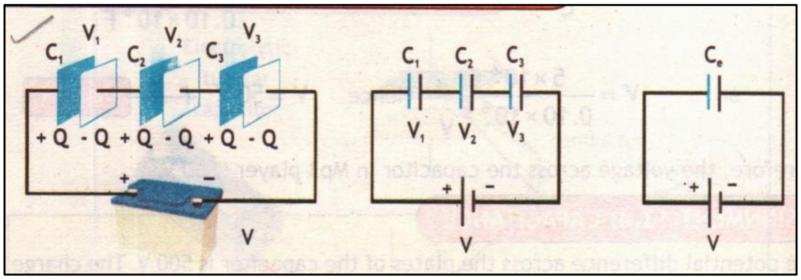
$1F = 1C/V$

The farad is a very large unit of capacitance. In practice, typical devices have capacitances ranging from microfarads (10^{-6} F) to Pico farads (10^{-12}F).

Q10. What is series combination of capacitors? How we can determine equivalent capacitors for different capacitors connected in series?

Ans. Series Combination of Capacitors:

When the capacitors are connected plate to plate then they are said to be connected in series, three capacitors having capacitance C_1, C_2 and C_3 are shown in the figure as series combination.



(i) When battery is connected to a series combination of capacitors, the same current flows through each capacitor which means charge of +Q is placed on the left plate of each capacitor and an equal charge of –Q on the right plate of each capacitor. As a result, each capacitor gets an equal amount of charge Q on each of its plates.

$Q_1=Q_2=Q_3=Q$ ------------- (1)

(ii) When the three capacitors in the circuit are charged, the sum of the potential drops across all three must equal the potential difference supplied by the battery.

$V=V_1+V_2+V_3$ ------------- (2)

Since the capacitance of capacitor is

$C=\frac{Q}{V}$ or $V=\frac{Q}{C}$

Therefore, each voltage can be written as

$V_1=\frac{Q_1}{C_1}$ and $V_2=\frac{Q_2}{C_2}$ and $V_3=\frac{Q_3}{C_3}$ and $V=\frac{Q}{C_e}$

Where C_e is the equivalent capacitance of a single capacitor that has the same effect on the circuit as the series combination, when it is connected to the battery. Hence equation (2) can be written as

$\frac{Q}{C_e}=\frac{Q_1}{C_1}+\frac{Q_2}{C_2}+\frac{Q_3}{C_3}$------------(3)

Putting equation (1) in equation (3) we get $\frac{Q}{C_e}=\frac{Q}{C_1}+\frac{Q}{C_2}+\frac{Q}{C_3}$

Or $\frac{Q}{C_e}=Q\left(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}\right)$

Hence $\frac{1}{C_e}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$ ------------- (4)

(iii) Generally for ‘n’ number of capacitors connected in series

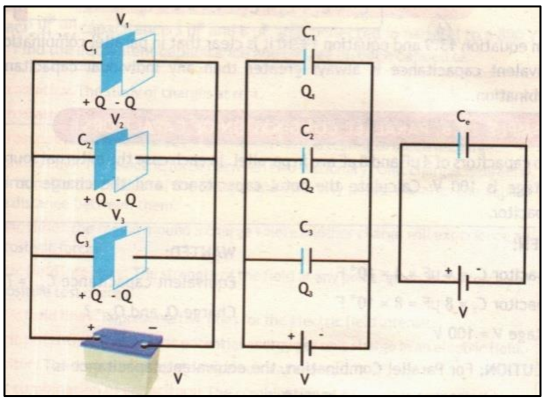
$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{-------------} + \frac{1}{C_n} \text{ ---------- } (5)$$

From equation (4) and equation (5) it is clear that in series combination, the equivalent capacitance is always smaller than any individual capacitance in combination.

Q11. What is parallel combination of capacitors? How we can determine equivalent capacitors for different capacitors connected in parallel?

Ans. Parallel Combination of Capacitors:

When the capacitors are connected in different branches of the circuit, the capacitors are said to be connected in parallel. Three capacitors having capacitance C_1, C_2 and C_3 are shown in the figure as parallel combination.



(i) In this configuration, the potential applied across each capacitor is same and is equal to the applied potential.

$V_1=V_2=V_3 = V$ ------------- (1)

(ii) Depending upon the capacitance, the capacitors acquire different amount of charges. The charge Q of the equivalent capacitor be equal to the sum of the charges on the individual capacitors. Such that the total charge is equal to the sum of all the individual charges.

$Q = Q_1+ Q_2+Q_3$ ------------- (2)

Since the capacitance of capacitor is

$C= \frac{Q}{V}$ or $Q = CV$

Therefore, each charge can be written as

$Q_1 = C_1V_1$ and $Q_2 = C_2V_2$ and $Q_3 = C_3V_3$ and $Q = C_e V$

Where C_e is the equivalent capacitance of a single capacitor that has the same effect on the circuit as the series combination, when it is connected to the battery.

Hence equation (2) can be written as $C_eV = C_1V_1 +C_2V_2+C_3V_3$ --------------- (3)

Putting equation (1) in equation (3) we get $C_eV = C_1V+ C_2V+ C_3V$

Or $C_eV = V (C_1+C_2+C_3)$

Therefore, $C_e=C_1+C_2+C_3$ -------------- (4)

(iii) Generally, for ‘n’ number of capacitors connected in parallel

$$C_e = C_1 + C_2 + C_3 + \ldots\ldots + C_n \text{------------}(5)$$

From equation (4) and equation (5) it is clear that in parallel combination the equivalent capacitance is always greater than any individual capacitance in combination.

Conceptual Questions

Q1. Normally, objects with large number of electrons are electrically neutral, why?

Ans. An electrically neutral object contains the same amount of positive charge as negative charge, resulting in no net charge i.e.

Number of electrons = Number of protons.

Under such conditions the potential difference will be zero and electric field intensity “E” will be zero. Thus, the objects with large number of electrons will remain neutral.

Q2. How does shuffling feet across a carpet cause hair to stand on our body?

Ans. The rubbing of certain materials against one another can transfer negative charges or electrons. i.e. one loses electrons and other gains that electrons.

When we shuffle our feet on the carpet, we are rubbing electrons off the carpet and onto our body. These negatively charged particles i.e. electrons are accumulate on our body’s hair. As similar charges repel each other, these hairs try to repel each other as far away from each other as possible. This is why the hair actually strands up on our body when we rub carpet with our feet.

Q3. Why neutral objects are always attracted by charged object? Not repelled.

Ans. Since neutral objects are composed of atoms which have equal number of positive and negative charges. When a charged body is brought near a neutral body, then due to electrostatic induction, opposite charge in the neutral body is brought towards the charged body and same charge to the other end.

For example, if a positively charged rod is brought near a neutral body, it attracts negative charge in the neutral body towards itself while repel the positive charges to the other end. Because of this reason neutral objects are always attracted by charged objects.

Q4. Why the pieces of paper initially attracted by charged comb fly away when they touch it?

Ans. When a charged comb is brought in contact with dry paper due to electrostatic induction opposite charge is induced on the tiny pieces of dry paper. As a result, electrostatic fore of attraction exists between comb and pieces of paper, the charged comb attracts the pieces of paper. However, when these pieces touch the charged comb, then they got the same charge as that of comb. Now electrostatic force of repulsion is created between same charges due to which pieces of paper fly away. Thus, the pieces of paper first attracted by a charged comb due to electrostatic induction and then repelled on touching it.

Q5. Is it necessary for a charged body actually to touch the ball of the electroscope for the leaves to diverge? Defend your answer.

Ans. No, it is not necessary for the charged body to touch the ball of an electroscope for the leaves to diverge.

When we bring a negative charge body near the ball, electrons in the ball are repelled and driven to the leaves, leaving the ball positively charged. Similarly, when we bring positive charge near the ball, electrons will be attracted and move up to the ball to make it negative and leave the leaves positively charged. The leaves of an electroscope diverge due to repulsion between them as both carry same charge. This is charge separation due to induction and it is not necessary for the charged body to physically touch the ball.

Q6. How electrostatic painting is better than conventional spray painting?

Ans. In electrostatic painting, when the paint leaves the nozzle of the spray gun, it is given a positive charge. The negatively charged grounded metal (vehicle) attracts the positively charged droplets of paint spray to its surface just like a magnet. There are many benefits of using electrostatic painting, some of which are given by.

1. It makes a stronger bond to cover an object move evenly, even if the vehicle has many angles.
2. This method saves paint by ensuring more paint lands on the charged vehicle surface.
3. It creates a better looking finish because the paint is distributed more evenly and uniformly.

Q7. Why are lighting rods normally at a higher elevation than the building they protect?

Ans. Lightening occurs when the electric field between clouds and grounds gets high to overcome the resistance of the air between them. Putting the lightning rods gives an easy path to be conducted to the earth. As the rod gives an easy path to the charge, so buildings become safe and not damaged. Lightening hits the tallest objects in its path e.g. trees, high rise buildings etc. Therefore, lightning rods should be taller in order to be hit first by the lightning storm leaving the building safe.

On the other hand, if these were shorter than the building then lightening will hit the building first causing damage to it. That's why, the lightning rods are normally at higher elevation than the building for protection purpose.

OR

The lightning rods are normally at higher elevation than the building for the reason that lightening first hit the rods and not the building.

Lightening always takes the path of least resistance and air is pretty resistant stuff. If the lightening rod is shorter the current will find another path, like the plumbing of a house or even through solid wood (i.e. tree). This is bad.

Q8. What would happen if two insulating plates were used instead of conducting plates to construct a capacitor?

Ans. A capacitor is made of two conducting (metal) plates and an insulating material in between them. The metal plates lie very close to each other, but insulating material prevents them from touching. When a potential difference or battery is connected to the plates of the capacitor, its positive terminal draws free electrons from the plate to which it is connected. Thus, this plate acquires a net positive charge on it.

Due to electrostatic induction, equal and opposite charge is induced on the other plate of the capacitor. Thus, a capacitor stores equal and opposite charges on its two plates facing each other. This accumulation of charge is very less in case of insulating plates, as insulators have no free electrons. Therefore, only conducting plates are used in a capacitor not insulating ones.

Q9. The sum of the charges on both plates of a capacitor is zero. What does a capacitors store?

Ans. The capacitor stores electrical energy in the form of its electric field between its plates. Because the plates are equal but oppositely charged, a potential difference exists between them. That means there is energy available to do work. And since there is a potential difference, there is an electric field which points from the positive plate to the negative one.

Q10. If you wish to store a large amount of energy in a capacitor bank, would you connect capacitors in series or parallel? Explain.

Ans. If we wish to store a large amount of energy in a capacitor bank, then connect all the capacitors in parallel because charge storing ability increase in parallel rather than series.

i.e. $C = C_1 + C_2 + C_3$

When in parallel, capacitor values add up, and energy storage goes in proportion. For a given fixed voltage, parallel combination is the only way. Series connection reduces capacitor value and hence the stored energy.

ASSIGNMENTS

13.1 A small metal sphere with a charge of -2.10×10^{-6} C is brought near an identical sphere with a positive charge of 1.50×10^{-6} C so that the distance between the centers of the two spheres is 3.30 cm. Calculate the magnitude of the force that each charge exerts on the other?

Given data:

Charge of one sphere $=q_1=2.10\times10^{-6}$ C

Charge of other sphere $=q_2=1.50\times10^{-6}$ C

Distance =r =3.30 cm

$r = \frac{3.30}{100} m$

r=0.033m

Coulomb's constant $=k=9\times10^9\ Nm^2/C^2$

Required:

Force $=F_E=?$

Solution:

As we know that

$$F_E = k\frac{q_1 q_2}{r^2}$$

$$F_E = 9 \times 10^9 \frac{(2.10 \times 10^{-6}) \times (1.50 \times 10^{-6})}{(0.033)^2}$$
$$F_E = \frac{9 \times 2.10 \times 1.50 \times 10^9 \times 10^{-6} \times 10^{-6}}{0.001089}$$
$$F_E = \frac{28.35 \times 10^{9-6-6}}{0.001089}$$
$$F_E = \frac{28.35 \times 10^{9-12}}{0.001089}$$
$$F_E = 26033.0 \times 10^{-3}$$
$$F_E = 26.033\ N$$
Or
$$F_E = 26.0\ N$$

13.2 If a charge of 4μC is placed in a uniform field of strength 2 NC^{-1}, what force will it experience?

Given data:

Charge =q =4μC

=4×10^{-6}C

Electric field intensity = E =2NC^{-1}

Required:

Force =F_E=?

Solution:

We know that
$$E = \frac{F_E}{q}$$
$$\Longrightarrow F_E = qE - - - - - - (1)$$
Putting values in eq (1), we get
$$F_E = 4 \times 10^{-6} \times 2$$
$$F_E = 4 \times 2 \times 10^{-6}$$
$$F_E = 8 \times 10^{-6} N$$
$$F_E = 8\mu N$$

13.3 How much work is done in moving a charge of 3C from a point at 118V to a point at 138V in an electric field?

Given data:

Charge=q=3C

Potential at one point=V_1=118V

Potential at other point=V_2=138V

Potential difference =ΔV=V_2- V_1

ΔV=138V-118V

ΔV=20V

Required:

Work done=W=?

Solution:

We know that

$$\Delta V = \frac{W}{q}$$

$$\Longrightarrow W = q\Delta V$$

Putting values

$$W = 3 \times 20$$

$$W = 60\text{J}$$

13.4 The potential difference across the plates of the capacitor is 500V. The charge on each plate is 0.02C. What is the capacitance of the capacitor?

Given data:

Potential difference =V=500V

Charge on each plate=Q=0.02C

Required:

Capacitance of the capacitor =C=?

Solution:

As we know that

$$Q = CV$$

$$\Longrightarrow C = \frac{Q}{V}$$

Putting values

$$C = \frac{0.02}{500}$$

$$C = 0.00004F$$

$$C = 4.0 \times 10^{-5}F$$

$$C = 40.0 \times 10^{-6}F$$

Or

$$C = 40\mu F$$

13.5 Two capacitor of capacitance of 3μ*F* and 6 μ*F* are connected in series to a 100V battery. Calculate the equivalent capacitance and the voltage across each capacitor.

Given data:

Capacitance of one capacitor =C_1=3μF=3×10^{-6}F

Capacitance of other capacitor =C_2=6μF=6×10^{-6}F

Voltage =V=100V

Required:

Equivalent capacitance=C_e=?

Voltage across C_1=V_1=?

Voltage across C_2=V_2=?

Solution:

For series combination the Equivalent capacitance is

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

Or

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

$$\Longrightarrow C_e = \frac{C_1 C_2}{C_2 + C_1}$$

Putting values

$$C_e = \frac{3 \times 6}{6 + 3}$$

$$C_e = \frac{18}{9}\ \mu F$$

$$C_e = 2\ \mu F$$

$$C_e = 2\ \times 10^{-6} F$$

In series combination, charge remains the same, so we have

$$Q_1 = Q_2 = Q$$

The charge on each capacitor is

$$Q = C_e V$$

Putting values

$$Q = 2\ \times 10^{-6} \times 100$$

$$Q = 2\ \times 10^{-4} C$$

Now, the voltage across capacitor C_1 and capacitor C_2 as V_1 and V_2 respectively

The voltage across C_1 is given by

$$V_1 = \frac{Q}{C_1}$$

Putting values

$$V_1 = \frac{2\ \times 10^{-4}}{3 \times 10^{-6}}$$

$$V_1 = 0.666 \times 10^2 V$$

$$V_1 = 66.6V$$

Similarly, voltage across C_2 is

$$V_2 = \frac{Q}{C_2}$$

$$V_2 = \frac{2\ \times 10^{-4}}{6\ \times 10^{-6}}$$

$$V_2 = 0.333 \times 10^2 V$$

$$V_2 = 33.3V$$

13.6 Two capacitors of capacitance 3μF and 6μF are connected in parallel to an 800V battery. Find the equivalent capacitance and charge on each capacitor.

Given data:

Capacitance of one capacitor $=C_1=3\mu F=3\times10^{-6}F$

Capacitance of other capacitor $=C_2=6\mu F=6\times10^{-6}F$

Voltage $=V=800V$

Required:

Equivalent capacitance$=C_e=?$

Charge on $C_1=Q_1=?$

Charge on $C_2=Q_2=?$

Solution:

For parallel combination the Equivalent capacitance is

$$C_e = C_1 + C_2$$

Putting values

$$C_e = (3+6)\mu F$$
$$C_e = 9\mu F$$

Or

$$C_e = 9\times10^{-6}F$$

In parallel combination, that voltage remains the same, so

$V_1=V_2=V=800V$

Now the charge on C_1 is given by

$$Q_1 = C_1V$$

Putting values

$$Q_1 = 3\times10^{-6}\times800$$
$$Q_1 = 3\times800\times10^{-6}$$
$$Q_1 = 2400\times10^{-6}C$$

Or

$$Q_1 = 2400\mu C$$

Similarly, the charge on C_2 is given by

$$Q_2 = C_2V$$

Putting values

$$Q_2 = 6\times10^{-6}\times800$$
$$Q_2 = 6\times800\times10^{-6}$$
$$Q_2 = 4800\times10^{-6}C$$

Or

$$Q_2 = 4800\mu C$$

NUMERICAL QUESTIONS

1. Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the single proton that is the atom's nucleus. Assume the average distance between the electron and the proton is $r=5.3\times10^{-11}$m and charge on electrons and proton is 1.6×10^{-19}C.

Given data:

Charge on electron=q_1=1.6×10^{-19}C
Charge on proton =q_2=1.6×10^{-19}C
Distance between electron and proton = r =5.3×10^{-11}m
Coulomb's constant=k=9×10^9Nm^2/C^2

Required:

Magnitude of the electric force=F_E=?

Solution:

We know that

$$F_E = k\frac{q_1q_2}{r^2}$$

Putting values

$$F_E = 9\times10^9\frac{(1.6\times10^{-19})(1.6\times10^{-19})}{(5.3\times10^{-11})^2}$$

$$F_E = \frac{9\times1.6\times1.6\times10^9\times10^{-19}\times10^{-19}}{28.09\times10^{-22}}$$

$$F_E = \frac{23.04\times10^{9-19-19}}{28.09\times10^{-22}}$$

$$F_E = \frac{23.04\times10^{-29}}{28.09\times10^{-22}}$$

$$F_E = 0.82\times10^{-29+22}$$

$$F_E = 0.82\times10^{-7}N$$

Or

$$F_E = 8.2\times10^{-8}N$$

2. A 5μC point charge is placed 20cm from a 10μC point charge. (a) Calculate the force experienced by the 5μC charge. (b) What is the force on the 10μC charge? (c) What is field strength 20cm from the 10μC point charge?

Given data:

Charge= q_1=5μC
$q_1=5\times10^{-6}$C
Charge= q_2=10μC
$q_2=10\times10^{-6}$C
Distance between charges=r=20cm

$$r=\frac{20}{100}m$$

$$r=0.2m$$

Coulomb's constant =k=9×10^9Nm^2/C^2

Required:

Force on 5μC charge=F_E=?
Force on 10μC charge=F_E'=?
Electric field strength=E=?

Solution:

(a) Force on 5μC charge:

We know that

$$F_E = k\frac{q_1q_2}{r^2} - - - - -(1)$$

Putting values

$$F_E = 9 \times 10^9 \frac{(5 \times 10^{-6})(10 \times 10^{-6})}{(0.2)^2}$$

$$F_E = \frac{9 \times 5 \times 10 \times 10^9 \times 10^{-6} \times 10^{-6}}{0.04}$$

$$F_E = \frac{450 \times 10^{9-6-6}}{0.04}$$

$$F_E = 11250 \times 10^{-3} N$$

$$F_E = 11.250 N$$

$$F_E = 11.25 N$$

(b) Force on 10μC charge:

We know that

$$F_E' = k\frac{q_1q_2}{r^2} - - - - -(1)$$

Putting values

$$F_E' = 9 \times 10^9 \frac{(5 \times 10^{-6})(10 \times 10^{-6})}{(0.2)^2}$$

$$F_E' = \frac{9 \times 5 \times 10 \times 10^9 \times 10^{-6} \times 10^{-6}}{0.04}$$

$$F_E' = \frac{450 \times 10^{9-6-6}}{0.04}$$

$$F_E' = 11250 \times 10^{-3} N$$

$$F_E' = 11.250 N$$

$$F_E' = 11.25 N$$

According to eq (1), force on both charges will be the same.

$$F_E = F_E'$$

(c) Electric field strength:

We know that

$$E = \frac{F_E}{q_1}$$

Putting the values

$$E = \frac{11.25}{5 \times 10^{-6}}$$

$$E = 2.25 \times 10^6 N/C$$

$$E = 2.25 \times MN/C$$

3. In a certain region of space, a uniform electric field has a magnitude of 4.60×10^4N/C and points in the positive x-direction. Find the magnitude and direction of the force this field exerts on a charge of (a) +2.80μC (b) -9.30μC.

Given data:

Magnitude of electric field=E=4.60×10^4 N/C

Required:

(a) Magnitude and direction of force exerted on q_1=F_E=?
(b) Magnitude and direction of force exerted on q_2=F_E'=?

Solution:

(a) Magnitude and direction of force exerted on q_1

We know that

$$E = \frac{F_E}{q}$$
$$\Rightarrow F_E = qE$$
$$\Rightarrow F_E = q_1 E$$

Putting values

$$F_E = 2.80 \times 10^{-6} \times 4.60 \times 10^4$$
$$F_E = 2.80 \times 4.60 \times 10^{-6} \times 10^4$$
$$F_E = 12.88 \times 10^{-6+4}$$
$$F_E = 12.9 \times 10^{-2} N$$
$$F_E = +0.129\ N$$

The positive sign shows that the force is directed towards positive x-axis.

(b) Magnitude and direction of force exerted on q_2

For q_2 we have

$$F_E' = q_2 E$$

Putting values

$$F_E' = -9.30 \times 10^{-6} \times 4.60 \times 10^4$$
$$F_E' = -9.30 \times 4.60 \times 10^{-6} \times 10^4$$
$$F_E' = -42.78 \times 10^{-6+4}$$
$$F_E' = -42.8 \times 10^{-2} N$$
$$F_E' = -0.428\ N$$

The negative sign shows that the force is directed towards negative x-axis.

4. The potential difference between two points is 110V. When an unknown charge is moved between these two points, the work done is 550J. What is the amount of charge?

Given data:

Potential difference=V=110V

Work done=W=550J

Required:

Amount of charge=q=?

Solution:

We know that

$$V = \frac{W}{q}$$

$$\Rightarrow q = \frac{W}{V}$$

Putting values

$$q = \frac{550}{110}$$

$$q = 5C$$

5. The capacitance of a capacitor is 3200pF. If the potential difference between its plates is 220V. What is the charge on each of its plates?

Given data:

Capacitance=C=3200pF

$C=3200\times10^{-12}F$

Potential difference=V=220V

Required:

Charge on each plate=Q=?

Solution:

We know that

$$Q = CV$$

Putting values

$$Q = 3200 \times 10^{-12} \times 220$$

$$Q = 3200 \times 220 \times 10^{-12}$$

$$Q = 704000.0 \times 10^{-12}C$$

$$Q = 0.704 \times 10^{-6}C$$

$$Q = 0.704\mu C$$

6. Three capacitors of capacitance 1µF, 2µF and 3µF are connected in series to an 110V battery. Calculate the equivalent capacitance and voltage across each capacitor.

Given data:

Capacitance of capacitor C_1= 1µF

$\Rightarrow C_1= 1\times 10^{-6}F$

Capacitance of capacitor C_2= 2µF

$\Rightarrow C_2=2\times 10^{-6}F$

Capacitance of capacitor C_3= 3µF

$\Rightarrow C_3=3\times 10^{-6}F$

Voltage=110V

Required:

Equivalent capacitance=C_e=?

Voltage across C_1=V_1=?
Voltage across C_2=V_2=?
Voltage across C_3=V_3=?

Solution:

For series combination the equivalent capacitance

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Putting values

$$\frac{1}{C_e} = \frac{1}{1} + \frac{1}{2} + \frac{1}{3}$$

$$\frac{1}{C_e} = \left(\frac{6+3+2}{6}\right)$$

$$\frac{1}{C_e} = \frac{11}{6}$$

$$\Rightarrow C_e = \frac{6}{11}\mu F$$

$$C_e = 0.54\mu F$$

Or, $C_e = 0.54 \times 10^{-6} F$

In series combination, charge remains the same so we have

$$Q_1=Q_2= Q_3=Q$$

The charge on each capacitor is

$$Q=C_eV$$

Putting values

$$Q=0.54 \times 10^{-6} \times 110$$

$$Q=0.54 \times 110 \times 10^{-6}$$

$$Q=59.5 \times 10^{-6} C$$

$$Q=60 \times 10^{-6} C$$

Now, the voltage across capacitor C_1, capacitor C_2 and capacitor C_3 as V_1, V_2 and V_3 respectively

The voltage across C_1 is given by

$$V_1 = \frac{Q}{C_1}$$

Putting values

$$V_1 = \frac{60 \times 10^{-6}}{1 \times 10^{-6}}$$

$$V_1 = 60V$$

Similarly, voltage across C_2 is

$$V_2 = \frac{Q}{C_2}$$

$$V_2 = \frac{60 \times 10^{-6}}{2 \times 10^{-6}}$$

$$V_2 = 30V$$

And, voltage across C_3 is

$$V_3 = \frac{Q}{C_3}$$

$$V_3 = \frac{60 \times 10^{-6}}{3 \times 10^{-6}}$$

$$V_3 = 20V$$

7. Two capacitors of capacitance 2pF and 3pF are connected in parallel to a 9V battery. Calculate the equivalent capacitance and the charge on each of capacitor.

Given data:

Capacitance of one capacitor $=C_1=2pF=2\times10^{-12}F$

Capacitance of other capacitor $=C_2=3pF=3\times10^{-12}F$

Voltage =V=9V

Required:

Equivalent capacitance$=C_e=?$

Charge on $C_1=Q_1=?$

Charge on $C_2=Q_2=?$

Solution:

For parallel combination the Equivalent capacitance is

$$C_e = C_1 + C_2$$

Putting values

$$C_e = (2+3)pF$$

$$C_e = 5pF$$

Or

$$C_e = 5 \times 10^{-12}F$$

In parallel combination, that voltage remains the same, so

$V_1=V_2=V=9V$

Now the charge on C_1 is given by

$$Q_1 = C_1V$$

Putting values

$$Q_1 = 2 \times 10^{-12} \times 9$$

$$Q_1 = 2 \times 9 \times 10^{-12}$$

$$Q_1 = 18 \times 10^{-12}C$$

Or

$$Q_1 = 18pC$$

Similarly, the charge on C_2 is given by

$$Q_2 = C_2V$$

Putting values

$$Q_2 = 3 \times 10^{-12} \times 9$$

$$Q_2 = 3 \times 9 \times 10^{-12}$$

$$Q_2 = 27 \times 10^{-12}C$$

Or

$$Q_2 = 27pC$$