ELECTRIC FIELD AND ELECTROSTATICS

Electro – Electricity

Statics – Stationary

Therefore, electrostatics is the study of stationary charges.

Electrostatics deals with the properties and characteristics of stationary electrical charges (+ve/-ve). Charges of the same sign repel each other while charges of opposite signs attract each other

Rubbing ebonite with fur makes the ebonite rod negatively charged

Electric fields are defined as regions where electric forces can be experienced.

The electric lines of forces can be used to show the direction of the electric field. For a positively charged body, the (arrows of the) lines point outwards while for a negatively charged body, they point inwards.

If the lines are close together and parallel, that indicates a strong field.

Conventionally, like charges (like positive and positive or negative and negative) repel (i.e. they move away from each other) while unlike charges (like positive and negative or negative and positive) attract (i.e. they come together)

The force that an object experiences in an electric field is dependent on the charge (q) of the electric field.

E in the equation above is known as the electric field intensity.

It can be defined as the ratio of the Force experienced in the field to the electric charge of the field.

COULOMB’S LAW OF ELECTROSTATICS

This states that

In free space, the electrostatic force (of attraction or repulsion) between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of their distance apart.

But

Also,

Is called the permittivity of free space; for charges located in vacuum,

In vector notation,

But

Note the following:

Every charge has vector electric field around it which causes attraction/repulsion

The direction of the field (electric) around any charge object is the direction in which the positive charge will move if it is placed close to the object

Questions:

Calculate the distance between point charges Q1, 26uC and Q2, 47uC. The electrostatic force between them is 5.7N

Formula

F = kq1q2/r^2 (k=9 times 10^-9 Nm^2C^2)

Answer: r=1.39

Two charges with magnitude, 2 time 10^-6 are 60cm apart. Find the magnitude of the force exerted by these 2 charges on a third charge 4time10^-6C that is 50cm away from each of the 2 charges

F1 = kq1q2/r1^2

F2 = kq2q3/r2^2

F3 = F1 + F2

Answer: 0.576N

At what distance will the electric force between 2 electrons have a magnitude of 1.0N e=1.6 times 10^-19C,

Answer: r=1.52 times 10^-14

How many excess electrons must be placed on each of 2 small spheres spaced by 3cm apart if the force of repulsion between the spheres is to be 10^-19

Recall that q=ne. First, you have to find the q1 and q2 which are equal.

2 charges are located on the positive x-axis of a coordinate system. Charge Q1, 2 times 10^-9 and is 2cm from the origin charge. Q2 is 3 times 10^-9C and is 4cm from the origin. What is the magnitude of the total force exerted by these 2 charges on a charge Q3, 5 times 10^-9 placed at the origin

First Find, F\_13 then F\_23

F\_r = F\_13+F\_23

F\_R = 3.09 times 10^-4

F = kq1q2/|r\_12|^2 cdot r\_12

where r\_12=r\_12/|r\_12| =

An alpha particle is a nucleus of densely ionized Helium. It has a mass of 6.69 times 10^-27kg and a charge of -2e^- or -3.2 times 10^-19C. Compare the force of electrostatic repulsion between them.

For equal charges,

2 positively charged spheres have a combined charge of 4 times 10^-8C. Calculate the charge on each sphere if they are repelled by a force of 27 times 10^-5 when placed 0.1m apart.

q1+q2 = 4times10^-8C, F = 27times10^-5, r=0.1m

F=kq1q2/r^2

q1q2=3times10^-16C

q1+q2 = 4times10^-8C

Answers:

q1=1 times 10^-8C

q2=3 times 10^-8C

2 charges, q, 500uC and q2, 100uC are located at the xy-plane at the position r1={3j}m and r2=4im. Find the force exerted on q2

F = kq1q2 dot r\_12/|r\_12|^3

F=14.4i-10.8j

F=18N

3 point charges lie along 0the x-axis

But

Therefore,

As seen above, electric fields obey the inverse square law

ELECTRIC POTENTIAL

This can be defined as the work done in moving a unit charge from infinity to the point in consideration.

Here, q is the magnitude of the charge

Here, V is the electric potential

From the above, it can also be defined as the work done per unit charge

The potential difference from a point (A) to another point (B) is the work done against electrical forces in carrying a unit (positive) charge from A to B.

ABSOLUTE POTENTIAL

The absolute potential of a point is the work done against electrical forces in carrying a unit (positive) charge from infinity to that point.

Electric potential (V) can also be expressed as the product of the electric field intensity (E) and the distance (d)

And

Also,

Therefore,

For two or more cases, the principle of superposition can be used

EQUIVALENT SURFACE

An equivalent surface is an imaginary surface on which all points have the same potential. In an equivalent surface the work done in moving a charge from one point to another is zero.

Since work done is the product of force and distance,

ELECTROSTATICS

This is the branch of science that deals with charges at rest.

It should be noted that all bodies or objects contain charges.

Accord to Franklin, a body can be positively charged or negatively charged.

A body is said to have a positive charge if it contains excess positive charges (more positive charges than negative charges) or deficient negative charges. Likewise, a body is said to be negatively charged if it has excess negative charges and deficient positive charges. However, a body is said to be neutral if has an equal number of positive and negative charges.

METHODS OF CHARGING BODIES

1. Charging by contact: This involves putting a charged body in contact with a neutral body. In this process, a neutral body is placed in contact with a charged body. During contact, charges will flow from the charged body to the uncharged (the neutral body) until the two bodies have equal magnitude of the same charge. After the separation of the two bodies it will be observed that body bodies have equal magnitude and have the same type of charge (either positive or negative).

The two bodies should always be placed on insulating stands in order to prevent the flow of charge from the body to the earth or from the earth to the object.

1. Charging by friction: This involves rubbing two bodies against each other in order to produce charges

Negative charges can be produced by rubbing ebonite rod with fur. The fur becomes positively charged and the ebonite (hard rubber) rod is then negatively charged.

Positive charges can be produced by rubbing glass rod with silk. The glass acquires a net positive charge.

In charging by friction, the net charge is zero (that is the amount of charge lost is equal to the amount of charge gained)

1. Charging by induction: In charging by induction there is no contact between the some steps are taken which include

A body called the induced body (or induced charge) is being charged by another object called the inducing body (or inducing charge)

Step 1: To make a body negatively charged, a positively charged rod is brought near the body. Since unlike charges attract and like charges repel, the positive charges (in the body) are repelled from the rod while the negative charges are attracted to the rod. However, the rod must not touch the body

Step 2: Earthling is carried out by touching the body making negative charges to flow into the body to neutralize the positive charges

Step 3: The finger is then removed

Step 4: The rod is also removed thereby leaving the body negatively charged.

To make the body positively charged, a negative rod is used.

It can be observed that after the induction process, both the induced charge and the inducing charge have equal magnitude but opposite charges.

This process is also used in charging the gold leaf (or gold foil) electroscope

DISTRIBUTION OF CHARGES ON A BODY

According to the ice-pail experiment, the net charge on a body is always found outside the body.

Any excess charge on a conductor resides on the surface of the conductor and not in the conductor; remember excess charges.

For a uniform body like a spherical body, the charges are distributed uniformly outside the body and are in are orderly manner.

For a pear shaped body or a pointed body, the charges are concentrated at the pointed end (i.e. the surface charge density is maximum at the pointed end)

The concept of charge distribution on bodies is used in lightning conductors.

LIGHTNING CONDUCTOR

These are conductors mainly made of copper which are used (a lot in houses and buildings) to transfer excess charges from the atmosphere (during lightning or thunder storms) to the earth’s crust. These conductors help to prevent lightning damages on electric materials.

A lightning conductor consists of a copper strip with shatply pointed end projecting above the building to be protected while the lower end is connected to a metal plate buried below the earth.

If a positively charged cloud passes over the building, negative electric charges are induced at the tip of the lightning conductor, thereby forming a dipole with the cloud. The high electric field thus set up between the cloud and the tip of the conductor results in the ionization of the atoms of the air, with negative ions drifting towards the cloud and thereby neutralizing the positive charges.

Lightning is caused by a storm cloud which is highly charged as a result of the rubbing action between the cloud and the air (charging by friction). The sudden flow of charges between the cloud and the earth results in a lightning flash.

GOLD LEAF ELECTROSCOPE

This is a device used for detecting the nature of charges (whether positive or negative charges) on a body. It comprises a metal cap, a thin conducting rod and a gold leaf all enclosed in a glass window.

Before a gold leaf electroscope can be used it must first be charged.

The gold foil is charged by the process of induction. A charged body is placed close to the cap of the electroscope and then the cap is earthed. The electroscope can also be charged by contact.

When a body is placed on a gold leaf electroscope and the gold leaf diverges, it implies that the body and the electroscope have identical charges. However, once the body is placed on the gold leaf and the gold leaf collapses, it indicates that the body and opposite charges.

However, if the body placed on the electroscope is neutral, the gold leaf will also collapse.

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| --- | --- | --- |
| Charge of Electroscope | Charge of body | Effect on Gold leaf |
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USES OF THE GOLD LEAF ELECTROSCOPE

They are used to detect the nature of charges

They are used for comparing the magnitude of charges

They can also be employed as volt meters

OTHER DEVICES IN ELECTROSTATICS

1. Proof plane: This device is used for transferring large amount of charges from one body to another
2. Electrophorus: This device is used for securing large amount of similar charges by induction.
3. Faraday’s Net: This device is used for comparing the magnitude of charges between the order and inner part of a hollow conductor
4. Capacitor: This is a passive device used for storing charges

CAPACITORS

A capacitor is a passive device used for storing charges (i.e. it is a charge storage device). It is also called a condenser.

A capacitor consists essentially of two charged flat sheets of metals (called plates) separated by an insulator (called a dielectric). The plates are connected to the plates of a battery. One plate is connected to the positive plate of the battery and the other plate of the capacitor is connected to the negative plate of the battery and the plates then become positively and negatively charged respectively.

The charge (q) stored in a capacitor is directly proportional to the potential difference (or voltage (V)) across it.

Here, c is a constant called the capacitance of the capacitor.

CAPACITANCE

This is defined as the ability of a material to store charges (when its plates are at different potentials). The capacitance of a capacitor is defined as the ratio of the charge stored to the potential difference (p.d.)

The unit of capacitance is the farad.

FACTORS AFFECTING THE CAPACITANCE OF A CAPACITOR

1. Area of the plate:
2. Distance between the plates of the capacitor:
3. Nature of the dielectric: A dielectric is an insulator placed between the plates of the capacitor in order to increase the capacitance value of the capacitor.

Every material has a dielectric constant (K) and the capacitance is directly proportional to the dielectric constant. The dielectric constant is also called relative permittivity or permittivity constant.

The dielectric constant of a vacuum is 1. That of air is 1.0006 and that of glass is 5. Other materials like wood, paper, rubber, foam, cotton, polythene and all insulators can be used as dielectric materials.

The dielectric constant (K) of a material can be expressed as

Dielectric constant can also be expressed as

On combining,

For a vacuum,

Therefore, in a vacuum,

The unit of capacitance is called the Farad (F)

The unit of charge is called the coulomb (C)

ARRANGEMENT OF CAPACITORS

1. Arrangement in series: When two or more capacitors are arranged in series,

They store equal amount of charges

Total voltage in a circuit is the sum of potential differences across the capacitors

The equivalent capacitance is always the smallest capacitance value

The smallest capacitance will have the highest voltage across it

But since the charges stored are equal,

1. Capacitors in parallel:
2. They have equal voltage
3. Total charge in the circuit is equal to the sum of the charges stored in each capacitor
4. The combine capacitance is always greater than the biggest individual capacitance value.
5. The capacitor with the highest capacitance value will store the greatest charge
6. Capacitors in series lead to minimum capacitance value while capacitors in parallel lead to maximum capacitance value

ENERGY STORED IN A CAPACITOR

The energy stored in a capacitor is equal to the work dome in building up the charges on the plates.

The energy stored in a capacitor can be expressed in calculus form as

But

Therefore,

Therefore,

But

Also, in a graph of charge (q) against voltage or potential difference (V), the slope gives the capacitance of the capacitor and the area under the graph gives the energy stored in the capacitor.

USES OF CAPACITORS

1. They are used for storing charges
2. They are also used for storing electrical energy
3. They are used for establishing desired electric (field) configuration
4. They can be used for creating electronic time delays
5. They are employed in induction coils to prevent electric sparks
6. They are used in the inverter and the UPS (Uninterrupted power supply) for storing energy
7. They can be used for lowering the value of current flowing in a circuit
8. They are essential components of radios, TVs and computers.

ELECTROCHEMICAL CELLS

These are devices used for changing chemical energy into electrical energy.

There are two types of cells namely:

1. Primary cells: These are cells whose reactions (through which electric current is generated) are irreversible. They cannot be recharged after they have been used. They have high resistances and hence generate low currents. They are affected by local action and polarisation. Examples include Leclanche cell (also called dry cell) and the Daniel cell

2. Secondary cells: These are also called accumulators. They are the opposite of primary cells.

An electrochemical cell consists of two electrodes of which each has its own electrolyte. The two electrodes are connected by a salt bridge or a porous partition.

One electrode with its electrolyte is called a half-cell. The electrode is an element (mostly metals although it may me non-metals) and the electrolyte is a salt of the element. The element is said to be in contact with its own ions.

A half-cell can be represented as

An electrode has a quantitative property called the electrode potential.

Electrode potential is a measure in volts of the tendency of an atom of an element of the electrode to undergo oxidation and reduction.

of an electrode have the same value but different signs (one is negative while the other is positive).

When all the concentrations of aqueous solutions are 1moldm-3, all gases taking part in the reactions are at 1atm and the temperature is 25⁰C (Room temp), the electrode potential is called the standard electrode potential.

The standard hydrogen electrode was assigned a standard electrode potential of 0.000Volts

The standard electrode potentials of other elements can be determined using the standard hydrogen electrode as a reference.

The standard electrode potential of an element is the potential difference set up between a standard hydrogen electrode and a half-cell.

It is called the electromotive force (emf) when a standard hydrogen electrode is coupled to the electrode of the element.

NB:

1. Is represented as
2. is represented as

E.g.

Is represented as

When calculating the emf of a cell,

i. Write the anodic reaction (Oxidation)

ii. Write the cathode reaction (Reduction)

iii. Make electrons gain equal to electrons lost.

iv. Add the two electrode potentials i.e.

If the emf of a cell (after calculation) is positive, then the reaction is spontaneous and the Gibb’s free energy is negative.

If the emf is negative, the reaction will not take place.

The table below shows the standard potentials of elements.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Element | Half-cell reaction (Reduction) | Half-cell reaction (Oxidation) | Standard reduction potential | Standard oxidation potential | Reducing ability | Oxidising ability |
| K |  |  | -2.93 |  | Highest reducing ability (but can be easily oxidised) | Lowest oxidising ability |
| Na |  |  | -2.87 |  |  |  |
| Ca |  |  | -2.71 |  |  |  |
| Mg |  |  | -2.37 |  |  |  |
| Al |  |  | -1.67 |  |  |  |
| Zn |  |  | -0.76 |  |  |  |
| Fe |  |  | -0.44 |  |  |  |
| Sn |  |  | -0.14 |  |  |  |
| Pb |  |  | -0.13 |  |  |  |
| H |  |  | 0.00 |  |  |  |
| Cu |  |  | 0.34 |  |  |  |
| Hg |  |  | 0.79  0.85 |  |  |  |
| Ag |  |  | 0.80 |  |  |  |
| Au |  |  | 1.5 |  |  |  |
| OH |  |  | Not an element |  |  |  |
| I |  |  | 0.54 |  |  |  |
| Br |  |  | 1.09 |  |  |  |
| Cl |  |  | 1.36 |  |  |  |
| NO |  |  | Not an element |  |  |  |
| SO |  |  | Not an element |  |  |  |
| F |  |  | 2.87 |  | Lowest reducing ability | Highest oxidising ability |
|  |  |  |  |  |  |  |

DEFECTS OF PRIMARY CELLS

1. Local action: This is caused by the presence of impurities on the zinc plate electrode. The impurities on the electrode prevent the free flow of current. Local action can be prevented by Amalgamation. Amalgamation is the process of coating the zinc electrode with mercury. Local action can also be prevented by using a pure zinc electrode (which can be gotten from electrolytic process).

2. Polarization: This is defined as the process whereby hydrogen bubbles produced at the zinc electrode prevent free flow of current. The hydrogen bubbles also increase the resistance of the electrode. The bubbles produce what is known as Hydrogen Electrode. These bubbles also create a back emf.

Polarization can be prevented using chemical substances called Depolarizers.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Cell Name | Anode | Cathode | Electrolyte | Depolarizer | EMF value |
| Leclanche cell | Carbon (C) | Zinc (Zn) | Ammonium Chloride | Manganese (IV) oxide |  |
| Daniel Cell | Copper (Cu) | Zinc (Zn) | Tetraoxosulfate (VI) acid |  |  |
| Lead-acid accumulator | Lead oxide | Lead (Pb) |  | None |  |
| Alkaline accumulator | Nickel Hydroxide | Cadmium (Cd) or Iron (Fe) | Potassium Hydroxide | None |  |

ARRANGEMENT OF CELLS

Series Arrangement: Ccells are arranged in series in order to increase their effective emf

The effective internal resistance of the combined cells in series is expressed

Parallel Arrangement: Cells are arranged in parallel in order to reduce their effective internal resistance and hence increasing the amount of current

The effective emf of all the cells have is value in a parallel arrangement in the circuit.

DIFFERENCE BETWEEN THE ELECTROLYTIC CELL AND THE ELECTROCHEMICAL CELL

|  |  |
| --- | --- |
| Electrolytic cell | Electrochemical cell |
| Converts electrical energy to chemical energy | Converts chemical energy to electrical energy |
| Electrons are pushed by an outside force such as a battery | Electrons are generated by oxidation at the electrode (anode) |
| Cathode is negative electrode | Cathode is the positive electrode |
| Anode is the positive electrode | Anode is the negative electrode |
| Electrodes are in the same compartment | Electrodes are in separate compartments |
| Salt bridge is not needed | Salt bridge is needed |
| Only one electrolyte is used | Two electrolytes are used |
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UNIFORM ELECTRIC FIELD BETWEEN TWO PLATES

The electric field between plates is the area or space where the plates’ charges influences can be seen. For example, if a charged particle is placed near any charged plate, the plate exerts an electric force to attract or repel the charged particle.

If the two parallel plates are oppositely and uniformly charged, then each plate carries an equal charge density allowing the electric field between the two plates to be uniform. An electric field between two plates needs to be uniform. Therefore, charges must be equally distributed on the two plates.

Once a plate is charged, it carries either negative or positive charges. It creates an electric field around it that may attract or repel other electric particles by exerting an electric force. Gauss’s law gives the electric field flux through a closed surface (such as a charged plate) as product of the electric field vector standing perpendicular to the surface’s area multiplied by the area of that surface. A two charged and parallel plates will create a uniform electric field when both carry equally distributed opposite charges. Still, if the plates have the same charge (positive or negative), the electric field equals zero. The lines are vectors perpendicular to both plates for a uniform electric field.

The magnitude of the electric field of two parallel plates is given by the formula E=V/d

The motion’s acceleration of a particle placed in the electric field E is a=qV/md

MOTION OF A CHARGED PARTICLE IN A UNIFORM ELECTRIC FIELD

Consider a charge subjected to a uniform electric field, electric force of the charge is

F = Eq. From newton’s 2nd law of motion

F = ma. Therefore, a = F over m

But F = Eq

a = Eq over m

Here, m is the mass of the charge.

For a positively charged particle, the direction of accelerated particle is the same as that of the electric field

Fir a negatively charged particle, the direction of the accelerated particle is opposite direction of the electric field

Examples2 very large parallel metal plates separated by distance, d, create a uniform electric field, E in the space between them. An electron of charge -e is projected with initial velocity {v rsub o} through a small hole in the positive plate. It travels halfway along the gap between the plates before stopping and reversing direction. What is the electric field, E, in terms of initial velocity.

V^2 = v\_o^2 + 2aS

v=0, a=-Eq/m, S=d/2

0^2 = v\_0^2 – 2(Eq/m)(d/2)

v\_o^2 = (Eq/m)d

E = v\_o^2m/qd

Alternative solution using energy principle

Energy principle states that the loss in KE is equal to work done against E.

KE=1/2 mv^2 = FS = Eqd/2

mv^2=Eqd

E = mv^2/qd

A charged particle fired between two plates of distance,d. One of the plates is positive while the other one is negative. The particle is projected with initial velocity v\_o parallel to the plates. If the length of each plate is l, through what angle will the particle be deflected.