Electrostatic Lab
Nvis 6002

Learning Material
Ver 1.2

Designed & Manufactured by:

Nvis Technologies Pvt. Ltd.

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Electrostatic Lab
Nvis 6002
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Introduction

Electrostatic Lab Nvis 6002 is a versatile training kit to be used in laboratories. It introduces the basic concepts of electrostatics and provides a good basis for understanding the fundamentals of electrostatics like charging by induction, charging by conduction and charging by friction. This trainer kit is provided with a Digital electroscope, Pith ball pendulum, Charge demonstration tube. A set of different rods and clothes are also provided to study the electrostatic charges by their different combinations.

Electrostatics is the study of electric charges at rest. Therefore, it is also called 'static electricity'. The charges at rest are produced due to friction between two bodies which are rubbed against each other. That is why it is also called 'frictional electricity'.

The static charge produced can be observed by Electroscope. An electroscope is an instrument used to detect the presence of electric charge on a body.

Various types of electroscope can be made. In our Electrostatic Lab we are detecting electric charge by following electroscopes – Digital electroscope, Pith ball pendulum, Charge demonstration tube.

In Digital Electroscope, charge can be detected by two ways. Firstly, by the Charge Polarity Indicator and secondly, by the Display, charge Polarity Indicator detects the presence of negative charge by Blue LED and positive charge by Green LED. Display y detects the presence of negative and positive charge in digitized form with sign (negative or positive) indication. ON/OFF Switch is provided to switch on and off supply. Charge Polarity Indicator/ Display Switch is provided to select the either mode. A Charge Receiver (sensor) is provided for receiving charge. This receiver receives the charge and then the circuitry gets activated. It receives charge by two methods- Electrostatic Induction and Electrostatic Conduction.

Electrostatic Induction is a method by which an electrically charged species can be used to create an electrical charge in a second species, without contact between the two species. In Induction, charged induced in the second species is opposite to that of species which is inducing the charge.

Electrostatic Conduction is a method by which an electrically charged species can be used to create an electrical charge in a second species, with contact (by touching) between the two species. In Conduction, charge transferred (conducted) in second species is similar to that of species which is transferring the charge.

So in Induction , charge received by the receiver is opposite to that of the electrically charged species (or body) and in Conduction, charge received by the receiver is similar to that of the electrically charged species (or body).

In our Electroscope, we have used an INVERT circuitry which inverts the charge received by the receiver. That's why Charge Polarity Indicator and Display Unit shows actual charge (of the body) during induction and opposite charge (to that of the body) during conduction. Second Electroscope is the Pith ball pendulum. Pith ball is a very small, lightweight object that picks up electric charge quite well. So it is used in this experiment as only light weighted balls can freely move in air. It is hanged (by a string) on L –shaped plastic rod fitted on a base. Both Induction and Conduction can be observed when a charged body (i.e. a rod rubbed by a cloth, in our experiment) is brought near it.

Third one is a demonstration tube. It is made up of Perspex material consisting of light weighted styrene balls with aluminum foil covering. When Perspex tube is rubbed with some material (in our experiment, cloth is provided for rubbing), Induction and Conduction both can be observed.

Features

- Complete training kit to study the basics of electrostatics
- Electrostatic charging by:
    - § Induction
    - § Conduction
    - § Friction
- Digital Electroscope
- Accessories are provided in a good quality carrying case with foam inserts
- Provided with different rods, clothes etc
- Pith ball pendulum
- Provided with Charge Demonstration Tube

Technical Specifications

Display	**:**	Measures relative intensity of charge in millivolt
Charge polarity Indicators:		Blue LED - Negative charge Green LED - Positive charge
Rods	**:**	Teflon, Perspex
Clothes	**:**	Silk, Cotton, Woolen
Pith ball pendulum	**:**	Single & pair is provided for different Observations
Mains Supply	**:**	230 V AC ± 10%, 50 Hz

Safety Instructions

Read the following safety instructions carefully before operating the instrument. To avoid any personal injury or damage to the instrument or any product connected to the instrument.

Do not operate the instrument if suspect any damage to it.

The instrument should be serviced by qualified personnel only.

For your safety:

Use proper Mains cord : Use only the mains cord designed for this instrument. Ensure that the mains cord is suitable for your country.

Ground the Instrument : This instrument is grounded through the protective earth conductor of the mains cord. To avoid electric shock, the grounding conductor must be connected to the earth ground. Before making connections to the input terminals, ensure that the instrument is properly grounded.

Use in proper Atmosphere : Please refer to operating conditions given in the manual.

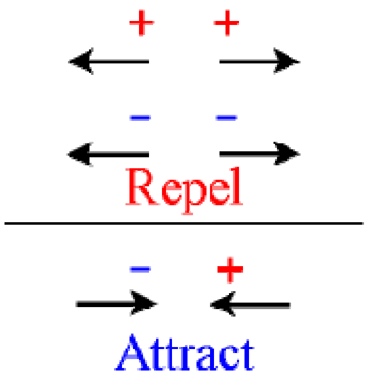
1. **Do not operate in wet / damp conditions.**
2. **Do not operate in an explosive atmosphere.**
3. **Keep the product dust free, clean and dry.**

Theory

Electrostatics

When a glass rod is rubbed with silk, this acquires power to attract light bodies such as small pieces of paper. The bodies which acquire this power are said to be charged. If these charges do not move they are called static charges and the branch of physics which deals with static charges is called electrostatics.

Electrostatic phenomena arise from the forces that electric charges exert on each other. Such forces are described by Coulomb's law. Even though electro statically induced forces seem to be rather weak, the electrostatic force between e.g. an electron and a proton, that together make up a hydrogen atom, is about 40 orders of magnitude stronger than the gravitational force acting between them.

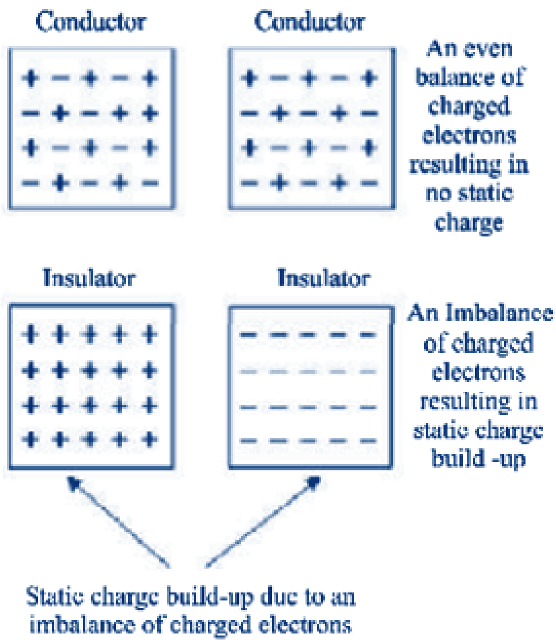


"Static Electricity" and "Current Electricity" are two types of science. Now we see how the static electricity differs from current electricity. In professional circles "Static Electricity" is actually called "Electrostatics". Static electricity or Electrostatics is the study of electric charges at rest and the way they separate and combine. Static Electricity studies the attraction and repulsion between charges, and the invisible electrical fields they create.

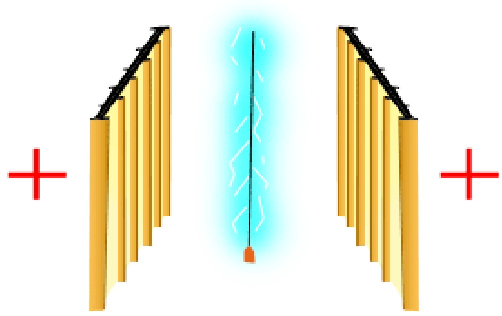
Scientists have a more official name for "Current Electricity"; they call it "Electrodynamics". Current Electricity is the study of the flowing or wiggling of charges, of the magnetic attraction and repulsion they create, and of the way they can move electrical energy around. "Current Electricity" is not stuff and not energy. It is a science. And electric charge might flow inside wires, but this is not a flow of "electricity". Electrical science cannot flow in wires!

We are dealing here with Electrostatics or Static electricity. The parameter of basic importance in electrostatics is charge'.

Electrostatics is associated with insulating materials and electrically isolated conductors. 'Insulation' and 'isolation' prevents easy migration of charge. So charges stay in place (are 'static'). The effects the charges produce are then important.



It is charge which gives rise to the electric fields generating forces that attract thin films and particles to surfaces and charge which gives rise to high voltages in low capacitance systems. High voltages can cause sparks. If these have sufficient energy they may ignite flammable gases, cause shocks to personnel damage, semiconductor devices and upset the operation of microelectronic equipment.



Voltage is sent through an electrode

Courtsy By :
http://www.iowadnr.gov/Environment/AirQuality/HowAirPollutionIsControlled/ElectrostaticPrecipitators.aspx

Methods of Charging

1. Charging by Friction
2. Charging by Induction
3. Charging by Conduction
4. Grounding – the removal of a charge

Triboelectricity

The origin of static electricity deals with friction and generation of charges, without understanding the frictional fundamentals you can't understand the electrostatics fundamentals. So details are shown below:

Friction is a resistance offered to the movement of one body past another body with which it is in contact. Due to frictional force, electrons are either loose from or gain by the surface of the body.

Most commonly during the winter season, when the air is drier, you are likely to experience turboelectric charging of objects on a frequent basis. Getting out of the car and reaching back to close the door, or removing a jacket made of synthetic fabric, can lead to a startling electric shock, and sometimes garments taken off in total darkness will give a dazzling display of sparks and glowing fabric.

As you walk across a carpet, and then touch a door knob and ZAP! You get a static shock.

Diagram showing transfer of electrostatic charge from door knob to hand

Or, you come inside from the cold, pull off your hat and. BOING!!! Static electricity makes your hair stand on end. What is going on here? And why do static problems only seem to happen in the winter?

Here two objects rubbing together create electrostatic charges. Whenever two different materials rub against each other it is likely that one will leave with more electrons than it started with.

The other will leave with less. This is called Triboelectricity (tribo means friction). From the study of chemistry we learn that different materials have different desire for electrons. (This is called electro negativity).Some materials are very greedy and will always steal electrons from things they come in contact with; others are more willing to give up electrons. So,

"Triboelectricity is the electricity (charge) produced due to friction"

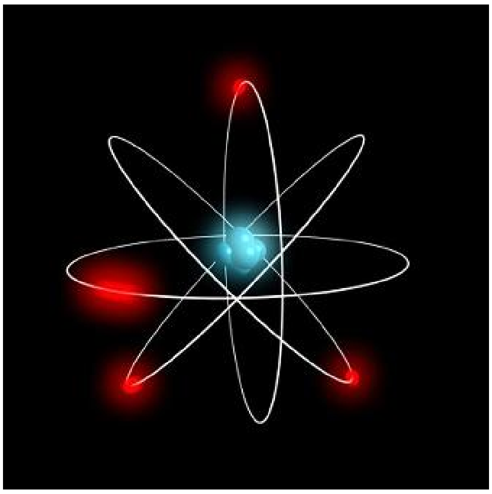
Static cling and other nuisance electrostatic charging has become more common due to the wide spread use of synthetic fabrics and plastics, since these synthetic materials are good insulators and do not readily dissipate charge once it has been separated. The nature of tribo electrification is very complex, but we can make a beginning.

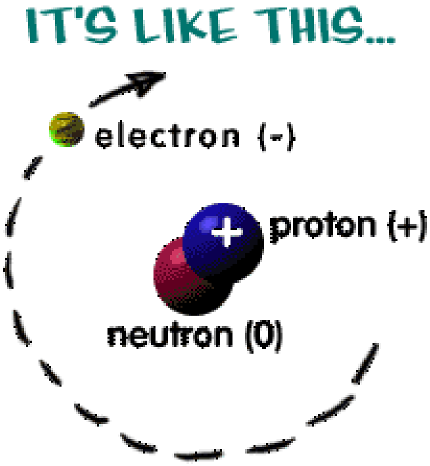
To understand static electricity, we have to learn a little bit about the nature of matter. Or in other words, what is all the stuff around us made of?

Everything around us is made of atoms. Scientists so far have found only 115 different kinds of atoms. Everything you see is made of different combinations of these atoms.

Parts of an atom

So what are atoms made of? In the middle of each atom is a "nucleus." The nucleus contains two kinds of tiny particles, called protons and neutrons. Orbiting around the nucleus are even smaller particles called electrons. The 115 kinds of atoms are different from each other because they have different numbers of protons, neutrons and electrons.



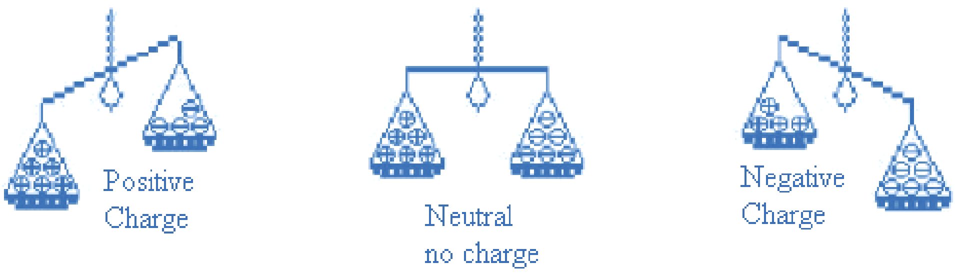


Model of Atom

It is useful to think of a model of the atom as similar to the solar system. The nucleus is in the center of the atom, like the sun in the center of the solar system. The electrons orbit around the nucleus like the planets around the sun. Just like in the solar system, the nucleus is large compared to the electrons. The atom is mostly empty space. And the electrons are very far away from the nucleus. While this model is not completely accurate, we can use it to help us understand static electricity.

Electrical Charges

Protons, neutrons and electrons are very different from each other. They have their own properties, or characteristics. One of these properties is called an electrical charge. Protons have what we call a "positive" (+) charge. Electrons have a "negative" (-) charge. Neutrons have no charge, they are neutral. The charge of one proton is equal in strength to the charge of one electron. When the number of protons in an atom equals the number of electrons, the atom itself has no overall charge, it is neutral. The protons and neutrons in the nucleus are held together very tightly. Normally the nucleus does not change. But some of the outer electrons are held very loosely. The y can move from one atom to another. An atom that looses electrons has more positive charges (protons) than negative charges (electrons). It is positively charged. An atom that gains electrons has more negative than positive particles. It has a negative charge. A charged atom is called an "ion."



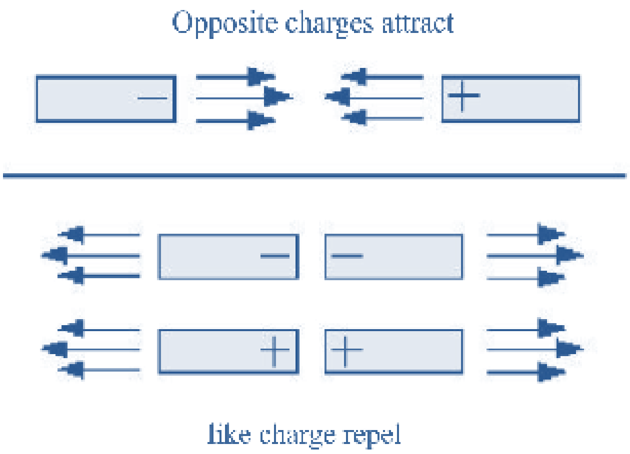
Balance of charges

Some materials hold their electrons very tightly. Electrons do not move through them very well. These things are called insulators. Plastic, cloth, glass and dry air are good insulators. Other materials have some loosely held electrons, which move through them very easily. These are called conductors. Most metals are good conductors.
How can we move electrons from one place to another? One very common way is to rub two objects together. If they are made of different materials, and are both insulators, electrons may be transferred (or moved) from one to the other. The more rubbing, the more electrons move, and the larger the static charge that builds up. (Scientists believe that it is not the rubbing or friction that causes electrons to move. It is simply the contact between two different materials. Rubbing just increases the contact area between them.)So,

"Static electricity is the imbalance of positive and negative charges"

Opposite attract

Now, positive and negative charges behave in interesting ways. Did you ever hear the saying that opposites attract? Well, it's true. Two things with opposite, or different charges (a positive and a negative) will attract, or pull towards each other. Things with the same charge (two positives or two negatives) will repel, or push away from each other.



Attraction and Repulsion of charges

Electrostatics or Static Electricity or Frictional Electricity

Everything we see is made up of tiny little parts called atoms. The atoms are made of even smaller parts. These are called protons, electrons and neutrons. They are very different from each other in many ways. One way they are different is their "charge." Protons have a positive (+) charge. Electrons have a negative (-) charge. Neutrons have no charge.

Usually, atoms have the same number of electrons and protons. Then the atom has no charge, it is "neutral." But if you rub things together, electrons can move from one atom to another. Some atoms get extra electrons. They have a negative charge. Other atoms lose electrons. They have a positive charge. When charges are separated like this, it is called static electricity.

If two things have different charges, they attract, or pull towards each other. If two things have the same charge, they repel, or push away from each other.

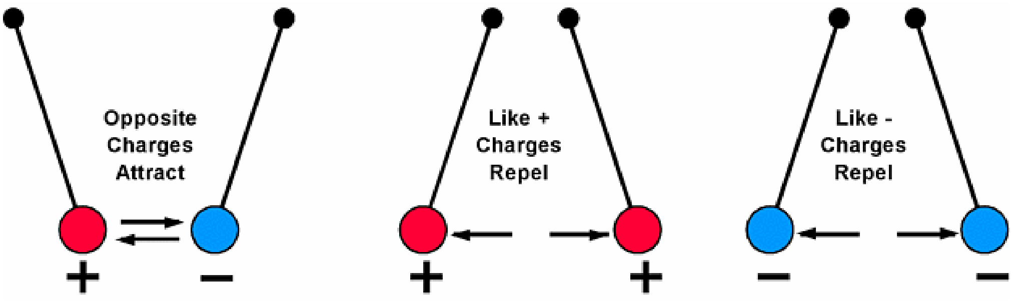


Diagram showing attraction and repulsion

Now we can understand that why a person felt the zap of an electric shock after walking across a carpet and then touching a metal door knob.

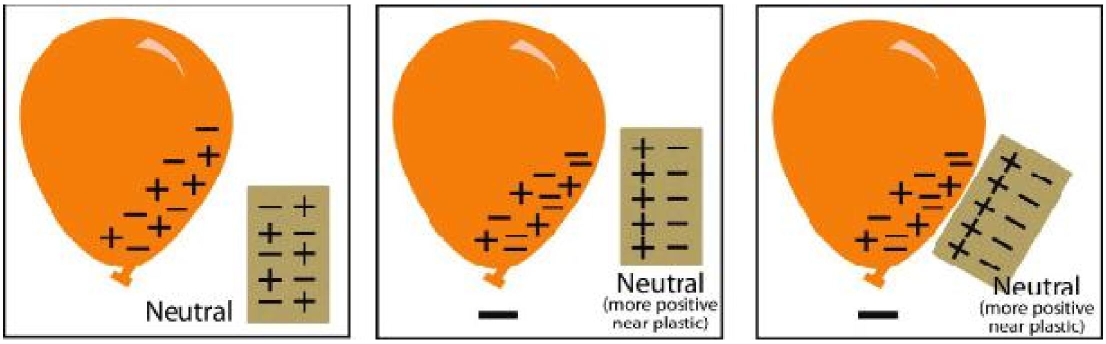
As the neutrally charged person walks across the wool carpet, his leather soled shoes have less desire for electrons than the wool carpet. As a result, electrons get stolen from the shoe by the carpet. With every step the person becomes more and more positively charged. That charge distributes itself over the body. When the positively charged person gets near the metal door he will actually attract charges from the door which jump in the form of a spark. Notice how only the negative charges (electrons) are free to move.

It is important to point out that if he was wearing rubber soled shoes on a wool carpet, his shoes would steal electrons from the carpet. He would become more negatively charged with each step.

When he gets near the door the electrons will jump from him to the door. From his point of view it would look and feel the same as it did in the first example. He can't tell whether charges jumped to or from him.

Next is, why does your hair stand up after you take your hat off? When you pull your hat off, it rubs against your hair. Electrons move from your hair to the hat. Now each of the hairs has the same positive charge. Things with the same charge repel each other. So the hairs try to move away from each other. The farthest they can get is to stand up and away from all the other hairs.

A charged object will also attract something that is neutral. Think about how you can make a balloon stick to the wall. If you charge a balloon by rubbing it on your hair, it picks up extra electrons and has a negative charge. Holding it near a neutral object will make the charges in that object move. If it is a conductor, many electrons move easily to the other side, as far from the balloon as possible. If it is an insulator, the electrons in the atoms and molecules can only move very slightly to one side, away from the balloon. In either case, there are more positive charges closer to the negative balloon. Opposites attract. The balloon sticks. (At least until the electrons on the balloon slowly leak off.) It works the same way for neutral and positively charged objects.



Balloons showing attraction and repulsion

We usually only notice static electricity in the winter when the air is very dry, during the summer, the air is more humid. The water in the air helps electrons move off you more quickly, so you can not build up as big a static charge.

Triboelectric Series

When we rub two different materials together, which becomes positively charged and which becomes negative? Scientists have ranked materials in order of their ability to hold (gain) or give up (loose) electrons. This ranking is called the triboelectric series. So, triboelectric series is a series in which materials are ranked according to there tendency to gain or loose electrons by the method of friction i.e. charges are produced when two objects are rubbed. A list of some common materials is shown here. Under ideal conditions, if two materials are rubbed together, the one higher on the list should give up electrons and become positively charged. You can experiment with things on this list for yourself.

Triboelectric Series

+ Positive End of Series (materials with lower work function)

Human hands (Greatest tendency to giving up electrons and becoming highly positive (+) in charge)

Rabbit Fur Glass

Human hair Nylon
Wool
Fur
Lead
Silk
Aluminum
Paper
(Neutral)
Cotton
Steel
Wood
Amber
Hard rubber (Ebonite)
Nickel
Copper
Brass
Silver
Gold
Platinum
Polyester
Styrene (Styrofoam)
Saran Wrap
Polyurethane
Polyethylene (like Scotch Tape)
Polypropylene
Vinyl (PVC)
Silicon
(Negative)
Teflon (Greatest tendency of gathering electrons on its surface and becoming highly negative (-) in charge)

- Negative End of Series (materials with higher work function)

Note - Hard rubber's brand name is 'Ebonite' that's not universally used.

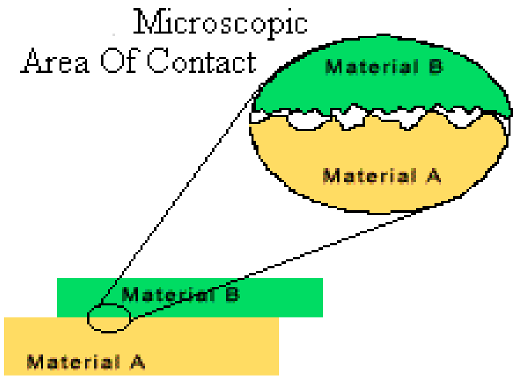
If we did a study of many materials and put them in order from those with the least desire for electrons to those with a very strong desire for electrons we would have created a triboelectric series.

If two items from the list are rubbed together, then the item that is higher on the list will end up more positive and the lower one will end up more negatively charged. For example, if leather were rubbed with wool, the leather becomes positive and the wool negative. Yet if Teflon is rubbed with wool, the Teflon becomes negative and the wool positive. It is important to note that this series is true only if the samples are clean and dry. The presence of moisture, dirt, or oils may cause some of the items to interact differently.

There are several mechanisms that contribute to the resulting charge that is generated by the triboelectric process. There appear to be 4 major factors that have the greatest influence on the Triboelectric charging process and they are: surface contact effects; work function; charge back flow; and gas breakdown**.** The amount that each mechanism influences the net charge is not well understood at this time.

1. Surface contact effects include the surfaces roughness, contact force, and frictional heating (caused by rubbing), all of which influence the amount of surface area that is in contact with the other material during Tribocharging. The greater the surface contact, the greater the resulting net charge may be when two surfaces are separated after contact.

Though surface contact may seem rather intuitive, there are some subtleties that should be elaborated on; one being surface friction, the other surface roughness [figure]. When the coefficient of friction between two surfaces increases, this indicates that the surface roughness between the two surfaces may be greater, which results in decreased surface contact. As an illustration, when two surfaces come into contact on a work surface, let's say 1.0 square inch, the actual or physical contact may only be 0.2 square inches because of surface roughness. Now, if you press down onto surface, the contact area may increase to 0.4 square inches, depending on this contact force and again the surface roughness of both surfaces. If both surfaces were polished to an extremely smooth and flat area (micro-polished), the contact area may be further increased to 0.8 square inches. The smoother either surface is, the more contact both surfaces will make with each other resulting in possible increase of the exchange of charges.



The actual area of contact is dependent on the surface roughness

Surface charge imbalance is related to friction in that both are dependent on the adhesion between to surfaces on the molecular level. Two surfaces may stick together because chemical bonds form on the surface. When surfaces in contact are separated, some bonds may rupture, and any asymmetrical bonds will tend to leave imbalanced charges behind. Which surface bonds rupture is dependent on their work function.

2. The work function is the property of a material's ability to hold onto its free electrons (the electrons orbiting the outer most shell of the material). The greater the materials work function, the less likely it is to give up its free electrons during contact (Triboelectric generation). The weaker the work function is, the more likely the material will acquire a more positive charge by giving up or loosing some of its free electrons.

In general, during rubbing, a body which has lower work function loses electrons and becomes positively charged and a body having higher work function becomes negatively charged by gaining electrons.

It is important to note that this series is true only if the samples are clean and dry. The presence of moisture, dirt, or oils may cause some of the items to interact differently.

3. Charge backflow occurs when two materials have been charged possibly from the above mechanisms and are then separated from intimate contact. The backflow of some of this charge imbalance may flow back to the original material reducing to some degree the net charge (charge imbalance) on either surface from Tribocharging.

4. Gas breakdown can occur between two surfaces during separation. The microscopic surface topology of a surface has many peaks and valleys. It is one of these peaks that may have substantial charge that yields a large electric field in a very small area causing corona discharge or the breaking down of the air molecules which were acting as a dielectric (insulator between the two separating surfaces). During this breakdown, charge can be transferred from one surface to the other via the path of the electrified air (plasma).The amount of charge transferred is dependent on the distance of separation and the gas pressure(s).

Conservation Of Charge

When we charge something with static electricity, no electrons are made or destroyed. No new protons appear or disappear. Electrons are just moved from one place to another. The net, or total, electric charge stays the same. This is called the principle of conservation of charge.

Coulomb's Law

Charged objects create an invisible electric force field around themselves. The strength of this field depends on many things, including the amount of charge, distance involved, and shape of the objects. This can become very complicated. We can simplify things by working with "point sources" of charge. Point sources are charged objects which are much, much smaller than the distance between them.
Charles Coulomb first described electric field strengths in the 1780's. He found that for point charges, the electrical force varies directly with the product of the charges. In other words, the greater the charges, the stronger the field and the field varies inversely with the square of the distance between the charges. This means that the greater the distance, the weaker the force becomes. This can be written as the formula:

$$F = k\frac{q_1 q_2}{d^2}$$

Where F is the force, q_1 and q_2 are the charges, and d is the distance between the charges. k is a positive constant of proportionality constant called electrostatic force constant or Coulomb constant. Its value depends upon the system of units and also on the medium between the two charges.

If the point charges are in vacuum, then

$$K = \frac{1}{4\pi\varepsilon_0}$$

Where ε_0 is the permittivity of free space

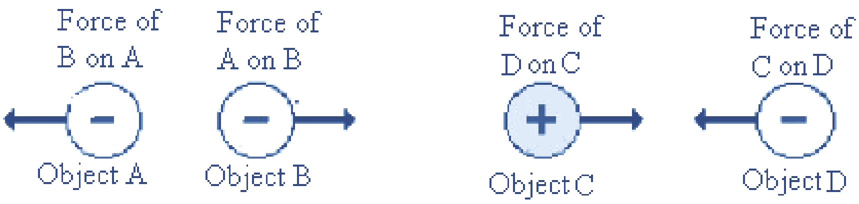
If the point charges are immersed in matter, then

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

Where ε is the absolute permittivity of the dielectric medium

For any medium, the ratio $\varepsilon/\varepsilon_0$ is known as dielectric constant or relative permittivity y or specific inductive capacity or dielectric coefficient. This is denoted by ε_r.

Coulomb's law states that the electrical force between two charged objects is directly proportional to the product of the quantity of charge on the objects and inversely proportional to the square of the separation distance between the two objects.



Determining the Direction of the Electrical Force Vector

The Coulomb's law equation provides an accurate description of the force between two objects whenever the objects act as point charges. A charged conducting sphere interacts with other charged objects in a manner that it is as though its charge were located at its center. While the charge is uniformly spread across the surface of the sphere, the center of charge can be considered the center of the sphere. The sphere acts as a point charge with its excess charge located at its center. Since Coulomb's law applies to point charges, the distance d in the equation is the distance between the centers of charge for both objects (not the distance between their nearest surfaces).

The fundamental equation of electrostatics is Coulomb’s law, which describes the force between two point charges q1 and q2

The electric field

The electric field (in units of volts per meter) is defined as the force (in Newton’s) per unit charge (in coulombs). From this definition and Coulomb's law, it follows that the magnitude of the electric field E created by a single point charge q is

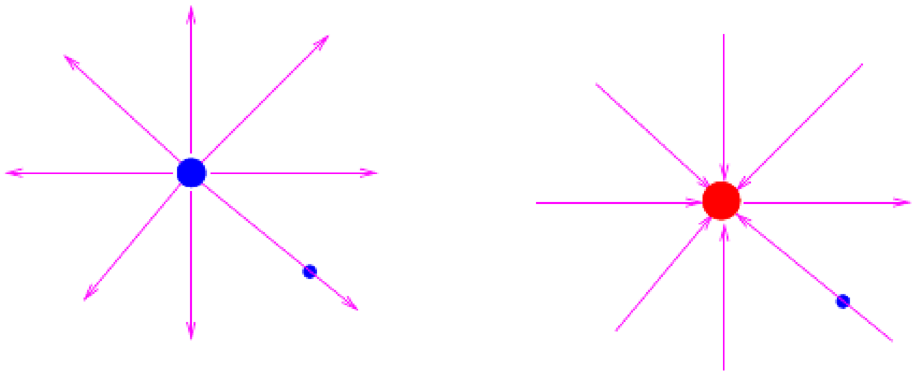
Gauss’s Law and Applications

Though Coulomb’s law is fundamental, one finds it cumbersome to use it to calculate electric field due to a continuous charge distribution because the integrals involved can be quite difficult. An alternative but completely equivalent formulation is Gauss's Law which is very useful in situations which exhibit certain symmetry.

Electric Lines of Force

Electric lines of force (also known as field lines) are a pictorial representation of the electric field. These consist of directed lines indicating the direction of electric field at various points in space.

- There is no rule as to how many lines are to be shown. However, it is customary to draw number of lines proportional to the charge. Thus if N number of lines are drawn from or into a charge Q, 2N number of lines would be drawn for charge 2Q.
- The electric field at a point is directed along the tangent to the field lines. A positive charge at this point will move along the tangent in a direction indicated by the arrow.
- Lines are dense close to a source of the electric field and become sparse as one moves away.
- Lines originate from a positive charge and end either on a negative charge or move to infinity.



- Lines of force due to a solitary negative charge are assumed to start at infinity and end at the negative charge.
- Field lines do not cross each other. (if they did, the field at the point of crossing will not be uniquely defined.)
- A neutral point is a point at which field strength is zero. This occurs because of cancellation of electric field at such a point due to multiple charges.

Charging by Friction

It was explained that atoms are the building blocks of matter. Furthermore, it was explained that material objects are made of different types of atoms and combinations of atoms. The presence of different atoms in objects provides different objects with different electrical properties. One such property is known as **electron affinity**.

Simply put, the property of electron affinity refers to the relative amount of *love* that a material has for electrons. If atoms of a material have a high electron affinity, then that material will have a relatively high love for electrons. This property of electron affinity will be of utmost importance as we explore one of the most common methods of charging - charging by friction or rubbing.

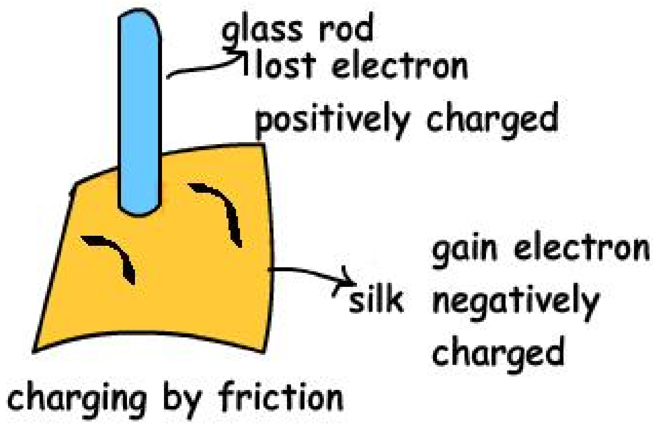
Suppose that a rubber balloon is rubbed with a sample of animal fur. During the rubbing process, the atoms of the rubber are forced into close proximity with the atoms of the animal fur. The electron clouds of the two types of atoms are pressed together and are brought closer to the nuclei of the other atoms. The protons in the atoms of one material begin to interact with the electrons present on the other material. Amidst the sound of crackling air, you might even be able to hear the atoms saying, "I like your electrons." And of course, the atoms of one material - in this case, the atoms of rubber - are more serious about their claim for electrons. As such, the atoms of rubber begin to take electrons from the atoms of animal fur. When the rubbing has ceased, the two objects have become charged.

The procedure of rubbing a rubber balloon against your hair is quite easily performed. You might try it now if you've never performed it. When done, you will likely notice that the rubber balloon and your hair will attract each other. On a dry day, you might even be able to let go of the balloon and have it adhere to your hair. (You will also probably notice that the procedure will initiate a bad hair day. Sorry.) This attraction between the two charged objects is evidence that the objects being charged are charged with an opposite type of charge. One is positively charged and the other is negatively charged. How does this happen? How does the simple rubbing together of two objects cause the objects to become charged and charged oppositely?

How Charging by Friction Works

The frictional charging process results in a transfer of electrons between the two objects that are rubbed together. Rubber has a much greater attraction for electrons than animal fur. As a result, the atoms of rubber pull electrons from the atoms of animal fur, leaving both objects with an imbalance of charge. The rubber balloon has an excess of electrons and the animal fur has a shortage of electrons. Having an excess of electrons, the rubber balloon is charged negatively. Similarly, the shortage of electrons on the animal fur leaves it with a positive charge. The two objects have become charged with opposite types of charges as a result of the transfer of electrons from the least electron-loving material to the most electron-loving material. Frictional charging is often demonstrated in Physics class. Two rubber balloons can be suspended from the ceiling and hung at approximately head height. When rubbed upon a teacher's head, the balloons became charged as electrons are transferred from the teacher's fur to the balloons. Since the teacher's fur lost electrons, it became positively charged and the subsequent attraction between the two rubbed objects could be observed. Of course, when the teacher pulls away from the balloons, the balloons experienced a repulsive interaction for each other.

As mentioned, different materials have different affinities for electrons. By rubbing a variety of materials against each other and testing their resulting interaction with objects of known charge, the tested materials can be ordered according to their affinity for electrons. Such an ordering of substances is known as a **triboelectric series**. One such ordering for several materials is shown in the table at the right. Materials shown highest on the table tend to have a greater affinity for electrons than those below it. Subsequently, when any two materials in the table are rubbed together, the one that is higher can be expected to pull electrons from the material that is lower. As such, the materials highest on the table will have the greatest tendency to acquire the negative charge. Those below it would become positively charged.



The Law of Conservation of Charge

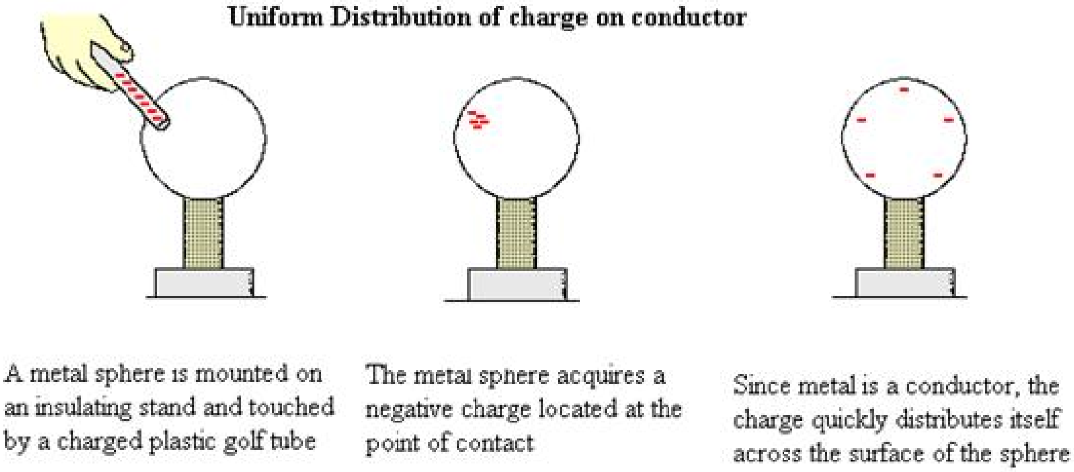
The frictional charging process (as well as any charging process) involves a transfer of electrons between two objects. Charge is not created from nothing. The appearance of negative charge upon a rubber balloon is merely the result of its acquisition of electrons. And these electrons must come from somewhere; in this case, from the object it was rubbed against. Electrons are transferred in any charging process. In the case of charging by friction, they are transferred between the two objects being rubbed together. Prior to the charging, both objects are electrically neutral. The **net charge** of the system is 0 units. After the charging process, the more electron-loving object may acquire a charge of -12 units; the other object acquires a charge of +12 units. Overall, the system of two objects has a net charge of 0 units. Whenever a quantity like charge (or momentum or energy or matter) is observed to be the same prior to and after the completion of a given process, we say that the quantity is conserved. Charge is always conserved. When all objects involved are considered prior to and after a given process, we notice that the total amount of charge amidst the objects is the same before the process starts as it is after the process ends. This is referred to as the **law of conservation of charge**.

Charging by Induction

Induction charging is a method used to charge an object without actually touching the object to any other charged object. **An understanding of charging by induction requires an understanding of the nature of a conductor and an understanding of the polarization process.**

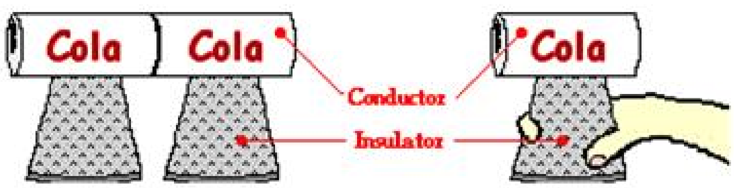
Conductors and Insulators

The behavior of an object that has been charged is dependent upon whether the object is made of a conductive or a nonconductive material. **Conductors** are materials that permit electrons to flow freely from atom to atom and molecule to molecule. An object made of a conducting material will permit charge to be transferred across the entire surface of the object. If charge is transferred to the object at a given location, that charge is quickly distributed across the entire surface of the object the distribution of charge is the result of electron movement. Since conductors allow for electrons to be transported from particle to particle, a charged object will always distribute its charge until the overall repulsive forces between excess electrons is minimized. If a charged conductor is touched to another object, the conductor can even transfer its charge to that object. The transfer of charge between objects occurs more readily if the second object is made of a conducting material. Conductors allow for charge transfer through the free movement of electrons.



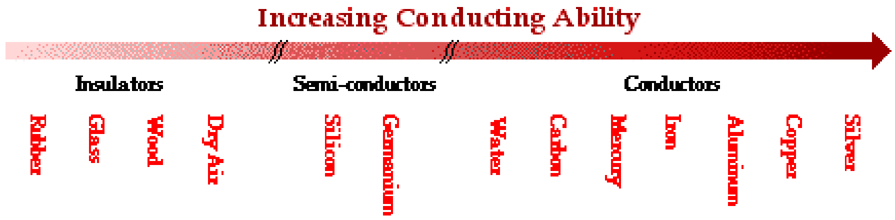
In contrast to conductors, **insulators** are materials that impede the free flow of electrons from atom to atom and molecule to molecule. If charge is transferred to an insulator at a given location, the excess charge will remain at the initial location of charging. The articles of the insulator do not permit the free flow of electrons; subsequently charge is seldom distributed evenly across the surface of an insulator.

While insulators are not useful for transferring charge, they do serve a critical role in electrostatic experiments and demonstrations. Conductive objects are often mounted upon insulating objects. This arrangement of a conductor on top of an insulator prevents charge from being transferred from the conductive object to its surroundings. This arrangement also allows for a student (or teacher) to manipulate a conducting object without touching it. The insulator serves as a handle for moving the conductor around on top of a lab table. If charging experiments are performed with aluminum pop cans, then the cans should be mounted on top of Styrofoam cups. The cups serve as insulators, preventing the pop cans from discharging their charge. The cups also serve as handles when it becomes necessary to move the cans around on the table

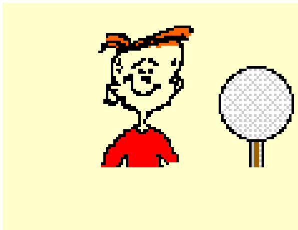


Mounting a conductor (pop cans) on insulating (styrofoam cups) prevents charge from escaping to the surroundings, It also makesfor a conveniant handle

Examples of conductors include metals, aqueous solutions of salts (i.e., ionic compounds dissolved in water), graphite, water and the human body. Examples of insulators include plastics, Styrofoam, paper, rubber, glass and dry air. The division of materials into the categories of conductors and insulators is a somewhat artificial division. It is more appropriate to think of materials as being placed somewhere along a continuum. Those materials that are super conductive (known as **superconductors**) would be placed at on end and the least conductive materials (best insulators) would be placed at the other end. Metals would be placed near the most conductive end and glass would be placed on the opposite end of the continuum. The conductivity of a metal might be as much as a million trillion times greater than that of glass.



Along the continuum of conductors and insulators, one might find the human body somewhere towards the conducting side of the middle. When the body acquires a static charge it has a tendency to distribute that charge throughout the surface of the body. Given the size of the human body, relative to the size of typical objects used in electrostatic experiments, it would require an abnormally large quantity of excess charge before its affect is noticeable. The affects of excess charge on the body are often demonstrated using a **Van de Graff generator.** When a student places their hand upon the static ball, excess charge from the ball is shared with the human body. Being a conductor, the excess charge could flow to the human body and spread throughout the surface of the body, even onto strands of hair. As the individual strands of hair become charged, they begin to repel each other. Looking to distance themselves from their like-charged neighbors, the strands of hair begin to raise upward and outward - a truly hair-raising experience.



Van D Graff generator demo

Courtsy By
http://www.physicsclassroom.com/class/estatics/u8l1d.cfm

Many are familiar with the impact that humidity can have upon static charge buildups. You have likely noticed that bad hair days, doorknob shocks and static clothing are most common during winter months. Winter months tend to be the driest months of the year with humidity levels in the air dropping to lower values. Water, being a conductor, has a tendency to gradually remove excess charge from objects. When the humidity is high, a person acquiring an excess charge will tend to lose that charge to water molecules in the surrounding air. On the other hand, dry air conditions are more conducive to the buildup of static charge and more frequent electric shocks. Since humidity levels tend to vary from day to day and season to season, it is expected that electrical affects (and even the success of electrostatic demonstrations) can vary from day to day.

Distribution of Charge via Electron Movement

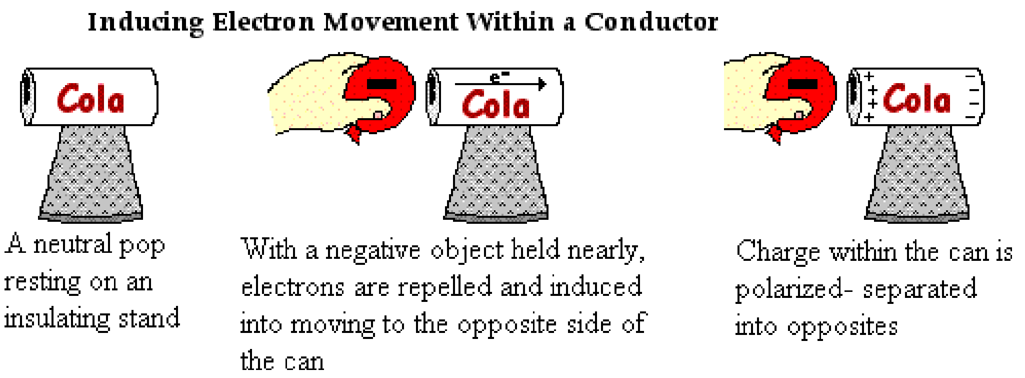
Predicting the direction that electrons would move within a conducting material is a simple application of the two fundamental rules of charge interaction. Opposites attract and likes repel. Suppose that some method is used to impart a negative charge to an object at a given location. At the location where the charge is imparted, there is an excess of electrons. That is, the multitude of atoms in that region possesses more electrons than protons. Of course, there are a number of electrons that could be thought of as being quite contented since there is an accompanying positively charged proton to satisfy their attraction for an opposite. However, the so-called excess electrons have a repulsive response to each other and would prefer more space. Electrons, like human beings, wish to manipulate their surroundings in an effort to reduce repulsive affects. Since these excess electrons are present in a conductor, there is little hindrance to their ability to migrate to other parts of the object. And that is exactly what they do. In an effort to reduce the overall repulsive affects within the object, there is a mass migration of excess electrons throughout the entire surface of the object. Excess electrons migrate to distance themselves from their repulsive neighbors. In this sense, it is said that excess negative charge distributes itself throughout the surface of the conductor.

But what happens if the conductor acquires an excess of positive charge? What if electrons are removed from a conductor at a given location, giving the object an overall positive charge? If protons cannot move, then how can the excess of positive charge distribute itself across the surface of the material? While the answers to these questions are not as obvious, it still involves a rather simple explanation that once again relies on the two fundamental rules of charge interaction. Opposites attract and likes repel. Suppose that a conducting metal sphere is charged on its left side and imparted an excess of positive charge. (Of course, this requires that electrons be removed from the object at the location of charging.) A multitude of atoms in the region where the charging occurs have lost one or more electrons and have an excess of protons. The imbalance of charge within these atoms creates affects that can be thought of as disturbing the balance of charge within the entire object. The presence of these excess protons in a given location draws electrons from other atoms. Electrons in other parts of the object can be thought of as being quite contented with the balance of charge that they are experiencing. Yet there will always be some electrons that will feel the attraction for the excess protons some distance away. In human terms, we might say these electrons are drawn by curiosity or by the belief that the grass is greener on the other side of the fence. In the language of electrostatics, we simply assert that opposites attract - the excess protons and both the neighboring and distant electrons attract each other. The protons cannot do anything about this attraction since they are bound within the nucleus of their own atoms. Yet, electrons are loosely bound within atoms; and being present in a conductor, they are free to move. These electrons make the move for the excess protons, leaving their own atoms with their own excess of positive charge. This electron migration happens across the entire surface of the object, until the overall sum of repulsive affects between electrons across the whole surface of the object are minimized.

Polarization

As discussed previously, an atom consists of positively charged protons and negatively charged electrons. The protons are in the nucleus of the atom, tightly bound and incapable of movement. The electrons are located in the vast regions of space surrounding the nucleus, known as the electron shells or the electron clouds. Relative to the protons of the nucleus, these electrons are loosely bound. In conducting objects, they are so loosely bound that they may be **induced** into moving from one portion of the object to another portion of the object. To get an electron in a conducting object to get up and go, all that must be done is to place a charged object nearby the conducting object.

To illustrate this induced movement of electrons, we will consider an aluminum pop can that is taped to a Styrofoam cup. The Styrofoam cup serves as both an insulating stand and a handle. A rubber balloon is charged negatively, perhaps by rubbing it against animal fur. If the negatively charged balloon is brought near the aluminum pop can, the electrons within the pop can experience a repulsive force. The repulsion will be greatest for those electrons that are nearest the negatively charged balloon. Many of these electrons will be induced into moving away from the repulsive balloon. Being present within a conducting material, the electrons are free to move from atom to atom. As such, there is a mass migration of electrons from the balloon's side of the aluminum can towards the opposite side of the can. This electron movement leaves atoms on the balloon's side of the can with a shortage of electrons; they become positively charged. And the atoms on the side opposite of the can have an excess of electrons; they become negatively charged. The two sides of the aluminum pop can have opposite charges. Overall the can is electrically neutral; it's just that the positive and negative charge has been separated from each other. We say that the charge in the can has been **polarized**.



In general terms, polarization means to separate into opposites. In the political world, we often observe that a collection of people becomes polarized over some issue. For instance, we might say that the United States has become polarized over the issue of the death penalty. That is, the citizens of the United States have been separated into opposites - those who are for the death penalty and those who are against the death penalty. In the context of electricity, **polarization** is the process of separating opposite charges within an object. The positive charge becomes separated from the negative charge. By inducing the movement of electrons within an object, one side of the object is left with an excess of positive charge and the other side of the object is left with an excess of negative charge. Charge becomes separated into opposites.

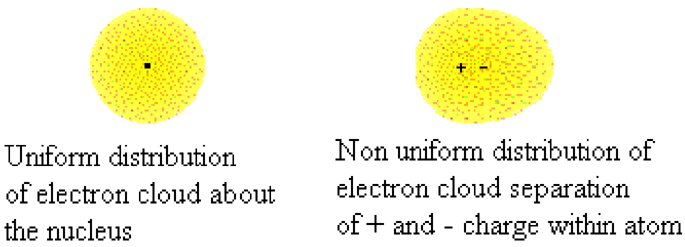
The polarization process always involves the use of a charged object to induce electron movement or electron rearrangement. In the above diagram and accompanying discussion, electrons within a conducting object were induced into moving from the left side of the conducting can to the right side of the can. Being a conductor, electrons were capable of moving from atom to atom across the entire surface of the conductor. But what if the object being polarized is an insulator? Electrons are not free to move across the surface of an insulator. How can an insulator such as a wooden wall be polarized?

How Can an Insulator be polarized?

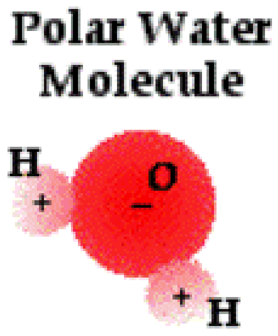
Polarization can occur within insulators, but the process occurs in a different manner than it does within a conductor. In a conducting object, electrons are induced into movement across the surface of the conductor from one side of the object to the opposite side. In an insulator, electrons merely redistribute themselves within the atom or molecules nearest the outer surface of the object. To understand the electron redistribution process, it is important to take another brief excursion into the world of atoms, molecules and chemical bonds.

The electrons surrounding the nucleus of an atom are believed to be located in regions of space with specific shapes and sizes. The actual size and shape of these regions is determined by the high-powered mathematical equations common to Quantum Mechanics. Rather than being located a specific distance from the nucleus in a fixed orbit, the electrons are simply thought of as being located in regions often referred to as **electron clouds**. At any given moment, the electron is likely to be found at some location within the cloud. The electron clouds have varying density; the density of the cloud is considered to be greatest in the portion of the cloud where the electron has the greatest probability of being found at any given moment. And conversely, the electron cloud density is least in the regions where the electron is least likely to be found. In addition to having varying density, these electron clouds are also highly distortable. The presence of neighboring atoms with high electron affinity can distort the electron clouds around atoms. Rather than being located symmetrically about the positive nucleus, the cloud becomes asymmetrically shaped. As such, there is a polarization of the atom as the centers of positive and negative charge are no longer located in the same location. The atom is still a neutral atom; it has just become polarized.

Electron Cloud Distribution



The discussion becomes even more complex (and perhaps too complex for our purposes) when we consider molecules - combination of atoms bonded together. In molecules, atoms are bonded together as protons in one atom attract the electrons in the clouds of another atom. This electrostatic attraction results in a bond between the two atoms. Electrons are shared by the two atoms as they begin to overlap their electron clouds. If the atoms are of different types (for instance, one atom is Hydrogen and the other atom is Oxygen), then the electrons within the clouds of the two atoms are not equally shared by the atoms. The clouds become distorted, with the electrons having the greatest probability of being found closest to the more electron-greedy atom. The bond is said to be a **polar bond**. The distribution of electrons within the cloud is shifted more towards one atom than towards the other atom. This is the case for the two hydrogen-oxygen bonds in the water molecule. Electrons shared by these two atoms are drawn more towards the oxygen atom than towards the hydrogen atom. Subsequently, there is a separation of charge, with oxygen having a partially negative charge and hydrogen having a partially positive charge.



It is very common to observe this polarization within molecules. In molecules that have long chains of atoms bonded together, there are often several locations along the chain or near the ends of the chain that have polar bonds. This polarization leaves the molecule with areas that have a concentration of positive charges and other areas with a concentration of negative charges. This principle is utilized in the manufacture of certain commercial products that are used to reduce static cling. The centers of positive and negative charge within the product are drawn to excess charge residing on the clothes. There is a neutralization of the static charge buildup on the clothes, thus reducing their tendency to be attracted to each other. (Other products actually use a different principle. During manufacturing, a thin sheet is soaked in a solution containing positively charged ions. The sheet is tossed into the dryer with the clothes. Being saturated with positive charges, the sheet is capable of attracting excess electrons that are scuffed off of clothes during the drying cycle.)

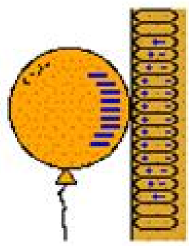
How Does Polarization Explain the Balloon and the Wall Demonstration?

A complete discussion of the world of atoms, molecules and chemical bonds is beyond the scope of The Physics Classroom. Nonetheless, a model of the atom as a distortable cloud of negative electrons surrounding a positive nucleus becomes essential to understanding how an insulating material can be polarized. If a charged object is brought near an insulator, the charges on that object are capable of distorting the electron clouds of the insulator atoms. There is a polarization of the neutral atoms. As shown in the diagrams below, the neutral atoms of the insulator will orient themselves in such a manner as to place the more attractive charge nearest the charged object. Once polarized in this manner, opposites can now attract.

Polarization of an Atom

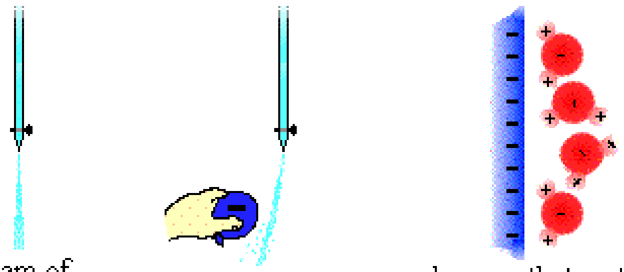
The electron cloud surrounding the nucleus can become distorted in response to a nearby object.Depending upon the charge of the object, the electron cloud can be repelled or attracted towards the object

A common demonstration performed in class involved bringing a negatively charged balloon near a wooden door or wooden cabinet. The molecules of wood will reorient themselves in such a way as to place their positive charges towards the negatively charged balloon. The distortion of their electron clouds will result in an alignment of the wood molecules in a manner that makes the wooden cabinet attracted to the negatively charged balloon. In human terms, one might say that the wood does some quick grooming and then places its most attractive side towards the balloon and its most repulsive side away from the balloon. In the world of static electricity, closeness counts. The negative balloon is closer to the positive portion of the wood molecules and further from the more repulsive negative portion. The balloon and the wall attract with sufficient force to cause the balloon to *stick* to the wall. From a mechanics standpoint, we would say that the balloon and the wall are pressed together with a large force. The large normal force on the balloon results in a large static friction force. This friction force balances the downward force of gravity and the balloon remains at rest.



The charged balloon causes the wood molecules to become polarized attraction is then possible

Another common physics (and chemistry) demonstration involves using a charged object to deflect a stream of water from its path. Most often, a comb is charged negatively by combing one's hair or a rubber balloon is charged in a similar manner. The negatively charged object is then brought near to a falling stream of water, causing the stream to be attracted to the comb or balloon and alter its direction of fall. The demonstration illustrates the polar nature of water molecules. The hydrogen atoms serve as the positive poles within a water molecule; oxygen serves as the negative pole. Molecules of a liquid are free to rotate and move about; the water molecules realign themselves in order to put their positive poles towards the negatively charged object. Once polarized, the stream and the balloon (or comb) are attracted. As the water molecules within the stream fall past the balloon, this realignment of individual molecules happens quickly and the entire stream is deflected from its original downward direction.



A stream of water falling vertically can.... ....be deflected by the presence of a charged object.... ...showing that water molecules are polar and can align themselves to be attracted to charged objects

Examples of the attraction between charged objects and neutral objects are numerous and often demonstrated by physics teachers. Paper bits become polarized and are attracted to a charged piece of acetate. Small penguins cut from a sheet of paper are attracted to a charged plastic golf tube and demonstrate their happy feet. A long wooden 2x4 is placed on a pivot and becomes polarized and attracted to a charged golf tube. To the astonishment of students, the force of attraction on the wood is large enough to rotate it about the pivot point.

Polarization is Not Charging

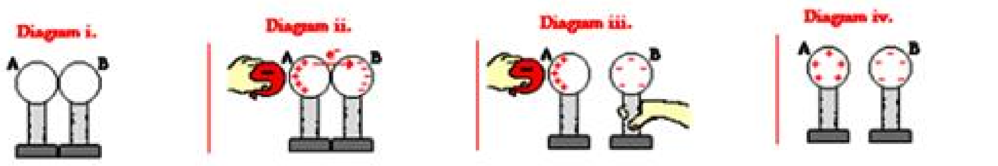
Perhaps the biggest misconception that pertains to polarization is the belief that polarization involves the charging of an object. Polarization is not charging! When an object becomes polarized, there is simply a redistribution of the centers of positive and negative charges within the object. Either by the movement of electrons across the surface of the object (as is the case in conductors) or through the distortion of electron clouds (as is the case in insulators), the centers of positive and negative charges become separated from each other. The atoms at one location on the object possess more protons than electrons and the atoms at another location have more electrons than protons. While there are the same number of protons and electrons within the object, these protons and electrons are not distributed in the same proportion across the object's surface. Yet, there are still equal numbers of positive charges (protons) and negative charges (electrons) within the object. While there is a separation of charge, there is NOT an imbalance of charge. When neutral objects become polarized, they are still neutral objects

Charging a Two-Sphere System Using a Negatively Charged Object

One common demonstration performed in a physics classroom involves the induction charging of two metal spheres. The metal spheres are supported by insulating stands so that any charge acquired by the spheres cannot travel to the ground. The spheres are placed side by side (see diagram i. below) so as to form a two-sphere system. Being made of metal (a conductor), electrons are free to move between the spheres - from sphere A to sphere B and vice versa. If a rubber balloon is charged negatively (perhaps by rubbing it with animal fur) and brought near the spheres, electrons within the two-sphere system will be induced to move away from the balloon. This is simply the principle that like charges repel. Being charged negatively, the electrons are repelled by the negatively charged balloon. And being present in a conductor, they are free to move about the surface of the conductor. Subsequently, there is a mass migration of electrons from sphere A to sphere B. This electron migration causes the two-sphere system to be polarized (see diagram ii. below). Overall, the two-sphere system is electrically neutral. Yet the movement of electrons out of sphere A and into sphere B separates the negative charge from the positive charge. Looking at the spheres individually, it would be accurate to say that sphere A has an overall positive charge and sphere B has an overall negative charge.

Once the two-sphere system is polarized, sphere B is physically separated from sphere A using the insulating stand. Having been pulled further from the balloon, the negative charge likely redistributes itself uniformly about sphere B (see diagram iii. below). Meanwhile, the excess positive charge on sphere A remains located near the negatively charged balloon, consistent with the principle that opposite charges attract. As the balloon is pulled away, there is a uniform distribution of charge about the surface of both spheres (see diagram iv. below). This distribution occurs as the remaining electrons in sphere A move across the surface of the sphere until the excess positive charge is uniformly distributed.

Charging by Induction



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

The Law of Conservation of Charge

The law of conservation of charge is easily observed in the induction charging process. Considering the example above, one can look at the two spheres as a system. Prior to the charging process, the overall charge of the system was zero. There were equal numbers of protons and electrons within the two spheres. In diagram ii. Above, electrons were induced into moving from sphere A to sphere B. At this point, the individual spheres become charged. The quantity of positive charge on sphere A equals the quantity of negative charge on sphere B. If sphere A has 1000 units of positive charge, then sphere B has 1000 units of negative charge. Determining the overall charge of the system is easy arithmetic; it is simply the sum of the charges on the individual spheres.

Overall Charge of Two Spheres = +1000 units + (-1000 units) = 0 units

The overall charge on the system of two objects is the same after the charging process as it was before the charging process. Charge is neither created nor destroyed during this charging process; it is simply transferred from one object to the other object in the form of electrons.

Charging a Two-Sphere System Using a Positively Charged Object

The above examples show how a negatively charged balloon is used to polarize a two-sphere system and ultimately charge the spheres by induction. But what would happen to sphere A and sphere B if a positively charged object was used to first polarize the two-sphere system? How would the outcome be different and how would the electron movement be altered?

Consider the graphic below in which a positively charged balloon is brought near Sphere A. The presence of the positive charge induces a mass migration of electrons from sphere B towards (and into) sphere A. This movement is induced by the simple principle that opposites attract. Negatively charged electrons throughout the two-sphere system are attracted to the positively charged balloon. This movement of electrons from spheres B to sphere A leaves sphere B with an overall positive charge and sphere A with an overall negative charge. The two-sphere system has been polarized. With the positively charged balloon still held nearby, sphere B is physically separated from sphere A. The excess positive charge is uniformly distributed across the surface of sphere B. The excess negative charge on sphere A remains crowded towards the left side of the sphere, positioning itself close to the balloon. Once the balloon is removed, electrons redistribute themselves about sphere A until the excess negative charge is evenly distributed across the surface. In the end, sphere A becomes charged negatively and sphere B becomes charged positively.

Charging by Induction

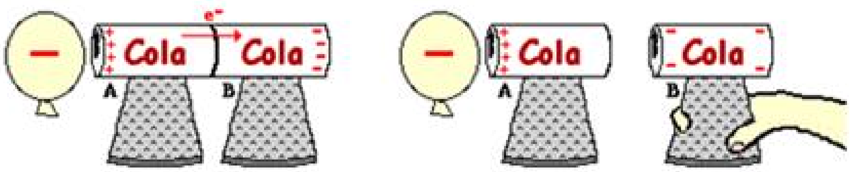
Two metal spheres are mounted on insulating stands

The presence of a + charge induces e- to move from sphere B to A. 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 sphere

This induction charging process can be used to charge a pair of pop cans. It is a simple enough experiment to be repeated at home. Two pop cans are mounted on Styrofoam cups using scotch tape. The cans are placed side-by-side and a negatively charged rubber balloon (having been rubbed with animal fur) is brought near to one of the cans. The presence of the negative charge near a can induces electron movement from Can A to Can B (see diagram). Once the cans are separated, the cans are charged. The type of charge on the cans can be tested by seeing if they attract the negatively charged balloon or repel the negatively charged balloon. Of course, we would expect that Can A (being positively charged) would attract the negatively charged balloon and Can B (being negatively charged) should repel the negatively charged balloon. During the process of induction charging, the role of the balloon is to simply induce a movement of electrons from one can to the other can. It is used to polarize the two-can system. The balloon never does supply electrons to can A (unless you hear a spark, indicating a lightning discharge from the balloon to the can).

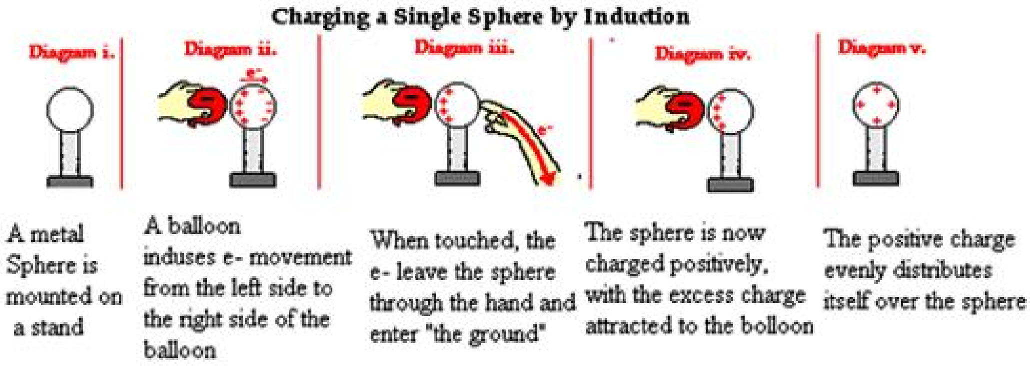


The negatively charged balloon induces movement of electrons within the two pop cans. With electrons moving from Can A to Can B , the two-can system becomes polarised. Once the two cans are separated using the insulating handle, Can A has a + charge and Can B has a - charge.

The Importance of a Ground in Induction Charging

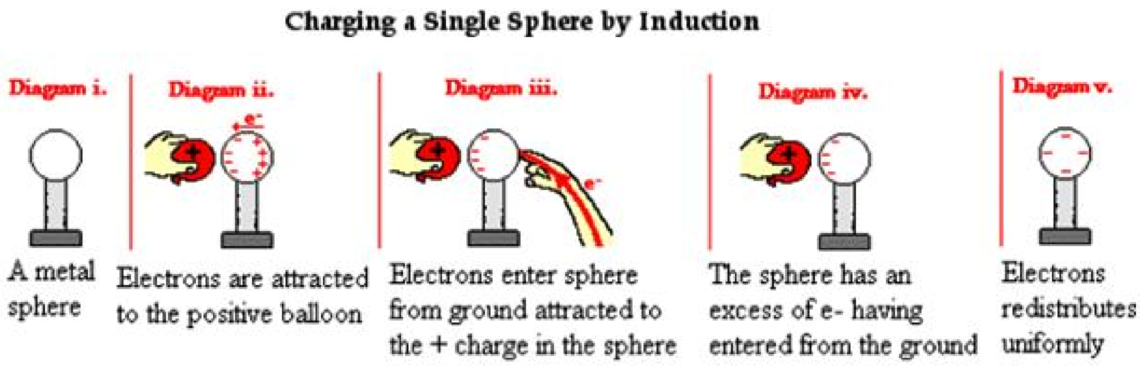
In the charging by induction cases discussed above, the ultimate charge on the object is never the result of electron movement from the charged object to the originally neutral objects. The balloons never transfers electrons to or receive electrons from the spheres; nor does the glass rod transfer electrons to or receive electrons from the spheres. The neutral object nearest the charged object (sphere A in these discussions) acquires its charge from the object to which it is touched. In the above cases, the second sphere is used to supply the electrons to sphere A or to receive electrons from sphere A. The role of sphere B in the above examples is to serve as a supplier or receiver of electrons in response to the object that is brought near sphere A. In this sense, sphere B acts like a **ground**.

To further illustrate the importance of a ground, consider the induction charging of a single conducting sphere. Suppose that a negatively charged rubber balloon is brought near a single sphere as shown below (Diagram ii). The presence of the negative charge will induce electron movement in the sphere. Since like charges repel, negative electrons within the metal sphere will be repelled by the negatively charged balloon. There will be a mass migration of electrons from the left side of the sphere to the right side of the sphere causing charge within the sphere to become polarized (Diagram ii). Once charge within the sphere has become polarized, the sphere is touched. The touching of the sphere allows electrons to exit the sphere and move through the hand to "the ground" (Diagram iii). It is at this point that the sphere acquires a charge. With electrons having left the sphere, the sphere acquires a positive charge (Diagram iv). Once the balloon is moved away from the sphere, the excess positive charge redistributes itself (by the movement of remaining electrons) such that the positive charge is uniformly distributed about the sphere's surface.



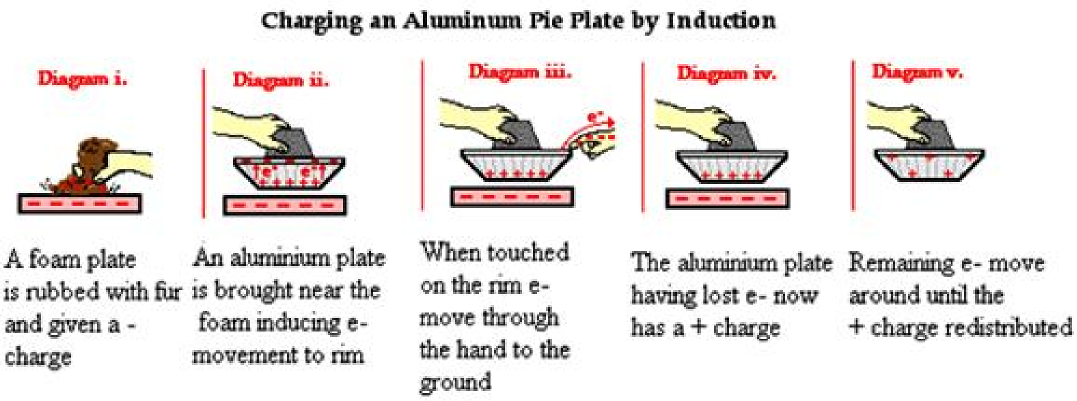
There are several things to note about this example of induction charging. First, observe that the third step of the process involves the touching of the sphere by a person. The person serves the role of the ground. If compared to the induction charging of a two-sphere system, the person has simply replaced the second sphere (Sphere B). Electrons within the sphere are repelled by the negative balloon and make an effort to distance them from it in order to minimize the repulsive affects. While these electrons crowd to the right side of the sphere to distance themselves from the negatively charged balloon, they encounter another problem. In human terms, it could be said that the excess electrons on the right side of the sphere not only find the balloon to be repulsive, they also find each other to be repulsive. They simply need more space to distance themselves from the balloon as well as from each other. Quite regrettably for these electrons, they have run out of real estate; they cannot go further than the boundary of the sphere. Too many electrons in the same neighborhood is not a good thing. And when the hand comes nearby, these negative electrons see opportunity to find more real estate - a vast body of a human being into which they can roam and subsequently distance themselves even further from each other. It is in this sense that the hand and the body to which it is attached (assuming of course that the hand is attached to a body) serve as a ground. A **ground** is simply large objects that serves as an almost infinite source of electrons or sink for electrons. A ground contains such vast space that it is the ideal object to either receive electrons or supply electrons to whatever objects needs to get rid of them or receive them

The second thing to note about the induction charging process shown above is that the sphere acquires a charge opposite the balloon. This will always be the observed case. If a negatively charged object is used to charge a neutral object by induction, then the neutral object will acquire a positive charge. And if a positively charged object is used to charge a neutral object by induction, then the neutral object will acquire a negative charge. If you understand the induction charging process, you can see why this would always be the case. The charged object that is brought near will always repel like charges and attract opposite charges. Either way, the object being charged acquires a charge that is opposite the charge of the object used to induce the charge. To further illustrate this, the diagram below shows how a positively charged balloon will charge a sphere negatively by induction.



The Electrophorus

A commonly used lab activity that demonstrates the induction charging method is the Electrophorus Lab. In this lab, a flat plate of foam is rubbed with animal fur in order to impart a negative charge to the foam. Electrons are transferred from the animal fur to the more electron-loving foam (Diagram i.). An aluminum pie plate is taped to a Styrofoam cup; the aluminum is a conductor and the Styrofoam serves as an insulating handle. As the aluminum plate is brought near, electrons within the aluminum are repelled by the negatively charged foam plate. There is a mass migration of electrons to the rim of the aluminum pie plate. At this point, the aluminum pie plate is polarized, with the negative charge located along the upper rim farthest from the foam plate (Diagram ii.). The rim of the plate is then touched, providing a pathway from the aluminum plate to the ground. Electrons along the rim are not only repelled by the negative foam plate, they are also repelled by each other. So once touched, there is a mass migration of electrons from the rim to the person touching the rim (Diagram iii.). Being of much greater size than the aluminum pie plate, the person provides more space for the mutually repulsive electrons. The moment that electrons depart from the aluminum plate, the aluminum can be considered a charged object. Having lost electrons, the aluminum possesses more protons than electrons and is therefore positively charged. Once the foam plate is removed, the excess positive charge becomes distributed about the surface of the aluminum plate in order to minimize the overall repulsive forces between them (Diagram iv.).

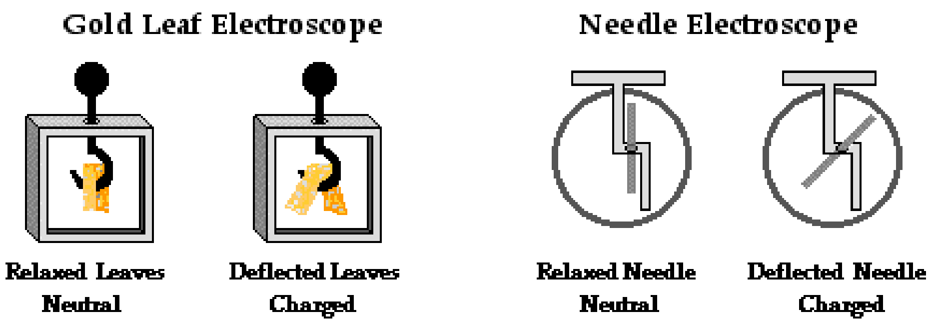


The Electrophorus Lab further illustrates that when charging a neutral object by induction, the charge imparted to the object is opposite that of the object used to induce the charge. In this case, the foam plate was negatively charged and the aluminum plate became positively charged. The lab also illustrates that there is never a transfer of electrons between the foam plate and the aluminum plate. The aluminum plate becomes charged by a transfer of electrons to the ground. Finally, one might note that the role of the charged object in induction charging is to simply polarize the object being charged. This polarization occurs as the negative foam plate repels electrons from the near side, inducing them to move to the opposite side of the aluminum plate. The presence of the positive charge on the bottom of the aluminum plate is the result of the departure of electrons from that location. Protons did not move downwards through the aluminum. The protons were always there from the beginning; it's just that they have lost their electron partners. Protons are fixed in place and incapable of moving in any electrostatic experiment.

The Electroscope

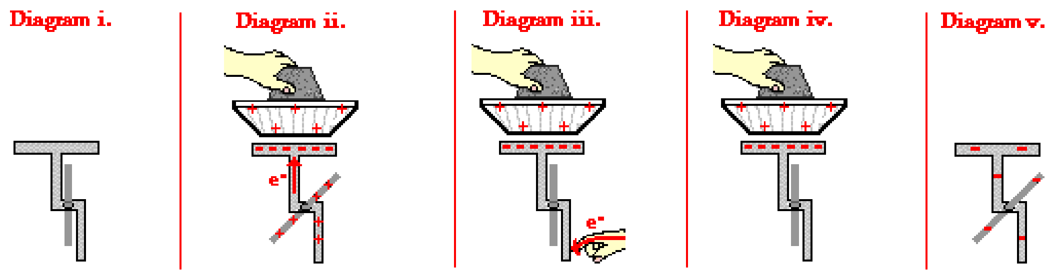
Another common lab experience that illustrates the induction charging method is the Electroscope Lab. In the Electroscope Lab, a positively charged object such as an aluminum pie plate is used to charge an electroscope by induction. An electroscope is a device that is capable of detecting the presence of a charged object. It is often used in electrostatic experiments and demonstrations in order to test for charge and to deduce the type of charge present on an object. There are all kinds of varieties and brands of electroscope from the gold leaf electroscope to the needle electroscope.

While there are different types of electroscopes, the basic operation of each is the same. The electroscope typically consists of a conducting plate or knob, a conducting base and either a pair of conducting leaves or a conducting needle. Since the operating parts of an electroscope are all conducting, electrons are capable of moving from the plate or knob on the top of the electroscope to the needle or leaves in the bottom of the electroscope. Objects are typically touched to or held nearby the plate or knob, thus inducing the movement of electrons into the needle or the leaves (or from the needle/leaves to the plate/knob). The gold leaves or needle of the electroscope are the only mobile parts. Once an excess of electrons (or a deficiency of electrons) is present in the needle or the gold leaves, there will be a repulsive affect between like charges causing the leaves to repel each other or the needle to be repelled by the base that it rests upon. Whenever this movement of the leaves/needle is observed, one can deduce that an excess of charge - either positive or negative - is present there. It is important to note that the movement of the leaves and needle never directly indicate the type of charge on the electroscope; it only indicates that the electroscope is detecting a charge.



Suppose a needle electroscope is used to demonstrate induction charging. An aluminum pie plate is first charged positively by the process of induction (see discussion above). The aluminum plate is then held above the plate of the electroscope. Since the aluminum pie plate is not touched to the electroscope, the charge on the aluminum plate is NOT conducted to the electroscope. Nonetheless, the aluminum pie plate does have an affect upon the electrons in the electroscope. The pie plate induces electrons within the electroscope to move. Since opposites attract, a countless number of negatively charged electrons are drawn upwards towards the top of the electroscope. Having lost numerous electrons, the bottom of the electroscope has a temporarily induced positive charge. Having gained electrons, the top of the electroscope has a temporarily induced negative charge (Diagram ii. below). At this point the electroscope is polarized; however, the overall charge of the electroscope is neutral. The charging step then occurs as the bottom of the electroscope is touched to the ground. Upon touching the bottom of the electroscope, electrons enter the electroscope from the ground. One explanation of their entry is that they are drawn into the bottom of the electroscope by the presence of the positive charge at the bottom of the electroscope. Since opposites attract, electrons are drawn towards the bottom of the electroscope (Diagram iii.). As electrons enter, the needle of the electroscope is observed to return to the neutral position. This needle movement is the result of negative electrons neutralizing the previously positively charged needle at the bottom of the electroscope. At this point, the electroscope has an overall negative charge. The needle does not indicate this charge because the excess of electrons is still concentrated in the top plate of the electroscope; they are attracted to the positively charged aluminum pie plate that is held above the electroscope (Diagram iv.). Once the aluminum pie plate is pulled away, the excess of electrons in the electroscope redistribute themselves about the conducting parts of the electroscope. As they do, numerous excess electrons enter the needle and the base upon which the needle rests. The presence of excess negative charged in the needle and the base causes the needle to deflect, indicating that the electroscope has been charged (Diagram v.).

Charging an Electroscope by Induction



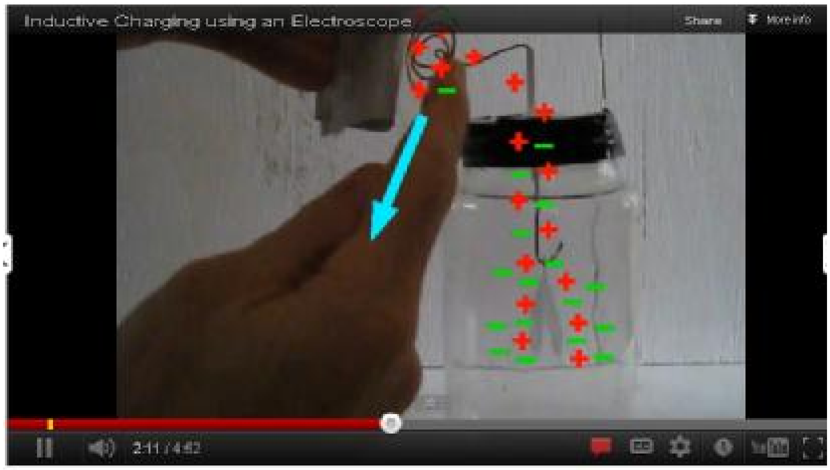
A neutral electroscope | The + aluminium plate attracts e- from the bottom of the e-scope to the top plate of the e-scope | When touched e- enter from ground to neutralize the + charge in needle | The e-scope has - charge,this - charge is still located in the top plate | The excess electrons redistribute themselves

The above discussion provides one more illustration of the fundamental principles regarding induction charging. These fundamental principles have been illustrated in each example of induction charging discussed on this page. The principles are:

- The charged object is never touched to the object being charged by induction.
- The charged object does not transfer electrons to or receive electrons from the object being charged.
- The charged object serves to polarize the object being charged.
- The object being charged is touched by a ground; electrons are transferred between the ground and the object being charged (either into the object or out of it).
- The object being charged ultimately receives a charge that is opposite that of the charged object that is used to polarize it.

Charging by Conduction

Charging by conduction involves the contact of a charged object to a neutral object. Suppose that a positively charged aluminum plate is touched to a neutral metal sphere. The neutral metal sphere becomes charged as the result of being contacted by the charged aluminum plate. Or suppose that a negatively charged metal sphere is touched to the top plate of a neutral needle electroscope. The neutral electroscope becomes charged as the result of being contacted by the metal sphere. And finally, suppose that an uncharged physics student stands on an insulating platform and touches a negatively charged Van de Graff generator. The neutral physics student becomes charged as the result of contact with the Van de Graff generator. Each of these examples involves contact between a charged object and a neutral object. In contrast to induction, where the charged object is brought near but never contacted to the object being charged, conduction charging involves making the physical connection of the charged object to the neutral object. Because charging by conduction involves contact, it is often called **charging by contact**.



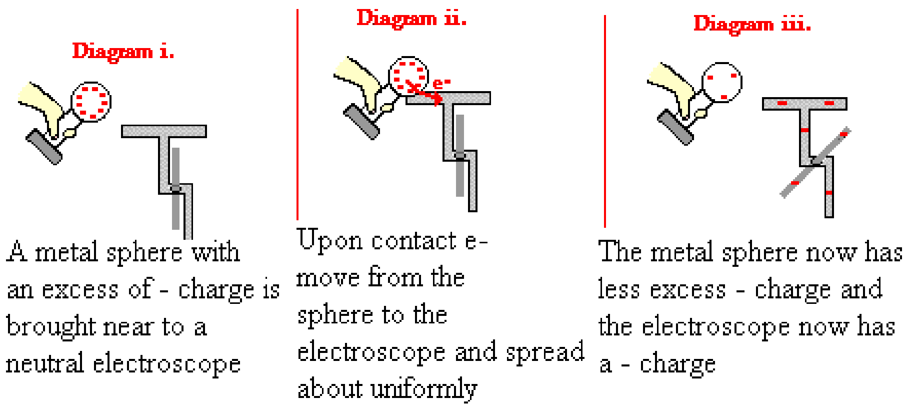
Courtsy By
http://vidgrids.com/charging-by-conduction

Charging by Conduction Using a Negatively Charged Object

To explain the process of charging by contact, we will first consider the case of using a negatively charged metal sphere to charge a neutral needle electroscope. Understanding the process demands that you understand that like charges repel and have an intense desire to reduce their repulsions by spreading about as far as possible, a negatively charged metal sphere has an excess of electrons; those electrons find each other repulsive and distance themselves from each other as far as possible. The perimeter the sphere is the extreme to which they can go. If there was ever a conducting pathway to a more spacious piece of real estate, one could be sure that the electrons would be on that pathway to the greener grass beyond. In human terms, electrons living in the same home despise each other and are always seeking a home of their own or at least a home with more rooms.

Given this understanding of electron-electron repulsions, it is not difficult to predict what excess electrons on the metal sphere would be inclined to do if the sphere were touched to the neutral electroscope. Once the contact of the sphere to the electroscope is made, a countless number of excess electrons from the sphere move onto the electroscope and spread about the sphere-electroscope system. In general, the object that offers the most space in which to "hang out" will be the object that houses the greatest number of excess electrons. When the process of charging by conduction is complete, the electroscope acquires an excess negative charge due to the movement of electrons onto it from the metal sphere. The metal sphere is still charged negatively, only it has less excess negative charge than it had prior to the conduction charging process.

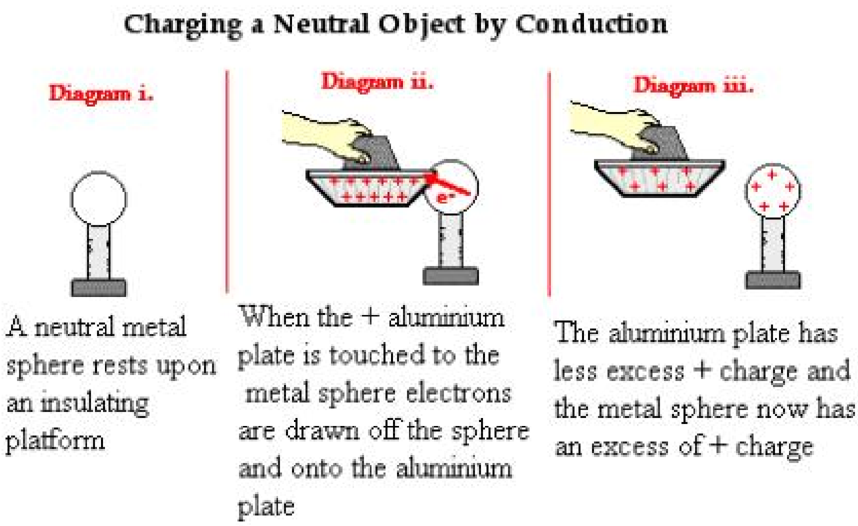
Charging a Neutral Object by Conduction



Charging by Conduction Using a Positively Charged Object

The previous example of charging by conduction involved touching a negatively charged object to a neutral object. Upon contact, electrons moved from the negatively charged object onto the neutral object. When finished, both objects were negatively charged. But what happens if a positively charged object is touched to a neutral object? To investigate this question, we consider the case of a positively charged aluminum plate being used to charge a neutral metal sphere by the process of conduction.

The diagram below depicts the use of a positively charged aluminum plate being touched to a neutral metal sphere. A positively charged aluminum plate has an excess of protons. When looked at from an electron perspective, a positively charged aluminum plate has a shortage of electrons. In human terms, we could say that each excess proton is rather discontented. It is not satisfied until it has found a negatively charged electron with which to co-habitat. However, since a proton is tightly bound in the nucleus of an atom, it is incapable of leaving an atom in search of that longed-for electron. It can however attract a mobile electron towards itself. And if a conducting pathway is made between a collection of electrons and an excess proton, one can be certain that there is likely an electron that would be willing to take the pathway. So when the positively charged aluminum plate is touched to the neutral metal sphere, countless electrons on the metal sphere migrate towards the aluminum plate. There is a mass migration of electrons until the positive charge on the aluminum plate-metal sphere system becomes redistributed. Having lost electrons to the positively charged aluminum plate, there is a shortage of electrons on the sphere and an overall positive charge. The aluminum plate is still charged positively; only it now has less excess positive charge than it had before the charging process began.



The above explanation might raise a rather difficult question: Why would an electron on the previously neutral metal sphere desire to move off the metal sphere in the first place? The metal sphere is neutral; every electron on it must be satisfied since there is a corresponding proton present. What would possibly induce an electron to go through the effort of migrating to a different territory in order to have what it already has?

The best means of answering this question requires an understanding of the concept of electric potential. But since that concept does not arise until the next unit of The Physics Classroom, a different approach to an answer will be taken. It ends up that electrons and protons are not as independent and individualized as we might think. From a human perspective, electrons and protons can't be thought of as independent citizens in a free enterprise system of government. Electrons and protons don't actually do what is best for them, but must be more social-minded. They must act like citizens of a state where the rule of law is to behave in a manner such that the overall repulsive affects within the society at large are reduced and the overall attractive affects are maximized.

Electrons and protons will be motivated not by what is good for them, but rather by what is good for the country. And in this sense, a country's boundary extends to the perimeter of the conductor material that an excess electron is within. And in this case, an electron in the metal sphere is part of a country that extends beyond the sphere itself and includes the entire aluminum plate. So by moving from the metal sphere to the aluminum plate, an electron is able to reduce the total amount of repulsive affects within that country. It serves to spread the excess positive charge over a greater surface area, thus reducing the total amount of repulsive forces between excess protons.

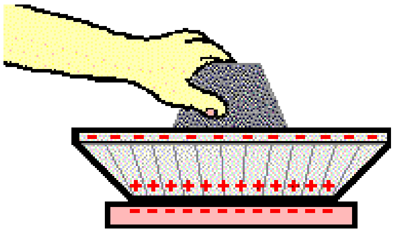
Law of Conservation of Charge

In each of the other methods of charging discussed charging by friction and charging by induction - the law of conservation of charge was illustrated. The law of conservation of charge states that charge is always conserved. When all objects involved are considered prior to and after a given process, we notice that the total amount of charge among the objects is the same before the process starts as it is after the process ends. The same conservation law is observed during the charging by conduction process. If a negatively charged metal sphere is used to charge a neutral electroscope, the overall charge before the process begins is the same as the overall charge when the process ends. So if before the charging process begins, the metal sphere has 1000 units of negative charge and the electroscope is neutral, the overall charge of the two objects in the system is -1000 units.

Perhaps during the charging process, 600 units of negative charge moved from the metal sphere to the electroscope. When the process is complete, the electroscope would have 600 units of negative charge and the metal sphere would have 400 units of negative charge (the original 1000 units minus the 600 units it transferred to the electroscope). The overall charge of the two objects in the system is still -1000 units. The overall charge before the process began is the same as the overall charge when the process is completed. Charge is neither created nor destroyed; it is simply transferred from one object to another object in the form of electrons.

Conduction Charging Requires a Conductor

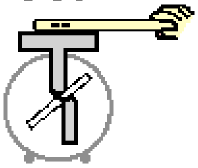
In all the above examples, the charging by conduction process involved the touching of two conductors. Does contact charging have to occur through the contact of two conductors? Can an insulator conduct a charge to another object upon touching? And can an insulator be charged by conduction? A complete discussion of these questions can get messy and quite often leads to a splitting of hairs over the definition of conduction and the distinction between conductors and insulators. The belief is taken here that only a conductor can conduct charge to another conductor. The process of noticeably charging an object by contact involves the two contacting objects momentarily sharing the net excess charge. The excess charge is simply given a larger area over which to spread in order to reduce the total amount of repulsive forces between them. This process demands that the objects be conductors in order for electrons to move about and redistribute themselves. An insulator hinders such a movement of electrons between touching objects and about the surfaces of the objects. This is observed if an aluminum pie plate is placed upon a charged foam plate. When the neutral aluminum plate is placed upon the charged foam plate, the foam plate does not conduct its charge to the aluminum. Despite the fact that the two surfaces were in contact, charging by contact or conduction did not occur. (Or at least whatever charge transfer might have occurred was not noticeable by the customary means of using an electroscope, using a charge testing bulb or testing for its repulsion with a like-charged object.)



Many might quickly suggest that they have used a charged insulator to charge a neutral electroscope (or some other object) by contact. In fact, a negatively charged plastic golf tube can used to charge an electroscope. The plastic tube is touched to the top plate of the electroscope. On most occasions, the plastic tube is even rubbed or rolled across the plate of the electroscope? Wouldn't this be regarded as charging by conduction? No. Not really. In this case, it is more than likely that the charging occurred by some process other than conduction. There was not a sharing of charge between the plastic tube and the metal parts of the electroscope. Of course, once some excess charge is acquired by the electroscope, that excess charge distributes itself about the surface of the electroscope. Yet the charge is not uniformly shared between the two objects. The protons and electrons within both the plastic golf tube and the electroscope are not acting together to share excess charge and reduce the total amount of repulsive forces.

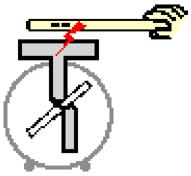
The charging of an electroscope by contact with a negatively charged golf tube (or any charged insulating object) would best be described as **charging by lightning**. Rather than being a process in which the two objects act together to share the excess charge, the process could best be described as the successful effort of electrons to burst through the space (air) between objects. The presence of a negatively charged plastic tube is capable of ionizing the air surrounding the tube and allowing excess electrons on the plastic tube to be conducted through the air to the electroscope. This transfer of charge can happen with or without touching. In fact, on a dry winter day the process of charging the metal electroscope with the charged insulator often occurs while the insulator is some distance away. The dry air is more easily ionized and a greater quantity of electrons is capable of bursting through the space between the two objects. On such occasions, a crackling sound is often heard and a flash of light is seen if the room is darkened. This phenomenon, occurring from several centimeters away, certainly does not fit the description of contact charging.

Charging by Contact?



or

Charging by Lightning?



A charged insulating object is certainly capable of transferring its charge to another object. The result of the charge transfer will be the same as the result of charging by conduction. Both objects will have the same type of charge and the flow of electrons is in the same direction. However, the process and the underlying explanations are considerably different. In the case of charging an object with a charged insulator, the contact is not essential. Contacting the object simply reduces the spatial separation between touching atoms and allows charge to arc and spark its way between objects. Rubbing or rolling the insulating object across the conductor's surface facilitates the charging process by bringing a greater number of atoms on the insulator in close proximity to the conductor that is receiving the charge. The two materials do not make any effort to share charge nor to act as a single object (with a uniform electric potential) in an effort to reduce repulsive affects.

Induction and Conduction

When an object gets charged by induction, a charge is created by the influence of a charged object but not by contact with a charged object. The word **i**nduction means to influence without contact.

When an object gets charged by conduction, a charge is created by the influence of a charged object by direct contact (touch) with a charged object. The word conduction means to influence with contact. There are several advantages to charging something by induction. The originally charged object never loses any charge so it need not be recharged. (Work does not need to be done creating the charge again)

The induced charge can be quite strong and subsequent charges will be equally strong. The table below compares charging by Conduction to charging by Induction.

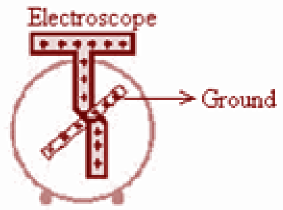
In the study of electrostatics, we must differentiate between two different types of materials: insulators and conductors and we are discussing with the behavior of different type of insulators.

Charging by Conduction	Charging by Induction
Charged object touches the	Charged object does not touch the
Electroscope ends up similarly charged to the object used to	Electroscope ends up oppositely charged to the object
The first charge is strong but gets weaker each time the electroscope is recharged. (This is due to the original object giving up some charge every	The first charge is strong and stays strong each time the electroscope is recharged. (This is due to the original object not losing any charge in the

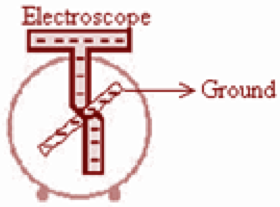
In insulators, although it may be relatively easy for electrons to come loose from atoms and even be transferred to other materials, there are few pathways by which such freed electrons can flow within the material. By contrast, conducting materials have electrons (conduction electrons) which are not only permanently free of their atoms, but which are free to flow in the material. Such flowing charge is referred to as electrical current.

Grounding – the removal of charge

The previous sections discussed the three common methods of charging – charging by friction, charging by induction, and charging by conduction. A discussion of charging would not be complete without a discussion of unchanging. Objects with an excess of charge - either positive or negative - can have this charge "removed" by a process known as grounding. Grounding is the process of removing the excess charge on an object by means of the transfer of electrons between it and another object of substantial size.



Grounding a positively charged electroscope involes the transfer of electrons from "the ground" to the electroscope



Grounding a negatively charged electroscope involes the transfer of electrons from "the electroscop to"the ground".

When a charged object is grounded; the excess charge is balanced by the transfer of electrons between the charged object and a ground. A ground is simply an object which serves as a seemingly infinite reservoir of electrons; the ground is capable of transferring electrons to or receiving electrons from a charged object in order to neutralize that object. In this section, the process of grounding will be discussed.

To begin our discussion of grounding, we will consider the grounding of a negatively-charged electroscope. Any negatively-charged object has an excess of electrons. If it is to have its charge removed, then it will have to lose its excess electrons. Once the excess electrons are removed from the object, there will be equal numbers of protons and electrons within the object and it will have a balance of charge. To remove the excess of electrons from a negatively-charged electroscope, the electroscope will have to be connected by a conducting pathway to another object which is capable of receiving those electrons. The other object is the ground. In typical electrostatic experiments and demonstrations, this is simply done by touching the electroscope with one's hand. Upon contact, the excess electrons leave the electroscope and enter the person who touches it; these excess electrons subsequently spread about the surface of the person.

This process of grounding works because excess electrons find each other repulsive. As is always the case, repulsive effects between like-charged electrons force them to look for a means of spatially separating themselves from each other. This spatial separation is achieved by moving to a larger object that allows a greater surface area over which to spread. Because of the relative size of a person compared to a typical electroscope, the excess electrons (nearly all of them) are capable of reducing the repulsive forces by moving into the person (i.e., the ground). Like contact charging discussed earlier, grounding is simply another example of charge sharing between two objects. The extent to which an object is willing to share excess charge is proportional to its size. So an effective ground is simply an object with significant enough size to share the overwhelming majority of excess charge.

The previous discussion describes the grounding of a negatively-charged electroscope. Electrons were transferred from the electroscope to the ground. But what if the electroscope is positively-charged? How does electron transfer allow an object with an excess of protons become neutralized? To explore these questions, we will consider the grounding of a positively-charged electroscope. A positively-charged electroscope must gain electrons in order to acquire an equal number of protons and electrons. By gaining electrons from the ground, the electroscope will have a balance of charge and therefore be neutral. Thus, the grounding of a positively-charged electroscope involves the transfer of electrons from the ground into the electroscope. This process works because excess positive charge on the electroscope attracts electrons from the ground (in this case, a person). While this may disrupt any balance of charge present on the person, the significantly larger size of the person allows for the excess charge to distance itself further from each other. As in the case of grounding a negatively-charged electroscope, the grounding of a positively-charged electroscope involves charge sharing. The excess positive charge is shared between the electroscope and the ground. And once again, the extent to which an object is willing to share excess charge is proportional to its size. The person is an effective ground because it has enough size to share the overwhelming majority of excess positive charge.

Any object can be grounded provided that the charged atoms of that object have a conducting pathway between the atoms and the ground.

Applications of Electrostatics

Static electricity is usually regarded as a nuisance or hazard responsible for process problems, electric shocks and, most seriously, industrial fires and explosions. The effect of Electrostatics is of considerable industrial importance both in terms of safety and also potential damage to manufactured goods. The spark produced is fully capable of igniting flammable vapors, for example, petrol or ether fumes. Means have to be found to discharge carts which may carry such liquids in hospitals. Even where only a small charge is produced, this can result in dust particles being attracted to the rubbed surface. In the case of textile manufacture this can lead to a permanent grimy mark where the cloth has been charged. Some electronic devices, most notably MOSFETs, can be accidentally destroyed by high-voltage static discharge. Such components are usually stored in conductive foam for protection. Grounding oneself by touching the workbench or using a special bracelet or anklet is standard practice while handling unconnected integrated circuits.

It may seem surprising therefore that a large proportion of work performed (for industrial clients) which involves its uses and benefit. In these cases, electrostatic forces are carefully controlled and put to work at improving industrial processes. The results can be increased efficiency, smoother plant operation and a cleaner working environment.

1.Electrostatic Precipitator

A device used to remove liquid droplets or solid particles or dust or other finely y divided particles from a gas in which they are suspended. The process depends on two steps. In the first step the suspension passes through an electric discharge (corona discharge) area where ionization of the gas occurs. The ions produced collide with the suspended particles and confer on them an electric charge. The charged particles drift toward an electrode of opposite sign and are deposited on the electrode where their electric charge is neutralized. The phenomenon would be more correctly designated as electrode position from the gas phase.

The use of electrostatic precipitators has become common in numerous industrial applications. Among the advantages of the electrostatic precipitator are its ability to handle large volumes of gas, at elevated temperatures if necessary, with a reasonably small pressure drop, and the removal of particles in the micrometer range. Some of the usual applications are: (1) removal of dirt from flue gases in steam plants; (2) cleaning of air to remove fungi and bacteria in establishments producing antibiotics and other drugs, and in operating rooms; (3) cleaning of air in ventilation and air conditioning systems; (4) removal of oil mists in machine shops and acid mists in chemical process plants; (5) cleaning of blast furnace gases; (6) recovery of valuable materials such as oxides of copper, lead, and tin; and (7) separation of rustle from zirconium sand.

Electrostatic Precipitators for Power Plants

Many countries around the world, including our own, depend on coal and other fossil fuels to produce electricity. A natural result from the burning of fossil fuels, particularly coal, is the emission of fly ash. Ash is mineral matter present in the fuel. For a pulverized coal unit, 60-80% of ash leaves with the flue gas. Historically, fly ash emissions have received the greatest attention since they are easily seen leaving smokestacks.

Two emission control devices for fly ash are the traditional fabric filters and the more recent electrostatic precipitators. The fabric filters are large bag house filters having a high maintenance cost (the cloth bags have a life of 18 to 36 months, but can be temporarily cleaned by shaking or back flushing with air). These fabric filters are inherently large structures resulting in a large pressure drop, which reduces the plant efficiency. Electrostatic precipitators have collection efficiency of 99%, but do not work well for fly ash with a high electrical receptivity (as commonly results from combustion of low-sulfur coal).

The flue gas laden with fly ash is sent through pipes having negatively charged plates which give the particles a negative charge. The particles are then routed past positively charged plates, or grounded plates, which attract the now negatively-charged ash particles. The particles stick to the positive plates until they are collected. The air that leaves the plates is then clean from harmful pollutants. Just as the spoon picked the salt and pepper up from the surface they were on, the electrostatic precipitator extracts the pollutants out of the air.

Electrostatic precipitators are not only used in utility applications but also other industries (for other exhaust gas particles) such as cement (dust), pulp & paper (salt cake & lime dust), petrochemicals (sulfuric acid mist), and steel (dust & fumes).

As we can see Electrical Engineers can play an important part in the fight against pollution. Through devices such as the electrostatic precipitator, electrical engineers can protect the environment from harm. Such a design also appeals to the general public as the electricity can be produced cheaply. The electrostatic precipitator is just one example of a device designed by electrical engineers to help the environment. Engineers are responsible for considering environmental impact as part of their original design work.

Recent Applications

Recent examples include an airless electrostatic atomization system for applying resin to lithographic plates, a comprehensive range of novel technologies for identifying plastics for recycling and a revolutionary new system for electrostatic powder coating.

2.Electrostatic Atomization & Spraying

The efficient atomization of liquids into a uniformly dispersed aerosol and the application o f surface coatings of controlled thickness can be achieved using electrostatic techniques. Many paints, resins, solvents and oils can be atomized into near equal-sized droplets and sprayed electrostatic ally without the use of atomizing air or significant hydraulic pressure.

Airless application of liquids

Electrostatic atomization is achieved by directing the liquid to be sprayed through an electrified applicator - this may be a nozzle, array of tubes, blade or other geometry suited to the spraying requirements and conditions. As the charged liquid leaves the applicator it is dispersed by the electric field (which is established between the emerging liquid and the work-piece or a counter electrode). Depending on the operating conditions and physical properties of the liquid, a liquid jet extends toward the work-piece with the end of the jet disrupting into a stream of uniform droplets.

The advantages of airless electrostatic spraying over conventional air atomization are considerable and include uniformity of deposition, minimal wastage of liquid and greater control. In addition, electrostatic applicators are far less prone to blockage than conventional nozzles. There are significant environmental and health and safety y benefits too. Since the droplet cloud is charged and attracted to the target, there is virtually no overspray. The spraying operation produces no significant air currents and, with a properly balanced system, no particulates are left in the atmosphere.

Although this technique works well with many liquids, water-based liquids have a relatively high electrical conductivity and can not be easily atomized by electrostatic forces alone. In these cases a 'hybrid' applicator which incorporates mechanical atomization together with electrostatic charging can be utilized. Such systems are used in crop-spraying and combine high liquid throughputs with very high charging levels to improve deposition and transfer efficiency.

Printing and Coating

Electrostatics has been closely linked to printing and coating technology for many years. A novel system is developed for applying a thin coating of resin to lithographic plates. This patented technology is installed on production lines throughout the world and is required to operate continuously and virtually maintenance free.

Electrostatics application is looking for developing new techniques in the industry for the application of specialist coatings to a variety of substrates, including plastic films, fabrics and glass. It includes improving ESA (electrostatic assist) in gravure and other printing techniques, and the efficient application of thin uniform coatings to 'difficult' surfaces such as high-speed plastic webs.

3.Plastics Identification & Recycling

The wide range of polymer types comprising consumer products make recovering waste plastics a challenging task.

As a conservative estimate, in the UK for example almost 4.5 million tones of plastic products are used annually and between 3 and 3.5 million tones of waste plastics require disposal. For obvious environmental reasons it is becoming increasingly important to recycle 'waste' plastics rather than send them to landfill.

It is necessary to distinguish between certain types of plastic if recycling is to become a practical reality. Different plastics, particularly different polymer groups, can have significantly different physical and chemical properties which may include mechanical strength, flexibility, chemical resistance, etc. Hybrids of these plastics or those which have been contaminated by the presence of other materials may have these properties seriously affected.

European initiatives are currently underway for waste electrical and electronic equipment (WEEE Directive) and for end-of-life motor vehicles (ELV Directive). The common aim of these directives is to increase the re-use and recycling of WEEE/ELV by setting recovery and recycling targets and by introducing producer responsibility for disposal. The weak link in the recycling loop is material identification.

Tribopen and the Pollyanna are the two plastic identification systems to aid in the recycling of automotive components. These two are the results of development programmers sponsored by Ford Motor Company and the Landfill Tax Credit Scheme and have won Millennium Product Awards from the UK Government in 2000. Another invention for identifying asbestos in vehicle clutch plates during recycling gained the 'Ford of Europe Technical Achievement Award' - the first time this award has gone outside the Ford Company.

Electrostatics Industry is concentrating on using electrostatic techniques to distinguish between different items of plastic packaging (PET/PE/PVC bottles, PS/PVC/PP food trays & cartons etc.) on an automatic sorting line. An electrostatic method for sorting plastics from non-plastic packaging was also developed.

The pilot sorting line - a five meter long conveyor is currently in use at Southampton University. Mixed plastic and non-plastic waste packaging is loaded onto the conveyor system which automatically recognizes the polymer comprising the packaging item and ejects it according to polymer type into the appropriate bin. Non-plastic packaging such as cardboard and wood are automatically directed to a separate bin.

During the project entitled ' Plastics Identification Technology for Recycling ' three new pieces of plastics identification technology have been developed. These include improved versions of the Tribopen and Pollyanna - the latter incorporating the new Nicollet Avatar spectrometer with latest ‘Omnic’ software. A completely new instrument - the 'tribo-discriminator’ enables the user to quickly distinguish between two or three materials and is particularly useful in identifying contaminant plastics such as PVC from a mixed stream

Sorting shredded and granulated waste

The application of electrostatics provides an ideal means of identifying and manipulating shredder and granulator residue. Due to their size, relatively large surface area and light weight, the particles comprising the stream can be charged and either attracted or repelled using an electric field. Since different materials may have significantly different electrical properties they will often charge to different magnitudes or polarities. Electrostatic techniques can then be used to sort mixed streams or preferentially remove contaminant plastics.

4.Powder Applications

Processes and operations involving the handling of pellets, flakes, granules, powders and fine particles can often benefit from the application of electrostatics. Static electricity is a surface phenomenon and materials in particle form constitute a large total surface area to which electrostatic charge can be applied. Since most industrial powders are relatively electrically insulating, any applied charge is retained by the medium and can be used to attract, deflect, levitate, disperse or manipulate the particles.

A fully equipped powder laboratory contained electrostatic applicators, coating booths and process equipment. Novel electrostatic powder coating techniques have alread y been developed using this facility. Examples include application of flavorings to food, development of uniform thin-film coatings for glass and optimization of electrostatic powder coating systems.

Powder Coating

Although electrostatic powder coating has been around for decades, conventional application equipment and paint technology is not well suited to coating modern materials such as plastics and composites. In addition the paint formulations may be far from optimized in terms of their propensity to acquire and retain electrostatic charge. Important work undertaken recently has studied novel means of charging the powder without the generation of free-ions (which can quickly charge a non-metallic surface and actually repel the paint!). Studies to improve the chargeability of paint have also been undertaken.

Particle manipulation

Particles ranging in size from a few microns (cigarette smoke) up to several millimeters (tablets, flakes, chips, shredder residue etc.) can be manipulated by electrostatic forces. These forces can be used to precipitate the particles from an air stream, separate out different media and control adhesion of particles to a surface.

Material separation particularly in the contexts of improving production yields and purifying recycling streams is an important electrostatic application. Work in this area has ranged from the design of systems to enhance the quality of agricultural products such as carob medium by removing cracked seed fragments to removal of contaminants from plastics recycling streams.

Many material handling operations generate static electricity as an unwanted by-product. This uncontrolled charge can cause a host of difficulties including flow problems, interference to electrical control equipment and even fires. In such cases the removal of charge by the application of bipolar or unipolar ions in controlled doses can alleviate the problem and ensure trouble-free operation.

Forensic Science

Identifying and examining small particles - particularly fragments of glass, paint and individual cloth fibers are of great interest to the forensic scientist. Often these particles which can provide crucially important information need to be separated from large amounts of mixed debris and this can be undertaken using electrostatics.

A bench top system is developed for achieving effective separation of paint chips and glass fragments from mixed debris. The system uses a pulsed electric field applied to an array of electrodes. The resultant 'electric curtain' effect progressively removes the debris leaving the paint particles behind.

5. Bio electrostatics

Electrostatic Allergen Denaturing

Allergens within the domestic environment are becoming an increasingly important consideration in relation to the triggering of asthma and other related respiratory diseases. Levels of the house dust mite allergen (Der p1) and the cat allergen (Fel d1) appear to have increased dramatically in recent years; probably as a direct result of improvements in home insulation, heating and extensive use of carpeting. Mechanical barrier systems, acaroids and other non-pharmaceutical remedies seem to have had little effect.

Electrets Carpets

Electrets are media which carry a permanent electrical charge and electrets technology has been used extensively in filter applications. The permanently polarized electrets fibers have superior particle attracting properties and are ideal for applications requiring the manipulation of small particles such as dust**.** Electrets fibers are woven into the carpet backing, or in some instances incorporated into the carpet pile. The enhanced particle anchoring properties of this structure can lead to a significant reduction in aeroallergens during vacuum cleaning and other related household chores. Carpeting that can significantly reduce the release of potent allergens into the air compared to conventional carpets, without the use of applied chemicals, should offer an acceptable median between carpeting benefits and allergen exposure.

Electrostatic Carpet Care

The benefits of conventional 'carpet care' powder can be substantially enhanced b y adopting a passive electrostatic charging product dispenser. Conventional carpet care products offer no more than the distribution of fragrance into the carpet and room. With the added benefit of the powder being electrostatic ally charged on delivery, this technology offers important added value to the product. Removal of dust particles from carpets using charged carpet care powders represents a significant development in tackling the vast dust source associated with carpets. Up to 99.5% of dust was recovered from polypropylene carpets using a charged powder. Assuming a pro-rata removal of allergenic particles, this technique could provide a method for removing allergens from carpets that is non-specific to allergen type and only weakly affected by carpet type.

Electrostatic Bacteria Killing

Exposure of bacteria cells (Pseudomonas veronii and Escherichia coli) to both positive and negative ions has demonstrated the ability of unipolar ions to destroy up to 95% of these bacteria colonies. Unipolar ions have been shown to have similareffects on bio-films, and this technology is now being developed for household application

Hazards of Electrostatics

Uncontrolled static electricity is responsible for a large number of serious industrial fires and explosions around the world every year. Any environment in which sensitive flammable media are present is at risk and statistics indicate that due to increased process speeds, finer powders and higher purity fuels & solvents, the problem is growing.

Static electricity is difficult to detect, quantify and control. In addition to the threat of ignition, static can cause a host of other industrial problems often resulting in production difficulties, quality issues and expensive plant shutdowns.

With the continual introduction of new synthetic materials and ever-faster process line speeds, electrostatic problems have become increasingly prevalent in all sectors of industry. Electrostatic charging has frequently caused:

- Fires and explosions
- Disruption of production lines
- Degradation of products
- Equipment malfunction, computer downtime
- Electrostatic shocks to personnel.

Precautions

1. A complete static program requires proper environment with proper material selection. Otherwise partial solutions produce partial results.
2. Small change in surrounding affects the result.
3. Hands should be clean.
4. Keep the training kit near the dry and warm place for better results.

Suggestions

1. Before using charged rods and pith balls again it should be grounded or neutralized by hands.
2. All clothes used to charge objects should be freshly laundered and fluffy, and kept in a clean bag.

Experiment 1

Objective : Study of the Charge Induction in Electrostatics

Items Required

1. Digital Electroscope
2. Teflon rod
3. Perspex rod
4. Woolen cloth.

Procedure

1. Take digital electroscope, Teflon rod and woolen cloth from the carrying case.
2. Make sure that ON/OFF switch of the electroscope is off. Select Charge Polarity Indicator/ Display Switch towards Charge Polarity Indicator position.
3. Connect the mains cord to electroscope and switch on the mains supply.
4. Now switch on the ON/OFF switch of the electroscope.
5. As you switch on the electroscope, depending upon the charge(s) present in the atmosphere, blue LED or green LED or both glow and indicate the charge(s) present in the atmosphere.
6. Take a Teflon rod and rub it on the woolen cloth. When you approach this rod towards the charge receiver, there will be negative charge indicated by blue LED.

   Note: Do not touch rod with charge receive point, otherwise results may vary.
7. When you recede it from the charge receiver point, you can observe that the positive charge is indicated by green color LED. Since we know that Teflon rod carries the negative charge, when it is rubbed with a cotton cloth, also we know in induction opposite charge is induced so we have intentionally used a INVERT circuit to prove the actual charge polarity. After sometimes, it may possible that blue LED glows again (with green LED) as positive charge becomes weak and charge(s) present in the atmosphere are shown.

When rod is approaching: Teflon rod (negative) induces the positive charge on charge receiver point (Induction Theory) and INVERT circuit will indicate the negative charge.

When rod is receding: Teflon rod (negative) induces the negative charge on charge receiver point. Invert circuit will indicate the positive charge.

8. Repeat the experiment with Perspex rod (positive charge) and observe the result.
Compare your results with the expected results given in following table.

S. No.	Rods	Clothes	Approaching	Receding
1	Teflon	Woolen	Negative	Positive
2	Perspex	Woolen	Positive	Negative

Experiment 2

Objective: Study of the Charge Conduction in Electrostatics

Items Required

1. Digital Electroscope
2. Teflon rod
3. Perspex rod
4. Woolen cloth.

Procedure

1. Take digital electroscope, Teflon rod and woolen cloth from the carrying case.

2. Make sure that ON/OFF switch of the electroscope is off. Select Charge Polarity Indicator/ Display Switch towards Charge Polarity Indicator position.

3. Connect the mains cord to electroscope and switch on the mains supply.

4. Now switch on the ON/OFF switch of the electroscope.

5. As you switch on the electroscope, depending upon the charge(s) present in the atmosphere, blue LED or green LED or both glow and indicate the charge(s) present in the atmosphere.

6. Take Teflon rod and rub it on the woolen cloth. When you approach this rod towards the charge receiver there will be negative charge indicated by blue color LED. But when you touch the rod with charge receiver point, you can observe that the positive charge is indicated by green color LED.
   Note: Touch that portion of rod with charge receiver point which is rubbed effectively with cloth

7. We know that in conduction similar charge is produced on the objects. When we touch the rod on charge receiver point, conduction takes place. Since Teflon rod is negative charge carrying rod the same negative charge is produced on charge receiver point. Due to INVERT circuit the positive charge is indicated by green color LED.

8. It may possible that blue LED glows (with green LED) as conduction charge becomes weak and charge(s) present in the atmosphere are shown.
Note: Conduction depends upon intensity of charges present which depends upon the strength of rubbing i.e. frictional force with which rod is rubbed with cloth.

9. Repeat the experiment with positive charge carrying Perspex rod, and observe the results. Record the results in the following table.

S. No.	Rods	Clothes	Result of Conduction
1	Teflon		
2	Perspex		

Experiment 3

Objective : Study of the Pith ball pendulum Electroscope

Items Required

1. Pendulum stand
2. Pith balls
3. Teflon rod
4. Woolen cloth.

Procedure

1. Take a pendulum stand and a pith ball with string from the accessory box.

2. Hang this single ball on the stand.

3. Take a Teflon rod and rub it on the woolen cloth.

4. Approach this charged (negatively charged) rod near the pith ball. Due to induction the opposite charge i.e. positive charge is induced on the surface of the ball. So it will attract towards the rod.

a. (Note : Before performing the experiment hold the balls with your hands to neutralize the charge present on them.)

5. As the ball makes the contact with the rod (charged area of the rod), because of the conduction similar charge (negative) will be produced on the surface of the ball and that's why the ball will be repelled from the rod.

Inducti	Conduction
Charged object doesn't touch the electroscope	Charged object touches the electroscope
Electroscope ends up oppositely charged to the object used to charge it.	Electroscope ends up similarly charged to the object used to charge it.

The first charge is strong and stays strong each time the electroscope is recharged. (This is due to the original object not losing any charge in the	The first charge is strong but gets weaker each time the electroscope is recharged. (This is due to the original object giving up some charge every time it is touched)

6. Since we know that each time the induction is strong so the ball will be again attracted by the rod and in the same way repulsion may occur. This attraction and repulsion generates the oscillations in the pith ball pendulum.

7. After some oscillations depending on the intensity of the charges, conduction will become weak and the ball will be attracted by rod and then no repulsion will take place.

8. Remove this single ball from the pendulum stand and take the pair of pith balls with string from the accessory box.

9. Hang this pair on the pendulum stand, in such a way that the balls should be in contact with each other i.e. both should be at same height from the ground.

10. Now charge the Teflon rod and approach it near the balls. The same induction and conduction results may be observed on the pith ball electroscope.

11. Repeat he experiment with positive charge carrying Perspex rod and observe the result. Record the results.

Experiment 4

Objective : Study of the relative charges of different rods with the help of Digital Display in millivolt

Items Required

1. Digital Electroscope
2. Rods
3. Clothes.

Procedure

1. Take digital electroscope, Teflon rod and woolen cloth from the carrying case.

2. Make sure that ON/OFF switch of the electroscope is off. Select Charge Polarity Indicator/ Display Switch towards Display position

3. Connect the mains cord to electroscope and switch on the mains supply.

4. Now switch on the ON/OFF switch of the electroscope.

5. Take a Teflon rod & rub it on the silk cloth. As you approach this charged (negative) rod near the charge receiver point you may observe the negative millivolt reading in the display. Now as you recede the rod from charge receiver point opposite charge i.e. Positive charge is displayed. Value of charges displayed for a moment only when the charged rod is approaching or receding i.e. if rod is stationary then proper charge will not be displayed. Its value depends on many factors like rubbing, rods characteristics, movement, surrounding etc.

6. You can perform this experiment with different rods & clothes and result may be recorded.

(Note: This is only a observational type experiment. Here students can do the qualitative analysis.)

Experiment 5

Objective : Study of the electrostatic charge with the help of Charge Demonstration Tube

Items Required

1. Charge Demonstration Tube
2. Silk cloth.

Procedure

1. Take the charge demonstration tube and silk cloth from the carrying case.

2. Rub the demonstration tube on the silk cloth. You can observe that the styrene balls are moving inside the tube, repelling each other and then finally different balls may adopt different positions in the tube

3. Now approach charged Teflon rod (negatively charged) near the charged balls. It may be observed that balls are repelling from Teflon rod. This is because electrons from the surface of positively charged Perspex tube are gained by the styrene balls as Perspex has tendency to loose electrons and styrene balls become negatively charged.

4. Repeat the experiment by approaching charged Perspex rod (positively charged) towards the charged balls and you can observe that balls are attracting towards Perspex rod.

Experiment 6

Objective : Study of the electrostatic charge by the combination of different rods & clothes

Items Required

1. Digital Electroscope.

2. Rods

3. Clothes

Procedure

1. Take the electroscope, different rods and clothes from the carrying case.

2. Make sure that ON/OFF switch of the electroscope is off. Select Charge Polarity
   a. Indicator/ Display Switch towards Charge Polarity Indicator position

2. Connect the mains cord to electroscope and switch on the mains supply.

3. Now switch on the ON/OFF switch of the electroscope.

4. As you switch on the electroscope, depending upon the charge(s) present in the atmosphere, blue LED or green LED or both glow and indicate the charge(s) present in the atmosphere.

5. Take any one rod and one type of cloth. Rub the rod on the cloth and approach it towards the charge receiver point. Observe the result indicated by LED.

6. Record your results in the table and compare the results with following expected results. Repeat the experiment with different combination.

Rod	Cloth	Charge Produced
Teflon	silk	Negative
Teflon	Woolen	Negative
Teflon	Cotton	Negative
Perspex	Silk	Positive
Perspex	Woolen	Positive
Perspex	Cotton	Positive

The above results may be studied with the digital display

Glossary

1. **Conductor.** A conductor is a medium through which an electric current will flow.

2. **Dielectric.** An electric insulator. A non conducting medium.

3. **Dielectric constant.** The ratio of the capacitance with a particular material separating the plates of a capacitor to the capacitance with a vacuum between the plates.

4. **Electric field line.** An imaginary line that shows the electric field around a charged object.

5. **Electric conductor.** A material through which charge easily moves.

6. **Electric current.** The ratio of the amount of charges that pass a point per unit of time .

7. **Electric insulator.** A material through which charge does not easily move.

8. **Electric potential difference.** The ratio of change in potential energy per unit of charge .

9. **Friction.** Friction is a resisting force between two surfaces rubbing against each other.

10. **Insulators**. Materials that are poor conductors of heat-for example, heat flows slowly through materials with air pockets because the molecules making up air are far apart; also, materials that are poor conductors of electricity, for example, glass or wood.

11. **Ion.** A charged atom or molecule. A positive ion (or Cation) will have lost one or more electrons. A negative ion (or anion) will have gained one or more electrons. Ions cannot be formed by the loss or gain of protons.

12. **Ionization.** An atom or molecule is said to be ionized when it has gained or lost one or more electrons. If an atom or molecule gains an electron, it is negatively charged, losing an electron makes it positive.

13. **Negative electric charge.** One of the two types of electric charge; repels other negative charges and attracts positive charges.

14. **Negative ion.** Atom or particle that has a surplus, or imbalance, of electrons and, thus, a negative charge.

15. **Net force.** The resulting force after all vector forces has been added; if a net force is zero, all the forces have canceled each other and there is not an unbalanced force.

16. **Nucleons.** Name used to refer to both the protons and neutrons in the nucleus of an atom

17. **Nucleus.** Tiny, relatively massive and positively charged center of an atom containing protons and neutrons; the small, dense center of an atom numerical constant a constant without units; a number.

18. **Static electricity.** An electrical charge that builds up due to friction between two dissimilar materials. Friction removes some electrons from one object and deposits them on the other.

Frequently Asked Questions

Q1.What is the value of k in electrostatics?

Ans. In the formula for electrostatic forces, the value of k is 8.99×10^9 N m^2 C^{-2}

Q2. Give examples of good resistors?

Ans. Good resistors should have properties of adjustable electrical resistance, such as slide rheostat, resistance box. The resistance of slide rheostat can be capable of continuous alteration; this is a good characteristic for slide rheostat. But we can not measure the definite number of the slide rheostat resistance. For resistance box, we can read the exact numerical value of its resistance. Nevertheless, its resistance is discontinuous.

Q3. How is the dipole moment formed?

Ans. A positive charge and a negative charge separated by a distance.

Q4. Is your body a conductor?

Ans. Yes it is. It isn't a very good one but the water and ions in your body allow currents to flow. If your body was a perfect insulator, nobody would ever get an electric shock.

Q5. Is electrostatic force a central force?

Ans. he electromagnetic force, as defined by Coulomb's Law, is one of 4 fundamental forces known to exist in our universe, the others being gravitational force, and the strong and weak nuclear forces. You might say, therefore, that it is a central force.

Q6. State Coulomb's law of electrostatics?
Ans. The force between two point charges is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance between them.

Q7. What is Van de Graff generator?
Ans. A particle accelerator that transfers a charge from an electron source to an insulated sphere by means of a moving belt composed of an insulating material.

Warranty

1) We warranty the product against all manufacturing defects for 12 months from the date of sale by us or through our dealers. Consumables like dry cell etc. are not covered under warranty.

2) The warranty will become void, if

   a) The product is not operated as per the instruction given in the learning material

   b) The agreed payment terms and other conditions of sale are not followed.

   c) The customer resells the instrument to another party.

   d) Any attempt is made to service and modify the instrument.

3) The non-working of the product is to be communicated to us immediately giving full details of the complaints and defects noticed specifically mentioning the type, serial number of the product and date of purchase etc.

4) The repair work will be carried out, provided the product is dispatched securely packed and insured. The transportation charges shall be borne by the customer.

Check List

Nvis Technologies Pvt. Ltd.

Model No.: Nvis 6002 **Serial No.:** ____________

List of Material	Testing Engineer	Qty.	Dispatch Department
Digital Electroscope		1 no	
Pith balls with string (Single)		1 no	
Pith balls with string (Pair)		1 no	
Pith ball pendulum stand		1 no	
Demonstration Tube (With styrene balls)		1 no	
Teflon rod		1 no	
Perspex rod		1 no	
Silk cloth		1 no	
Woolen cloth		1 no	
Cotton cloth		1 no	
Mains cord		1 no	
Product Tutorial (CD)		1 no	
	Testing Engineer		**Dispatch Member**

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