7.3.1 ELECTROSTATICS[M6,1]

Until we start to deal with atomic nuclei and sub-nuclear particles, all the phenomena we observe in nature are explicable in terms of only two kinds of force[2]: gravitational and electromagnetic.

The simplest manifestations of the electromagnetic force are familiar to most people. If you run a comb through your hair, it will attract tiny bits of paper and dust, not to mention leave your hair standing on end if it's very dry. A rubber balloon will stick to the wall if it is first rubbed on woollen clothing. Dust has an annoying tendency to stick to a newly polished table. In all of these cases we are dealing with forces between objects at rest. The electromagnetic forces between objects at rest are called *electric forces*, and the science that deals with them is called *electrostatics*.

7.3.1.1 Electric Charge[3]

Any objects that attract others in the way described above are said to possess an electric *charge*.

Electric charge is a characteristic of subatomic particles, and is quantised. When expressed as a multiple of the so-called elementary charge *e*, electrons have a charge of −1. Protons have the opposite charge of +1. Quarks have a fractional charge of −1/3 or +2/3. The antiparticle equivalents of these have the opposite charge. There are other charged particles.

The electric charge of a macroscopic object is the sum of the electric charges of its constituent particles. Often, the net electric charge is zero, since naturally the number of electrons in every atom is equal to the number of the protons, so their charges cancel out. Situations in which the net charge is non-zero are often referred to as static electricity. Furthermore, even when the net charge is zero, it can be distributed non-uniformly (*e.g.* due to an external electric field), and then the material is said to be polarised, and the charge related to the polarisation is known as bound charge (while the excess charge brought from outside is called free charge). An ordered motion of charged particles in a particular direction (typically these are the electrons) is known as electric current.

7.3.1.1.1 History

As reported by the Ancient Greek philosopher Thales of Miletus around 600 BC, charge (or electricity) could be accumulated by rubbing fur on various substances, such as amber. The Greeks noted that the charged amber buttons could attract light objects such as hair. They also noted that if they rubbed the amber for long enough, they could even get a spark to jump. This property derives from the triboelectric effect.

In 1600 the English scientist William Gilbert returned to the subject in De Magnete, and coined the modern Latin word electricus from (elektron), the Greek word for "amber", which soon gave rise to the English words electric and electricity. He was followed in 1660 by Otto von Guericke, who invented what was probably the first electrostatic generator. Other European pioneers were Robert Boyle, who in 1675 stated that electric attraction and repulsion can act across a vacuum; Stephen Gray, who in 1729 classified materials as conductors and insulators; and C. F. Du Fay, who proposed in 1733 that electricity came in two varieties which cancelled each other, and

1 http://www.slvhs.slv.k12.ca.us/~pboomer/physicstextbook/ch16.html
2 Together with the Strong and Weak Forces that exist between nuclear particles, these comprise the Four Fundamental Forces.
3 http://en.wikipedia.org/wiki/Electric_charge

expressed this in terms of a two-fluid theory. When glass was rubbed with silk, DuFay said that the glass was charged with vitreous electricity, and when amber was rubbed with fur, the amber was said to be charged with resinous electricity.

One of the foremost experts on electricity in the 18th century was Benjamin Franklin, who argued in favour of a one-fluid theory of electricity. Franklin imagined electricity as being a type of invisible fluid present in all matter; for example he believed that it was the glass in a Leyden jar that held the accumulated charge. He posited that rubbing insulating surfaces together caused this fluid to change location, and that a flow of this fluid constitutes an electric current. He also posited that when matter contained too little of the fluid it was "negatively" charged, and when it had an excess it was "positively" charged. Arbitrarily (or for a reason that was not recorded) he identified the term "positive" with vitreous electricity and "negative" with resinous electricity. William Watson arrived at the same explanation at about the same time.

We now know that the Franklin/Watson model was close, but too simple. Matter is actually composed of several kinds of electrically charged particles, the most common being the positively charged proton and the negatively charged electron. Rather than one possible electric current there are many: a flow of electrons, a flow of electron "holes" which act like positive particles, or in electrolytic solutions, a flow of both negative and positive particles called ions moving in opposite directions. To reduce this complexity, electrical workers still use Franklin's convention and they imagine that electric current (known as conventional current) is a flow of exclusively positive particles. The conventional current simplifies electrical concepts and calculations, but it ignores the fact that within some conductors (electrolytes, semiconductors, and plasma), two or more species of electric charges flow in opposite directions. The flow direction for conventional current is also backwards compared to the actual electron drift taking place during electric currents in metals, the typical conductor of electricity, which is a source of confusion for beginners in electronics.

7.3.1.1.2 Elementary Observations

Observe the results of Experiments 6.1[4]

We can see from our experiments that we can impart an electric charge on one object (*e.g.* an acrylic or an ebonite rod) by rubbing it against another (*e.g.* a piece of silk or woollen cloth). The object charged in this way exerts an attractive force on all kinds of uncharged materials. If held near a thin stream of water, flowing from a tap, the stream will even bend towards it.

Observe the results of Experiments 6.2

We can also see that, while there are many similarities, the charge acquired by an acrylic rod when rubbed with silk is different to that acquired by an ebonite rod when rubbed with wool. We notice that nylon behaves in a similar fashion to acrylic, and that polyethylene behaves in a similar fashion to ebonite. Styrene seems sometimes to behave like acrylic (when rubbed with silk) and sometimes like ebonite (when rubbed with wool).

As we have noted in our discussion of atomic theory, there are in fact two types of electric charge: positive (that which exists on a proton) and negative (that which exists on an electron). This characteristic of a charge is known as its **polarity**.

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[4] Electrostatic experiments are best performed in dry air. In moist air an invisible film of water condenses on the surfaces of objects, including those of charged insulators. Dissolved impurities in the film make these surfaces conductive, and an isolated charge cannot be maintained for any length of time.

7.3.1.1.3 The Law of Attraction and Repulsion of Electric Charges

This Law can be simply expressed as:

Like charges repel each other. Unlike charges attract each other.

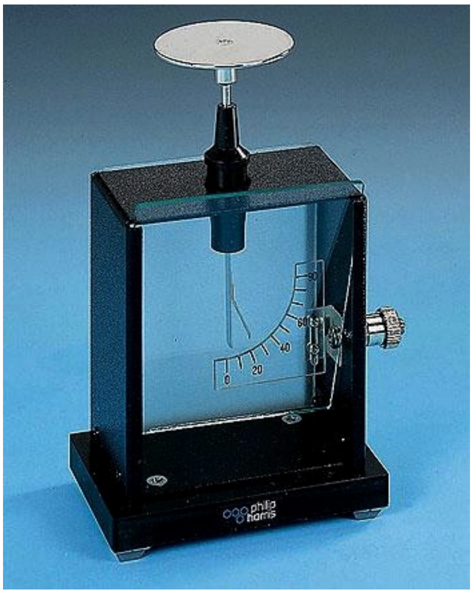
With direct reference to the polarity of charges, the Law is also expressed in the following way:

A positive charge attracts a negative charge but repels another positive charge;

A negative charge attracts a positive charge but repels another negative charge.

7.3.1.1.4 The Electroscope

The electroscope, invented by Jean Antoine Nollet (1700–1770) in 1748, is an instrument that is designed to indicate the presence of an electric charge. Although the principle of operation is the same, there are several different electroscope designs. The two most common today are the gold leaf and metal vane types illustrated below.



Gold Leaf Electroscope[5]

Metal Vane Electroscope[6]

The leaf electroscope consists of strips of gold leaf suspended from a metal stem, or a single gold leaf suspended against the metal stem, that is capped with a metal plate or knob. The leaves are enclosed in a metal case with glass windows for their protection, and the metal stem is insulated from the case. When electrified, the leaves diverge, or the single leaf is repelled from the stem, because of the force of repulsion which results from their having similar charge. Good sensitivity is realised because of the very low mass of the gold leaf.

The vane electroscope consists of a light aluminium rod mounted by means of a central bearing on a metal support that is insulated from its metal stand. When charged, the vane is deflected by electrostatic repulsion. The angle of deflection depends on the magnitude of the charge.

A typical school electroscope will show a deflection for a charge as small as 0.01 pC (the unit pC is a picocoulomb, 1×10^{-12} coulombs, equivalent to the charge on about 6 million electrons).

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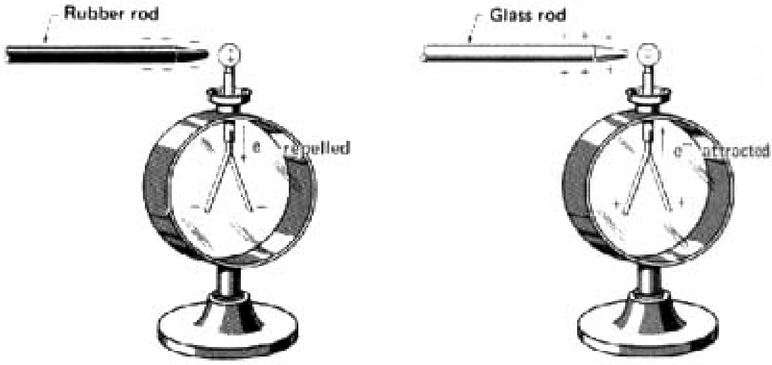
[5] http://www.practicalpgysics.org/go/Guidance_74.html?topic_id=40&guidance_id=1

[6] http://chem.ch.huji.ac.il/~eugeniik/instruments/archaic/electroscopes.html

Observe the results of Experiments 6.4



An electroscope may be charged temporarily by induction because of a redistribution of the free electrons of the metallic conductor.

7.3.1.1.5 Triboelectric Effects[7]

The triboelectric effect is a type of contact electrification in which certain materials acquire an electric charge after coming into contact with, and then separating from, another different material. Rubbing is not essential, but it helps as it enlarges the region of contact. The polarity and strength of the charges produced differ according to the materials, surface roughness, temperature, strain and other properties. It is therefore not very predictable, and only broad generalisations can be made. Amber (an orange-yellow fossil resin), for example, can acquire an electric charge by friction with a material like wool. This property, first recorded by Thales of Miletus (624–546 BC), suggested the word *electricity*, from the Greek word for amber, *elektron*.

The Triboelectric, or Electrostatic Series is a list of items sorted according to polarity of charge produced by rubbing. If any two of the substances in the Triboelectric Series are brought into contact, the substance higher in the list will lose electrons to become positively charged and the substance lower on the list will gain electrons and become negatively charged. Rubbing the materials together helps because most real surfaces are not smooth at the atomic level, and rubbing increases the area of contact. For example, if we rub glass (6) (2) with silk (14) (9), glass becomes positive and silk becomes negative. If we rub ebonite (25) (11) with wool (9) (4), ebonite becomes negative and wool becomes positive. If we rub perspex (23) styrene (8) with wool (9) (4), perspex styrene becomes negative and wool becomes positive. The further apart the materials, the greater the charge produced. The relative polarity depends on the specimen's molecular structure and the nature of the surface of that specimen.

The list below[8] is a composite list from several authorities with no two lists in complete agreement. If substances are touched instead of being vigorously rubbed, the sequence may change.

Positive polarity +, collects positive charges

Most positive

(1) Dry air
(2) Human skin
(3) Leather
(4) Asbestos
(5) Rabbit fur
(6) Glass rod (borosilicate glass)

[7] http://en.wikipedia.org/wiki/Triboelectric_effect
[8] http://www.uq.edu.au/_School_Science_Lessons/UNPh31.html#31.1.02

(7) Mica
(8) Human hair
(9) Wool knitted, flannel
(10) Nylon stocking
(11) Cat fur
(12) Polished glass, window glass
(13) Lead rod
(14) Silk cloth
(15) Aluminium foil, chocolate wrapping ("silver paper"), Zinc rod
(16) Paper (newspaper, filter paper, puffed rice, popcorn, pepper)
(17) Cellulose acetate, combs (acetyl cellulose, photographic film, overhead projector transparency)
(18) Cotton handkerchief, flannelette
(19) Steel (iron compounds)

Negative polarity, collects negative charges

(20) Dry wood, pith, cork (sunflower stem, artichoke stem, elder tree pith)
(21) Amber rod
(22) Perspex / Lucite, plastic ruler (Plexiglas, PMMA, polymethyl methacrylate thermoplastic, optical lenses, tubing)
(23) Paraffin wax, resin (sealing wax, esters, beeswax, shellac, turpentine)
(24) Ebonite rod, hard rubber (polymerised isoprene resin + sulfur, vulcanite, motor car tyres)
(25) Polycarbonate polymer, car battery casing (PC, Lexan, CR-39, spectacle lenses)
(26) Brass rod, copper. nickel, cobalt, silver (metals)
(27) Gold, platinum
(28) Sulfur
(29) Rayon (cellulose, artificial silk, tyre cord)
(30) Celluloid, ping-pong ball (nitrocellulose polymer, spectacle frame)
(31) Styrofoam, plastic Petri dish (Polystyrene, styrene resin)
(32) Saran wrap (vinylidene chloride and vinyl chloride chlorofibre)
(33) Orlon, polyesters (polyacrylonitrile polymer, acrylic resin, Acrilan, imitation fur, carpets)
(34) Polyurethane polymer, paints, rubber, foam plastics, tough linings, car body parts
(35) Polythene strip, plastic bag, cling film (Polyethylene, "Scotch Tape", "Glad Wrap", bin liners, wash bottles)
(36) Rubber, balloon (soft rubber, India rubber)
(37) Polypropylene rod, plastic bucket (tubing connectors, heavy duty bottles)
(38) PVC, gramophone record (polyvinyl chloride polymer, Vinyl, Vinylite, poly-chloroethane, tubing for burners, electrical cable)
(39) Silicon
(40) Teflon, non-stick surface of frying pans (polytetrafluoroethene polymer, PTFE, non-lubricated bearings)

Most Negative

Observe the results of Experiments 6.4a

We can derive the following sequence from the experiments we have conducted:

Most positive

(1) Acrylic (perspex) rod
(2) Glass rod
(3) Nylon rod
(4) Woollen cloth
(5) Rabbit Fur

(6) Flannel cloth
(7) Steel rod *(neutral)*
(8) Styrene rod
(9) Silk cloth
(10) Cotton cloth
(11) Ebonite rod
(12) Polyethylene rod

Most Negative

7.3.1.1.6 The Law of Conservation of Charge

Charge is another property of matter, like mass-energy and momentum, that is conserved within an isolated system, so we can state that:

> *The total electric charge of an isolated system remains constant regardless of changes within the system itself.*

Charge is not simply created. The triboelectric charging process that we have observed in our experiments, as with any charging process, involves a transfer of electrons between objects. The appearance of negative charge on an ebonite rod, for example, is merely the result of its acquisition of electrons, and these electrons must come from somewhere—in this case, from the woollen cloth with which it was rubbed.

7.3.1.1.7 Electrostatic Induction

Charges can be transferred between objects by two methods—**conduction** and **induction**.

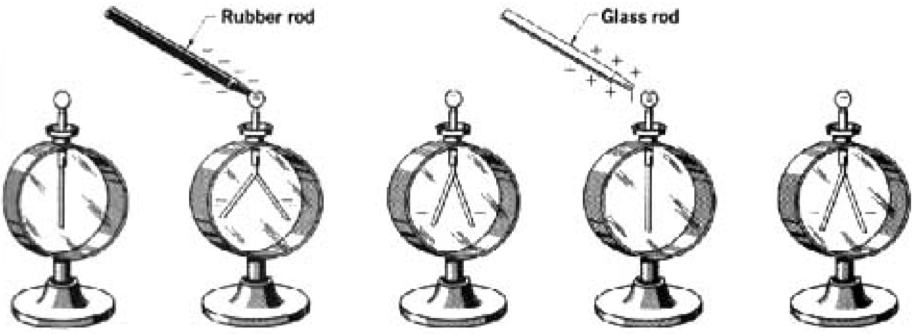
In all the experiments we have carried out so far, when charge has been transferred it has been by **conduction**—physically touching one object with another, so that charge flows between the two. If we touch the plate of an electroscope with a negatively charged ebonite rod, the leaves of the electroscope diverge. When the rod is removed, the leaves remain apart, indicating that the electroscope retains a charge. How can we determine the nature of this charge?

Observe the results of Experiments 6.4b

We can reason that some of the excess electrons on the rod have been repelled onto the plate of the electroscope. This would be true only for the region of the rod immediately in contact with the electroscope since ebonite is a very poor conductor and excess electrons do not migrate freely through it. Any free electrons thus transferred to the electroscope, together with other free electrons from the electroscope itself, would be repelled to the leaves by the excess electrons remaining on the parts of the rod not in contact with the electroscope.

When the rod is removed, and with it the force of repulsion, the electroscope is left with a residual *negative* charge of a somewhat lower density. This deduction can be verified by bringing a positively charged acrylic rod near the electroscope to draw the negative charge away from the leaves. The leaves collapse and diverge again when the acrylic rod is removed. In this way, an electroscope with a known residual charge can be used to identify the nature of the charge on another object. This second object merely needs to be brought near the plate of this charged electroscope.

When an isolated conductor is given a residual charge by **conduction**, *the charge has the same sign as that of the original charged object*.



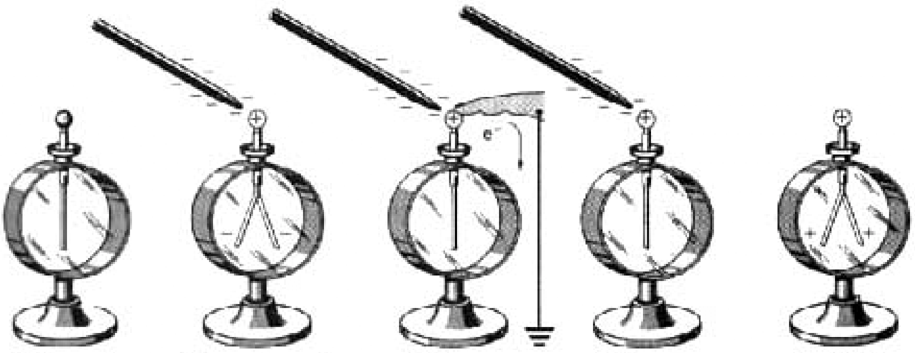
The residual charge on an electroscope, when charged by conduction, is of the same sign as the charge on the object that touches it.

When charging by **induction**, there is no physical contact between the two objects involved. If a charged ebonite rod is held near the plate of an electroscope, there is no transfer of electrons between the rod and the electroscope. If a path is provided for electrons to be repelled from the electroscope while the repelling force [of the ebonite rod] is present, however, free electrons escape. If the escape path is then removed, before removing the repelling force, the electroscope is left with a deficiency of electrons, giving it a residual *positive* charge.

We can verify this conclusion by bringing a positively charged acrylic rod near the plate of the charged electroscope. *The leaves of the electroscope diverge even more.* When the charged rod is withdrawn, the leaves fall back to their original divergence and remain apart.

Similarly, we can induce a residual negative charge an electroscope using a positively charged acrylic rod.

When an isolated conductor is given a residual charge by **induction**, *the charge is opposite in sign to that of the object inducing it.*



Steps in placing a residual charge on an electroscope by induction.

7.3.1.1.8 The Electrophorus

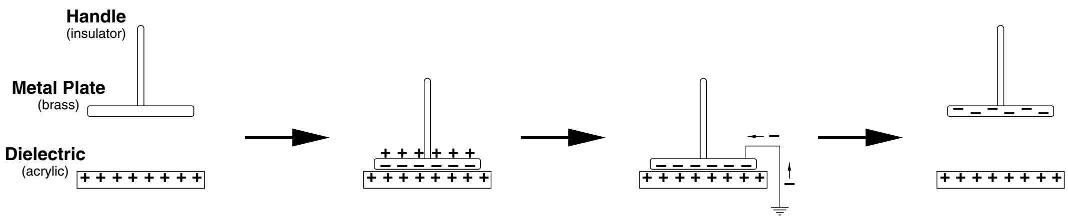
The electrophorus (named after the Greek word meaning *charge carrier*) has historically been used as a charge-dispensing device. It is simply a capacitor with separable plates. The electrophorus is charged not by an external voltage source, but rather the insulator separating the conductors is charged through triboelectrification.

The electrophorus was originally invented in 1762 by the Swedish physicist Johannes Wilcke. The device was modified and later improved by Allessandro Volta (1745–1827) in 1775. It was Volta who named the device an electrophorus, and it soon thereafter became known as the perpetual electrophorus. It was so-called because once the insulator was charged, the electrophorus could seemingly produce an endless quantity of electric charge.

It has been said that the electrophorus is the electrical analog to a permanent magnet in the way that it permanently keeps its charge. Interestingly, keeping the top plate on the electrophorus preserves its power in an analogous manner as a keeper (or iron rod) placed across the poles of a permanent magnet. All in all, the electrophorus is a magnificent device that played a significant role in the early development of electrostatic theory.

Demonstrate the 'operation' of an electrophorus.

Different dielectrics (electrical insulators, in our case types of plastic) can be used in an electrophorus to provide positive or negative charges. In our experiments, an acrylic plate is rubbed with silk to produce a positively charged dielectric. Since the plate of the electrophorus is charged by induction, it will acquire a negative charge.



Charging an Electrophorus

Note that while there is a small amount of charge transferred between the metal plate and the dielectric by contact (at the molecular level, the two surfaces are not actually very smooth), most of the charge is induced through the grounding process. The grounding process should only be brief, however, to limit any opportunity for charge to be transmitted between the metal plate and the dielectric.

When charged, an electrophorus displays the same characteristics as the charged rods we have used in previous experiments, although it tends to carry more charge. A spark is easily generated when a charged electrophorus is brought near any grounded object and is even capable of inducing a glow in a fluorescent tube.

7.3.1.1.9 The Natural Unit of Charge

The late nineteenth century saw a number of significant developments in atomic theory. In 1886, Eugen Goldstein (1850–1930) discovered that atoms had positive charges, while in 1897 J.J. Thompson (1856–1940) discovered the electron.

An experiment performed by Robert Millikan (1856–1953) in 1909[9] demonstrated the discrete nature of electric charge, and, together with the observations previously made by Thompson, that electrons were the carriers of these units of charge.

As we have already noted, there are two kinds of electric charge—positive and negative—and electric charges in an atom are balanced, with the positive charge of the protons in the nucleus offset by the negative charge of the orbiting electrons. The fundamental unit of charge is that which exists on a proton or an electron. Since,

[9] http://www68.pair.com/willisb/millikan/experiment.html
http://chem.ch.huji.ac.il/~eugeniik/history/millikan.html

however, atomic nuclei [in solids], and hence protons, are generally static, and it is electrons which are mobile, we normally talk about electric charge in terms of an excess or deficiency of electrons. Thus, an object acquires a negative electric charge when it gains electrons, and it acquires a positive electric charge when it loses electrons.

The SI unit of electric charge is the **coulomb** (C), named after the French physicist Charles Augustin de Coulomb (1736–1806), which represents approximately 6.24×10^{18} elementary charges (the charge on a single electron or proton[10]). The coulomb is defined as *the quantity of charge that has passed through the cross-section of a conductor carrying one ampere within one second*. The symbol **Q** is used to denote a quantity of electric charge.

7.3.1.2 Coulomb's Law

The first quantitative measurements of electrostatic forces were made by Charles Augustin de Coulomb in 1785. His many experiments with charged bodies led him to conclude that the forces of electrostatic attraction and repulsion obey a law similar to Newton's law of universal gravitation. Coulomb's Law can be stated as:

> *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.*

and expressed mathematically as the equation:

$$\mathbf{F} = \mathbf{k}\frac{\mathbf{Q_1Q_2}}{\mathbf{d^2}}$$

where:

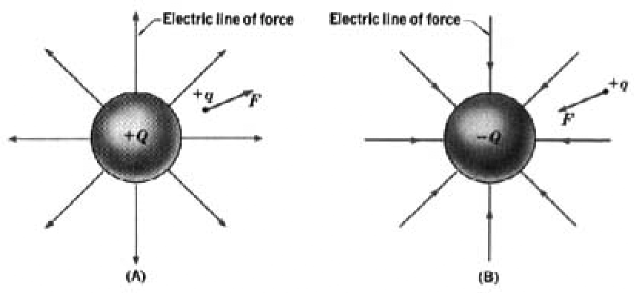
F	is the electrostatic force (in *newtons*)
$\mathbf{Q_1}$ & $\mathbf{Q_2}$	are respective magnitudes of the two point charges (in *coulombs*)
d	is the distance between the charges (in *metres*)
k	is the electric constant of free space (8.987×10^9 N m^2/C^2)

7.3.1.3 Electric Fields

The concept of a field of force will be helpful as we consider the region surrounding an electrically charged body. A second charge brought into this region experiences a force according to Coulomb's law. Such a region is an electric field. An electric field is said to exist in a region of space if an electric charge placed in that region is subject to an electric force.

Let us consider a positively charged sphere $+Q$ isolated in space. A small positive charge $+q$, which we shall call a test charge, is brought near the surface of the sphere as shown in Illustration (A).

[10] The elementary charge, ~1.6×10^{-19} coulomb, is the electric charge carried by a single proton, or the negative of that carried by a single electron.



The electric field surrounding a charged sphere isolated in space.

Since the test charge is in the electric field of the charged sphere and the charges are similar, it experiences a repulsive force directed radially away from +*Q*. Were the charge on the sphere negative, as in Illustration (B), the force acting on the test charge would be directed radially in toward -*Q*.

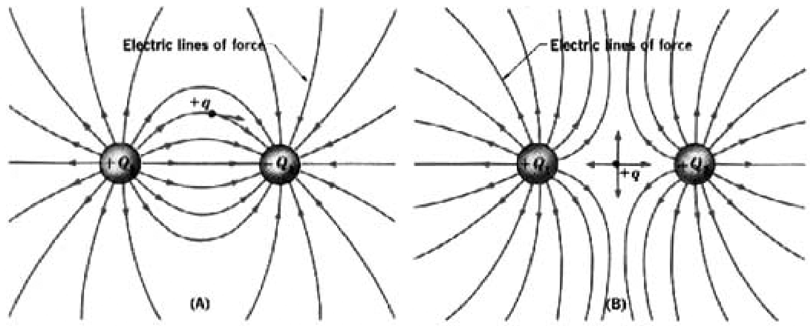
An electric line of force is a line so drawn that a tangent to it at any point indicates the orientation of the electric field at that point. We can imagine a line of force as the path of a test charge moving slowly in a very viscous medium in response to the force of the field. By convention, electric lines of force originate at the surface of a positively charged body and terminate at the surface of a negatively charged body, each line of force showing the direction in which a positive test charge would be accelerated in that part of the field.

A line of force is normal to the surface of the charged body where it joins that surface.

The intensity, or strength, of an electrostatic field, as well as its direction, can be represented graphically by lines of force.

The electric field intensity is proportional to the number of lines of force per unit area normal to the field. Where the intensity is high, the lines of force will be close together. Where the intensity is low, the lines of force will be more widely separated in the graphical representation of the field.

In Illustration(A) below, electric lines of force are used to show the electric field near two equally but oppositely charged objects. At any point in this field the resultant force acting on a test charge +*q* can be represented by a vector drawn tangent to the line of force at that point. The electric field near two objects of equal charge of the same sign is shown by the lines of force in Illustration (B). The resultant force acting on a test charge +*q* placed at the midpoint between these two similar charges would be zero.



Lines of force show the nature of the electric field near two equal charges of opposite sign (A), and near two equal charges of the same sign (B).

7.3.1.4 Electric Potential

Let us consider the work done by gravity on a wagon coasting down a hill. The wagon is within the gravitational field of the earth and experiences a gravitational force causing it to travel downhill. Work is done by the gravitational field, so the energy expended comes from within the gravitational system.

The wagon has less potential energy at the bottom of the hill than it had at the top—in order to return the wagon to the top, work must be done on it. In this instance, however, the energy must be supplied from an outside source to pull against the gravitational force. The energy expended is stored in the system, imparting to the wagon more potential energy at the top of the hill than it had at the bottom.

Similarly, a charge in an electric field experiences an electric force according to Coulomb's Law. If the charge moves in response to this force, work is done by the electric field. If the charge is moved against the coulomb force of the electric field, work is done on it using energy from some outside source, this energy being stored in the system.

If work is done as a charge moves from one point to another in an electric field or if work is required to move a charge from one point to another, these two points are said to differ in electric potential. The magnitude of the work is a measure of this difference in potential. Thus, the **potential difference**, **V**, between two points in an electric field is the work done per unit charge as a charge is moved between these points. Mathematically, potential difference is defined by the equation:

$$\mathbf{V} = \frac{\Delta \mathbf{E}_{elec}}{\mathbf{q}}$$

The SI unit for potential difference is the **volt** (V), after the Italian physicist Alessandro Volta[11] (1745–1827). A potential difference of one volt exists between two points when one joule of energy is required to move a charge of one coulomb between the two points.

7.3.1.5 Conductors and Insulators

A conductor is a material through which an electric charge is readily transferred. Most metals are good conductors. At normal temperatures, silver is the best solid conductor; copper and aluminium follow in that order. In general, metals and a few non-metallic solids, such as graphite, are good electrical conductors.

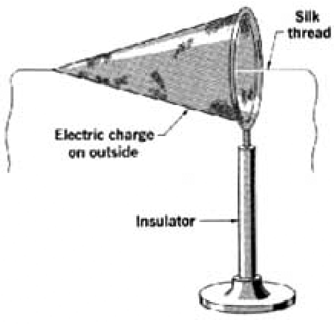
An insulator is a material through which an electric charge is not readily transferred. Good insulators are such poor conductors that for practical purposes they are considered to be non-conductors. Plastics and most other non-metallic solids are electrical insulators or non-conductors.

Thus, electrons travel readily through conductors but not so through insulators.

Observe the results of Experiments 6.7

[11] Known for his contribution, the voltaic pile (1800), to the development of the electric battery

7.3.1.6 Distribution of Charge



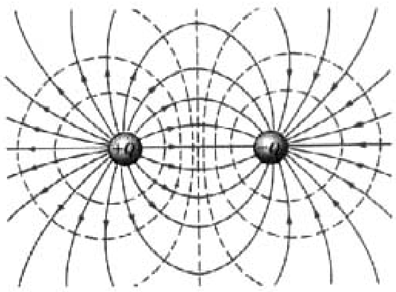
The type of conical silk bag used by Faraday to demonstrate that electric charges reside on the outside.

The British 'natural philosopher' Michael Faraday (1791–1867) performed several experiments to demonstrate the distribution of charge on an isolated object. In one such experiment, he charged a conical silk bag, like that shown in the illustration, and found that the charge was on the outside of the bag.

By pulling on the silk thread, he turned the bag inside out and found the charge was again on the outside. The inside of the bag showed no electric charge in either position.

From this and other experiments with isolated conductors we can easily develop a set of rules that will allow us to determine how charges will distribute themselves on a conductor, and what the nature of the field will b that is produced by these charges. The only assumption we need is that charges are free to move, so that when they stop moving all charges will be in equilibrium.

Rule 1 *All the charge on a conductor lies on its surface.* If there were any charge inside the conductor, it would create a field inside that would act on whatever charges are there and set them in motion. The charges cannot leave the surface (assuming the concentration of charge is not sufficient to produce a spark), so they move away from each other until they accumulate on the surface;

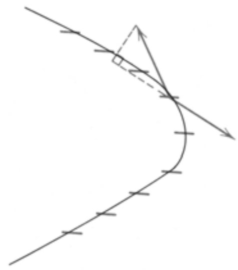


Lines of force (solid lines) and equipotential lines (dashed lines) define the electric field near two equal but opposite charges.

Rule 2 *Field lines leave a positive charge and enter a negative one.* This is merely a way of saying that the positive test charge used to examine the field is repelled from positive charges and attracted to negative ones;

Rule 3 *Field lines never cross each other.* Consider what it would mean if they did. A test charge placed at the point of intersection could be pushed in either of two directions. Since the force has a unique direction at any point, the field lines cannot cross;

Rule 4 *At the surface of a conductor through which no charge is moving, the field lines must be perpendicular to the surface.* If a field line were not perpendicular to the surface, the field vector at that point would have a component parallel to the surface. Then the free charges in the conductor would experience a force parallel to the surface. Since they are free to move in a conductor, readjusting the distribution of free charge until there were no longer any field lines forming acute angles with the surface. In insulators, where charges are not free to move, tis rule does not hold. Also, field lines may form some other angle to the surface of a conductor in which charges are in motion'



Forces on a charge on a curved surface.

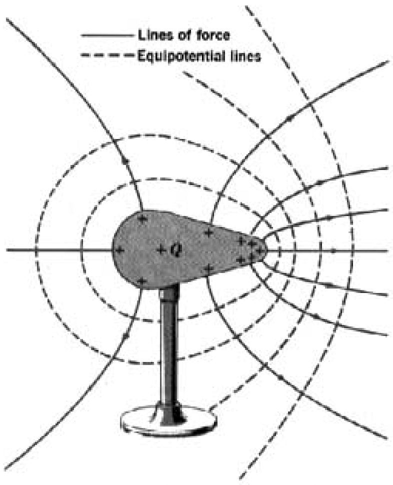
Rule 5 *The charges are most concentrated where the surface of a conductor is most sharply curved.* The reason for this can be seen with reference to the illustration. Let us assume that the charge is uniformly distributed on the surface, and consider the forces on a charge near the tip. The arrow pointing to the right represents the repulsive force due to the charges on the left of the test charge. Because of the curvature of the surface, the force of repulsion due to the charges at the point, although equal to the force in the other direction, is *not parallel to the surface*—it has a component pushing the test charge off the surface to the left. This means that the only component that the only component that can produce motion, the component of the force parallel to the surface, is *smaller* in the direction away from the point that toward the point. Therefore, the test charge must move toward the point. Only when there is a greater concentration of charge at the point than elsewhere will the test charge come into equilibrium.

Rule 6 *There is no field inside a conductor.*

7.3.1.6.1 Effect of the Shape of a Conductor

A charged spherical conductor perfectly isolated in space has a uniform charge density, or charge per unit area, over the outer surface. Lines of force extend radially from the surface in all directions and the equipotential surfaces of the electric field are spherical and concentric. Such symmetry is not found in all cases of charged conductors. A charge acquired by a non-conductor such as glass is confined to its original region until it gradually leaks away. The charge placed on an isolated metal sphere quickly spreads uniformly over the entire surface. If the conductor is not spherical, the charge distributes itself according to the surface curvature, concentrating around points.

The pear-shaped conductor illustrated shows the charge more concentrated on curved regions and less concentrated on the straight regions. If the small end is made more pointed, the density will increase at that end.



The charge density is greatest at the point of greatest curvature.

7.3.1.6.2 Discharging Effect of Points

In the adjacent illustration, lines of force and equipotential lines are shown more concentrated at the small end of the charged conductor. Geometry indicates that the intensity of the electric or potential gradient in this region is greater than elsewhere around the conductor.

If this surface is reshaped so that it has a sharply pointed end, the field intensity can become great enough to cause the gas molecules in the air surrounding the pointed end to ionize. Ionized air consists of gas molecules from which an outer electron has been removed thus allowing both the positively charged ion and the freed electron to respond to the electric force.

When the air is ionized, the point of the conductor is rapidly discharged. There are always a few positive ions and free electrons present in the air. The intense electric field near a sharp point of a charged conductor will set these charged particles in motion such that the electrons are driven in one direction and the positive ions in the opposite direction. Violent collisions with other gas molecules will knock out some electrons and produce more charged particles. In this way air can be ionized quickly when it is subjected to a sufficiently large electric stress.

In dry air at atmospheric pressure, a potential gradient of 30 kV/cm between two charged surfaces is required to ionize the intervening column of air. When such an air gap is ionized, a spark discharge occurs. There is a rush of free electrons and ionized molecules across the ionized gap, discharging the surfaces and producing heat, light, and sound.

Usually the quantity of static electricity involved is quite small and the time duration of the spark discharge is very short. Atmospheric lightning, however, is a spark discharge in which the quantity of charge is great. The intensity of an electric field near a charged object can be sufficient to produce ionization at sharp projections or sharp corners of the object. A slow leakage of charge can occur at these locations producing a brush or corona discharge. A faint violet glow is sometimes emitted by the ionized gases of the air. A glow discharge known as St. Elmo's fire can sometimes be observed at night at the tips of ship masts and at the trailing edges of wing and tail surfaces of aircraft. The escape of charges from sharply pointed conductors is important in the operation of electrostatic generators and in the design of lightning arresters.

7.3.1.7 Static Electricity[12]

The adjective *static* in this case is a bit of a misnomer[13]. Static electricity is not so much about stationery charges, but about charge imbalance, whether the charge is moving or not. It is the separation between positive and negative charges which is the basis for *static electricity*, and this separation can exist even when charges are flowing.

Normally, as we have seen in our discussion on the structure of matter, the positive and negative charges in matter balance out. Static electricity, however, refers to a class of phenomena involving objects with a net charge, or perhaps more specifically, phenomena resulting from charge separation. These phenomena also invariably involve high voltages—all of the familiar electrostatic phenomena that we encounter in everyday situations involve voltages above 1,000 volts, and ranging up to 50,000 volts. This, however, is voltage without current.

Static electricity can be a serious nuisance in the processing of analog recording media, because it can attract dust to sensitive materials. In the case of photography, dust accumulating on lenses and photographic plates degrades the resulting picture. Dust also permanently damages vinyl records because it can be embedded into the grooves as the stylus passes over. In both cases, several approaches exist to combat such dust deposition. Some brushes, particularly those with carbon fibre bristles, are advertised as possessing anti-static properties. Also available are handheld static guns which shoot streams of ions to discharge static on records and lenses.

7.3.1.7.1 Examples and Applications of Static Electricity[14]

The triboelectric effects that we have been studying in our experiments so far, and many others like them are examples of *static electricity*. Static electricity is also an important element in unexpected situations, like the biological process of pollination by bees, since the charge on a bee's body helps to attract and hold pollen. Some of the many other practical applications of static electricity include:

Gladwrap

Unrolling a piece of Gladwrap or similar plastic wrap creates negative charges on the sheet. It then tends to stick to neutral items.

Xerography

Photocopiers use static electricity to copy print to a page, via the process of xerography. Different machines use different variations of the process. In one case, the ink may be electrically charged so that it sticks to the paper in the designated areas. Another version uses a laser-generated charge on a drum to attract toner, which is then transferred to the paper.

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12 http://en.wikipedia.org/wiki/Electrostatics
13 http://www.amasci.com/emotor/stmiscon.html
14 http://www.chemclass.ca/science9/science9_unit2.html

Smoke Stack Pollution Control

Factories use static electricity to reduce pollution coming from their smokestacks. They give the smoke an electric charge. When it passes by an electrode of the opposite charge, most of the smoke particles cling to the electrode. This keeps the pollution from going out into the atmosphere.

Air Fresheners

Some people purchase what are called air ionizers to freshen and purify the air in their homes. They work on a similar principle to smokestack pollution control. These devices strip electrons from smoke and dust particles, and pollen in the air. These particles are then attracted and stick to a plate, with the opposite charge, on the device. Since charged particles will also stick to neutral surfaces, some of them often stick to the wall near the ionizer, making it dirty and difficult to clean.

Lightning Rods on Buildings

Lightning tends to strike the highest object in its vicinity. This will usually be the top of the nearest, tall tree or building. As a result, it is common practice to attach a metal rod, electrically connected to the ground, to the top of tall buildings (*e.g.* church steeples). In case of a lightning strike, the electric charge is carried quickly through the conductor to the ground, where it is dissipated without any damage to the building.

Petrol Station Safety

When petrol is transferred from a tanker into the underground tank at a petrol station, there is a lot of friction caused by the petrol flow. In order to avoid any build up of charge, and possible spark generation, the tanker uses a grounding device on the hose to draw any charge away from the petrol.

It is also generally recommended to place any container being filled with petrol on the ground, so that it remains earthed.

Grounding when Repairing Electronic Devices

An electrostatic spark can damage unprotected components in electronic devices. Technicians repairing computers use a special pad and a grounded strap on their wrist to avoid the build-up of electrostatic charge.