Hwa Chong Institution (High School) Name : _________________________ ( )
PHYSICS Notes Class : __________
Electrostatics Date : __________

Note: You should read your textbook and compare with these notes.

A. Introduction

Some objects (e.g. glass rod or ebonite rod) acquire a new property of being able to attract small pieces of paper after they have been rubbed with another material (e.g. silk or fur, respectively). This phenomenon belongs to the branch of physics called *electrostatics* or *static electricity*. It involves the study of static electric charges. Before rubbing, these objects do not attract small pieces of paper. This implies that friction due to rubbing has changed the nature of the surfaces of the rods. We say that friction has caused the rods to be 'electrified' or 'charged'.

B. Two types of charges

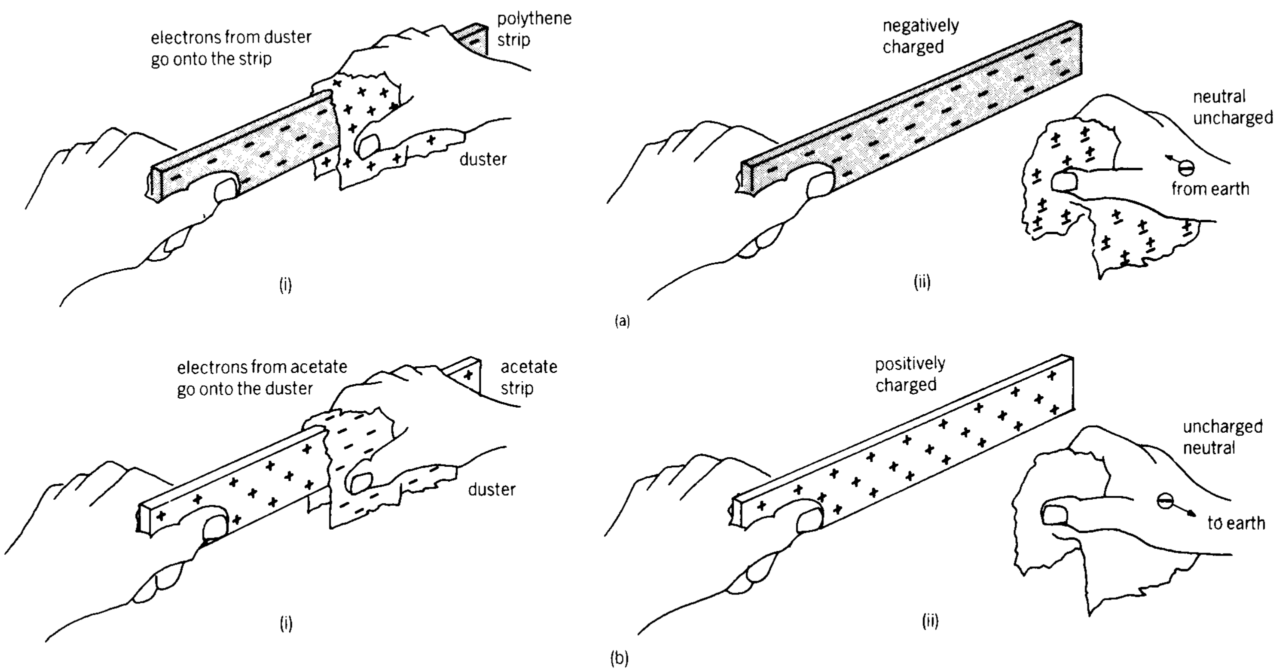
Only two kinds of charges exist: positive charge and negative charge. (note: in every case, equal amount of opposite charges are formed)

C. Separation of charges

a) By Friction

1. Rub polythene strip with a duster as shown in Fig (a). Test the polythene strip and the duster with an electroscope. It can be found that the polythene strip has become negatively charged while the duster is uncharged or neutral.

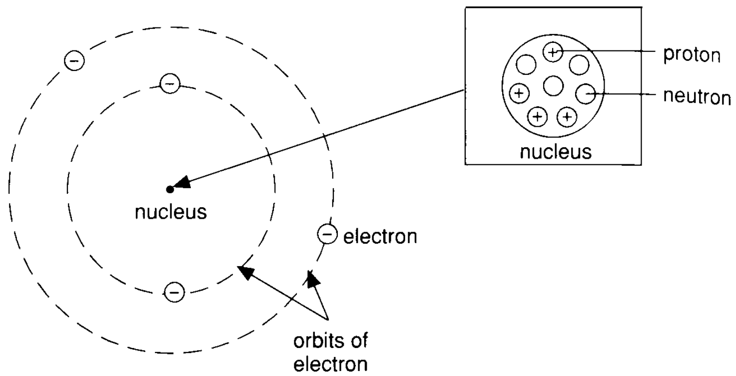
Similarly, rub the acetate strip with a duster, as in Fig (b). The acetate strip can be found to be positively charged, while the duster again is uncharged.



Charging by friction: (a) negative and (b) positive charge

2. How does friction give rise to separation of charges?

- Matter is made up of indivisible particles called atoms. Each atom has negatively charged electrons orbiting round a small massive nucleus which consists of positively charged particles called protons and neutral particles called neutrons, as shown in the diagram.
- The normal state of an atom is one that has equal numbers of electrons and protons, i.e. it is electrically balanced or uncharged.
- The electrified state is a state in which the electrical balance is upset. This occurs when some electrons are removed (i.e. positively-charged state) from the orbit, or are added to the orbit (i.e. negatively charged state). The atom is said to have ionised.



A neutral beryllium atom with 4 electrons, 4 protons and 4 neutrons

- Why is the electrical balance upset? Because the process of rubbing causes energy to be transferred to the outermost electrons to be dissociated from their orbits.
- In charging by friction (such as rubbing an acetate strip with a duster), some electrons from the surface atoms of one object (the acetate strip) are transferred to another object (the duster). This makes the acetate strip positively charged as it is now short of electrons. The duster becomes negatively charged as it gains excess electrons.
- Why then is the duster neutral in both cases? In Fig (a), electrons are removed from the duster and go onto the polythene strip where they remain because the polythene is a very good insulator. The duster, which has lost negative charge, acquires a positive charge. However, the duster is not a good insulator and electrons from earth quickly pass through the hand that holds it and neutralises the positive charge. Thus when the duster is tested for charge, it is found to be uncharged or neutral. Can you explain the case for Fig (b)?
- Note that only electrons are transferred from one object to another. Protons or positive charges do not move from one place to another. Also, charge is never made or destroyed in the friction process. It is transferred from one material to another (i.e. it is re-distributed).

3. Forces between electrically charged bodies

Suspend a positively charged acetate strip on a nylon thread as shown in Fig A (next page). Then bring a negatively charged polythene strip close to it. The acetate strip is seen to swing towards the polythene strip.

Now bring a positively charged acetate strip towards the suspended positive strip as in Fig B. The suspended positive strip is seen to move away.

The conclusions which can be drawn from these tests are:
LIKE CHARGES REPEL; UNLIKE CHARGES ATTRACT.

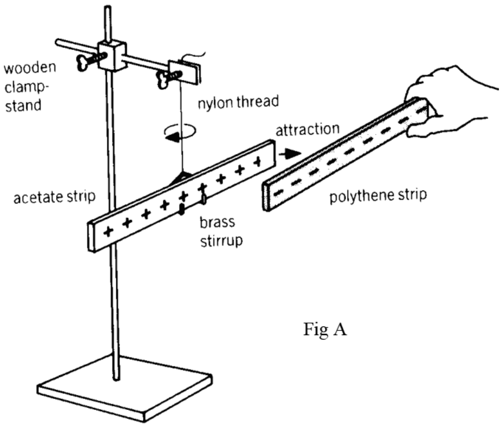


Fig A

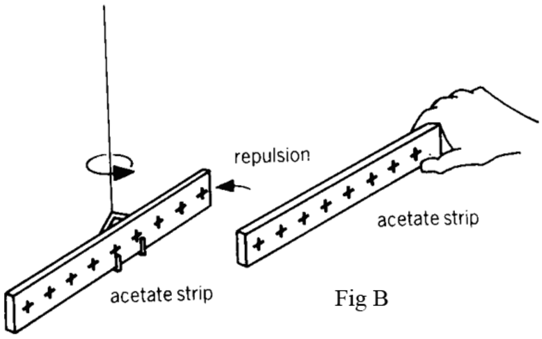


Fig B

4. Differences between insulators and conductors

For one category of materials (e.g. glass, ebonite, polythene, cellulose acetate), the electrons (negative charges) are transferred from one material to another and remain on the surface. They do not move about within the material but are confined at the region of rubbing. We call such materials electrical insulators because they do not have free electrons.

On the other hand, materials such as metals allow electrons to flow through them. For this category of materials, they are not easily electrified by rubbing with silk, fur or duster unless they are well insulated first. We call such materials electrical conductors because they have free electrons.

5. Neutralizing charged insulators and conductors

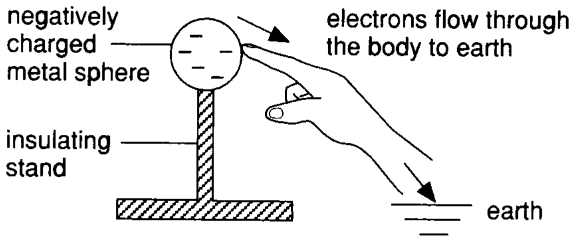
To neutralize a charged body is to remove the excess charges from it. This process is also known as discharging.

Charged insulators:

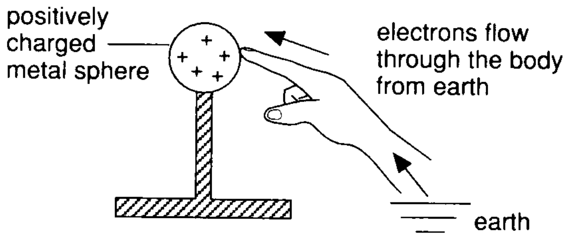
– One way to discharge the positively-charged acetate strip is to bring it over a bunsen flame. The intense heat causes the surrounding air of the strip to be ionised into positive and negative ions. These negative ions will neutralise the excess positive charges on the acetate strip.
– All charged insulators also discharge slowly when left in moist condition. The water vapour in the air causes the excess charges on the insulator to leak away slowly.

Charged conductors:

- For a charged conductor such as a metal sphere with excess electrons, the electrons can be removed by <u>earthing</u> it. To earth a charged conductor is to provide a path for the electrons to flow away or towards the charged conductor and cause it to become electrically neutral. The term "earth" refers to any large conductor from which electrons may be taken or to which electrons may be given without it become noticeably charged itself. The first figure on the right shows the neutralizing of a negatively charged metal sphere by means of earthing.
- For a positively charged metal sphere, earthing it will cause the electrons from the earth to flow towards the positively charged sphere and neutralize it, as shown in the next figure.
- In both figures, the purpose of the insulating stand is to prevent any electron flow between the charged metal sphere and the earth. The human body is a relatively good conductor and therefore acts as a conducting path for the electrons.



Earthing a negatively charged metal sphere



Earthing a positively charged metal sphere

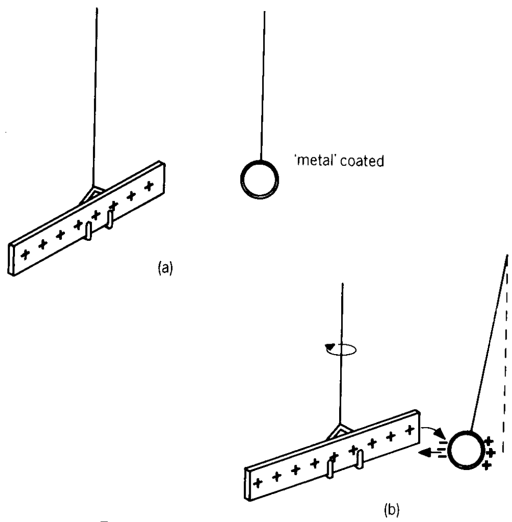
b) By Electrostatic Induction

1. A simple experiment

The figure shows a light polystyrene sphere which has been coated with a metal (conducting) paint suspended near a positively charged strip. The metal sphere is seen to move towards the positive strip. This phenomena occurs because of <u>electrostatic induction</u>.

2. Why do charges separate due to induction?

The metal 'coated' sphere is standing in the electric field set up by the charge on the acetate strip. This field causes the separation of equal amounts of charge on the sphere by induction (influence). Negative charges from within the neutral metal move towards the end nearer the positive strip leaving positive charges at the side of the sphere furthest from the strip.



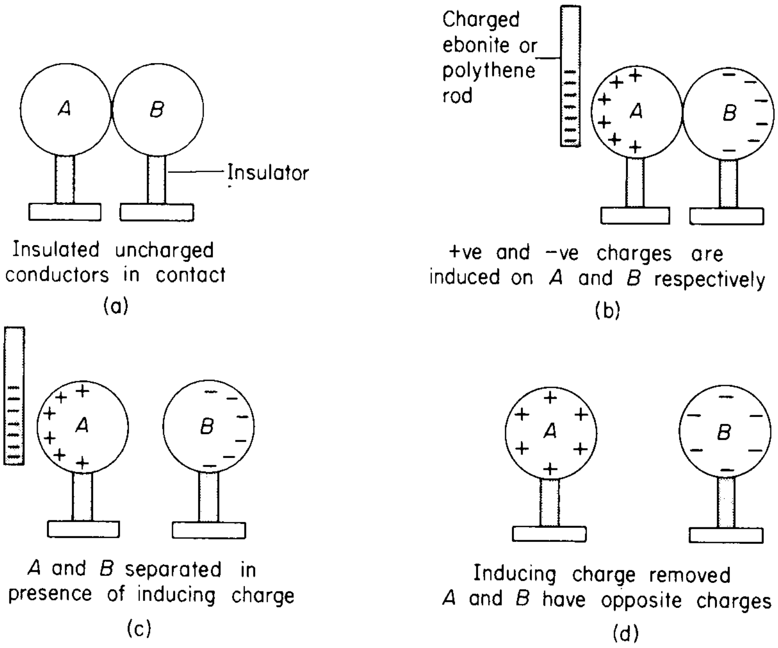
Electrostatic induction

3. Some examples of separation of charges by induction

(i) To charge two conductors with equal and opposite charges

Step 1: The two conductors (metallic spheres) on insulator stands are brought into contact with one another.

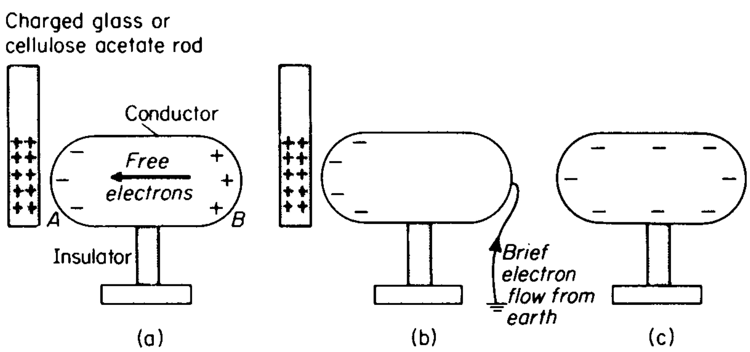
Step 2: A negatively charged rod is brought near to sphere **A**. This causes the electrons from **A** to be repelled to the remote side of **B**. Under this condition, sphere **A** alone will have excess positive charge (due to electron loss) while **B** alone has excess negative charge (due to gain of electrons).



Step 3: With the negatively charged rod in place, the two spheres **A** and **B** are separated using the insulating stands.

Step 4: Remove the rod. The sphere **A** will now have induced positive charges while **B** will carry an equal number of induced negative charges. The charge on the charging rod remains unchanged. The charges on each sphere will distribute themselves equally on the outside of the conductor. This is because the charges exert forces of repulsion on one another and the charges try to move as far apart as they can. The greatest separation they can achieve is when they are on the outside of the sphere.

(ii) To charge a single conductor by induction



Charging negatively by induction

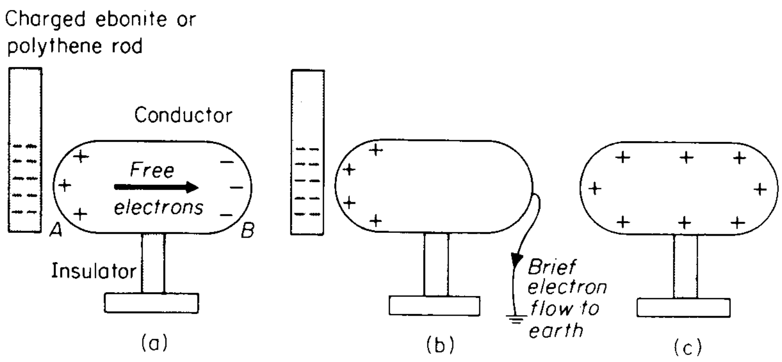
Step 1: Bring a positively-charged rod to the vicinity of the conductor held by an insulating stand.

Step 2: The free electrons in the conductor will be drawn towards the end of the conductor nearer to the positively charged rod, leaving the other remote end to have excess positive charge. Note that the conductor is still electrically neutral despite the redistribution of the free electrons on it.

Step 3: With the positively charged rod still in place, the conductor to be charged is earthed. This an be done by touching the conductor with our body momentarily. Being a relatively good conductor, our body will allow electrons to flow to the conductor to neutralise the excess positive charge on the far side of the conductor. Note that now the conductor will carry an excess negative charge.

Step 4: On removing the charging rod, the excess negative charge (electrons) will redistribute on the surface of the conductor to attain electrostatic equilibrium.

Note also that charging a single conductor by induction will always result in a charge that has the opposite sign to that of the charging rod. The following figure shows how the same conductor can be charged positively.



Charging positively by induction

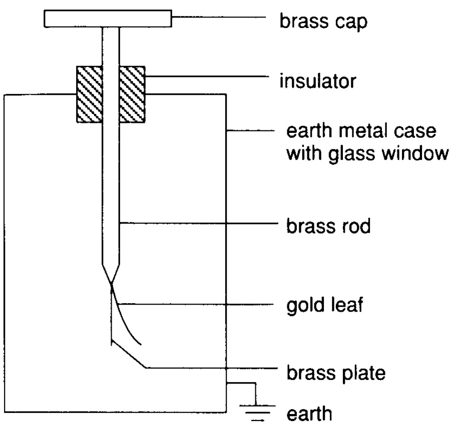
D. The Gold-Leaf Electroscope

1. Features

The figure shows the structure of a typical electroscope used for the detection of charges and to test for the sign of the charge.

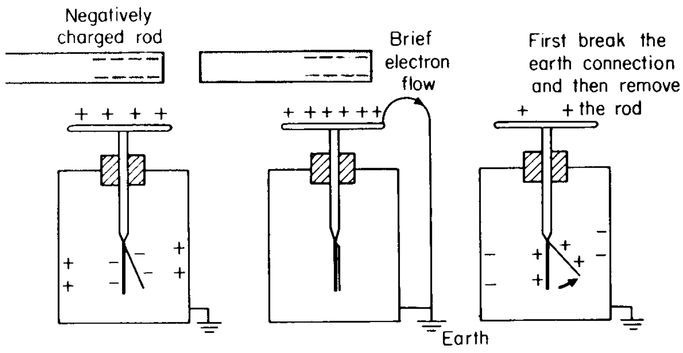
2. Testing for the sign of charge

To test for the sign of a charge on a charged body, we need to charge the electroscope first. The electroscope can be charged easily by induction. The following figures show the sequence of charging the electroscope by induction.

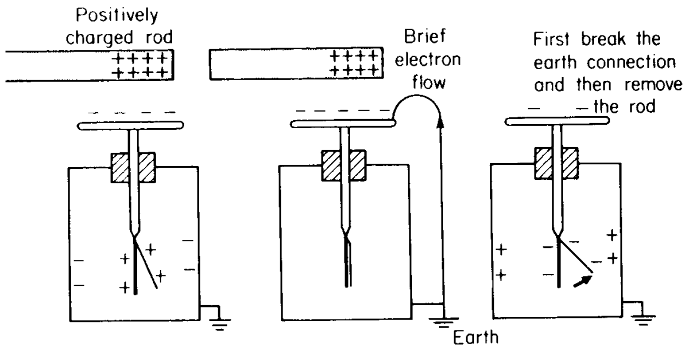


Structure of an electroscope

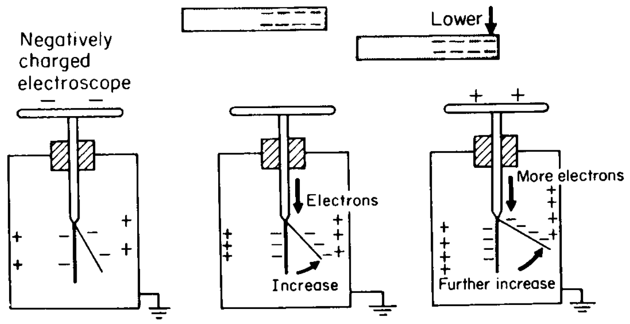
Try and explain how the charging works.



Charging a gold-leaf electroscope positively by induction



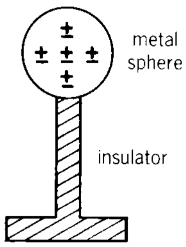
Charging a gold-leaf electroscope negatively by induction



Testing the sign of a charge

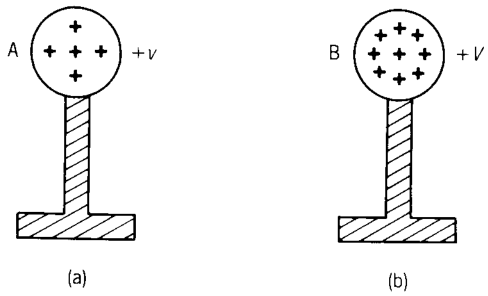
E. Electric Potential

An electric charge exerts a force on other electric charges. **The region in which force is exerted is called an <u>electric field</u>**, and it extends an infinite distance away. An uncharged metal sphere (in the figure) on an insulating stand has no external electric effect. It does contain many electric charges but, since these are present in equal and opposite amounts, the overall effect is electric neutrality.



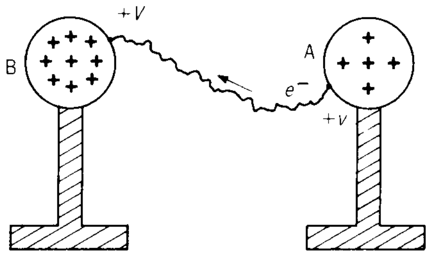
Equal and opposite charges produce no external electrical effect

If a metal sphere **A** [as shown in Fig (a)] acquires a small positive charge (by the removal of negative charges from the sphere), the charge acquired can exert a force of attraction on negative charges and a force of repulsion on positive charges. The acquisition of the positive charge is said to raise the electric potential of the sphere so that it is greater than that of the Earth (taken as zero potential). A small positive charge raises the sphere to a 'small' positive potential **+v**. If an identical sphere **B** [as shown in Fig (b)] were to acquire more positive charge it would be raised to an even higher positive potential **+V**. Hence sphere **B** is at a higher positive potential than sphere **A**.



A sphere at (a) a small positive potential and (b) a higher potential

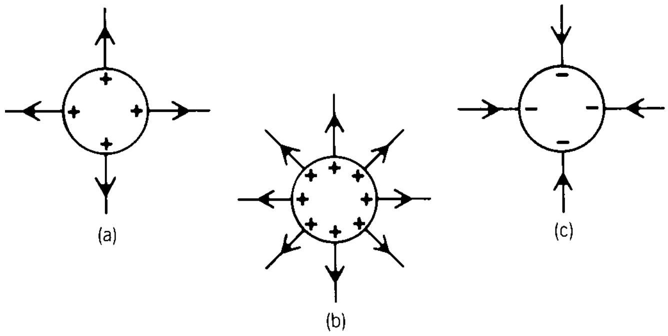
If the spheres **B** and **A** are connected by an insulated wire as shown in the figure, charge will flow because of the potential difference (**V - v**) between the two spheres. Positive charge, if it were free to move, would flow from high positive potential **+V** to lower positive potential **+v**. Negative charges (electrons) flow from **A** to **B,** i.e. towards the higher positive potential, until the potentials of **A** and **B** become equal. The removal of negative charge from **A** will result in an effective gain of positive charge, hence the potential of **A** becomes greater than **+v**. The gain of negative charge by sphere **B** results in an effective loss (neutralization) of some positive charge, hence the potential of **B** is lowered to less than **+V**. Electrons stop flowing when the potential of **B** equals the potential of **A**, i.e. when the potential difference is zero.



Charge flows when a wire joins two spheres at different potentials

F. Electric Field

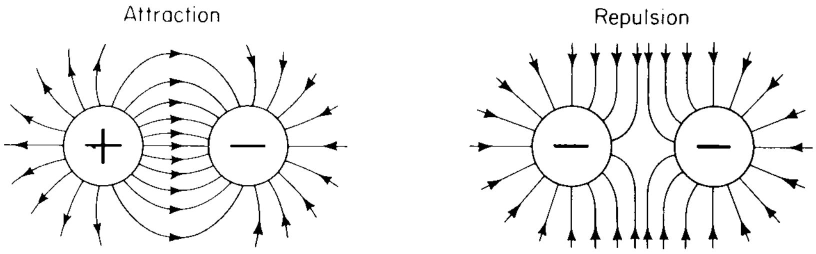
An electric field can be illustrated by drawing lines of electric force. These lines represent the direction of acceleration of a small 'free' positive charge placed in the field. The density of the lines is used to indicate the strength of the field. Thus the lines of electric force are directed away from the positively charged spheres but towards the negatively charged spheres, as shown in the figure. The closer the field lines, the stronger is the electric field in that region. It can be observed that the field lines are closer together when they are near the



charges. This means that the strength of the field is stronger nearer the charge, and decreases further away from the charge.

The figure illustrates a uniform electric field between two parallel oppositely charged plates. The electric lines of force at the central region are parallel to each other and equally spaced. The greater number of lines indicates a stronger uniform electric field.

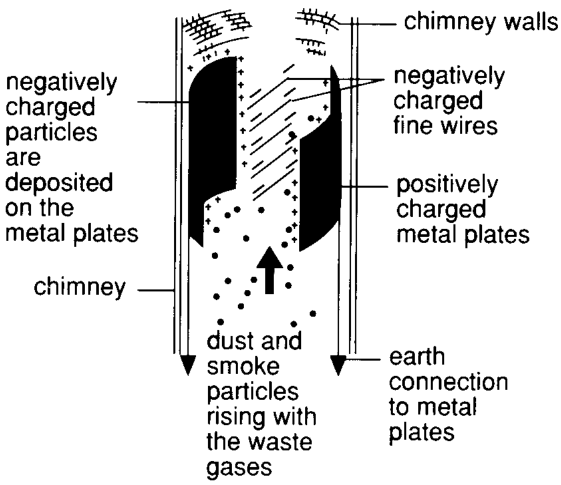
The following figure shows the field pattern set up by a pair of charges placed close together



G. Applications and Hazards of Electrostatics

a) Some applications

1. Flue-ash removal



One important application is the removal of flue-ash (a mixture of smoke and dust particles) from a modern coal-fired power station by means of an electrostatic precipitator. If the flue-ash is not removed, it would be discharged into the atmosphere causing serious air pollution. The figure shows how a precipitator attached to the chimney walls removes smoke and dust particles from the waste gases that flow through the chimney into the atmosphere.

A precipitator is made up of a number of wires and plates. The wires are made negatively charged so that they can charge the ash particles negatively when passing through.

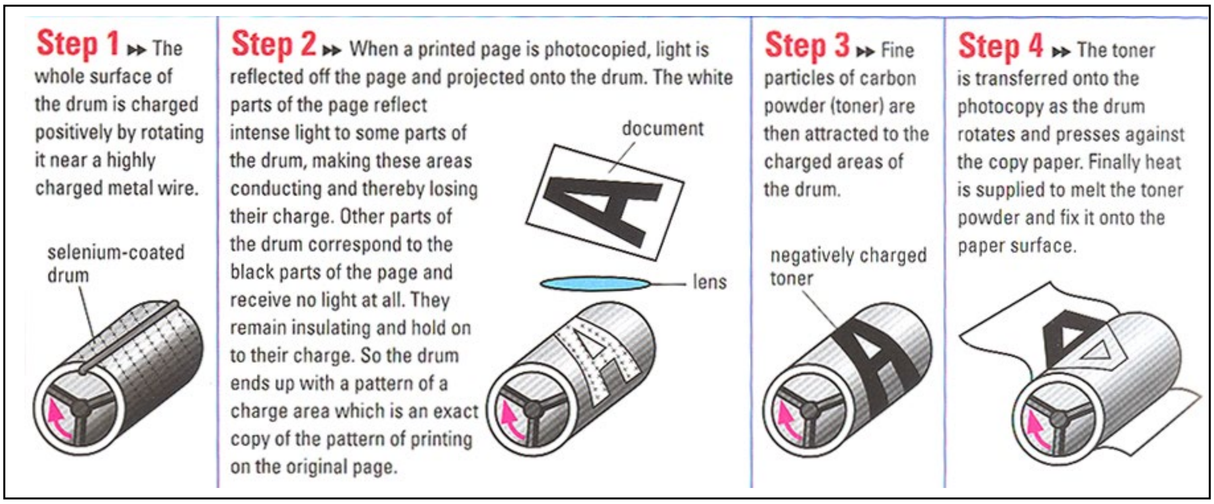
The collector plates are made positively charged to attract and collect the ash particles. The plates are then mechanically shaken to remove the ash which is collected and used as a by-product.

The electrostatic precipitation technique is also important in steel, cement and chemical industries which release large quantities of flue gases.

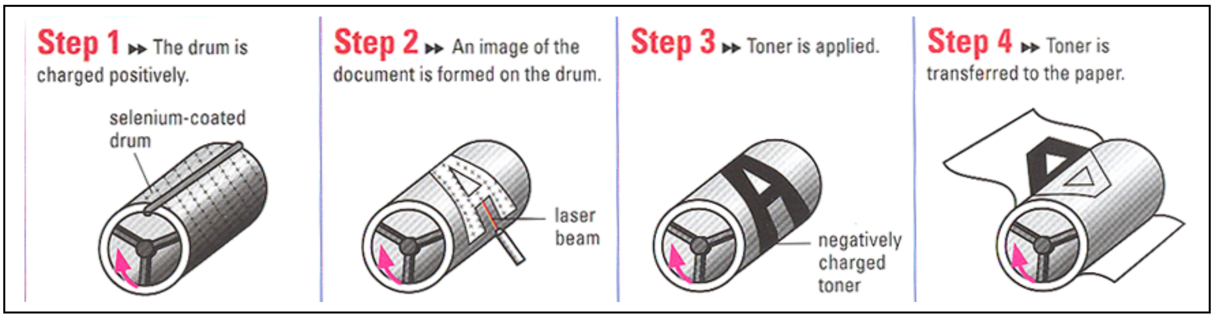
2. Spray painting

Where mass automation is required, such as in car production, electrostatic spray painting is commonly used. The object (such as a car's body) to be sprayed and the spray nozzle (and hence the paint) are given opposite charges. This will result in good adhesion of the paint to every corner of the object to give a uniform layer of paint. This method is effective, efficient and economical.

3. Photocopier



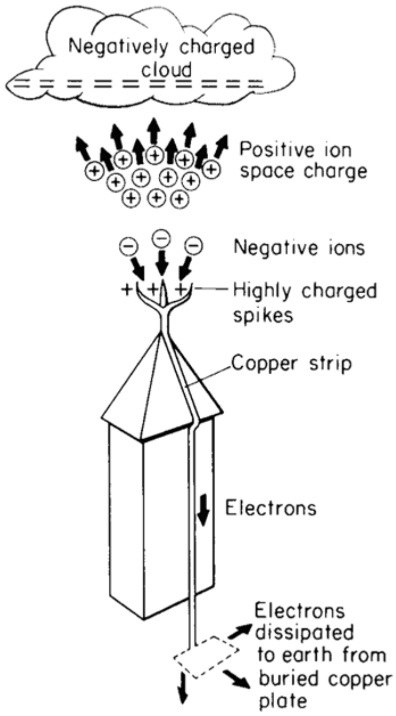
3. Laser Printer



b) Some hazards

1. Lightning

This is due to a large quantity of electric charge being built up in the heavy thunderclouds. The thunderclouds are charged by friction between the water molecules in the thunderclouds and the air molecules. When the charge on the thunderclouds is sufficiently large, it can ionise the air which then provides a conducting path for the huge quantity of charge to be discharged to the nearest or sharpest object on the ground. This explains why it is very dangerous to swim in the open sea, play in an open field or hide under a tree during a thunderstorm. To prevent lightning from damaging tall buildings, lightning conductors are used. The purpose is to provide a steady discharge path for the huge number of electrons in the air to flow from the top of the building to the earth.



Action of a lightning conductor

2. Fires or explosions

A fire or an explosion may occur due to excessive build-up of electric charges produced by friction. For example, electric charges accumulate on an aircraft during flight and on trucks transporting flammable liquids. Some preventive steps may be taken to avoid such hazards. In the case of the aircraft, the tyres are made of slightly conductive rubber so that the large amount of charge build-up on the body of the aircraft during flight can be discharged harmlessly during touch down.

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