5058 PHYSICS (NEW PAPERS WITH SPA)

5057 PHYSICS (NEW PAPERS WITH PRACTICAL EXAM)

TOPIC 16
STATIC ELECTRICITY

SUBJECT CONTENT	LEARNING OUTCOMES
- Laws of Electrostatics - Principles of Electrostatics - Electric Field - Applications of Electrostatics	a) State that there are positive and negative charges and that charge is measured in coulombs b) State that unlike charges attract and like charges repel c) Describe an electric field as a region in which an electric charge experiences a force d) Draw the electric field of an isolated point charge and recall that the direction of the field lines gives the direction of the force acting on a positive test charge e) Draw the electric field pattern between 2 isolated point charges f) Show understanding that electrostatic charging by rubbing involves a transfer of electrons g) Describe experiments to show electrostatic charging by induction h) Describe examples where electrostatic charging may be a potential hazard i) Describe an example of the use of electrostatic charging e.g. photocopier and laser printer

A Electrostatics

Electrostatics is the study of static electric charges.

Some objects like glass and silk will acquire electric charges when they are rubbed together. This is because rubbing transfers negative charges (called electrons) from one object to another.

For example, when you rub a glass rod with a piece of silk, the glass rod becomes positively charged (i.e. the glass rod has lost electrons). Some electrons are transferred from the glass rod to the silk. As the silk has gained electrons, it becomes negatively charged.

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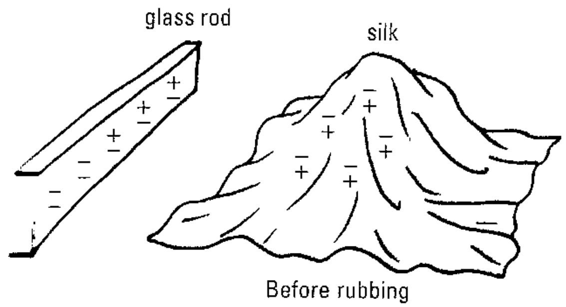
<td>
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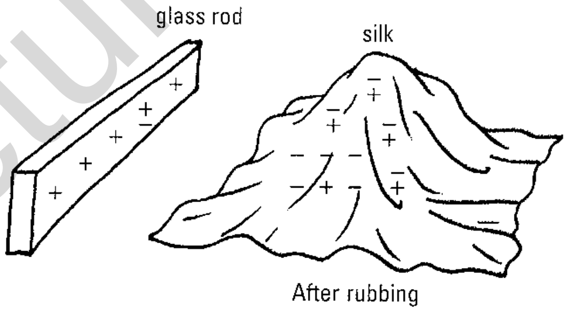
<td>
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<tr>
<td>The glass rod and silk are electrically neutral, i.e. they have the same number of positive and negative charges on them.</td>
<td>Some negative charges from the silk rod are transferred tot he silk. The silk has excess negative charges on the glass rod has excess positive charges.</td>
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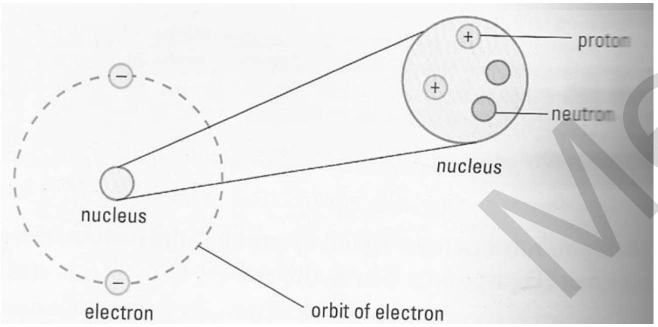


We know that mater is made of tiny particles called atoms. These atoms are too small to be seen by the naked eye.

Every atom has negatively charged electrons orbiting a small nucleus. The nucleus consists of positively charged particles called protons, and neutral (uncharged) particles called neutrons. An atom, in the neutral state, has an equal number of electrons and protons (i.e. it is electrically balanced).

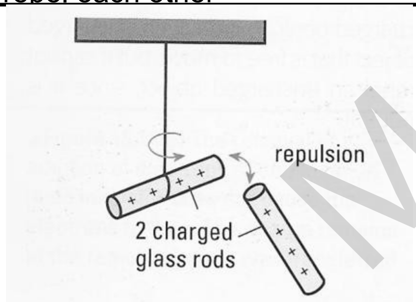
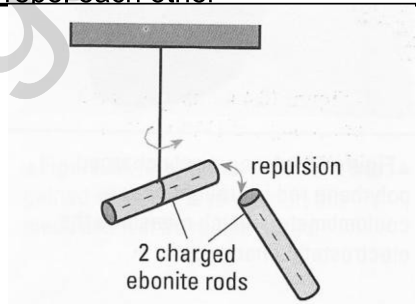
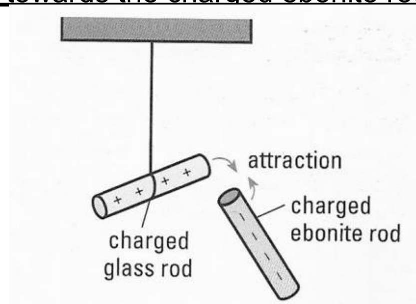
However, an atom becomes charged if the number of electrons and protons are not equal. This can occur when electrons are removed or added to the atom. If the electrons are added, the atom will become negatively charged. An atom that is electrically charged is called an ion.

When a glass rod and a piece of silk are rubbed together, the atoms at the surface are disturbed. This causes some electrons from the surface atoms of one object (glass) to be transferred to the other object (silk). In this case, the glass rod becomes positively charged as it has lost some electrons, and the silk becomes negatively charged as it has gained electrons.

From this, we can see that electric charge is not created or destroyed during the charging-by-friction process. It is only transferred. The following table shows the types of charges acquired when some materials are rubbed together.

Materials	**Positive Charge**	**Negative Charge**
Glass Rob rubbed with Silk	Glass	Silk
Ebonite Rod rubbed with Fur	Fur	Ebonite
Perspex Rob rubbed with Wool	Perspex	Wool
Rubber Balloon rubbed with Hair	Hair	Rubber
Polythene Rod rubbed with Wool	Wool	Polythene

Electrostatic Experimentations

Procedure	Charge two glass rods by rubbing them with silk. Both glass rods will become positively charged. Hang one of the rods with a piece of thread. Slowly move the other rod towards it.	Charge two ebonite rods by rubbing them with fur. Both ebonite rods will become negatively charged. Hang one of the ebonite rods with a piece of thread. Slowly move the other rod towards it.	Hang a charged glass rod with a piece of thread. Slowly move a charged ebonite rod towards the glass rod.
Observation	The charged glass rods are seen to repel each other	The charged ebonite rods are seen to repel each other	The charged glass rod is seen to move towards the charged ebonite rod.
Diagram			

From the above experiments, we can observe that when both rods are of the same charge, they will repel each other. However when both rods are of different charges, they will attract each other. The results from the experiments show that:

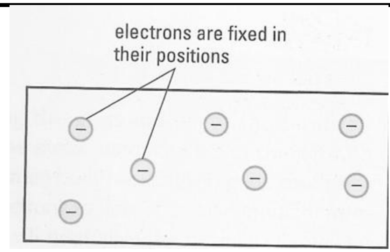
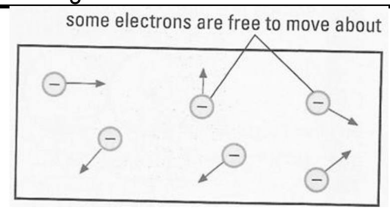
- There are two types of charges: Positive and Negative
- Like charges repel, unlike charges attract.

We have seen that there are only two types of electric charges – positive and negative. How are these charges measured?

Electric charge (whether positive or negative) is measured in coulombs (C) – the SI unit for electric charge. In an atom, the amount of charge an electron or proton has is 1.6 x 10^{-19} C. We can see that the charge carried by one electron or proton is very small. How many electrons are need to produce 1 C of charge? By simple calculation, we would need 6.25 x 10^{18} electrons to make up 1 coulomb.

This shows that one coulomb is a very large quantity. For most practical cases, we use submultiples of coulombs, e.g. millicoulombs (1 mC = 10^{-3} C) or microcoulombs (1 μC = 10^{-6} C).

B Insulators and Conductors

We have seen that when materials like glass, silk, Perspex or wool are rubbed together, they become charged. This is because electrons are transferred from one material to another. The electrons that are transferred are unable to move about freely within the new material, and they remain at the surface where the material has been rubbed. Such materials where electrons are not free to move about are known as electric insulators. Electric insulators do not conduct electricity and are charged by friction.	 The removal or addition of electrons at one location in an insulator does not cause the electrons to flow. The charge remains at the region where it was transferred.
On the other hand, there are materials that allow electrons to move freely within them, for example, metals like copper, iron or steel. Such materials are called electrical conductors. They are able to conduct electricity and are charged by induction. Other electrical conductors include graphite, liquid solutions and gase that have electric charges.	 When electrons are gained or lost in a conductor, the electrons will be redistributed.

When an object is charged, it can be neutralised by removing the charges from it. This is known as discharging.

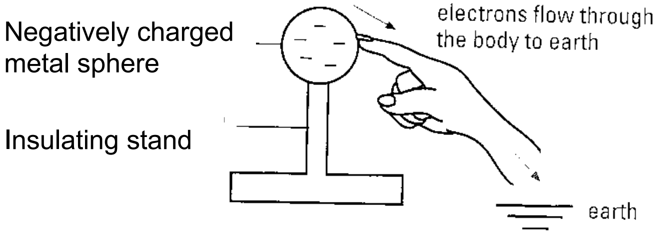
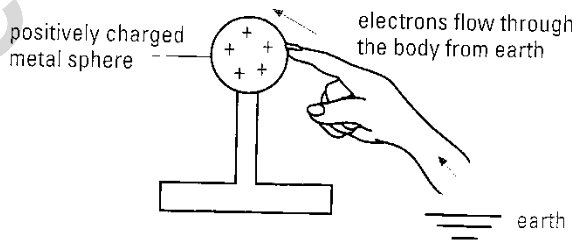
I Discharging a charged Insulator

Heating is an effective way of discharging a charged insulator. For example, heating a charged glass rod over a Bunsen flame can neutralise it. This is because the intense heat causes the air surrounding the glass rod to be ionised. The ions in the surrounding air then neutralise the excess charges in the glass rod.

Humid conditions will also neutralise a charged insulator over a period of time. This is because the water vapour in the air helps to remove the excess charges on the insulator.

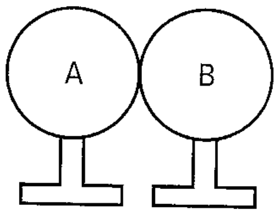
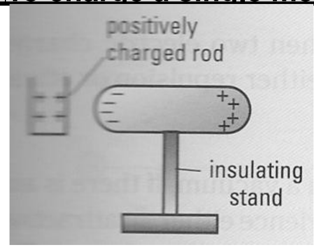
II Discharging a charged Conductor

A charged conductor can be neutralised by earthing it. To earth a charged conductor is to provide a path for the excess electrons to flow away or for electrons to flow to the conductor. This will cause the conductor to lose its charge and become neutral. (The term earth refers to any large conductor which electrons may be taken from or added to, without becoming noticeably charged itself:

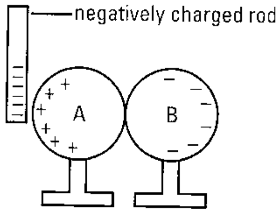
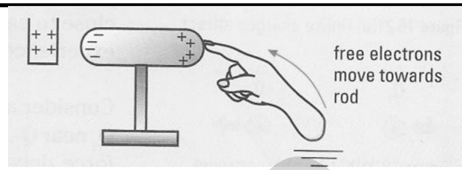
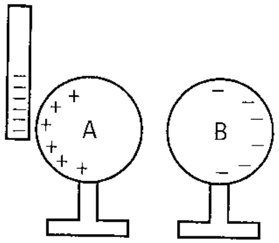
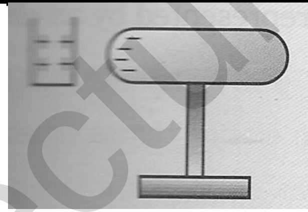
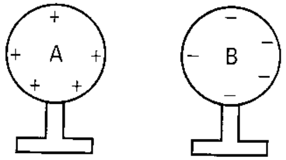
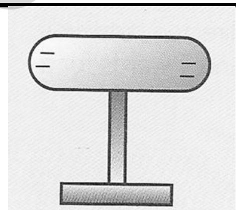
	
Earthing a negatively charged metal sphere will cause the excess electrons to flow away from the sphere to ground.	Earthing a positively charged metal sphere will cause electrons to flow from the ground to the sphere.

III Charging conductors by induction

We can charge a conductor by induction. Induction is the process of charging a conductor without any contact with the charging body. Insulators, however, cannot be charged by induction.

	To charge two metal spheres by induction		**To charge a single metal conductor by induction**	
STEP 1		Two conductors (metal spheres) on insulating stands are placed touching each other.		Bring a positively charged glass rod near the metal conductor on an insulating stand. The free electrons in the metal will be drawn towards the side nearer the positively charged glass rod.

Source: GCE 'O' Level Physics Matters, Marshall Cavendish Education, 2007, Charles Chew, Chow Siew Foong, Dr Ho Boon Tiong

STEP 2		A negatively charged rod is brought near sphere A. This causes the electrons in the metal spheres to be repelled to the far end of sphere B. Sphere A can be seen to have excess positive charges, while sphere B has excess negative charges.		Without removing the glass rod, earth the positively charged side of the metal conductor by touching it with your hand. The human body is a relatively good conductor and will allow electrons to flow into the conductor from the ground. This will neutralise the positive charges on the side of the conductor.
STEP 3		Without removing the rod, separate spheres A and B.		With the glass rod still in place, remove your hand from the conductor. This stops the earthing process.
STEP 4		Remove the charged rod. Spheres A and B now have equal amounts of opposite charges. Spheres A and B have been charged by induction.		Remove the glass rod. The negative charges will be redistributed on the surface of the conductor. The conductor is now negatively charged.

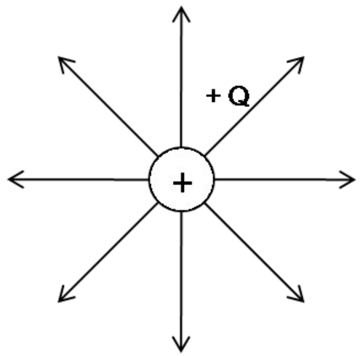
C Electric Field

Consider a single charge Q_1 in a vacuum. If there is another charge Q_2 near Q_1, Q_1 and Q_2 will experience either an attractive or repulsive force, depending on whether they are unlike or like charges respectively. This force is known as an electric force. This force is experienced without the charges being in contact with each other.

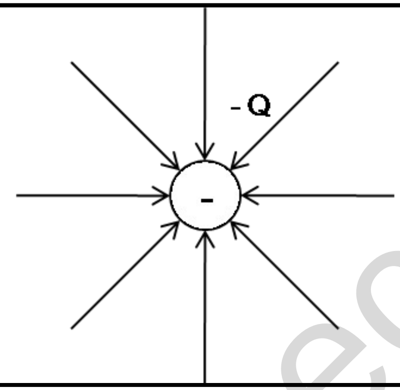
Since nearby charges exert forces on each other, the region where an electric force is experienced can be represented by an electric field.

An electric field is a region where an electric charge experiences an electric force.

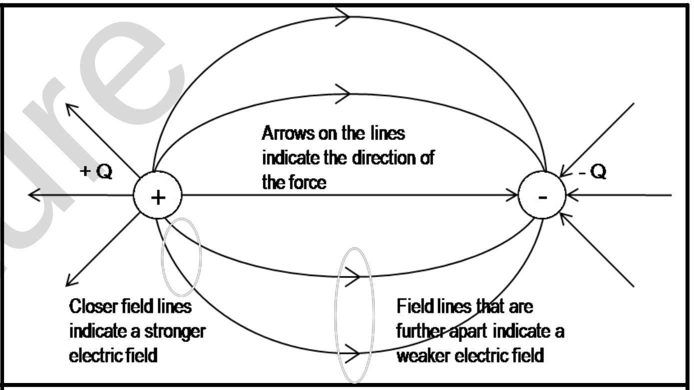
An electric field can be illustrated by drawing lines with arrows. The arrows on these lines indicate the direction of the electric field. Such lines are called electric lines of force. The lines show the path of a positive charge would it take if it were free to move. The strength of electric field is indicated by how close the field lines are to one another.



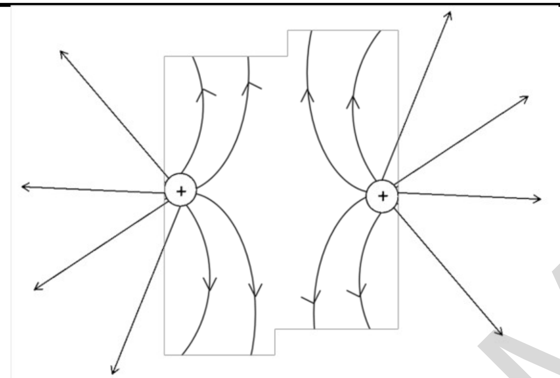
Field lines of positive charges



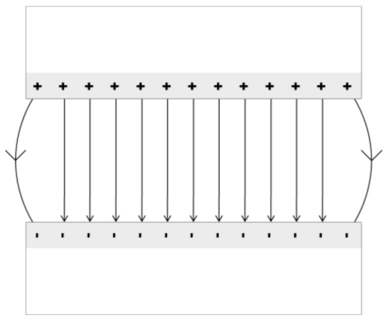
Field lines of negative charges



Field lines of two opposite charges placed together



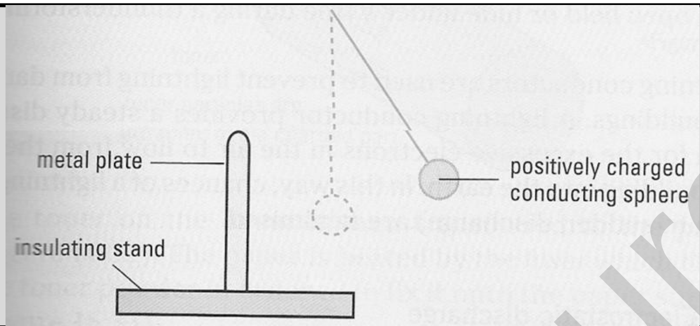
Field lines of two positive charges placed close together.



Field lines due to parallel charged plates. Take note that the field lines start from the positive charges on one plate and end on negative charges on the other plate. The field is said to be uniform in this region.

WORKED EXAMPLE

A light conducting sphere, positively charged, hangs vertically on an insulating thread. When a metal plate on an insulating stand is brought near, the sphere is immediately deflected as shown:



(a) Explain why the sphere moves immediately to the new position

The metal plate is also positively charged. As like charges repel, the conducting sphere is repelled and hence swings away from the plate.

(b) How does the movement of the ball illustrate the meaning of the term electric field?

When the plate is brought near the sphere, the sphere experiences a force causing it to deflect away from the plate. This force does not come from physical contact with any object. Hence, it can be deduced that the force on the sphere comes from the influence of the electric field on the plate.

[J83/I/13]

D Hazards of Electrostatics

Lightning	The flashes of lighting you see just before or during a thunderstorm are due to the discharge of a large quantity of electric charge built up in the thunderclouds. The thunderclouds are charged by friction between the water molecules in the thunderclouds and air molecules. When the charge in the thunderclouds becomes large enough, it ionises the air. The ionised air then provides a conducting path for the huge quantity of electric 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. Lighting conductors are used to prevent lightning from damaging tall buildings. A lightning conductor provides a steady discharge path for the excessive electrons in the air to flow from the top of the building onto the Earth. In this way, chances of a lightning strike (due to sudden discharge) are minimised.
Electrostatic Discharge	Excessive charges may build up between objects due to friction. For example, electric charges can accumulate on trucks due to friction between the road and the rotating tyres of the truck. When a sudden discharge occurs, this may cause sparks and

	ignite any flammable items that the truck may be carrying. It is quite common to see gas tankers with a metal chain at the rear end hanging close tot he ground. This chain provides an earthing path for excess charges to discharge. Electronic equipment, such as computer boards and hard drives, can be easily damaged by electrostatic discharges. To protect them from electrostatic discharges, the equipment is usually packaged in antistatic packaging materials. These materials usually have a thin layer of metallised film. The conducting film acts as an electrostatic shield for the components placed inside.

	How?	Example	Solution
Lightning	The flashes of lighting you see just before or during a thunderstorm are due to the discharge of a large quantity of electric charge built up in the thunderclouds. The thunderclouds are charged by friction between the water molecules in the thunderclouds and air molecules. When the charge in the thunderclouds becomes large enough, it ionises the air. The ionised air then provides a conducting path for the huge quantity of electric 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.		Lighting conductors are used to prevent lightning from damaging tall buildings. A lightning conductor provides a steady discharge path for the excessive electrons in the air to flow from the top of the building onto the Earth. In this way, chances of a lightning strike (due to sudden discharge) are minimised.
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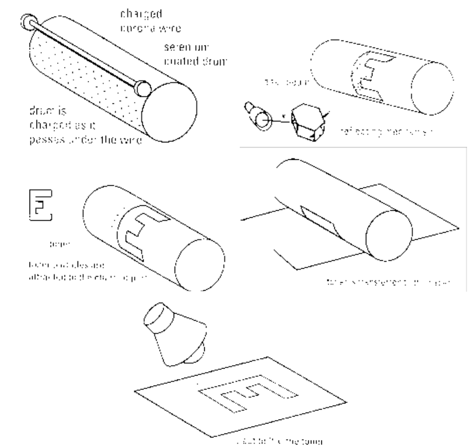
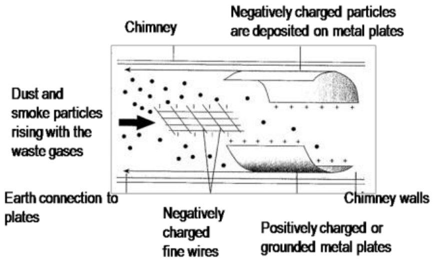
		Electronic equipment, such as computer boards and hard drives, can be easily damaged by electrostatic discharges.	The equipment is usually packaged in antistatic packaging materials. These materials usually have a thin layer of metallised film. The conducting film acts as an electrostatic shield for the components placed inside.

F Applications of Electrostatics

Laser Printer	A photoreceptor drum (which is a metal drum coated with a layer of photoconductive material) is rotated near a highly charged corona wire and becomes positively charged. (See 1st pic)	
	A laser assembly, consisting of a laser, a movable mirror and a lens, is then used to transfer page data onto the drum. When page data is sent to the laser, the beam casts an image of the data onto the rotating drum. The photoconductive layer on the parts of the drum surface that have been exposed to the laser discharges, creating a pattern similar to the print pattern on the page. (See 2nd pic)	
	Fine negatively charged powder, known as the toner, becomes attracted to the charged pattern on the drum. (See 3rd pic)	
	The toner on the drum is then transferred to the paper. (See 4th pic)	
	The paper is heated by the fuser which melts the toner powder in order to fix it onto the paper surface. (See 5th pic)	
Electrostatic Precipitator	The burning of fossil fuels by power plants will produce a mixture of smoke and dust particles, commonly known as flue-ash. The flue-ash produced by power plants is usually discharged through the chimneys. In recent years, flue-ash emissions have become a greater concern as they pollute the environment. Electrostatic precipitators are used to remove the flue-ash emitted from coal-fired power stations. The flue-ash is passed through a negatively charged wire grid, giving the ash particles a negative charge. The particles are then routed past positively charged or earth plates, which attract the negatively charged ash particles. Air leaving the plates is thus clean from harmful pollutants. The ash particles stuck to the positive plates are collected and used as a bonding agent in cement.	
Spray Painting	As the spray leaves the nozzle, the particles of paint become charged by friction. The paint particles contain like charges, thus they spread out when they are being sprayed on a car body. The charged paint particles would be attracted to the metallic car body, which is earthed. This way, a uniform coat of paint with excellent adhesion is produced.	
Crop Sprayers	A strongly charged metal wire charges tiny droplets of pesticide as they leave the nozzle. As the droplets al have the same charge, they repel one another and hence, spread out more evenly among the crops. Thus, when a droplet approaches a plant leaf, it induces an opposite charge on the leaf and is attracted to it. This reduces wastage of pesticides.	