CHAPTER I.

ELECTROSTATICS; FUNDAMENTAL FACTS.

1. Electric Attraction. The word electricity is derived from ἤλεκτρον the Greek for amber; if we take a piece of sealing-wax or a glass rod and rub it with dry flannel or silk it will be found to have acquired the power of attracting light objects such as bits of tissue paper or feathers. This property of attraction was first discovered by the Greeks in amber; hence when Dr Gilbert about 1600 found that numerous other substances possessed it when rubbed he called them all "Electrics."

This attraction may be illustrated in various ways. Take a dry glass rod and rub it with a dry silk handkerchief, then hold it over a number of bits of tissue paper; the tissue paper jumps up to the rod; probably some bits stick to the rod while others after touching it are repelled and fly away. The same effect can be shewn by rubbing a piece of sealing-wax or a rod of ebonite with dry flannel or catskin.

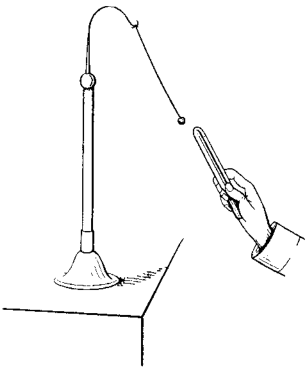

Fig. 1.

We can however study the effects better thus. Suspend a light pith ball or a small bit of feather by a thin silk thread; then rub a glass rod with silk and bring it near the ball; the ball is attracted to the glass as in Figure 1; allow the two to come into contact, the ball is then repelled from the glass.

Again take a second pith ball suspended in the same way and rub a rod of ebonite with dry flannel; then bring the rod near the ball, it is first attracted and then after contact is repelled from the rod.

The glass and the ebonite have both been electrified by friction, the first ball has been in contact with the glass, the second with the ebonite; the glass and the ebonite are both said to be electrified. Each has the power of attracting to itself a light body such as the pith ball and then repelling it. A body which has been electrified is said to be charged with electricity or to have an electric charge.

2. Two kinds of electrification. Many other substances can be electrified by friction, such as fur, wool, ivory, sulphur and india-rubber, but the states of electrification produced in these various bodies are not the same; we can shew in fact that there are two kinds of electrification.

EXPERIMENT 1. *To shew that there are two kinds of electrification produced by friction.*

A wire stirrup is suspended by means of a fine silk fibre as shewn in Figure 2. The stirrup is intended to support

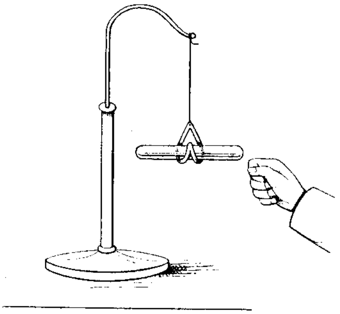

Fig. 2.

a rod of glass or of ebonite after it has been electrified. Rub one end of an ebonite rod with a piece of dry flannel and support it in the stirrup so that it hangs horizontally. Electrify in the same manner one end of a second ebonite rod and bring it near the electrified end of the suspended rod; the latter is repelled. Now electrify a glass rod by rubbing it with silk and bring it near the electrified end of the suspended ebonite rod; the ebonite rod is attracted. Thus while two ebonite rods when electrified repel each other, an ebonite rod and a glass one attract; the effects on the suspended ebonite rod of the glass and ebonite are opposite; we may express this by saying that the two states of electrification are of opposite sign; it is usual to call the electricity produced on glass by friction with silk positive, that produced on ebonite or sealing-wax when rubbed with wool or with catskin is called negative; these signs are matters of convention, the electricity on the glass might have been called negative, that on the ebonite positive, had this convention been agreed to instead of that which has actually been adopted.

Thus we have seen from the above experiment that there are two opposite states of electrification, and further that two bodies similarly electrified repel each other, while two bodies oppositely electrified attract each other.

We could vary the above experiment by electrifying a piece of glass by silk and supporting it in place of the ebonite; we should then find that it was attracted by electrified ebonite, repelled by electrified glass.

Moreover if the silk and the catskin be very dry we can shew in the same way that they also are electrified by friction, for on holding the catskin near to the suspended glass it is attracted while the silk which was used to rub the glass is repelled. Thus the catskin is positively electrified by rubbing ebonite, and the silk negatively by rubbing glass.

3. Conductors and non-conductors. If an electrified piece of ebonite be laid on another piece of ebonite or on a sheet of dry glass or a piece of dry silk, it will retain its electrification for some time; if however it be rubbed gently with a damp cotton cloth or with the hand or touched all over with a piece of tin-foil or other metal, it at once loses its electrification. The ebonite, the glass, and the silk are said to be non-conductors of electricity; the damp cloth, the hand, and the metal are called conductors of electricity. A conductor allows the free passage of electricity over its surface; if we hold a piece of brass tube in the hand and rub it with catskin or flannel, no sign of electrification is produced; if however we fix the brass tube on to an ebonite rod and rub it with dry catskin taking care to avoid touching the brass with anything but the fur, we find that the brass is negatively electrified; if brought near an ebonite rod suspended as in Experiment 1 it will repel it. The brass tube, the human body, and the earth are all conductors; some electricity is produced by the friction in the first case, but it spreads itself over the brass and passes through the body of the experimenter to the earth; in the second case also electricity is produced in the brass but is prevented from passing to the earth by the ebonite handle. Thus the tube remains electrified.

There is this difference however between it and the ebonite; that part only of the ebonite which has been rubbed is electrified, while the whole of the brass tube shews signs of electrification. Electrification produced by friction on a non-conductor remains where it was produced, while on a conductor it spreads itself over the whole surface.

This can be shewn in the following manner:—

On dusting a body with a mixture of powdered red lead and yellow sulphur which has been well shaken together, both powders become electrified by the friction, the lead being positive and the sulphur negative; if the body be unelectrified both powders can be easily removed by blowing on the surface; if the body be positively electrified the sulphur is held by it and the lead is removed by blowing, the surface becomes yellow when blown upon. If on the other hand the body be negatively electrified, the red lead is retained and the sulphur blown off, the surface becomes red; we have thus an easy test of the nature of the electrification of a body.

Now support a rod of ebonite and a brass tube, each in some non-conducting support. Rub one end of the ebonite with catskin and dust it with the red lead-sulphur mixture; the end which was rubbed becomes red, neither powder adheres to the other end, the ebonite is only electrified where it was rubbed. Repeat the experiment with the brass tube, it becomes red all over, the electrification has distributed itself all over the brass.

DEFINITION. *A substance which is a non-conductor of electricity is said to be an* **Insulator** *or to insulate, and a body supported by an insulator is said to be insulated.*

4. Properties of Insulators. Bodies can be divided roughly into two classes, conductors, which allow the free transference of electricity from point to point, and non-conductors or insulators in which that transference takes place very slowly indeed if at all. A perfect insulator would be a body which entirely stopped the passage of electricity; substances ordinarily classed as insulators, glass, shellac, silk, etc., are not perfect, but while in conductors the transference is so rapid as to be practically instantaneous, in a good insulator it is very slow. Indeed glass when thoroughly dry, fused quartz, paraffin wax and various other substances are practically perfect insulators. Water as we know it is a good conductor, though it appears probable that perfectly pure water would be an insulator. Air and the other permanent gases when dry are insulators, cotton thread especially if slightly damp is a conductor, silk is an insulator.

5. Electrification by induction. Bring an electrified ebonite rod near to a conductor supported on an insulating stand, and dust the conductor with the red lead and sulphur powder as described in Section 3; on blowing on the conductor the end near the ebonite will become yellow, the other end red; the nearer end has become positively electrified, the further end negatively. On removing the ebonite the electrification disappears. The conductor is said to be electrified by induction. If a positive body had been used instead of the ebonite to produce the induction, the nearer end would have been negative, the further end positive.

In the above experiment the state of induction lasts only so long as the charged body is near the conductor. We can however produce by induction a permanent state of electrification thus.

EXPERIMENT 2. *To electrify a conductor by induction.*

Bring an electrified ebonite rod near to an insulated conductor, and while the ebonite is in position touch the conductor for a moment with the finger. Then remove the ebonite; on dusting the insulated conductor with the lead-sulphur powder and blowing on it, it will become yellow shewing that it is positively electrified; if a positively charged body had been used instead of the ebonite to produce the induction, the insulated conductor would at the end of the experiment remain negatively electrified, it would thus appear red. Moreover in both these cases there is attraction between the charged rod and the insulated conductor.

To shew this, charge one end of the ebonite rod and suspend it in the stirrup as in Experiment 1. Then bring up near to it the insulated conductor on its stand, the charged end of the rod is attracted. If the conductor is not insulated the attraction is more marked; this can be shewn by touching the insulated conductor with the hand when near the rod, the rod is drawn still closer to the conductor.

We have already seen that on the insulated conductor there is positive electrification near the ebonite, and negative at a distance from it; this enables us to explain the attraction, for we may imagine the conductor divided into two parts, one of these is positively electrified, the other negatively. There is attraction between the ebonite and the positive part, repulsion between the ebonite and the negative part. But the distance between the first two being less than that between the second two, the attraction is greater than the repulsion and hence on the whole the ebonite is attracted to the conductor.

6. Explanation of electrical attraction. We may use these results to explain the phenomena of attraction and repulsion described in the first section, thus:

The bits of paper, the feather, and the pith balls are all of them conductors. When the charged ebonite rod is brought near the pith ball electric induction takes place, the ball becoming positively electrified on its side nearest the ebonite and negatively electrified on the opposite side; the ball is thus attracted by the ebonite; on contact the positive electrification of the ball is discharged by combination with some of the negative electrification of the ebonite, the induced negative charge remains on the ball; hence the ball and the ebonite being similarly charged repulsion takes place and the ball flies away from the ebonite.

7. Electroscopes. An instrument for detecting whether a body is electrified or not is called an electroscope.

In an electroscope as a rule the attraction or repulsion between two electrified bodies is made use of to determine the presence of electrification. Thus the pith ball suspended by a silk fibre might be used as an electroscope; a more sensitive electroscope however can be constructed as is shewn in Figure 3.

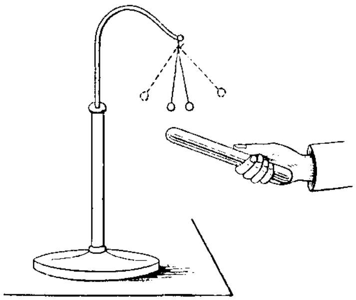

Fig. 3.

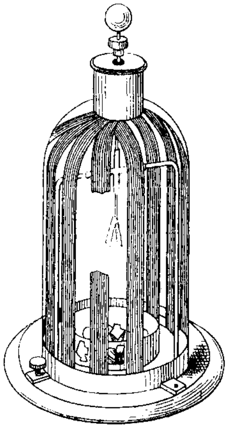

Fig. 4.

Two pith balls are connected by a linen or cotton thread and suspended from a glass support. Cotton or linen is used because it is a conductor so that any charge communicated to either ball is shared by the other. If the two balls become electrified they repel each other and stand apart. A number of observations might be made with such an electroscope. The gold-leaf electroscope however, Figure 4, which acts on the same principle, is much more delicate, the balls are replaced by two strips of gold or aluminium leaf. These hang from a metal rod inside a glass vessel. The rod is inserted into a glass tube which is well coated with shellac varnish and passes through a cork or stopper in the neck of the vessel. The shellac improves the insulating properties of the glass greatly[1]. The metal rod terminates in a metal plate or knob which is thus insulated but is in connexion with the gold leaves. For accurate work the surface of the glass vessel is partly covered with strips of tin-foil, spaces being left between the strips through which the gold leaves can be seen, or in some cases a cylinder or cage of wire gauze is placed inside the vessel. The object of these precautions is to prevent electrification on the surface of the glass or on external objects from influencing the gold leaves directly.

If the plate or knob becomes electrified by any means the gold leaves will also become charged with like electricity and will repel each other; the distance to which they stand apart will clearly depend in some way on their state of electrification and may be utilized to determine whether the original source of the electrification is strong or weak.

We can perform a number of experiments with the gold-leaf electroscope to illustrate the matters already referred to as well as some of the fundamental laws of the subject.

EXPERIMENT 3. *To determine whether a body is electrified and to shew that electrification is produced by friction.*

Bring a body such as a rod of ebonite or sealing-wax near the knob of an electroscope and observe what happens; if the gold leaves do not diverge the body is not electrified, if they do, the body is charged; in this case discharge the body either

[1] For delicate work fused quartz is now sometimes used as the insulator instead of the glass rod.

by drawing it across your hand or by passing it through a gas flame. Then rub the rod with a piece of dry flannel or fur. On again bringing it near the electroscope the leaves diverge, the body is electrified; if the fur is dry and is fastened to the end of an insulating rod and not held in the hand, it may be possible to shew that it is also electrified by the friction, by removing the ebonite and bringing the fur near, when the leaves again diverge.

This last experiment does not always succeed because the damp hand is a conductor and much of the electrification of the fur has escaped in the handling.

EXPERIMENT 4. *To shew that there are two kinds of electrification.*

This has already been shewn in Experiment 2.

Rub an ebonite rod with flannel and bring it near an electroscope, the leaves diverge; remove the ebonite rod and bring near a glass rod which has been rubbed with dry silk, the leaves again diverge. Repeat the experiment with the ebonite rod, but while it is near the electroscope bring up the glass rod, note what happens; as the glass rod is brought near, the leaves begin to fall together again; the electrification of the glass rod reduces the divergence due to that of the ebonite rod, the two states of electrification are opposite; if the glass be brought sufficiently near, the leaves may collapse entirely and then begin to diverge again; if this is the case on removing the ebonite rod they will diverge still more.

The electrification of the glass rod is said to be vitreous or positive, that on the ebonite resinous or negative.

EXPERIMENT 5. *To charge an electroscope* (*a*) *by conduction,* (*b*) *by induction.*

(*a*) Electrify the ebonite rod by friction with a piece of dry flannel, it will be negatively electrified; allow it to touch the knob of the electroscope, the leaves diverge and remain divergent when the ebonite is removed, though less widely than when the rod was in contact. The rod has given up part of its negative charge to the electroscope which has thus been negatively electrified by conduction. Discharge the electroscope by touching the knob for a moment with the finger;

on again bringing up the ebonite the leaves again diverge, shewing that only a part of the charge was in the first instance communicated to the electroscope.

(*b*) Electrify the ebonite again by friction and bring it near the knob of the electroscope, the leaves diverge. When the ebonite is in position touch the knob for a moment with your finger, the leaves collapse; remove your finger and then remove the ebonite rod; the leaves again diverge; the electroscope is charged but in this case the ebonite has not given up any of its electrification, the electroscope has been charged by induction. Moreover the charge in this case is positive. For we have seen that a negatively charged body induces positive electrification in the near parts of any neighbouring conductor and repels negative electrification to a distance. Thus in the first part of the experiment the knob is positively electrified by induction, the leaves negatively. When the electroscope is touched it becomes electrically part of the earth. The knob is still positively charged but the negative electrification passes to the earth. On removing the hand and then the ebonite this positive electrification is free to spread itself over the gold leaves, which thus diverge.

We may shew experimentally that the final electrification is negative in (*a*), positive in (*b*), thus: electrify a glass rod by friction with silk, and bring it near the electroscope. In case (*a*) it will be noted that the leaves collapse as the glass rod is brought near, they are therefore negatively electrified; in case (*b*) they diverge still further, they are positively electrified.

EXPERIMENT 6. *To illustrate the difference between conductors and non-conductors and to charge a conductor by friction.*

Charge the electroscope and then touch the knob with various substances held in the hand, taking care that none of them are previously electrified, and note the effects. With some substances the electroscope is practically unaffected, these are insulators; with others the leaves immediately collapse, these are good conductors; with others again there is a slow fall of the leaves, these last substances are bad conductors.

Again take a brass tube on an ebonite handle and holding