

Elementary Electricity

For Study And Use With The

GILBERT

Electrical Set

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My Dear Boys:



I am very glad indeed to be able to offer you this work on elementary electricity which we have prepared for studying use in connection with Gilbert Electrical Sets. You will find it, I am sure, one of the most interesting books you have ever read for the reason that you are on the threshold of the most fascinating, mysterious and wonderful course that we know of in this world—electricity.

This is the Electrical Age. Thousands of the greatest scientists are devoting their lives to the investigation of this strange power, and we have harnessed it and made it the Servant of Man. And yet, today just as little is known of

its origin as long ago at the time when Franklin and Volta were performing their wonderful experiments.

What is it? Where is the source of its power? Somewhere in the world there is a boy who will disclose to the world greater secrets of electricity than are at present known. As a boy I was always intensely interested in electrical experiments, and I know it to be true of almost every boy. There are so many things about it, telegraphy, wireless, electric motors, and strange experiments which can be conducted with the most simple apparatus.

I'm a great believer in boys; I want them to have real good times. I know what's good for them. I know boys need lots of play, entertainment, fun and pleasure, and at the same time I know they want something that requires brain. That is why in every toy that I manufacture it requires "gray matter" to get the most out of playing with them, and you will find this true of the Electrical Sets. It is one that will keep you right on your toes, you will never reach the end of it; it is simply the beginning, and it is a great sport, and perhaps it may, become your life work.

A.C. Gilbert

STATIC ELECTRICITY

What is Electricity? Of course, it should be the first question to be decided before we go ahead experimenting with electricity. And you see I am sorry to confess, that neither you nor I, nor anybody who lived, or is living, could answer this question. We do not know what electricity is. We cannot define the idea "electricity," but we can turn to advantage the phenomena of electricity. We can, and we do it. We have mastered this mighty force and made it our powerful servant. We can produce it and use it and—are now more the servants of electricity than it is our servant. It is hard to imagine what man's life would be without the use of electricity, and I think the time not very far off when the height of civilization will not be measured by soap, but by the electric meter.

While electricity is still a mystery, much is known about the rules and laws governing its nature. Although it is without doubt one and the same, it is for convenience sometimes classified according to its motion, as:

1. Static Electricity, or Electricity at rest.
2. Magnetism, or Electricity in rotation.
3. Current Electricity, or Electricity in motion.
4. Radiant Electricity, or Electricity in vibration.

You will learn in the following, why we give one and the same electricity different names and also how every one of the named chapters seems to be a special science by itself. But to understand the fundamentals of electricity, to be acquainted with Electrical Engineering, the purpose of this course, you must start with the first elements and advance step by step.

I. FRICTIONAL ELECTRICITY

Did you ever comb your hair with a common black ebony comb? Did you look at the same time in the mirror? What did you observe? Before we study this appearance, let us try an experiment with our hard rubber rod.

1. HARD RUBBER ELECTRICITY.

Tear a piece of paper in very small pieces and lay them on your experimenting table. Now, take your piece of flannel cloth and rub the ebonite rod with it until you feel it getting warm. Now, hold it near the small pieces of paper. How they jump! Some of them jump up and stick to the rod, some jump down again, and some lazy fellows just sit up. But the whole company was suddenly changed. Something happened to them.

2. GLASS ELECTRICITY.

Exactly the same thing happens if you rub the glass plate with the flannel

cloth, or better still, with a piece of silk. Bring the glass near the paper pieces. You may watch them perform the same evolutions as they did when you approached them with the ebonite rod.

3. FRICTIONAL ELECTRICITY.

It is hard to explain at once what happened, or why this happened so strangely. But we see, it was not the paper which caused the activity; it was the glass plate. We say that through the friction of these objects, electricity was produced. Therefore, we call it **Frictional Electricity**.

4. DR. GILBERT AND ELECTRICITY.

Over 2,000 years ago the highly cultivated Greeks already knew that amber would attract light bodies after being rubbed. They called amber—elektron.

For a long, long time, amber and jet were the only two bodies in which the power of electricity had been recognized. About the year 1600, an English professor, bearing a name very familiar to every boy, Dr. Gilbert, of Colchester, discovered by experimenting that not only amber and jet, but a very large number of other substances, such as diamonds, glass, sealing-wax, resin, etc., possessed the same property. He called these bodies—Electrics, and since his time the name—Electricity—has been used to denote the source of all the phenomena which will occupy us.

5. LAW OF ATTRACTION.

We found already the first law of Electricity: it attracts neutral bodies. A neutral body is a body which does not show signs of electricity. And here is the explanation for what you observed when you were combing your hair. The ebonite comb was rubbed by the hair and became electrified by friction. It attracted the hair and the little crackles you heard were the sounds of the electrical sparks which jumped from the electrified comb to the attracted neutral hairs.

6. PAPER ELECTRICITY.

Now, let us try some other experiments. Take a piece of newspaper, about five inches square and lay it on the table and try to lift it. You lift it easily and slide it along the table with a little push. Now, lay it again flat on the table and rub it several times from end to end with your hand. Try to lift it. It acts queerly. You can lift it, of course, but it offers little resistance. Now lift it against this resistance and try to slide it over the table. At the same moment it touches the table it immediately lays flat on it again. What happened now? Again the mysterious electricity! We rubbed the paper, and it became electrified and tried to attract the neutral body—the table. As the table did not give, the electrified paper attracted itself to the table.

7. HOW TO OBSERVE EXPERIMENTS.

Here is where I have to call your attention to a very important rule. Do not expect too much effect from these experiments, as the quantity of electricity produced by friction is very small, but watch for every little thing which seems unusual. In doing so you will sharpen your wits and be more successful in experimental work, than if you just rush through the experiment to observe simply the final effects.

8. ABOUT APPARATUS.

Now, let's go back to our paper. Put this paper on the radiator, or the stove, so that it gets hot. Now, take your flannel cloth and heat it, also. Rub the paper with the flannel cloth and you will see that it becomes greatly electrified.

It shows you that the same bodies can produce different results by changing the condition of their substances. This electrified paper will easily stick to the wall and stick to it longer than the cold paper rubbed by your hand.

Bear in mind, that for all experimental work, **your apparatus should be warm and dry to get the best results.**

9. REPULSION.

So far we have observed Electrical Attraction. We saw that neutral bodies are attracted by electrified objects.

Take an ordinary match and let it burn until it is charred through and through. Break the remaining substance, which is carbon, into small pieces and place them upon the top of your tin disk. Electrify the ebonite rod with the warmed flannel cloth and bring it near the carbon pieces. What do you see? When the paper pieces jumped up to the ebonite rod, they stuck onto it, but now the carbon jumps away as fast as it can. This "jumping away" is called **Electrical Repulsion**. The carbon is first attracted and then repelled.

10. CARBON PENDULUM.

Now, rig up your support for your electrical pendulum and tie a piece of carbon to one end with a silk thread. See fig. 1. Tie the other end to the wire support.

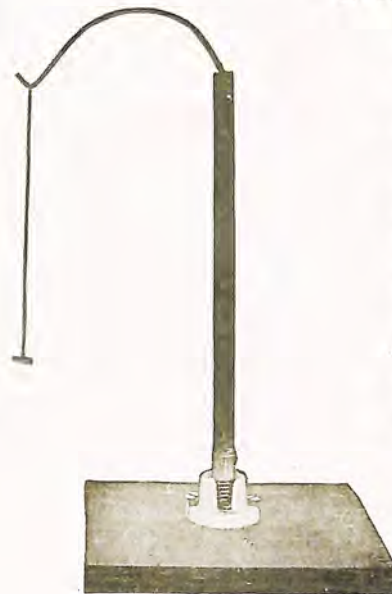


Fig. 1.

Electrify the ebonite rod and bring it near to the carbon pendulum. As soon as you touch the carbon pendulum with your electrified rod, you see it fly away from the rod as far as it can. The carbon is repelled as soon as it becomes electrified through touching the rod.

11. CHARGING BY CONTACT.

We call this kind of electrifying—"charging by contact," in contrast with "charging by friction," when we generate electricity in the ebonite rod, or on the glass sheet, by rubbing it with the flannel cloth.

12. CARBON FLIES.

Put some small carbon pieces in a tin cover and rub the warmed glass plate with a warm piece of silk. Cover the tin with the glass plate and see what happens. Why do the carbon pieces perpetually jump up to the glass and jump down again?

The electrified glass attracts them, charges them with electricity by contact, and repels them instantly. As soon as the carbon touches the tin bottom it loses its charge and becomes neutral again, and, as you know that neutral bodies are attracted by electrified bodies, the carbon pieces jump up again to the glass plate.

13. ELECTRIC SPIDER.

Take a piece of paper about four inches by two inches, and make a "Spider," as in the picture, by cutting it into small strips, but only up to about one-half an inch from one end. Lay it on your glass plate and rub it with your warmed flannel cloth from the head to the legs, so as to generate electricity in it. See fig. 2.

Now, lift the spider quickly and see what happens. The spider, which was fast asleep on the glass plate, wakes up quickly and stretches his feet out into the air. Some of them stretch way up and try to reach your hand.

14. UNLIKE ELECTRICITIES.

You know from your experiments that electrified objects attract neutral bodies, and repel them after the attraction. You saw how our spider stretched his legs and how the carbon pieces tried to fly away from our electrified rod, and now let us try one more experiment, which will seem to upset our experiences.

Electrify the ebonite rod and place it on a wire stirrup, made of a piece of wire



Fig. 2.

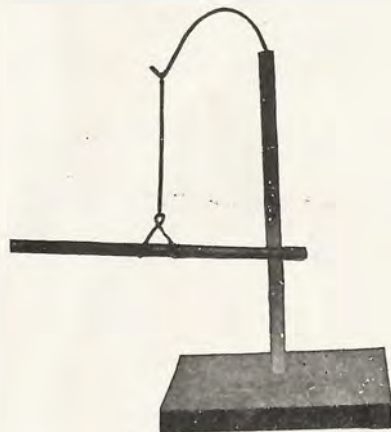


Fig. 3.

or a hairpin. The rod is charged by friction; that means, it is an electrified body. Now, rub the warmed glass plate with silk and bring this electrified body near to the electrified rod.

After all our experiments, we should expect that the two electrified bodies would repel each other. But we see that they attract each other very strongly. And, now, let me explain the mystery of all these experiments.

There are two kinds of electricity. One which we generate through friction of the ebonite rod, and the other which we produce by rubbing glass. It has been agreed for convenience to call the glass

electricity—positive, and the ebonite rod electricity—negative

Positive Electricity is represented by $+E$.

Negative Electricity, by $-E$.

15. LAWS OF ELECTRICITY.

As a result from our experiments we deduct the following laws of electricity.

1. Charges of the same kind of electricity repel each other.
2. Charges of unlike kinds of electricity attract each other.
3. Either kind of electricity attracts, and is attracted by a neutral body.

16. CONDUCTOR AND INSULATOR.

It is not often that we have to generate Frictional Electricity in one place and carry it to some other, but it happens sometimes and we have to see how this can be done. We don't know how electricity, itself, acts on our conducting line; we only accept for convenience again the fact that it flows through the conductor, usually a wire, like water through a pipe.

When electricity passes through a conductor, we say that we have an **Electric Current**, or a **Current of Electricity**, but, keep it clear in your mind—electricity is not a fluid. Nor is it a substance which can be moved. We say that it "flows."

When we conduct electricity through a neutral body, we have to be very careful to see that our conductor is entirely insulated from other conducting bodies. When we rubbed our spider, we put it on a glass plate just to prevent the electricity from flowing from the spider to the table. **The glass was the Insulator, or Non-**

Conductor, and bear this in mind, it is one of the best insulators we know of.

When we tied the carbon pieces to our pendulum, we used silk thread, because silk prevents the escape of electricity. Silk is an insulator. The ebonite rod is also an insulator.

No conductor is possible without insulators. In nature you will find that two of the most common elements—water and air—act differently. Dr. Gilbert, in his early experiments, observed that presence of moisture spoils the effects of electricity. His experiments prove that water is a good conductor and air a very good insulator. Now you understand more clearly why we want our apparatus to be warm and dry, and why our experiments show the best results on a warm day in a dry atmosphere.

17. POTENTIAL OF ELECTRICITY, (E. M. F.)

When you approached the electrified body with your finger, you saw a little spark jump to the tip of your finger, or knuckle. Your finger acted as conductor and the air around the electrified body as insulator to prevent the electricity from flowing out, as long as some force within the electrified body could overcome the resistance of the insulating air. **We call this inside power of electricity, its Potential or its Electro-Motive Force, (E. M. F.)**

It is something similar to the pressure of water which is kept in a tank on the top of a roof. The water tries to get down to the ground—to reach the surface of all water. The Potential of Electricity acts nearly in the same manner, but not only downwards. It tries to use every conducting body in any direction. This is the reason why the spark jumps over to your finger. You are the neutral body which conducts the electricity down to the earth, because **the Potential of the earth, and of all neutral bodies, is assumed as Zero—0—.**

The electricity passes from the body with the high potential to anyone which has a lower potential. We say that the difference of potentials of two bodies causes an electric current flowing through a conducting line between these two bodies.

18. THE ELECTROPHORUS.

A simple and effective instrument for generating larger quantities of electricity, and more convenient than the glass plate or ebonite rod, is our **Electrophorus.**

This is a small electric machine, the source of our future supply of static-electricity. It consists of the conductor, a tin box, and a non-conductor, the hard rubber sheet. The ebonite rod forms the insulating handle for the cover. See fig. 4.



Fig. 4

19. HOW TO USE THE ELECTROPHORUS.

We will first get acquainted as to how to use it, and later on we will learn how it works.



Fig. 5.

Fit the ebonite rod tightly in the hole of the tin cover by wrapping a small piece of paper around the end of the rod so you can lift the cover by its handle. (a) Place the rubber sheet upon a wooden table and rub it with a warm flannel cloth for a minute to thoroughly electrify it. (b) Grasp the handle of the cover by its extreme end and place it upon the rubber sheet, without touching the tin end of the cake. (c) Touch the cover for an instant with your finger. See fig. 5. (d) After you have removed your finger entirely from the cover, lift it by the end of the ebonite rod.

Bring your left hand near the cover and if you have done everything exactly as directed, you will see a fine spark jump from the cover to your finger through a distance of a half-inch. See fig. 6.

You cannot get a second spark from the cover at the same time. To re-charge it, simply place it upon the rubber sheet again and let it remain there a few seconds. **Touch it as before and lift it by the handle.** You can re-charge your cover many times before you will have to electrify the rubber sheet again.

The first three or four sparks are usually smaller than those immediately following. As soon as the sparks begin to get too small, charge the rubber sheet again by rubbing it.

The charge in the cover is +E.

That in the rubber sheet is -E.

20. EQUAL POTENTIALS.

Now, let us see what we can do with our electric machine. Hang your tin cover by means of a silk thread and one of the clamps to your pendulum. See fig. 7.

The tin is insulated from the table to the earth. The potential of the disk at the start is 0 (zero). It is a neutral body.



Fig. 6.

another closely with a hissing sound. Again charge the cover and approach it slowly with the point of the pin. You don't see or hear anything. However, you will find that the cover was discharged by a **silent discharge**.

Charge the cover of the electrophorus and bring it near the suspended disk. It will be attracted by the cover and a good spark will jump over. Re-charge the cover and watch the next spark. How is the third one? Sometimes a fourth spark will not pass to the disk, and the disk, itself, will be repelled by the cover. Its potential is raised to the same as that of the cover, and as the cover and the tin are full of the same kind of electricity, they repel each other.

21. DISRUPTIVE DISCHARGING.

But, if you approach the tin with your finger slowly, it will move immediately in the direction of your finger until the disk is discharged by bringing the knuckle near enough to allow the spark to pass.

If you have taken out one spark, the disk becomes neutral. This is a very important fact in distinguishing a good conductor from a non-conductor. A good conductor is discharged at once—**disruptive**. A non-conductor, like glass or our rubber sheet, will have to be discharged many times before it becomes neutral.

22. SILENT DISCHARGING.

Charge the cover again and bring the head of a pin slowly towards it. Watch the many little sparks which follow one

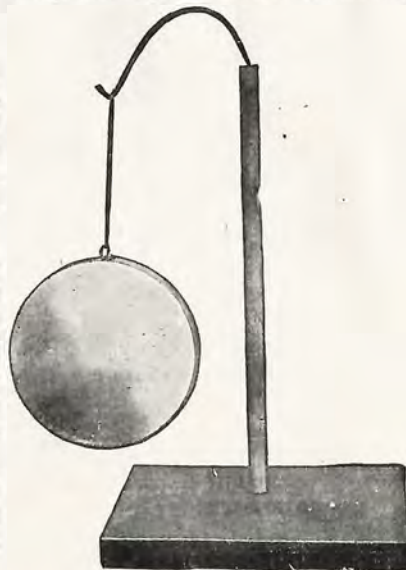


Fig. 7.

23. ELECTRIC CLAPPER.

By means of our carbon pendulum we can discharge the electrified cover slowly. If you hold a disk on one side of the pendulum and the charged cover on the other side, the carbon will swing back and forth between the cover and the disk, like a tiny clapper. See fig. 8. It always takes a load of electricity from the electrified cover and brings it to the neutral disk.

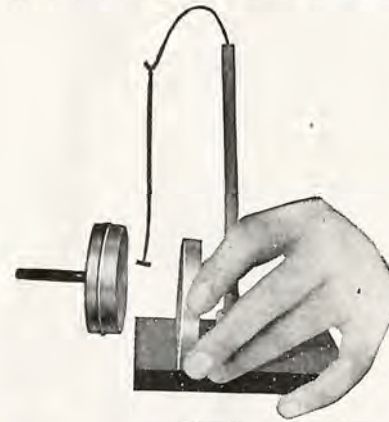


Fig. 8.

As the carbon is a little body it can carry only a small amount of electricity, and as it is a good conductor of electricity, it is quickly charged by the cover and discharged through the "grounded" tin, that is, the tin connected through your body with the ground.

24. ELECTRIC DENSITY.

The charged cover will hardly lose any electricity if you hold it in the air by its insulating handle for some certain time, but if you put a bent pin on the top of the cover, so that its point sticks out in the air as in Fig. 9, you will find it discharged within a few seconds.

Electricity may escape from a point so rapidly that the flame of a candle will be deflected when placed near the point. This current of air is called—**Electric Wind**.

If you try these experiments in a dark room, you will see that the point of the pin will show a luminous phenomenon—the escaping electricity.

Sharp corners or points are the best means for the electricity of escaping to the air and at such places electricity piles up and is more dense than at others. For this reason, avoid sharp corners and points in your conductor if you want to keep a charge for any length of time.

II. ELECTRIFICATION BY INDUCTION

Up to this time we have studied the effects of electricity, which was either generated by friction or transferred from the electrified object to the neutral body by contact. Now, let us see what happens in the neutral insulated conductor when we approach it with an electrified body, before any spark passes over.



Fig. 9.

25. POLARIZATION BY INDUCTION.

For this experiment let us rig up our stand and put the tin in a position that will prevent it from swinging around by means of silk threads and a few clamps. See fig. 10. A moist cotton thread hangs down from the loop in the top clamp. This thread is our Electroscope.

An Electroscope is an instrument which indicates the presence of electricity. We will learn more about this later on.

Now, charge the disk by touching it with the charged cover. The thread and disk have the same kind of electricity and you will see the thread standing off from the disk. Discharge the disk through your finger and watch the thread. At the moment the charge of electricity leaves the disk, the thread drops flat. In this experiment we charged the disk by contact.

But, now bring the charged cover slowly near the neutral disk, keeping them apart about one-half inch so that no spark can pass to the disk. See fig. 10.

Without charging the disk by contact, as we did in our previous experiment, the thread stands off. Take the cover

away from the disk and the thread drops. Bring it near again, and the thread stands off as before, showing that it and the disk are electrified without contact, but only while you are holding the cover in place.

26. THEORY OF NEUTRALITY.

To explain this phenomenon, we have to go back to the laws of electricity. If we accept the theory of two kinds of electricity within a neutral body, then we have to take it for granted that both kinds of electricity are equal in power. As they are equal in power, we cannot see their effect, because the laws of electricity teach us that their action neutralizes each other. That is the explanation of why this neutral body does not show any effects of electricity.

If we charge a neutral insulated body with one kind of electricity, this superfluous electricity shows its power in the way we have learned before, attraction and repulsion.

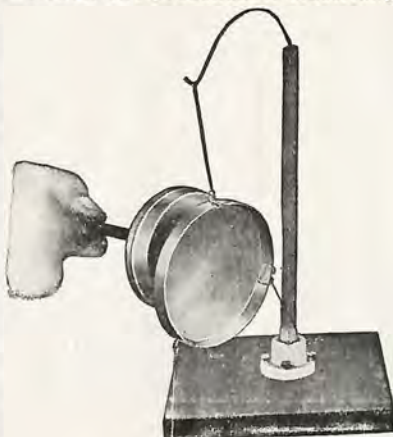


Fig. 10.

27. THEORY OF INDUCTION.

Our insulated disk with the cotton thread electroscope is neutral. As soon as the positively charged cover is brought near our disk, it destroys the neutrality of the tin by attracting the $-E$ within the neutral body and by repelling its $+E$ as far as it can in the opposite direction. **The charged cover produces a separation of the two kinds of electricity within the neutral body, by induction.** As soon as the inductive action of the electrified cover is removed, the disk becomes neutral again.

28. BOUND AND FREE ELECTRICITY.

We say that the electrified cover **polarizes** our disk. The $-E$ is drawn towards the electrified cover and as a result of the mutual attraction, it is held, **or bound**, there as long as the electrified cover is within the right distance. The $+E$ is actually repelled and **free** to escape. Its tendency to escape causes the divergence of the cotton thread.

29. CHARGING BY INDUCTION.

Again, bring the cover near our disk and polarize it. Keep the cover at the right distance so that the thread stands off, and touch the disk with your finger. The thread drops. Now, remove your finger and take the cover away rapidly. You will see the thread is repelled again.

We have learned that through induction we create bound and free electricity. When we approached the disk with the plus electrified cover, we bound the $-E$, and made the $+E$ free at the other end of the disk.

This freed $+E$ escaped through your arm when you touched the tin. The $-E$ could not escape but it became free as soon as the plus electrified cover was taken away. This charge of $-E$ filled the disk and caused the thread to stand out again.

Just a few words more about induction. Insulators and non-conductors are not easily polarized. This is the reason why a conductor is attracted more strongly by a charged body than an insulator, or non-conductor. The neutral body, then, is really no longer neutral when it is brought within the area of the inductive power of an electrified object. We call the area of an electrified body, in which the polarization can be observed—its **Electrical Field**.

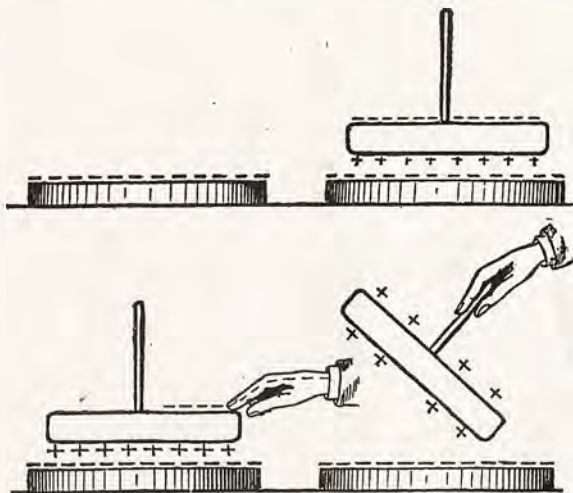
30. DIELECTRICS.

Try the experiment of induction again and hold the glass plate between the disk and the cover. The inductive force penetrates and acts through glass, air, paper, etc. These kinds of substances which allow the inductive influence to act through are called—**Dielectrics**.

31. THEORY OF THE ELECTROPHORUS.

If you have entirely grasped the rules of induction, you will easily understand how our little machine, the electrophorus, works.

You generate a charge of $-E$ in the rubber sheet by rubbing it. See fig. 11. Although its surface and that of the cover seem to be very smooth, they are uneven and there is a thin layer of air between them, except at a few points of contact. Hence, the cover becomes polarized by induction as shown in fig. 12. Its $+E$ is bound through the $-E$ of the rubber sheet and its free minus charge escapes when you touch the cover with your finger. See fig. 13. When the cover is lifted by the insulating handle, the plus charge, which was held bound by the minus charge of the rubber sheet becomes distributed throughout the entire surface and is ready for action. See fig. 14. As long as the rubber sheet retains its charge—under normal conditions for some time—we are able to re-charge the cover by induction.



Figs. 11—14.

32. CONDUCTIVE BODIES.

Cut out small figures from paper, about a half-inch high. Moisten a few of them and place them on the cover. Charge it and lift the cover. Why do they jump off? Why do the moistened figures jump quicker than the dry ones?

Put little pieces of charcoal, some bread crumbs, and a few small pieces of paper on the cover. Which one will jump first? Try the same experiment with small pieces of cotton thread and silk threads. Moisten one of the cotton threads. Now, what do you see? Which one will jump quicker?

The answer to these questions is to be found in the substances of our experimental objects, as the more conductive they are (charcoal, cotton thread, moist bodies, etc.), the better they will be polarized, charged, and repelled.

33. CONDENSER.

The principle of Induction is used to give a conductor a much greater charge than it would otherwise receive. You remember that our insulated disk in fig. 7 does not take more than three or four sparks. These sparks fill its **capacity**.



Fig. 15.

Cut out a few pieces of tin foil the same shape and size as your disk and pile them on the table. Place the glass plate between the disk and the tin foil so that it will not completely separate them on one side. See fig. 15.

Charge your cover and allow the sparks to pass to the center of the disk and see how many sparks it will take. You may charge your disk many times before a big spark passes through the air to the tin foil.

The capacity of the disk has been increased. The body of the disk is the same. As the potential of the electric cover—the charging body—did not increase, the potential of the disk must be the same. Therefore, **the electricity within the disk must have become denser**; it was condensed, and for that reason we call our apparatus a **Condenser**.

34. THEORY OF CONDENSERS.

All condensers consist of two conductors with a dielectric between them. One conductor is insulated from the earth and receives the electricity, and the other conductor is grounded. Every time a spark passes to the insulated conductor from our electrophorus cover the $+E$ in the tin foil is sent to the earth, and the $-E$ is drawn up near the glass.

After several sparks, we have a strong charge of $+E$ in the insulated conductor, and a strong charge of $-E$ in the lower grounded one. The glass keeps the plus and minus electricities apart for some time. The air is not as good an insulator as the glass, so the electricities push their way through the air as soon as the attraction between them becomes strong enough to overcome the resistance of the air.

If you place the glass plate between the two conductors, insulating them entirely, you may fill the condenser much stronger than before.

35. DISCHARGING THE CONDENSER.

To discharge our condenser, lift it by the corner of the glass plate and lay it on your hand. Notice how the tin foil sticks to the glass, attracting and attracted to