XLVIII. *Electrical Experiments, to explain how far the Phenomena of the Electrophorus may be accounted for by Dr.* Franklin's *Theory of positive and negative Electricity; being the annual Lecture instituted by the Will of* Henry Baker, *Esq. F. R. S. By* John Ingenhousz, *M. D. F. R. S.*

Read June 4, 1778.

HAVING had the honour of being appointed by the President and Council of the Royal Society to read the annual dissertation on some philosophical subject, instituted by our worthy member the late Mr. BAKER, I have endeavoured to pursue some electrical experiments, to explain how far the *Electrophorus perpetuus* may be accounted for upon the almost generally received theory of Dr. FRANKLIN of positive and negative electricity.

THIS electrical instrument consists of two different pieces; *viz.* 1. a metallic body, in the form of a plate, or any other convenient figure, furnished with an insulating handle, to be used for lifting it up; and 2. a flat non-conducting substance, such as glass, resin, or some

other non-conducting matter, upon which the ſaid metal plate is placed.

This machine, invented by Mr. VOLTA, a learned gentleman of Como, is certainly a valuable acquiſition to the Electrical apparatus. Once excited, it is for a long while ready to afford electricity enough for all experiments which do not require a very great force; and it has the advantage of not being ſo much affected by damp weather as the common machines with glaſs globes, cylinders, diſk, &c. It is very eaſily put in action by a ſlight friction with a dry hand, a piece of leather, a rough ſkin of a hare, a cat, or ſome other animal. It is as eaſy to excite with this machine a negative as a poſitive electricity. It has the advantage of being capable at almoſt all times of affording at pleaſure ſuch a force of electricity as is wanted, even to ſuch a degree, that the metal plate is no longer able to contain all the electric fluid communicated to it; but throws it out every way, either upon the metal upon which the reſinous cake is uſually fixed, or into the air: and this increaſe of electrical power is obtained by the eaſieſt means; for inſtance, by charging with the Electrophore a coated phial, and placing it afterwards upon the reſinous cake itſelf, or upon the metal plate placed upon the reſinous cake (provided the metal plate be leſs in circumference than the reſi-

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nous cake, and no metallic communication exiſt between the metal plate and that metal upon which the cake is faſtened). If the knob of the phial, thus placed, be touched by the finger, and then taken away, holding it by the knob, the force of the electrophore is found to be remarkably increaſed.

But a more pleaſing way of increaſing the electrical force of this inſtrument is by transferring alternately the metal plate from one reſinous cake to another, and touching it after it is placed upon the cakes. By this method both cakes acquire continually more and more electricity; ſo that in a ſhort time, by this alternate tranſlation, the metal plate returns from either cake quite overcharged; and thus Leyden phials may be charged by it very ſtrongly, and even ſo as to break them. It is very remarkable, that by this method the metal plate returns from one cake in a poſitive, and from the other in a negative ſtate.

This manner of increaſing the two electricities was found out by my learned friend Dr. KLINKOCH, profeſſor in the Univerſity of Prague, ſoon after I had given him a deſcription of this new inſtrument, which I had received from his Royal Highneſs the Arch-duke FERDINAND a very little while after Mr. VOLTA had invented it.

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It is true, that Father BECCARIA had a long while ago excited an electricity, almoſt perpetual, by two panes of glaſs, one placed upon the other, each having but one metal coating, and joined together ſo that no metal was placed between the two glaſſes. Theſe two glaſſes being applied to a prime conductor of an electrical machine, ſo as to receive a charge in the ſame way as one glaſs coated on both ſides is to be charged, afford numberleſs ſparks from both coatings, after the two glaſſes have been diſcharged in the common way, by making a communication between the two coatings.

In order to produce theſe ſparks, the two glaſſes muſt be ſeparated from one another, ſo as to avoid touching the coatings in the moment of ſeparation. Each of the coatings will give a ſpark, which may be repeated after having replaced the two glaſſes one upon another. After the two glaſſes have been thus joined again, and touched after their conjunction, another ſpark is obtained from both after their ſeparation; and theſe ſparks may be thus repeated almoſt *ad infinitum*; ſo that theſe two glaſſes, once excited, ſeem to be an unexhauſted ſource of electrical ſparks. Father BECCARIA calls this experiment *electricitas vindex*. Whether this denomination be a proper one to convey ſome idea of what is underſtood by it, I will not now undertake to determine.

The ſame Father BECCARIA had alſo found, that the coating of a glaſs, after being diſcharged, was able to give new ſigns of electricity, when taken off by means of ſilk ſtrings.

Some other experiments were made many years ago by Mr. CIGNA of Turin, and by ſome other electricians, which have a great deal of ſimilarity with the electrophore.

But as the inventors of theſe experiments did not adapt them as an electrical machine, they do not diminiſh at all, in my opinion, the honour which Mr. VOLTA deſerves, for having enriched the electrical apparatus with a very ſimple and handy machine, continually ready to excite as ſtrong an electricity as is requiſite for the moſt ordinary purpoſe.

The novelty and ſimplicity of the machine could not but ſtrike every electrician; I cannot expreſs how much I was pleaſed with the firſt ſight of it, and with what eagerneſs I ſet about endeavouring to underſtand the nature of it. I analyzed it in various ways: I compared it with Father BECCARIA's *electricitas vindex*, with an ordinary coated glaſs, and coated reſinous electrics.

Some electricians, puzzled with the ſtrange phenomena which it affords, thought it over-turned entirely the almoſt univerſally received theory of Dr. FRANKLIN, and

and that it could not be underſtood but by eſtabliſhing new principles.

After conſidering the matter maturely I thought, that theſe phenomena, though at firſt ſight extraordinary, could be explained by the ſame principles which were already received by almoſt every philoſopher.

But before I proceed to my intended explanation of the moſt obvious phenomena of the electrophorus, I muſt beg leave to ſet down ſome conſtant laws, which nature obſerves in the various motions of the electric fluid, and to which electricians do not ſeem to give a ſufficient attention.

1. The electric fluid exiſts in all ſubſtances, in a certain quantity, which is natural to them.

2. The electric fluid is repulſive of itſelf, that is to ſay, each particle of electric fluid tends to recede as far from another particle of the ſame fluid as it can.

3. The ſtate of electricity of a body is that in which it has acquired more electrical fluid than the neighbouring bodies, or in which it has leſs of this fluid than the ſurrounding bodies.

4. In the firſt caſe the electrical fluid tends to expand itſelf through all bodies near it, which can by their nature receive it. In the ſecond caſe, the electrical fluid of all the ſurrounding bodies finding leſs reſiſtance towards

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a body negatively electrified, or having lost a part of its natural share of electricity, rushes towards that body, and tends to diffuse itself through it, and thus to dispose itself into an equilibrium.

5. The reason why the electric fluid, existing every where, seems to remain inactive in the common state of nature is, because all other bodies having their ordinary share of this fluid, an equal pressure exists on all sides. Thus, if all the bodies upon the earth were to acquire more or less of electric fluid at the same time, in equal proportions, no electrical phenomena would be the consequence of such a state; because the pressure being every where equal, the repulsive force of the electrical particles would be every where balanced. Thus two bodies, both negatively or both positively electrified, will not give a spark to one another: they only recede more from one another, because the other surrounding bodies are not in the same situation with them. This assertion seems to be illustrated by Father BECCARIA's electrical well *(puteus electricus)*, which is nothing but a metal vessel electrified, in which two cork balls are suspended by silk threads; the balls do not show signs of electricity within the cavity of the vessel, because the electric fluid presses equally on every side.

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6. All non-conducting bodies may acquire on each part of their fubftance more or lefs of the electric fluid, as well as conducting bodies, at leaft to a certain proportion; but they do not allow it to pafs freely through their fubftance or over their furfaces.

7. All bodies whatfoever are fufceptible of electricity, pofitive and negative indifferently, either by exciting them by friction or any other way, or by bringing them within the fphere of action of a body already electrical; fo that even metals, the beft conductors, may be as eafily excited by friction, if infulated, as glafs or fealing wax. The only material difference between the conducting and non-conducting fubftances feems to be, that the electricity does not fpread itfelf fo eafily and fo rapidly through or upon thofe bodies which are non-conductors as upon thofe which are conductors. An electrical fpark thrown upon the furface of a piece of metal infulated, of whatever length it be, diffufes itfelf equally through the whole mafs, if this metal be left to itfelf out of the fphere of action of another body charged with electricity. The whole electricity communicated by this fpark is difcharged at once by touching any part of the fame metal. On the contrary, electricity feems rather to ftick to that part of a non-conducting body to which it is applied, fpreading but flowly and unequally over its furface, from

which it may be taken by degrees, by touching thofe parts to which it was applied. There are fome bodies which feem to be of a middle ftate between thefe two, *viz.* through which the electric fluid propagates as through good conductors, but flowly, fuch as common wood, moift air, and many other bodies. Electricity feems to diffufe itfelf through thefe bodies almoft as fugar and falt diffufe themfelves through water, fpreading farther and farther through the liquid.

8. All thofe bodies, which are non-conductors, feem to acquire a ftate of electricity with fome reluctance; and, after they have acquired it, to hold it more tenacioufly, or to part with it with more difficulty, than conductors. One touch takes away all the electricity of a metallic body, but does not abfolutely convey away all the electricity of a piece of glafs or another electric body, fuch as fealing wax, amber, &c. The metal plate of an electrophore takes almoft no electricity at all from the refinous cake, if it be lifted up without having been touched when it was upon the cake.

9. All refinous bodies, filk and many others, retain more tenacioufly their ftate of electricity than glafs, however dry. Thus a piece of glafs excited is almoft quite deprived of its electricity by a conducting fubftance

being applied to it; but a resinous body, though touched, retains still a great share of its electricity.

10. A conducting body insulated, being placed within the sphere of action of an excited non-conducting body, or even in contact with it, acquires at the same time two contrary electricities; *viz.* the part in contact, or very near the non-conducting electrified body, acquires a contrary electricity to that of the non-conducting body, at the same time that the opposite or farthermost extremity is possessed of the same electricity with the conducting body.

11. A conducting body insulated, being in contact with another conducting body excited with either electricity, acquires the same electricity throughout its whole extension, or divides with this body its electricity equally.

12. But an insulated conducting body, being only in the sphere of action of another electrified conducting body, acquires, as in the first mentioned case, two different electricities at the same time; *viz.* towards the electrified body it acquires a contrary electricity, and at the opposite extremity it acquires the same kind of electricity with the electrified body.

It seems therefore to be a law of nature, that the electric fluid which is accumulated upon a body, and finds an obstruction

obstruction in its free passage to another neighbouring body by the interposition of a non-conducting body (such as dry air, glass, &c.) forces by its repulsive power the electric fluid naturally contained in all bodies to the furthermost extremity of the neighbouring body, so as to excite in its nearest extremity a kind of defect of the electric fluid, or a kind of vacuum, till at last the accumulation of the electric fluid becomes so great upon the electrified body, that it overpowers the resistance of the intermediate non-conducting substance, forces its way through it, and rushes in the form of a spark upon the neighbouring body.

If the electric fluid be thrown upon the surface of a pane of glass, coated on both sides with a metallic substance, such as tin-foil; the fluid, finding an obstruction to its passage through the body, is crouded upon that surface of the glass which has received it; forces the electric fluid out of the other surface, if some conducting body is near it, or in contact with it, and can convey it away; till this fluid becomes so much crouded upon that surface as to overpower the resistance of the glass, and to force its way through the substance of the glass, in order to diffuse itself upon the other surface, upon which was produced a kind of vacuum. The glass being thus rent is no longer able to be what is called charged; but after the crouded

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electrical fluid of a prime conductor has in the ſame manner rent the plate of air (which obſtructed to a certain degree its free paſſage between the prime conductor and the neighbouring body) by giving it a ſpark, the ſame ſpark may be repeated at pleaſure, becauſe the opening formed by the ſpark through the plate of air is immediately ſhut up again according to the nature of all fluids.

If an inſulated conducting body be ſituated in the manner deſcribed, ſo as to poſſeſs at its different extremities a contrary electricity, it may impart to any other body brought in contact with it, or within its ſtriking diſtance, a ſhare of that electricity which it has acquired at its farthermoſt extremity. The former body, ſo touched, has effectually loſt that part of electrical fluid which was in a certain manner crouded upon that extremity; and therefore being taken out of the ſphere of action of the excited body, as, for inſtance, a prime conductor, after having thus loſt a part of the electric fluid crouded upon its extremity, is found to poſſeſs a negative electricity if the excited body had a poſitive, and a poſitive if the excited body had a negative one.

Thus we ſee how far we muſt believe what is commonly affirmed as a fact, that a body, plunged in the atmoſphere of an electrified body, acquires a ſtate of electricity contrary to that of the electrified body. If the body plunged

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in this atmosphere be of a small extent, it will be found so to all appearance, because the two extremities of a small body cannot be separately examined; whereas a body of a certain extent exhibits in a very perceptible manner the two distinct electricities. The reason of this wonderful phenomenon is to be understood by the principles adopted, and may without much attention be understood, if we suppose the excited body to be in a positive state of electricity; for in this case the atmosphere of electric fluid surrounding the excited body forces by its repulsive quality the electric fluid of the neighbouring body towards its farthermost extremity, and thus accumulates or crouds it upon that extremity, from which extremity it is therefore ready to fly off upon any other body, which is of a nature to receive it, being brought near enough.

If the excited body be in a state of negative electricity, the explanation is not so obvious as in the positive case: it requires some more attention to conceive what passes. The excited body, having lost a part of its natural share of electric fluid, a kind of vacuum, if I may call it so, takes place upon this body. The electric fluid of any other body being in its natural state, and therefore in a kind of inactivity, confined as it were within its limits by the electric fluid of all the surrounding bodies, is set

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at liberty, exerts its natural repulſive quality towards that body, upon which it does not find a ſimilar quantity of electric fluid reſiſting its ſpring, or its elaſtic and repulſive quality; it therefore ruſhes towards that kind of vacuum which exiſts upon a body negatively electrified; and thus the electric fluid of this body, loſing its natural ſtate of equilibrium, and accumulating itſelf towards the vacuum, produces there a real poſitive electricity, at the ſame time that the oppoſite extremity has a negative one.

Before I go farther, I muſt ſpeak one word more of that particular quality of conducting bodies, by which they receive, with a kind of reluctance, either ſtate of electricity; and, after having received it, part with the ſame with as much ſeeming difficulty. This quality, not unknown to attentive electricians, who muſt have obſerved it, has commonly appeared ſomewhat extraordinary and difficult to be believed by many electricians, to whom I have happened to explain my theory of the electrophore. As this quality is the foundation of this theory, I conceive it will not be amiſs to demonſtrate it by facts.

The firſt part of this inherent quality of non-conducting bodies, receiving a ſtate of electricity with more difficulty than conducting bodies, is eaſily ſhewn by the following ſimple experiment: a piece of dry glaſs, held

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near a prime conductor, will receive no electricity, or almost none, at the fame diftance as that at which a piece of metal or another conducting fubftance will have received a confiderable degree of electricity, or even a full fpark.

The fecond part of this inherent quality may be thus demonftrated: a piece of metal infulated, as, for inftance, the metal plate of an electrophore, placed upon the cake of refin excited with a confiderable degree of electricity, will not receive any electricity at all, or only a faint one, when it is feparated from the cake without having been touched when it was in contact with the cake, or in the fphere of action of the cake, though it was really in a ftate of actual electricity all the time it was upon the plate. Now, if the cake of refin did part as eafily with its ftate of electricity as the metal plate, it would leave a confiderable degree of electricity upon the metal plate; the more as it is well known that the metal does not at all refift the receiving of it.

Though it would be perhaps in vain to attempt a farther explanation of this inherent quality of non-conducting bodies, yet it will be eafy to illuftrate this law of nature by an example of another inherent quality in all matter, which Sir ISAAC NEWTON calls the *vis inertiæ*; and is a *vis infita*, by which matter refifts being put in motion, and when it is once put in motion requires as much

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force to ſtop its motion as it required to be brought from a ſtate of reſt to that of motion.

Let us now conſider attentively the ſtate of a body ſituated, as I have before deſcribed, in the ſphere of action of an excited electric; as, for inſtance, a cake of reſin, a flat glaſs, or any other non-conducting ſubſtance; or, in other words, let us conſider the ſtate of the metal plate placed upon the reſinous cake of an electrophore, ſuppoſing this cake to be excited with a poſitive electricity; which electricity it acquires eaſily by ſliding the knob of a Leyden phial, charged in the common way, over its ſurface and by various other ways. The ſuper-abundant electric fluid of the cake repels the electric fluid of the metal plate to its farthermoſt extremity, and excites there an accumulation of that fluid; or, in other words, produces there a poſitive electricity, whilſt it produces a negative electricity at the ſurface in contact with the cake.

If in this condition a conducting body be brought in contact with the metal plate, or within its ſtriking diſtance, it receives a ſpark from it; which ſpark is the eletric fluid of the metal plate crouded upon the extremity of the metal by the repulſive force of the ſuper-abundant electric fluid of the cake.

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If the metal plate be touched at that ſide where it is really in a negative ſtate, it will, notwithſtanding, part with its accumulated poſitive electricity; becauſe the repulſive power of the atmoſphere of the cake will force this crouded electric fluid out of whatever part of the metal is touched, the electric fluid paſſing through metals very freely.

The metal plate, thus deprived of the electric fluid crouded upon it, becomes in a negative ſtate; but the repellent power of the electric fluid of the cake continuing to act upon the metal plate, forces what remains in it towards the farthermoſt extremity, ſo as to produce much the ſame ſtate as it had before it was put upon the cake; ſo that the negative ſtate, in which it is in reality, cannot appear but when this metal is taken out of the preſſing action of the atmoſphere of the cake; and therefore the metal plate being removed, by the inſulating handle, from the cake, gives evident ſigns of having loſt a part of its natural ſhare of electric fluid; or, in other words, of being electrified negatively, the reſinous cake being more tenacious of the ſtate of electricity, which it had acquired, than the metal plate.

If the reſinous cake be in a ſtate of negative electricity, (which it acquires by a friction either with a dry hand, a piece of leather, or a rough ſkin; or by ſliding the nega-

tive part of a charged phial upon it, or by many other ways) the contrary muſt happen, *viz.* the electric fluid of the metal plate, finding a kind of vacuum upon the reſin cake, ruſhes upon it, and thus leaves its oppoſite extremity in a negative ſtate.

A conducting body, having its natural quantity of electric fluid, being brought near this metal plate, gives it a ſpark, which ſpark the metal plate retains as an additional quantity. If the metal plate be afterwards ſeparated from the cake, it muſt retain this additional quantity which it has received from the approaching body; becauſe the reſinous cake being, from its nature, more tenacious of the ſtate of electricity acquired than the metal, remains thereabout in the ſame condition as it was before the metal plate was placed upon it; but the metal plate, having acquired an additional quantity in the time it was placed upon the cake, carries with it this quantity, and muſt therefore return from the cake in a poſitive ſtate.

This confirms what I ſaid before, that in the firſt caſe the cake of reſin does not quit readily the electric fluid which it had acquired; and, in the ſecond caſe, does not ſteal from the metal plate the electric fluid which it had loſt.

What happens to the metal plate placed upon the reſinous cake happens alſo to the metal upon which the reſinous cake is commonly fixed; but the reverſe muſt

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take place, that is to ſay, when the upper plate is taken off the cake in a poſitive ſtate, the metal under the cake muſt be found in a negative ſtate, if the electrophore be placed upon an electrical ſtand.

It may be aſked, what difference there is between an electrophore and a coated phial, or a flat glaſs coated on both ſides and charged? I anſwer, that there is none at all, if both or only one of the metallic coatings can be taken off by ſilk ſtrings, a piece of ſealing wax, or any other inſulating ſubſtance. The very ſame day I received the electrophore ſent to me by his Royal Highneſs the Archduke FERDINAND from Milan (which electrophore was a thin reſinous cake ſtuck upon a flat piece of metal, to which was adapted a metal plate furniſhed with a glaſs handle to lift it up) I produced the ſame appearance by a common pane of glaſs and the metal plate of the electrophore; but ſoon finding that glaſs, however dry, quickly loſes its electricity (probably from its eaſily attracting moiſture from the air) I tried to cover it with a reſinous ſubſtance, or to varniſh it over with a hard copal varniſh; by which means it was eaſily excited by friction, and retained a long while the electrical power, though not ſo long as the reſinous cake.

I will now explain the nature of an electrophore in a manner more familiar to electricians, who underſtand

the received theory, by taking inftead of an electrophore only a common pane of glafs, adapted as a magical picture, with this difference only, that both coatings may be taken off by filk ftrings faftened to them, or by pieces of fealing wax. Having eftablifhed a free communication between the common ftock and the under coating, apply the upper coating to the prime conductor of an ordinary electrical machine, the pane of glafs is charged in the common way. The prime conductor has forced a fuper-abundant quantity of electric fluid upon the furface next to it, by means of the coating, and as much is forced out of the oppofite furface, and driven into the common ftock. Open a metallic communication between the two coatings, and inftantly the glafs will be, as we call it, difcharged: and, indeed, it is fo to all appearance; but, if we examine more accurately what has happened, we fhall find, that the upper metallic coating has parted, by the difcharge, with all the electric fluid which the prime conductor had forced upon it, and even with that part of its own electric fluid which the repellent power of the fuper-abundant electric fluid, communicated to that furface of the glafs by the force of charging, had driven into it; and that the under coating has recovered as much as the glafs had forced through it into the common ftock, and has above that acquired or abforbed that additional

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quantity which that furface of the glafs, being brought into a negative ftate, had drawn from the metal itfelf. And thus it will appear, that the glafs had, in the difcharging, by no means parted with that ftate of electricity which it had acquired by the force of charging.

Now, glafs and all electric fubftances receiving with more difficulty a ftate of electricity, and parting with it with more reluctance, the confequence muft be, that, when the two coatings are feparated from the glafs, fo as not to be in the way of abforbing or lofing the electric fluid by other conducting bodies being near them, the upper coating, which was pofitive when the glafs was charged, and nearly in its natural ftate, when after the difcharge it remained in conjunction with the glafs, muft now give figns of a negative electricity, having loft by the difcharge a fhare of even its natural electric fluid in the manner mentioned. The under coating, which was in a negative ftate when the glafs was charged, and (like the other coating) in a natural ftate when after the difcharge it remained in conjunction with the glafs, muft now, being feparated from the glafs, be in a pofitive ftate, becaufe it had abforbed a quantity of electric fluid in the manner explained; which fuper-abundant quantity it muft take with it in the moment of feparation from the glafs, becaufe the glafs being unwilling eafily to change its

its acquired ſtate of electricity leaves the metal without robbing it of that quantity of fluid which it had acquired.

If theſe two coatings, ſeparated from the glaſs, are brought near one another, they attract each other; a ſpark enſues, becauſe the coating, which has acquired a ſuper-abundant quantity of electric fluid, imparts it to the other, which had loſt as much; and thus a perfect equilibrium is reſtored between them.

If both theſe coatings are applied as before upon the ſame glaſs, a poſitive ſpark may be obtained from the uppermoſt coating, and a negative one from the other. If they are ſeparated again from the glaſs, as in the firſt caſe, the uppermoſt coating will afford a negative ſpark, and the undermoſt a poſitive; and theſe alternate ſparks may be continued a very long while.

This explanation or theory agrees perfectly with the experiments exhibited by our deceaſed member, the late Mr. CANTON, with elder pith balls hanging by linen threads from a wooden box, which balls are excited either negatively or poſitively by a piece of excited glaſs.