Introduction: Thinking About Electricity

THROUGHOUT the *Experimental Researches,* Faraday contrives phenomena that permit, to a truly remarkable extent, the essential characters and forms of electric and magnetic action to reveal themselves quite directly. That, along with his extraordinary gift for prose narrative, helps to make his writings both accessible and rewarding to the nonspecializing thoughtful reader. Nevertheless, he regularly employs instruments, and alludes to theories (sometimes theories with which he is profoundly dissatisfied), to which many readers may desire some introduction. In these instances it is not so important for the reader to gain scientific or historical grounding as it is to attain a measure of independence from present-day preconceptions and conventionalities about electricity and magnetism. As examples, we may point to the persistent notion of electricity as an active fluid, and to the image of electric *current* as the transport of that fluid. We acquire such ideas not only from our formal education but from the very artifacts of our culture. The idea of electric flow is seemingly confirmed every time we plug in a household appliance. The idea of electricity as a store of active substance is seemingly validated every time we replace a flashlight battery.

This makes electricity hard to think about, since to do so accurately requires us to remove a patina of insufficiently examined concepts, images, and habitual associations. We are after all surrounded with things we have always known to be "electrical."* Every one of us has grown up with electricity, the most ubiquitous of industrial age amenities—available, as used to be said, "at the touch of a button."

But when Faraday wrote, most of the things that were undoubtedly "electrical" in nature required at least some skillful effort, and often some specialized equipment, to witness; while those phenomena that were within everyday reach, and which were *perhaps* electrical in nature, were at the same time highly questionable. Was lightning "electrical"? Was the spark one produced when stroking a cat's fur on a dry day? Was the shock of the Mediterranean torpedo fish "electrical"?

For many years Faraday carried on a program of young people's lectures on scientific topics, which he offered annually during the Christmas holidays. Part of Faraday's success as a public lecturer was to

* Almost at a glance, it seems, we recognize the following as "electrical": light bulb, motor, spark, shock; but is it obvious that all these have anything in common, by virtue of which they are ranked together? And if so, what would that be? Note how much of our so-called "electrical" experience depends on *devices* which were in large measure shaped by theoretical conceptions.

bring natural phenomena, which in fact required practice, skill, and dexterity to produce, within the compass of experience and interpretive ability possessed by people of general background, even by children. Faraday's young audience had, otherwise, scant occasion to witness such wonderful phenomena. But they evidently needed little more than access to them—the wonder came of itself. We have the opposite problem of excessive familiarity with electricity, both in our experience and in our conventional discourse about it. The ubiquity of electrical and other natural powers has paradoxically distanced them from us and has deprived us of the ability to be "at home" among them. We recognize them as facts but not as the bearers of meanings. They seldom speak to us; they seldom occasion wonder.

Actually, even Faraday's audience seems to have experienced our problem, though not in connection with electricity. In the first of the 1859 young people's lectures* Faraday remarks on the difficulty of remembering to *wonder* (the special gift, he thinks, of children):

> Let us now consider, for a little while, how wonderfully we stand upon this world. Here it is we are born, bred, and live, and yet we view these things with an almost entire absence of wonder to ourselves respecting the way in which all this happens. So small, indeed is our wonder, that we are never taken by surprise; and I do think that, to a young person of ten, fifteen, or twenty years of age, perhaps the first sight of a cataract or a mountain would occasion him more surprise than he had ever felt concerning the means of his own existence—how he came here; how he lives; by what means he stands upright; and through what means he moves about from place to place. Hence, we come into this world, we live, and depart from it, without our thoughts being called specifically to consider how all this takes place; and were it not for the exertions of some few inquiring minds, who have looked *into* these things and ascertained the very beautiful laws and conditions by which we *do* live and stand upon the earth, we should hardly be aware that there was anything wonderful in it.

The purpose of the following remarks, then, is not to instruct readers in the fundamentals of electrical theory, nor is it to provide "historical background." It is rather to trace a path that springs not

* Michael Faraday, *On the Various Forces of Matter and their Relations to Each Other, a course of lectures delivered before a juvenile audience at the Royal Institution.* Ed. William Crookes. London, 1860. See the opening of Lecture I. The "1859 lectures," six in number, began in December 1859 and concluded in January 1860.

from our conventional representations of electricity but from a few seminal experiences, which you may at least imagine, and in some cases recreate for yourself. I hope that may help you to think about electric and magnetic phenomena independently of the conventionalities that currently frame them. Perhaps you will even be moved to *wonder* at them.

So our position is not so very different from that of Faraday's young Christmas Lecture audiences after all: They needed to see instances of electric and magnetic action; we need to see them with fresh eyes. For that reason the remainder of this introduction will incorporate some generous excerpts from those lectures. You could say, as one early reader did, that I've arranged to have *Faraday* write the introduction!

If, therefore, you read the remainder of this introduction before beginning the First Series, you will still be engaged in reading Faraday's words. But if you decide instead to turn right away to the First Series itself—and there is much to be said in favor of that—you will find that I have supplied references to the topics discussed so that you may turn back and consult individual sections of the introduction as needed.

Frictional electricity

Almost the only one of our "electrical" experiences that does not depend on sophisticated industrial devices is *frictional electricity*—the electricity developed when walking across some kinds of carpeting on a dry day, or sliding along a sofa upholstered with certain fabrics—electricity developed, in general, by rubbing one material against another.

The earliest known instance of frictional electricity, and the one that gave electricity its name, is mentioned by Thales of Miletus (600 B.C.E.) as a peculiarity of the substance *amber* (Greek *elektron*). This fossilized resin, when rubbed with silk or flannel, acquires the power of attracting bits of thread or dust. Similar attractive powers are found in glass, especially when rubbed with silk, and also in rubber, especially when stroked with fur. The condition, properly called *electrification*, can often be transferred from one body to another, either directly by contact or through intermediate bodies; and such transferability suggested to many investigators the idea of electricity as a mobile or even fluid substance that becomes concentrated or accumulated in the electrified body. It is probably to that conception of a material fluid that we owe the electrical term most familiar to us, the term *charge*—from its archaic meaning of a material *load* or *weight*. As we will see in his writings, however, Faraday was consistently skeptical of this "fluid" image.

Faraday described several of the chief characteristics of frictional electricity in the Christmas Lectures of 1859. The lectures were transcribed verbatim and subsequently published with illustrations. The following excerpt is from Lecture V. The remarks in bracketed italics, which provide a running narrative of Faraday's manipulations, were supplied by William Crookes:

> To-day we come to a kind of attraction even more curious than the last, namely, the attraction which we find to be of a double nature—of a curious and dual nature. And I want first of all to make the nature of this double-ness clear to you. Bodies are sometimes endowed with a wonderful attraction, which is not found in them in their ordinary state. For instance, here is a piece of shell-lac,* having the attraction of gravitation, having the attraction of cohesion; and if I set fire to it, it would have the attraction of chemical affinity to the oxygen in the atmosphere. Now all these powers we find in it as if they were parts of its substance; but there is another property which I will try and make evident by means of this ball, this bubble of air [*a light India-rubber ball, inflated and suspended by a thread*]. There is no attraction between this ball and this shell-lac at present: there may be a little wind in the room slightly moving the ball about, but there is no attraction. But if I rub the shell-lac with a piece of flannel [*rubbing the shell-lac, and then holding it near the ball*], look at the attraction which has arisen out of the shell-lac, simply by this friction, and which I may take away as easily by drawing it gently through my hand. [*The Lecturer repeated the experiment of exciting the shell-lac, and then removing the attractive power by drawing it through his hand.*] Again, you will see I can repeat this experiment with another substance; for if I take a glass rod and rub it with a piece of silk covered with what we call amalgam,** look at the attraction which it has, how it draws the ball towards it; and then, as before, by quietly rubbing it through the hand, the attraction will be all removed again, to come back by friction with this silk.

* *Shell-lac* is a resinous substance prepared from a secretion of certain insects. It can be cast into solid forms, as in Faraday's examples. Dissolved in alcohol, it becomes the "shellac" we know as a wood finish.

** *Amalgam*: usually a soft metallic alloy with mercury (from Greek *malassein*, to soften); by extension, any combination with mercury. In his *History and Present State of Electricity* (London, 1767) Priestley described the benefits of impregnating oiled silk with "an amalgam of mercury and tin, with a very little chalk or whiting." A glass object rubbed with the treated silk "may be excited to a very great degree with very little friction."

But now we come to another fact. I will take this piece of shell-lac and make it attractive by friction; and remember that whenever we get an attraction of gravity, chemical affinity, adhesion, or electricity (as in this case), the body which attracts is attracted also; and just as much as that ball was attracted by the shell-lac, the shell-lac was attracted by the ball. Now, I will suspend this piece of excited shell-lac in a little paper stirrup, in this way [Fig. 33],* in order to make it move easily, and I will take another piece of shell-lac, and after rubbing it with flannel, will bring them near together. You will think that they ought to attract each other; but now what happens? It does not attract; on the contrary, it very strongly *repels*, and I can thus drive it round to any extent. These, therefore, repel each other, although they are so strongly attractive—repel each other to the extent of driving this heavy piece of shell-lac round and round in this way. But if I excite this piece of shell-lac, as before, and take this piece of glass and rub it with silk, and then bring them near, what think you will happen? [*The Lecturer held the excited glass near the excited shell-lac, when they attracted each other strongly.*] You see, therefore, what a difference there is between these two attractions—they are actually two *kinds* of attraction concerned in this case, quite different to anything we have met with before; but the force is the same. We have here, then, a double attraction—a dual attraction or force—one attracting, and the other repelling.

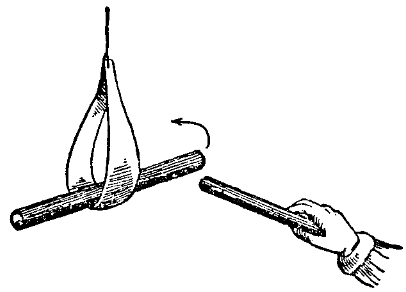


FIG. 33.

Again, to shew you another experiment which will help to make this clear to you. Suppose I set up this rough indicator again [*the excited shell-lac suspended in the stirrup*]—it is rough, but delicate enough for my purpose; and suppose I take this other piece of shell-lac, and take away the power, which I can do by drawing it gently through the hand; and suppose I take a piece of flannel [Fig. 34], which I have shaped into a cap for it and made dry. I will put this shell-lac into the flannel, and here comes out a very beautiful result. I will rub

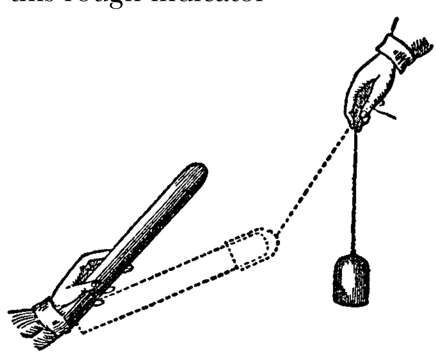


FIG. 34.

* Figure numbers are those of the published lecture.

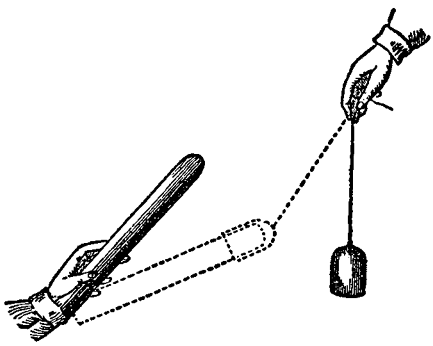


Fig. 34.

this shell-lac and the flannel together (which I can do by twisting the shell-lac round), and leave them in contact; and then, if I ask, by bringing them nearer our indicator—what is the attractive force?—it is nothing! But if I take them apart, and then ask what will they do when they are separated—why, the shell-lac is strongly repelled, as it was before, but the cap is strongly attractive; and yet if I bring them both together again, there is no attraction—it has all disappeared. [*The experiment was repeated.*] Those two bodies, therefore, still contain this attractive power: when they were parted, it was evident to your senses that they had it, though they do not attract when they are together.

This, then, is sufficient in the outset to give you an idea of the nature of the force which we call electricity. There is no end to the things from which you can evolve this power. When you go home, take a stick of sealing-wax—I have rather a large stick, but a smaller one will do—and make an indicator of this sort [Fig. 35].* Take a watch-glass (or your watch itself will do; you only want something which shall have a round face), and now, if you place a piece of flat glass upon that, you have a very easily moved centre. And if I take this lath and put it on the flat glass (you see I am searching for the centre of gravity of this lath—I want to balance it upon the watch-glass), it is very easily moved round; and if I take this piece of sealing-wax and rub it against my coat, and then try whether it is attractive [*holding it near the lath*], you see how strong the

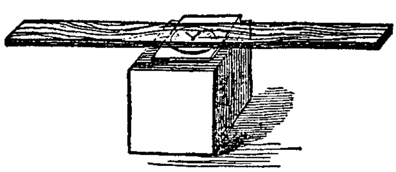


Fig. 35.

* In Figure 35, a block of wood or other material serves as the base. Upon it rests the convex glass of his pocket-watch; then a piece of flat glass; finally the wooden strip ("lath") is balanced upon the whole. The curved and flat glass surfaces together make a low-friction pivot, which permits the lath to turn easily.

Because Faraday interrupts his thought in mid-sentence ("take a stick of sealing-wax … and make an indicator of this sort"), you might think the sealing wax is part of the indicator. It is not, though. As Faraday soon explains, the function of the sealing wax is to be made attractive by rubbing, like the glass rod and the stick of shell-lac in his previous examples.

attraction is; I can even draw it about. Here, then, you have a very beautiful indicator, for I have, with a small piece of sealing-wax and my coat, pulled round a plank of that kind; so you need be in no want of indicators to discover the presence of this attraction. There is scarcely a substance which we may not use. Here are some indicators. I bend round a strip of paper into a hoop [Fig. 36], and we have as good an indicator as can be required. See how it rolls along, travelling after the sealing-wax. If I make them smaller, of course we have them running faster, and sometimes they are actually attracted up into the air. Here also is a little collodion* balloon. It is so electrical that it will scarcely leave my hand unless to go to the other. See, how curiously electrical it is: it is hardly possible for me to touch it without making it electrical; and here is a piece which clings to anything it is brought near, and which it is not easy to lay down. And here is another substance, gutta-percha,** in thin strips: it is astonishing how, by rubbing this in your hands, you make it electrical. But our time forbids us to go further into this subject at present. You see clearly there are two kinds of electricities which may be obtained by rubbing shell-lac with flannel, or glass with silk.

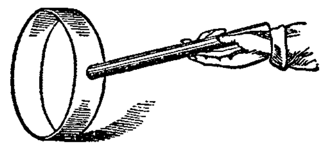


FIG. 36.

In the experiments illustrated in Figs. 33 and 34 of the preceding excerpt, Faraday showed that *the electric condition exists in two varieties*, which moreover are *antithetical*: that is, they are capable of nullifying or neutralizing one another. The conventional terms *positive* (for the electric condition exhibited by glass) and *negative* (for the condition exhibited by shell-lac) express perfectly that relation of opposition.*** It does not take too much more experimentation of the sort illustrated

* *Collodion* is a glutinous material used as a coating in photography and medicine, also in theatrical makeup.

** *Gutta-percha* is the tough plastic substance also called "hard rubber" because it contains more resin than true rubber. It is often used for pocket combs.

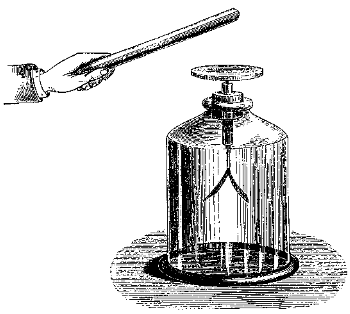
*** The nomenclature "positive" and "negative" was introduced by Benjamin Franklin. He interpreted the contrary electrical conditions as representing *excess* (+) and *deficiency* (–) of a single electrical fluid, whereas other theorists had postulated the existence of dual electric fluids—a "vitreous" fluid in glass and a "resinous" fluid in rubber, shell-lac, sealing wax, and similar materials. Faraday willingly employs the Franklin terminology in his *Experimental Researches* but, as I noted earlier, he is highly skeptical of *any* "fluid" imagery, single or dual.

in Fig. 33 to verify that *oppositely-electrified bodies attract one another,* and *similarly-electrified bodies repel one another.* We have, however, yet to explain how *nonelectrified* bodies are attracted to *electrified* bodies, whether positive or negative—as in Faraday's figure 36.

The distinctively *electrical* power, then—and for now our principal sign of the presence and degree of electrification—is *attraction and repulsion.* All of the "indicators" Faraday exhibited in the preceding excerpt made use of the attractive or repulsive power of electrified bodies.

The electroscope

The *electroscope* is a more refined indicator that employs repulsion to show the electrical condition of bodies near it or in contact with it. The drawing shows a common *leaf electroscope,* which consists of two metal foil leaves suspended side by side from a metal support; this in turn is connected to a sensing plate. The foil leaves are protected from air currents by a glass enclosure.

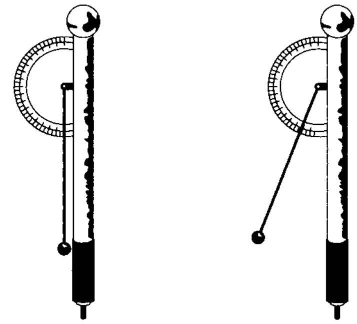


If now an electrified rod is brought into the vicinity of the plate, we observe the leaves begin to diverge. Their separation increases as the rod approaches, and it decreases if the rod is again withdrawn. Is this indeed a case of mutual repulsion, as in Faraday's shell-lac indicator, which was repelled by a similarly-charged rod of shell-lac?

The question is clarified to some extent if we permit the electrified rod to *touch* the plate; for then the leaves separate—*and remain separated even when the rod is removed to a great distance.* It is reasonable to infer that through contact, the electrified rod has communicated a portion of its electrification to the electroscope, and that consequently the two leaves, being now in a similar electrical condition, repel one another and diverge. It follows then that the angle of their divergence will indicate (roughly) the degree of the electroscope's charge, and hence (even more roughly) the degree of electrification of the body that contacted it.

Thus it seems necessary to infer that even when the divergence is maintained by the approach, without contact, of an electrified rod, the diverging leaves have taken on similar electrical conditions. And yet electrification has not been permanently *transferred* from rod to leaves, as the divergence ceases as soon as the rod is withdrawn. Evidently an electrical state in the *leaves* has been somehow "induced"—that is the conventional name, but it explains nothing, as Faraday fully realizes—by the presence of the electrified *rod*. Faraday will allude to this kind of *electric induction* in the opening paragraph of the present Series.

A form of electroscope much favored by Faraday uses only a *single* moving indicator, usually a dried straw lightly weighted with a pith or cork ball.* As the drawing shows, it is pivoted at one end. The principle is evidently the same as for the leaf electroscope: when the supporting post is electrified it communicates some of its condition to the straw, which is therefore repelled by the similarly-electrified post.



"Static" electricity and electric discharge

Loss of the electrified or charged condition is *discharge*. Discharge may occur when an electrified body is brought into contact with a much larger body. In the lecture excerpt, for example, Faraday called attention to the discharge (he did not use that term) of electrified rods that occurred when he passed them across his hands.** Discharge can also occur with a *spark*, as Faraday will demonstrate on page 11 below.

We are thus led to distinguish between the persistent or *static* condition of electrification, which is manifest primarily by the power to attract and repel, and the condition of *discharging*, which is a passing condition, usually too short-lived to be studied in itself. Thus frictional electricity was conceived as *essentially* static—literally, quiescent or unchanging. That conception survives in our present term, "static electricity." It is however an awkward nomenclature, because the phenomena we usually have in mind when we use that term—from the shock we sometimes experience in a carpeted room to the crashing noises that intrude in radio and telephone reception—are instances of

* The chief function of the ball, though, is not to add weight but to provide a blunt surface in place of the sharp straw end. As Faraday discusses elsewhere, a sharp or pointed body readily tends to discharge into the air. The terminating ball helps to prevent such a discharge.

** For example: "look at the attraction which has arisen out of the shell-lac, simply by this friction, and which I may take away as easily by drawing it gently through my hand" on page 4 above. Another way to discharge a body, or even prevent it from acquiring an electrical charge, is by suitably connecting it to the *earth*—thereby *grounding* (or, as the British say, *earthing*) it.

discharge, not in any way quiescent. I can think of only one everyday instance of "static" electricity that really is static: that is *clinging*—as when a rubbed balloon clings to a wall, or when clothing clings together after removal from a clothes dryer.

For centuries after its discovery in amber, frictional electricity, as evidenced by attraction and repulsion, was the *only* electricity. Even Faraday calls it "ordinary" electricity (for example, paragraphs 24 and 25 in the First Series); and when he uses the term "excitation," he refers specifically to the raising of an electrical condition by rubbing or friction.* Up to now the only frictional processes we have considered have been *discontinuous*: In the lecture excerpt above, for example, Faraday described experiments that repeatedly cycled between frictional *excitation* of glass or shell-lac, and subsequent *discharge* of those materials. But later in the same talk he employs a mechanism that exhibits *continuous* excitation and discharge. This device, and a whole class of similar ones, Faraday calls electric "machines." Let us return to his account:

> ... And now we will return for a short time to the subject treated at the commencement of this lecture. You see here [Fig. 41] a large machine, arranged for the purpose of

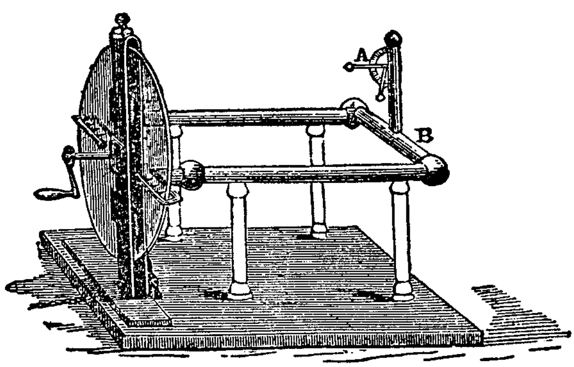


FIG. 41.

> rubbing glass with silk, and for obtaining the power called electricity; and the moment the handle of the machine is turned, a certain amount of electricity is evolved as you will

* For example: "I will suspend this piece of excited shell-lac..." on page 5 above.

see by the rise of the little straw indicator [*at* A].* Now, I know from the appearance of repulsion of the pith ball at the end of the straw, that electricity is present in those brass conductors and I want you to see the manner in which that electricity can pass away. [*Touching the conductor* B *with his finger, the Lecturer drew a spark from it, and the straw electrometer immediately fell.*] There, it has all gone; and that I have really taken it away, you shall see by an experiment of this sort. If I hold this cylinder of brass by the glass handle, and touch the conductor with it, I take away a little of the electricity. You see the spark in which it passes, and observe that the pith-ball indicator has fallen a little, which seems to imply that so much electricity is lost; but it is not lost: it is here in this brass; and I can take it away and carry it about, not because it has any substance of its own, but by some strange property which we have not before met with as belonging to any other force. Let us see whether we have it here or not. [*The Lecturer brought the charged cylinder to a jet from which gas was issuing; the spark was seen to pass from the cylinder to the jet, but the gas did not light.*] Ah! the gas did not light, but you saw the spark; there is, perhaps, some draught in the room which blew the gas on one side, or else it would light. We will try this experiment afterwards. You see from the spark that I can transfer the power from the machine to this cylinder, and then carry it away and give it to some other body....

But with regard to the travelling of electricity from place to place, its rapidity is astonishing. I will, first of all, take these pieces of glass and metal, and you will soon understand how it is that the glass does not lose the power which it acquired when it is rubbed by the silk. By one or two experiments I will shew you. If I take this piece of brass and bring it near the machine, you see how the electricity leaves the latter, and passes to the brass cylinder. And, again, if I take a rod of metal and touch the machine with it, I lower the indicator; but when I touch it with a rod of glass, no power is drawn away—shewing you that the electricity is conducted by the glass and the metal in a manner entirely different: and to make you see that more clearly, we will take one of our Leyden jars—

The Leyden jar

I interrupt Faraday's narrative because, astonishingly, he seems to feel no need to introduce the *Leyden jar* to his young audience. Perhaps those devices were as commonplace to them as flashlight batteries are

* Note that this indicator is an electroscope of the kind described on page 9 above.