



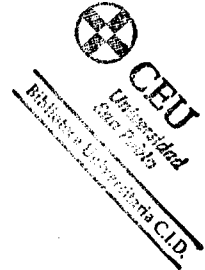
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ORIGINS OF ELECTROTHERAPY

Part I

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We find ourselves compelled to admit that there is in existence a certain power, which by the very emissions therefrom is enabled to affect the members of the human body. What then are we not to hope from the remedial influences which Nature has centered in this and all animated creatures!

—Pliny the Elder, circa A.D. 70

The Sacred Books of the Hellenes related that Salmoneus, King of Elis, tried to imitate lightning. This affront so outraged Zeus that he killed him by a salvo of thunderbolts.

His successors have fared much better. The essence of lightning has been captured and yoked. When directed to healing purposes it has sometimes resuscitated even people suffering from effects similar to those which prostrated Salmoneus.

Animated minerals

The origins of magnetism and electricity are lost in the night of ages.

Amber is a fossil resin from coniferous forests which blanketed the Baltic basin during the Eocene era, some six to seven million years ago. When rubbed vigorously, amber attracts feathers, lint, chaff, bits of paper, pith, straw, and so on. This peculiar property did not escape the notice of even Neanderthal man. Considering the substance to be supernatural, he carved it into talismans or religious ornaments.

The Greeks called amber *elektron* after its sunshine hues. This name was vulgarized to *electron* by the Romans, although amber is *succinum* in pure Latin. The universality of observation is shown in the Arabian *karabé* and Persian *karubé*,

both of which are names for amber meaning literally "to pull straw."

Another mineral lay in vast deposits at Magnesia in the realm of Thessaly. This metallic ore, siderite or magnetite, had an affinity for pulverized fragments of the same substance and also iron filings. Its enigmatic attributes caused the stone to be prized. The indigenous name for it was *magneta* or *magnetis lithos*. Slivers or needles of the purified metal were observed to arrange themselves so as to point consistently in one direction.

Around 1000 B.C., when the Heraclidae migrated back to the Peloponnesus, they were guided across the trackless plains of Tartary by a magnetite effigy of a man whose outstretched arms, rotating freely on a pivot, always pointed south. Some Chinese, Florentine, and Venetian mariners had primitive compasses made from the metal. The English word, loadstone (or lodestone), derives from the Anglo-Saxon *laeden*, to lead or conduct.

The Hebrews tacitly regarded the wonderful minerals merely as the workings of the inscrutable Almighty. In the *Talmud* the loadstone is referred to by a word which signifies "the stone that attracts." Polytheistic or pantheistic civilizations, on the other hand, made more of a fuss over them.

In 600 B.C. Thales of Miletus, one of the Seven Sages of Greece, commented that "*elektron* is endowed with a soul which draws light bodies unto itself like a breath, and is nourished by them."

In one of his *Dialogues* Plato observed,

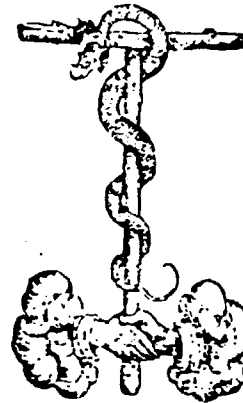
For as I was saying just now, this is not an art in you, whereby you speak well on Homer, but a divine power, which moves you like that in the stone which Eurip-



(a)

G V I L I E L M I G I L
B E R T I C O L C E S T R E N -
S I S . M E D I C I L O N D I -
N E N S I S .

D E M A G N E T E , M A G N E T I -
C I S Q V E C O R P O R I B V S . E T D E M A G -
n o m a g n e t e t e l l u r e ; P h y s i o l o g i a n o v a ,
plurimis & argumentis, & expe-
riementis demonstrata.



L O N D I N I
E X C V D E B A T P I E T R U S S A L I A N N O
M D C .

(b)

FIGURE 1. (a) William Gilbert. (b) Frontispiece of his book in which Latin equivalents of words "electricity" and "electric" were used for first time.

ides named Magnetis, but most people call Heraclea. For this stone not only attracts iron rings but also imparts to them a power whereby they in turn are able to do the very same thing as the stone, and attract other rings; so that sometimes there is formed quite a long chain of bits of iron and rings, suspended one from another; and they all depend for this power on that one stone.

The philosophic implications of the soul forces of both amber and the loadstone were discoursed on by Socrates, Diogenes Laërtius, Lucretius Carus, and others. How could anyone discount their kinship to the celestial firebolts favored by a motley group of wrathful deities, the Egyptian Amon-Re, the Vedic Dyauh Pitar, the Greek Zeus, the Etruscan Tinia, the Roman Jupiter Tonans?

In 1600 the Elizabethan physician William Gilbert proved that the magnetic pole was terrestrial rather than astral (Fig. 1).¹ Coincidentally he invented the word electric or rather its Latin equiva-

lent, to describe substances which behaved like amber when rubbed. Had Gilbert chosen any other than the Greek etymologic root, today we would doubtless be saying amberic or succinic. The historic sentences in Gilbert's treatise in which electric is used for the first time are:

Vim illam electricam nobis placet appellare quae ab humore provenit. . . . Electrica, quae attrahunt eadem ratione ut electrum.

Evidently, enlightened though he was, Gilbert, too, leaned toward the metaphysical in his interpretation of magnetism:

Magnetic force is animate, or imitates life; and in many things surpasses life, while this is bound up in the organic body.

While awaiting a proper scientific explanation, the prodigious qualities of both minerals were not

overlooked by our medical forebears. Starting around 9000 B.C., bracelets, necklaces, and other appurtenances were used to prevent or assuage headache, arthralgia, and numerous visceral upheavals.

Theoprastus Paracelsus, for one, was enchanted with the properties of the stones, which corresponded neatly with his tenets about the archaic etiology of disease.² He prescribed the loadstone with great abandon. Even the prestigious Jean van Helmont wrote a tract "on the magnetic cure of wounds."²

Naturally, the "fluid spirits" emanating from amber or loadstone were not perceptible to the senses; accordingly the devices made from them may be viewed in the same light as the countless amulets and kindred paraphernalia peddled throughout the centuries to ward off sickness or to neutralize it.

Did these fanciful superstitions taint only the ancients? No. In 1837 a sincere physician named Henry Sherwood³ blithely foisted on an all-too-gullible public a brand of electromagnetic "animated" minerals. His merchandise, advertised for the cure of scrofula, consisted of negatively charged gold pills and positively charged emplastrums. In 1881 a scientist (not Mesmer) insisted that he could modify cardiac rhythmicity and intestinal peristalsis by magnetism.⁴ As late as the end of the nineteenth century Swedish peasants still indulged in a deep-rooted custom of lying parallel to the magnetic meridian so as to thwart various maladies, principally neuralgia.⁵ And even to this day there are some people who carry a horseshoe magnet in their pocket as a sort of panacean prophylactic.

Electroichthyology

Much as the "animated minerals" impressed the ancients, a yet greater sense of awe was inspired by certain fish. Seldom similar phylogenetically, in appearance or in habitat, these creatures shared in common one sensational peculiarity, the ability to unloose a convective blast which was violent enough to stun other animals into immobility. Since this impact, an electric shock, was eventually utilized with therapeutic intent, we may consider it to be the first genuine application of electricity in medicine.

The electroichthyologic fauna comprise disparate species: eels, rays, stargazers, shad, and so forth. A few are denizens of the same oceans. Most were known by bygone societies, such as Pharaonic Egypt, probably as a food staple, since reliefs of fishing scenes show them being netted with other edible specimens (Fig. 2). In 1816 a naturalist reported:

The torpedo, termed la tremble by the lower orders in France, is met with in considerable quantities, as

has been long known, on the whole extent of coast between the Loire and the Garonne. It is generally caught by the trawl. Though not esteemed, it is yet eaten by the poorer inhabitants, being first skinned and dried. The electrical organs are carefully avoided in eating, being considered to possess some disagreeable properties.

... When the torpedos were placed in a bucket of water, the fishermen amused themselves by exposing the smaller fish to their electrical power.⁶

The Greeks designated the electric fish by the collective term "narke," or numbness-producing, from which the word "narcosis" originates. The name was subsequently latinized to torpedo from torpere, meaning to render sluggish, inert, stiff. Correctly speaking, the torpedos are the electric rays, or family Torpedinidae. It is interesting to note how different peoples independently coined similar names for the creatures: South American Indians called them arimna, "something that deprives of motion"; the Arabians, rahadh, "that which causes trembling"; and the Spaniards, trembladores, "tremblers" or "producers of trembling."

In the *Dialogues*, Plato said,

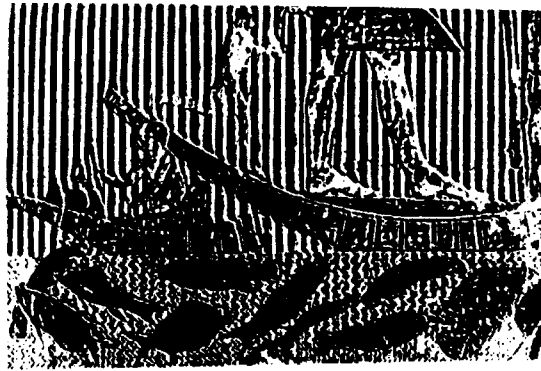
O Socrates, . . . if I may venture to make a jest upon you, you seem both in your appearance and in your power over others to be like a torpedo fish, who torpifies those who come near him and touch him, as you have now torpified me, I think. For my soul and my tongue are really torpid and I do not know how to answer you. . . .¹

In the *Historia Animalium*, Aristotle⁷ stated,

The torpedo narcotizes the creatures that it wants to catch, overpowering them by the force of shock that is resident in its body, and feeds upon them. It also hides in the sand and mud, and catches all the creatures that swim in its way and come under its narcotizing influence. This phenomenon has been actually observed in operation. . . . That the creatures get their living by this means is obvious from the fact that, whereas they are peculiarly inactive, they are often caught with mullets, the swiftest of fishes, in their interior. . . . The torpedo is known to cause a numbness even in human beings.

In his *Natural History*, Pliny⁸ observed,

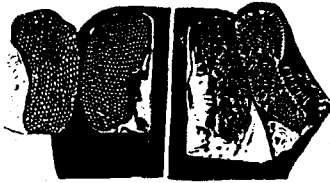
I marvel at them who are of opinion that fishes and beasts in the water have no sense. Why, the very cramp-fish Tarped (that is, Torpedo) knows its own force and power, and being itself not benumbed, is able to astonish others. It lies hidden over head and ears within the mud unseen, ready to catch those fishes, which as they swim over it, are taken with a numbness, as if they were dead. . . . From a considerable distance even, and if only touched with a spear or staff this fish has the power of benumbing even the most vigorous arm, and of riveting the feet of a runner, however swift he may be in the race.



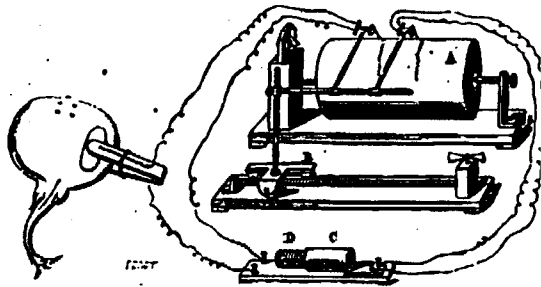
(a)



(b)



(c)



(d)

FIGURE 2. Electroichthyology. (a) Fishing scenes in bas-relief from Pharaonic Egypt show Nile shad which release electricity. (b) Torpedo, an electric ray, drawn by Engelbrecht Kaempfer in 1712. (c) Electric organ of torpedo dissected by John Walsh in 1773. (d) Etienne Marey's preparation for registering graphically electric discharges from torpedo.

Pliny added that in certain African nations Spartan tribes bred intrepidity in their offspring by making them swim in torpedo-infested lakes.

Plutarch's version, in the *Morals*, alluded to conveyance of the shock through water:

You know yourself the property of the torpedo or cramp fish, which not only benumbs all those that touch it, but also strikes a numbness through the very net into the hands of them that go about to take it. And some that have had greater experience of this fish report that if it happens to fall alive upon the land,



FIGURE 3. Alexander von Humboldt, true Renaissance man and giant personality of science and culture. His interests in electricity ranged from anatomic peculiarities of electric fish to its biologic manifestations on mammals. His name has been given to ocean current off western coast of South America.

they that pour water upon it shall presently perceive a numbness seizing upon their hands and stupefying their feelings, through the water affected with the quality of the fish. And therefore having an innate sense of this faculty, it never takes any resistance against any thing nor is it ever in danger. Only swimming circularly about his prey, he shoots forth the effluvioms of his nature like so many darts, and first infects the water, then the fish through the water which is neither able to defend itself nor escape, being (as it were) held in chains and frozen up.⁶

Of the many other antique recitals concerning this marine demon, two are noteworthy for ascribing emission of the shock from specialized zones of the anatomy of the fish. In the *Carminum minorum*, Claudian declared,

Who has not heard of the invincible skill of the dread torpedo and of the powers that win it its name?

Its body is soft and its motion slow. Scarcely does it mark the sand o'er which it crawls so sluggishly. But nature has armed its flanks with a numbing poison and mingled with its marrow chill to freeze all living creatures, hiding as it were its own winter in its heart. The fish seconds nature's efforts with its own gullibility; knowing its own capabilities, it employs cunning, and trusting to its power of touch lies stretched full length among the seaweed and so attacks its prey. It stays motionless; all that have

touched it lie benumbed. Then, when success has crowned its efforts, it springs up and greedily devours without fear the living limbs of its victim.⁷

In the *Halieutica* the poet Oppian chanted,

The Cramp-Fish, when the pungent pain alarms,
Exerts his magick Pow'rs and poison'd Charms.
Clings around the Line, and bids th' Embrace infuse
From fertile Cells compest his subtil Juice
Th' aspiring Tide its restless Volumes rears,
Rolls up the steep Ascent of slippery Hairs,
Then down the Rod with easy Motion slides
And entering in the Fisher's Hand subsides.
On every Joint and icy stiffness steals,
The flowing Spirits binds, and Blood congeals
Down drops the Rod dismist, and floating lies,
Drawn captive in its Turn, the Fish's Prize.⁸

Von Humboldt,¹⁰ a universal genius of science, related how electric eels (*gymnoti*) were procured for him during his sojourn in South America (Fig. 3).

To catch the *gymnoti* with nets is very difficult, on account of the extreme agility of the fish, which bury themselves in the mud. We would not employ the barbasco, that is to say, the roots of the *Piscidea erithyrna*, the *Jacquinia armillaris*, and some species of *phyllanthus*, which thrown into the pool, intoxicate or benumb the eels. These methods have the effect of enfeebling the *gymnoti*. The Indians therefore told us that they would "fish with horses," (*embarbascar con caballos*). We found it difficult to form an idea of this extraordinary manner of fishing; but we soon saw our guides return from the savannah, which they had been scouring for wild horses and mules. They brought about thirty with them, which they forced to enter the pool.

The extraordinary noise caused by the horses' hoofs, makes the fish issue from the mud, and excites them to the attack. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organization presents a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surround the pool closely; and some climb up the trees, the branches of which extend horizontally over the surface of the water. By their wild cries, and the length of their reeds, they prevent the horses from running away and reaching the bank of the pool. The eels, stunned by the noise, defend themselves by the repeated discharge of their electric batteries. For a long interval they seem likely to prove victorious. Several horses sink beneath the violence of the invisible strokes which they receive from all sides, in organs the most essential to life; and stunned by the force and frequency of the shocks, they disappear under the water. Others, panting, with mane erect, and haggard eyes expressing anguish and dismay, raise themselves, and endeavour to flee from the storm by which they are overtaken. They are driven back by the Indians into the middle of the water; but a small number succeed in eluding the active vigilance of the fishermen. These regain the shore, stumbling at

every step, and stretch themselves on the sand, exhausted with fatigue, and with limbs benumbed by the electric shocks of the gymnoti.

In less than five minutes two of our horses were drowned. The eel being five feet long, and pressing itself against the belly of the horses, makes a discharge along the whole extent of its electric organ. It attacks at once the heart, the intestines, and the caeliac fold of the abdominal nerves. It is natural that the effect felt by the horses should be more powerful than that produced upon man by the touch of the same fish at only one of his extremities. The horses are probably not killed, but only stunned. They are drowned from the impossibility of rising amid the prolonged struggle between the other horses and the eels.

We had little doubt that the fishing would terminate by killing successively all the animals engaged; but by degrees the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. They require a long rest, and abundant nourishment, to repair the galvanic force which they have lost. The mules and horses appear less frightened; their manes are no longer bristled, and their eyes express less dread. The gymnoti approach timidly the edge of the marsh, where they are taken by means of small harpoons fastened to long cords. When the cords are very dry the Indians feel no shock in raising the fish into the air. In a few minutes we had five large eels, most of which were but slightly wounded. Some others were taken, by the same means, towards evening.

As would be expected, the marvelous electric fish promptly found a place in the pharmacopoeia. The flesh or individual viscera were given as nutrients, aphrodisiacs, depilatories, and other nostrums. More germane to our topic is the use of the fish in the live state.

According to legend, a certain Anteros, freed from slavery by the Emperor Tiberius Claudius Nero Caesar, stepped on a torpedo while walking on the beach. After the initial excruciating cramp in his foot had abated, he found to his amazement that the pain he had long suffered from gutta (gout) was completely banished. This event reached the ears of Scribonius Largus, a physician, whose *Compositiones medicae*, circa A.D. 50, carries the first known commentaries on the medicinal utility of the live fish:

For any type of gout a live black torpedo should, when the pain begins, be placed under the feet. The patient must stand on a moist shore washed by the sea and he should stay like this until his whole foot and leg up to the knee is numb. This takes away present pain and prevents pain from coming on if it has not already arisen. In this way Anteros, a freeman of Tiberius, was cured Headache even if it is chronic and unbearable is taken away and remedied forever by a live black torpedo placed on the spot which is in pain, until the pain ceases. As soon as the numbness has been felt the remedy should be removed lest the ability to feel be taken from the part. Moreover several torpedos of the same kind should be

prepared because the cure, that is, the torpor which is a sign of betterment is sometimes effective only after two or three.⁹

Pedanius Dioscorides, a coeval of Scribonius, wrote a huge compendium on pharmacology entitled *De re medica*. The electric fish was recommended for anal prolapse, besides gout and headache, presumably because it stimulated intense spasm of the sphincters.⁹

Claudius Galen ascribed mortification by the torpedo to a chilling humor which induced "frigidity and compression of the nervous bodies." This frigorific juice, which he compared to the magnetic effect of a loadstone, evidently oozed only from the living animal.

The whole torpedo, I mean the sea-torpedo, is said by some to cure headache and prolapsus ani when applied. I indeed tried both of these things and found neither to be true. Therefore I thought that the torpedo should be applied alive to the person who has the headache, and that it could be that this remedy is anodyne and could free the patient from pain as do other remedies which numb the senses: this I found to be so. And I think that he who first tried this did so for the above-mentioned reason.⁹

Many authors until the end of the Renaissance continued to cite recipes for the torpedo and its ilk. Marcellus Empiricus, Aetius of Amida, Alexander of Tralles, and Paulus Aeginata listed it among the specifics for various cephalgias and arthralgias. Serapion called it *pisces stupefaciens*. The Arabians emphasized the virtues of the sleep which followed the jolting contact with fish. Haly Abbas referred to the latter as the *pisces dormitans*. Avicenna and Averrhoës thought it efficacious when placed on the brow of persons afflicted with migraine, melancholy, or epilepsy. Persistence of this belief to the sixteenth century is exemplified by Dawud al Antaki's statement that,

If (the torpedo) is brought near, while alive, to the head of an epileptic, the latter will be thoroughly cured . . . it removes chronic headache, unilateral headache, and vertigo even in desperate cases.¹¹

A devastating sort of electroichthyologic treatment is relevant to our topic because it was mimicked and enjoyed long vogue when nonbiologic generators of electricity were developed. In 1761 a Dutch surgeon, van der Lott,¹² related "experiments" made in Surinam with the ferocious Conger eel:

Mr. Abraham van Doorn, ex-Councillor of the same Colony had a Negro boy among his slaves whose estimated age was eight or nine years. He was afflicted by an obstruction in his nerves in such a way that his arms and legs were drawn crooked. This gentleman threw the boy daily into a tub of water in

which there was a large Conger eel of the black variety. The boy was so greatly shocked by this that he crawled out on his hands and knees, but sometimes he was unable to do this, and he had to be helped, however the helper then received a portion of the shock. The result was that the boy recovered completely from the nerve disease, but the malformation of the shinbone which was associated with it nevertheless remained.

The gentleman referred to has also made the following two experiments. He threw a slave boy, who had bad fever, similarly into a tub with a Conger eel. The lad was so strongly shocked that this gentleman was forced to help him out again, but several minutes later the fever had disappeared and did not return. The second experiment was with an Indian boy who, having the fever very badly while traveling, had himself shocked by a Conger eel, the result being the same as in the previous case.

Piscine electricity was still being used in medicine as late as 1860.^{9,13,14} Hydroelectrotherapy of a gentler sort for intrathoracic diseases remained in style until the first half of the present century.

Although scaleless, electric fish have a tegumentary coat of slimy mucus which is permeable to electrical currents. They are utterly insensitive to the formidable broadside with which they assail quarry, notwithstanding their being themselves immersed in the same conductive medium. To date, no one has provided a wholly satisfactory answer for this mysterious invulnerability.

Early generators of electricity

It is an intriguing theory that the holy ark which the Israelites escorted on their arduous trek in the arid Sinai may have functioned as an electric condenser of high tension and thereby been the masterwork of Moses, that paragon of thaumaturgists.¹⁵⁻¹⁷

Genesis and *Numbers* expatiate on the story of the ark. Detailed directives for its construction were given by God to the first great emancipator. They specified, in part,

And they shall make an ark of shittim wood: two cubits and a half shall be the length thereof, and a cubit and a half the breadth thereof, and a cubit and a half the height thereof.

And thou shalt overlay it with pure gold, within and without shalt thou overlay it, and shalt make upon it a crown of gold round about.

And thou shalt cast four rings of gold for it, and put them in the four corners thereof; and two rings shall be in the one side of it, and two rings in the other side of it.

And thou shalt make staves of shittim wood, and overlay them with gold.

And thou shalt put the staves into the ring by the sides of the ark, that the ark may be borne with them.

The staves shall be in the rings of the ark: they shall not be taken from it.

The journey through the wilderness was inter-

rupted periodically by electrical storms, consequent to which the tabernacle enclosing the ark, surmounted by its conducting crown, attracted lightning.

And on the day that the tabernacle was reared up the cloud covered the tabernacle, namely, the tent of the testimony: and at even there was upon the tabernacle as it were the appearance of fire, until the morning.

So it was always: the cloud covered it by day, and the appearance of fire by night.

Touching of the ark by unauthorized persons resulted in death. Only Levite priests could approach and handle the sacred objects with impunity.

Cut ye not off the tribe of the families of the Kohathites from among the Levites:

But thus do unto them, that they may live, and not die, when they approach unto the most holy things:

Aaron and his sons shall go in, and appoint them everyone to his service and to his burden.

The insensitivity of the Levites to the scathing force which killed instantly may be explained by the passage in *Genesis* giving elaborate stipulations about the panoply that they had to don when officiating. A breastplate and long trailing chains of gold "grounded" them, in effect, when they ventured into the tabernacle. It is unclear whether the Levites were spared when, at Taberah, the wanderers transgressed, so that "the fire of the Lord burnt among them, and consumed them that were in the uttermost parts of the camp."

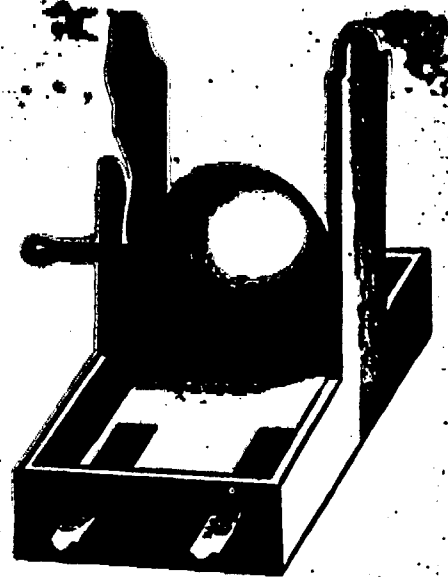
For a couple of millennia people were filled with alarm by inexplicable electrical phenomena. On long marches through dry regions the spear tips or helmets of soldiers sometimes acquired a strange effulgence. Sailors saw startling spectral flares clinging to riggings or masts; they called them Castor and Pollux, later St. Elmo's fire. These manifestations were not to be toyed with, let alone imitated. Remember what had happened to that rash King Salmoneus?

Girolamo Cardano in 1551, and Gilbert one-half century later, by clearly differentiating between magnetism and electricity, laid the groundwork for the production and leashing of man-made electricity. Gilbert's crude electrostatic induction machines were archetypal of apparatus of that kind for the next three hundred years.¹⁶⁻²¹ In 1650 Otto von Guericke described how to fabricate the "business end" of one such apparatus, which incidentally was put to medical service (Fig. 4).

Take a glass sphere, or, as it is called, a phial of the size of a child's head; place into it pieces of sulfur which has been comminuted in a mortar; then approach it to fire so as to melt the sulfur. After cooling, break the glass to withdraw the sulfur sphere and



(a)



(b)

FIGURE 4. (a) Otto Guericke in 1650 incepted man-made electricity. (b) Guericke's tool, archetypal of electrostatic machines.

store it in a dry place. The globe is pierced with a shaft of iron, and is then ready.¹⁸

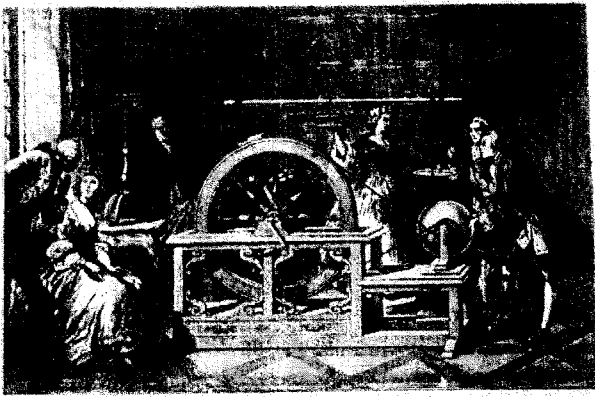
Guericke whirled the sphere while brushing it with his hand, a soft leather pad, or wool cloth. Thus charged, the sulfur spewed sparks and retained its electrification until it came into contact with various neutral bodies. Francis Hawkesbee prepared an incandescent bulb of sorts in 1709 when he substituted solid glass for the sulfur, so that a luminescence suffused the mass when charged.

Important experiments were undertaken in 1729 by Stephen Gray. He charged closed glass cylinders containing different materials and showed that some of the latter conducted electricity whereas others did not. The first were called "anelectric" and the second "idioelectric." He succeeded in conveying an electric discharge

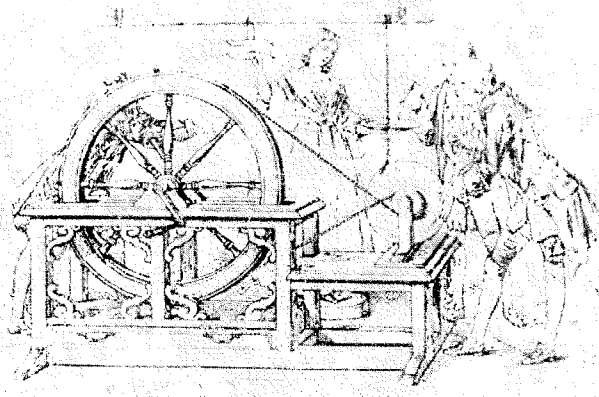
some 765 feet through hemp thread supported by silk.

Electricity was recruited for social amusement. To the great mirth of onlookers, participants vied with each other to produce such configurations as "halos" (raising hair on a person's head), "electrical kisses," "electrical rain," "electrical stars," and so on. Of these parlor games the pièce de résistance, which simultaneously illustrated the conductivity of the human body, was to suspend a youngster on hair cords from the ceiling and elicit some harmless sparks from the body. When the child's heels were touched with a charged tube, bits of copper leaf were attracted to the head (Fig. 5).

Gray's testing of conductors and insulators was the fountainhead of diversified researches. In 1733 Charles Dufay postulated the existence of two types of electricity, "resinous" and "vitreous,"



(a)

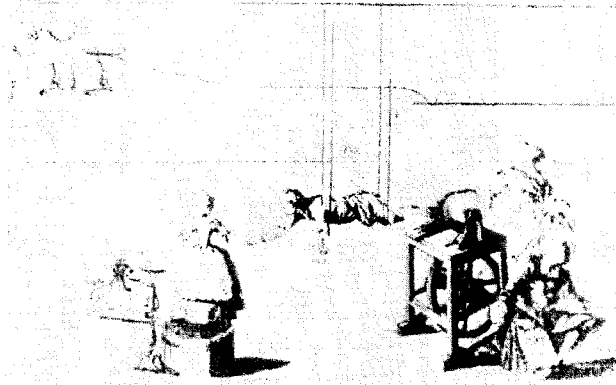


(b)



Machine zu der Electricitation.

(c)



(d)

FIGURE 5. Games people played when electricity was in bud principally exhibited conductivity of body. (a) Conductor. (b) Line drawing of old lithograph of conductor.

and that like ones repelled whereas unlike ones attracted each other. In 1744 Christian Ludolf dramatized the potency of man-made electricity by igniting sulfur with sparks from one of the electrostatic induction machines.

By now the stage was set for the invention of a capacitor, that is, a device that would create and conserve large quantities of electricity. This was accomplished independently by Georg von Kleist of Cammin in October, 1745, and by van Musschenbroek²² of Leyden in the spring of 1746 (Fig. 6). A letter, dated April 20, 1746, from Musschenbroek to the celebrated naturalist René Réaumur was widely publicized. It said in part:

I wish to communicate to you a new but terrible experience, and which I do not advise you to attempt yourself.

I was doing some researches on the force of electricity. To that purpose, I had suspended from two threads of blue silk an iron bar which received by conduction the electricity from a glass globe that was

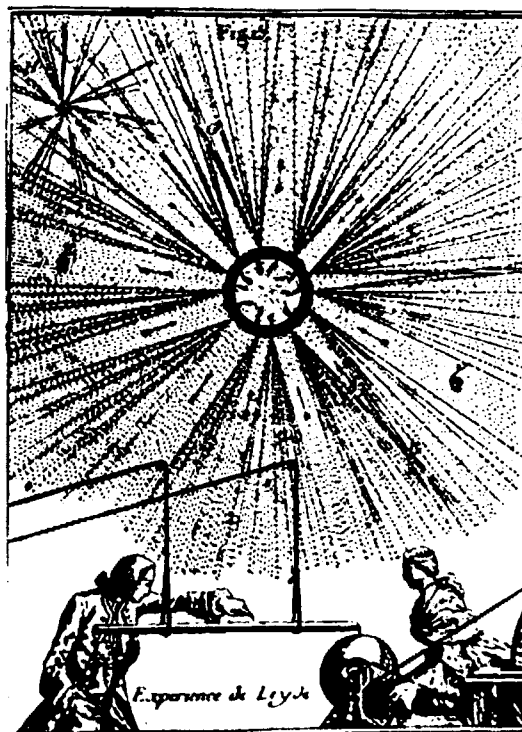
being spun rapidly on its axis and rubbed with the hands. To the other end there hung freely a brass wire which dipped in a round vase of glass, partly filled with water, and which I held in my hand. With the other hand I was trying to draw sparks from the electrified iron bar. Suddenly, my right hand was struck with such commotion that my body was rattled by a thunderbolt . . . My limb and entire body were affected terribly . . . and it was two days before I recovered from the blow and terror . . . I would not take a second shock for the kingdom of France.

Hardier souls were not cowed, especially when it was shown that the intensity of the concussions could be allayed somewhat.²³⁻²⁷ Nollet,^{28,29} who named the engine "Leyden jar," experimented with it on plants, fish, birds, and small mammals (Fig. 7). One of his tricks was to make sparks jump between persons. At open-air séances attended by Louis XV and courtiers he made an electric current travel across chains of 180 soldiers or 800 Carthusian monks holding hands.

The capacity of Leyden bottles and the speed



(a)



(b)

FIGURE 6. (a) Pieter van Musschenbroek described electrical capacitor which Nollet named "Leyden jar" in homage to Musschenbroek's city. (b) Essential features of jar: electricity generated by friction traverses iron rod into water-filled receptacle where it is concentrated

of propagation of electric shocks were measured by Louis Le Monnier and William Watson. The unitary theory of a single electrical fluid, refuting the "vitreous" and "resinous" categories,

was advanced by Benjamin Franklin, who also enunciated a law of conservation of charge.³⁰ Franklin likewise introduced the terms "positive" and "negative" to denote the relative state of



(a)



(b)

FIGURE 7. (a) Pierre Nollet, ardent investigator of biologic effects of electricity. (b) Nollet portrayed in one of his books inspecting influence of franklinic electricity on plants, puppy, hen, and canary.

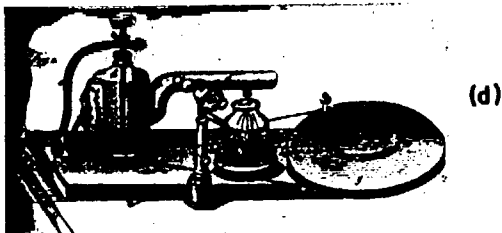
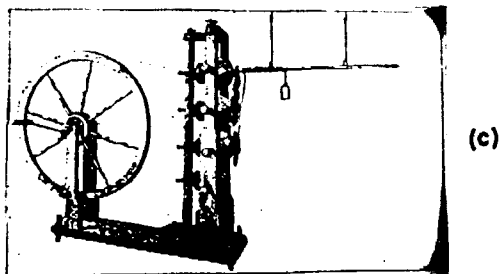
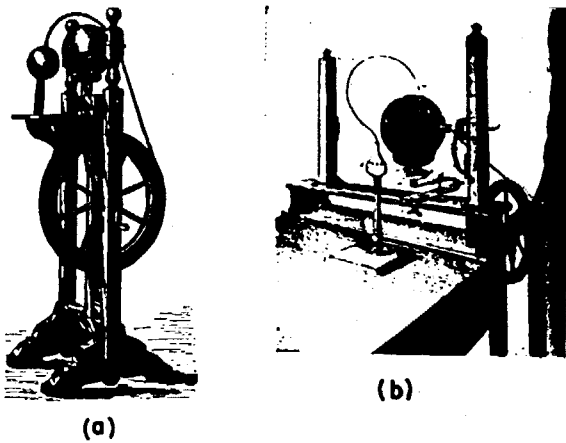


FIGURE 8. Electrostatic machines of eighteenth century. (a) Benjamin Franklin's and (b) Joseph Priestley's models.

electrification. He decided arbitrarily to call any body positively electrified if it was repelled by a glass rod which had been rubbed with silk and negatively electrified if it was repelled by sealing wax which had been rubbed with cat fur.

The experiments which Franklin was able to do with meager facilities at his command are fascinating to read but do not fall within the province of this essay. A small passage may be cited, however, both for illustration of the imaginative bend of his genial and fertile mind, and for its allusion to an effect of man-made electricity on a living being, antedated, one must admit, by Nollet's showing that fish and small birds could be killed quickly by discharges from a Leyden flask (Fig. 8). In a half-wistful epistle, Franklin mused,

Among other experiments which we shall exhibit for our diversion will be the firing of spirits by means of a spark sent from side to side through the river without any other conductor than the water—an experiment which we have some time since performed to the

amazement of many. A turkey is to be killed for dinner by an electrical shock, and roasted by the "electrical jack" before a fire kindled by the electrified bottle, when the health of all the famous electricians of England, Holland, France and Germany is to be drunk in "electrified bumpers," under the discharge of guns by the electrical battery.

Soon, Joseph Priestly formulated the inverse-square law of electrical attraction.³¹ The Leyden jar and modifications of it, such as the "electrophorus" and the plate condenser (or quadratum magicum) remained the principal tool of scientists until 1799, when Alessandro Volta invented the compound electric cell of dissimilar metals. Peter Roget showed that the workings of the voltaic pile were due to chemical reactions, and William Wollaston then described the process of electrolysis, whereupon Antoine Becquerel constructed an all-liquid battery. The two forces of electricity and magnetism were blended as "electromagnetism" in 1819 by Hans Oerstedt, and in 1831 Joseph Henry and Michael Faraday discovered electromagnetic induction, subsequently labeled "faradism."

The literature on electrotherapeutics for a couple of centuries was marred by a clutter of synonyms. Their equivalents are herewith indicated: franklinization, the application of electricity generated by friction, that is, frictional or statical electricity; galvanization, the application of electricity generated by chemical reaction, the current so produced being designated as galvanic, voltaic, dynamic, continuous, constant, direct, primary, uninterrupted, battery, or pile (actually the galvanic current may be interrupted as well as the continuous) and faradization, the application of electricity generated in a coil of wires adjoining another conductor through which the current traverses. The faradic current, which is necessarily interrupted by the apparatus that produces it, is also referred to as induced, induction, inductive, electromagnetic, magnetolectric, to-and-fro, indirect, or interrupted.

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