A history of electricity and electronics. How the puny electron at first bothered mankind, then gradually became useful and now dominates our lives. This is the story of the people who encountered it.

Much Ado About Almost Nothing

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Man's Encounter with the Electron

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1. Almost Nothing

Ancient superstitions, a skeptical Greek,
a siege in Italy, a physician in London
and shocking entertainment.

The little thing that threads through this book truly amounts to almost nothing. It is so small you can't see it, not even with the most powerful microscope. It is elusive, as if it were shy: it can appear as a tiny point with a weight (or more properly a mass) of much less than a billionth of a billionth of a billionth of a gram, scurrying around at near the speed of light; or it can shed its body and become a ghost, a wave.

We would never have noticed this strange particle were it not for the fact that there are many of them. They are everywhere, in every material, in numbers so huge they are beyond any human comprehension. In the point at the end of this sentence there are some 20 billion of them.

It was only a little over 100 years ago that man began to deduce the nature of this weird, minuscule thing and gave it a name: the electron. For most of history he was unaware of its existence, ascribing its effects to various gods. A large, powerful god who hurled lighting bolts, such as Zeus, Thor, or Jupiter. Or little ones who hid in amber, which attracted feathers or straw when rubbed, or in the lodestone (magnet), which attracted other stones of the same kind.

We shall follow man's encounter with the electron in this book: how a few people overcame their superstitions and began to investigate; how the electron gradually became useful, though man still had no idea what it was; how it finally revealed itself and then grew in importance to such an extent that we are now completely, utterly dependent on it.

The first incident of note happened around **600 BC**, in the city of Miletus (or, more accurately, Miletos). The city was Greek, but it was located on what is now the west coast of Turkey. At that time Miletus was the richest city in the Greek world and the most accomplished cultural center. Part of its status was due to Thales, who had gained fame in mathematics and astronomy and also proved himself to be a shrewd businessman [2].

Miletus had gained its wealth through trade. It had an excellent harbor and was strategically located on the way to Egypt from the north. And the trade routes already extended all the way to the Baltic sea, 2300km (1400 miles) away, from where the traders brought the most valuable gem then in existence: amber. Amber is a resin from trees, which grew some 40 million years ago, and are now deep underground [8]. Over time the resin has hardened and now appears to be a bright yellow rock; because of its sun-like appearance the Greeks named it ηλεκτρου (elektron).

Unlike other gems, amber has a fascinating property: when rubbed, it attracts light objects, such as straw. The Greeks (and just about everybody else) believed there was a tiny god inside. That was the explanation for everything they couldn't understand. The Greeks had a very large number of gods: every object on earth or in the heavens had a god, everything good or bad was personified as a deity, usually in human form; and each god had its own fantastic story.

There was another effect that couldn't be explained: magnetism. In some regions near Greece one could find rocks, which attracted each other (called a lodestone). More gods were created.

As far as we can tell, Thales was the first person to debunk this belief. He investigated the lodestone and amber and pronounced that the effects were not due to gods. But it was only a small step forward: his explanation was that amber and the lodestone had a "soul". (He also believed that the earth was a flat disk floating on water, and that everything comes from water and returns to water).

But we have to keep in mind that we know very little about Thales, about what he thought and said. Our only source of information is hearsay, comments by later scholars. If he wrote anything, nothing survived.

When you had something important to say in 600 BC, you wrote it on a scroll and let other people read it. There were no public schools, universities or libraries, not even in Miletus; only a small minority of people could even read. If your dissertation was popular, a rich, educated collector had a copy made by a scribe; if your ideas were out of favor, your scroll eventually decayed and was discarded.

Shortly after Thales, Miletus started to decline and Athens became the center of Greece. Miletus was captured by the Persians, its harbor silted up and then the town disappeared altogether.

For more than 1800 years there was only silence on the subject. It appears that no other Greek (or Roman) picked up where Thales left off. If there were any, all traces of them have disappeared.

And when the Roman Empire became Christian there was no longer any progress in other fields of science either. The church taught that every object and every effect was controlled by divine interference and thus the investigation of nature not only made no sense, but was sacrilegious. This belief was enforced by the inquisition.

So it is a surprise that we find a rather detailed investigation of the magnet during this time. It is in the form of a letter written in Latin by a Pierre de Maricourt to his neighbor [10]. We know very little about the author, who signed the letter as Petrus Peregrinus (Peter the Crusader); Roger Bacon mentions him in his writings and gives us the impression that Maricourt was one of the most impressive and knowledgeable people he knew. At the bottom of the letter it says: "Finished in the camp of the siege of Lucera on 8 August **1269**".

What was a Frenchman doing in Italy, laying siege to a town? Lucera is a town 200km (130 miles) east of Rome (not in Sicily, as most historians state) [9], and had become populated by Muslims. The pope took offense and asked the French for help. An army was dispatched, led by the brother of the king; Maricourt was almost certainly an engineer who built and operated the catapults, which hurled rocks and flaming tar-balls into the town.

A siege tends to be boring for the aggressor; one has to wait until the population starves. Thus Maricourt had plenty of free time on his hands and he put on paper what had been his passion for some time: investigating the magnet. He had found that each magnet has a south pole and north pole, which he determines by carefully tracing the magnetic field with an iron needle. With two magnets the north pole of one attracted the south pole of the other, but when two north or south-poles where held together they repelled each other. When he cut a magnet in half, each piece had its own north and south pole. He also found that he could magnetize a piece of iron with a lodestone and that a strong lodestone was able to reverse the magnetism of a weaker one.

Maricourt suggested improvement for the compass, which had been in crude use by mariners: a 360-degree scale which would let you find the course to be steered.

But he made two grave mistakes. He believed that the magnet in the compass pointed toward the north star, not the north pole of the earth. And, at the end of the letter, he proposes a motor with magnets that would run forever, a perpetuum mobile. If it doesn't work it is probably due to the lack of skill by the one who is building it, he said. The motor never had a chance of working.

That is all we know about Pierre de Maricourt. His letter was copied occasionally; some 28 copies are still in existence. No two copies are the same, all were altered while copying, the majority of them substantially. Which goes to show how uncertain our knowledge of the ancient past is.

For the next 300 years progress in the understanding of either magnetism or electricity again slowed to a crawl until in England, at the end of the 16th century, we find a physician by the name of William Gilbert who, as a hobby, investigated the phenomena of the lodestone and amber. In addition to medicine he had studied physics and astronomy and, while establishing a prosperous medical practice in London, he read everything available on the effects of the lodestone, the compass and amber. He interrogated countless sailors on their experience with the compass. But, above all, he experimented. Taking little for granted, he tried to verify every statement and belief [6]; it took him 18 years.

William Gilbert

In **1600** he published his findings in a book called De Magnete [3]. It became an instant bestseller, as bestsellers went in those days. In it he described the entire history of the beliefs surrounding the lodestone and amber and exposed dozens of misconceptions and superstitions. Garlic, for example, was supposed to destroy magnetism, so sailors were not allowed to chew it around a compass. Gilbert smeared garlic all over magnets and found no effect. The myth appears to have started with a bad copy of a book by Pliny (about 75 AD) where the word alio (other) was misspelled allio (garlic).

Gilbert discovered that lodestone and iron are the same and that iron can acquire poles if magnetized by a lodestone. He found that the magnetic effect penetrates paper or linen and worked even under water, whereas the effect of amber ceased in moisture. He vividly described how amber was not the only material that could cause attraction when rubbed, but that diamond, sapphire, opal, amethyst, rock crystal, sulphur, glass and many other materials did the same. He separated all known substances into "electrics" (which could attract when rubbed) and "non-electrics" [6].

His main interest, though, was in the magnet; he mentions electrics only briefly. He found that the earth is a magnet and that the compass points toward the North Pole, not the North Star. He explained the dip in the compass needle, described the variation of the magnetic field over the world and determined that the magnetic poles of the earth are shifted slightly from the geographic poles.

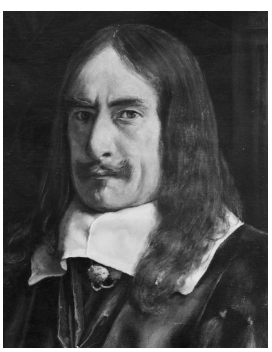
Gilbert made a model of the magnetic properties of the earth by filing a lodestone into a sphere. By doing this he could visualize and demonstrate much, but it also led him somewhat astray. This little sphere looked and behaved so much like the earth and he was so enamored by magnetism, he came to the conclusion that objects (like people) were held to the earth by magnetism. He also missed the fact that magnets (and "electrics") can not only attract but also repel.

But with all his studying and investigation he still did not know what either effect really was. He viewed magnetic attraction as entirely imponderable and incorporeal. He speculated that the "electrics" emitted "a subtle diffusion of humor or effluvium."

The year De Magnete was published, Gilbert became president on the College of Physicians and in 1601 physician to Queen Elizabeth. He died two years later, at age 59.

The next place we visit is Magdeburg, Germany. The time: around 1666. Otto Guericke (who was later raised to the peerage by the emperor and thus called *von* Guericke), had been the town engineer, then became a politician and was now the mayor of the city. He was also the town brewer, which made him rich.

Guericke had been an experimenter for most of his life and had acquired fame with his studies of vacuum. He had devised a pump similar to the ones used for water, but with a piston so tightly fitted that it could pump the air out of a hollow metal sphere. He demonstrated that you could not hear a ringing bell inside the sphere, i.e. that sound does not travel through vacuum. Then he built two hollow hemispheres, held them together, pumped the air out and showed that the two halves could not be pulled apart by two teams of eight horses. He repeated this brilliant piece of showmanship several times before kings and emperors in Regensburg, Vienna and Berlin [6]. (Actually, the second team of horses did nothing. He could have tied the chain to a large tree or building and gotten the same force, but two teams of horses were certainly more impressive).



Otto von Guericke

But now he had moved on to a different field: electricity. He poured a mixture of molten sulphur and minerals into a glass sphere. When the sulphur had cooled and become solid he broke the glass vessel, drilled a hole through the sulphur ball and put a rod through it. Then he mounted a crank at the end of the rod and put the assembly into a wooden stand. When he turned the crank and held his hand against the rotating sulphur, he could draw sparks from it [5].

Gilbert had favored magnetism because the effect was much stronger. Guericke increased the effect of the "electrics" manifold.

After spinning the sulphur and mineral globe and touching it with his hand, it would attract down feathers and other light objects over a much greater distance, and he noticed something very unusual. At first the feather was attracted to the globe. But when it touched the globe, the feather suddenly fled from it. The most curious behavior appeared when the charged globe was close to the floor and a feather was in between. In this situation the feather would dance between the ball and the floor. At first the feather was attracted by the charged sulphur ball. As soon as it touched it, though, it would move away from the ball toward the floor. Then, as it touched the floor, it would be attracted by the ball again.

Guericke then built larger contraptions with belts and wheels, which spun larger globes faster and created larger sparks. In **1672** he published the results of his experiments [5]. He confessed that he didn't understand the reason for the feather's strange behavior. "It must be the globe's own decision", he writes "whether it shall attract or repel. When it does not want to attract, it doesn't attract; nor does it permit the feather to approach it until it has cast it against something else, perhaps in order to acquire something from it."

Guericke made two more startling observations. When he held the globe to his ear, he heard "roaring and crashing." And when he attached a linen thread to the globe "an ell long" (a little more than a meter) he noticed that the linen thread also attracted light objects.

In **1729**, 62-year-old Stephen Gray made the next discovery. He had entered the Charterhouse, an institution for gentlemen who had fallen on hard times, ten years before. Although a dyer by profession, Gray had been involved in science and loved to experiment with electricity. Apparently he hadn't heard of Guericke or couldn't afford to build one of his machines. To generate electricity he used a glass tube, which was plugged with a cork at either end "to keep the dust out". When he rubbed the glass tube, he noticed that a feather was attracted not only to the glass, but to the cork as well. He concluded the cork must conduct the "electric virtue", and decided to test other materials. He drove a wooden stick into the cork and fixed an ivory ball at the end of the stick. When he rubbed the glass tube, feathers were attracted to the stick all the way out to the ivory ball. He replaced the wooden stick with a metal rod, and that worked, too [4].

Becoming excited now he wound twine around the glass tube and hung the twine down 10 meters (30 feet) from the balcony of the Charterhouse. Near the ground he affixed his ivory ball. And, sure enough, when an assistant rubbed the glass tube above on the balcony, Gray observed that feathers were attracted to the ball. He replaced the ivory ball with everything he could find around the Charterhouse without spending any money: stones, tile, chalk, coins, a kettle from the fireplace, vegetables and plants from the garden. They all worked.

Gray now ran out of height; the balcony was as high as he could go. Fortunately he met one Granville Wheler, who had a large house. Together they strung twine around Wheler's house, suspended by short lengths of the same twine. But this time the ivory ball at the end didn't attract anything.

The two amateur scientists suspected that it must be the way they suspended the twine, so they changed the suspending strings to thin pieces of silk. Now the ivory ball was as alive as before and they managed to conduct electricity over a distance of 100 meters (300 feet) [6].

But as they attempted longer distances, the silk threads began to break. Let's use something stronger that's also thin, they said to themselves. So they tried thin pieces of brass wire. But that didn't work at all.

It must be the material then, they thought, not its thickness. They used silk to suspend the twine again, this time thicker and stronger and achieved a distance of 253 meters (760 feet). Within a short time they learned which materials make good "insulators": silk, horsehair, resin and glass. Suddenly Gilbert's distinction between electrics and non-electrics made no sense anymore. The important distinction was now between insulators and conductors.

For his discovery Gray was made a member of the Royal Society and received a medal. He died at age 70, considerably more distinguished but still penniless.

In **1733** Charles Francois Dufay learned about Gray's experiments. The 35-year-old Dufay had been a soldier. His main interests were in chemistry, anatomy, mechanics and botany and he had already contributed a number of original papers to the French Academy [6].

Dufay absorbed the new subject of electricity rapidly. He experimented and found that twine conducted best when wet and that metals were better conductors. With this new knowledge he extended the distance of electrical conduction to 420 meters (1300 ft).

To determine the presence of electricity, Dufay used a thin gold leaf (instead of a feather) and he found something that had been missed until then. Some materials when rubbed attracted the gold leaf, others repelled it. Aha!, he said, there are two kinds of electricity, not just one. He called one kind vitreous (for glass and like materials), the other resinous (for resin).

Dufay was also the first one to notice the effects of electricity on the skin. He described how electricity passing over his face felt like a spider web and how it sometimes could sting and burn when discharged through his fingers [6].

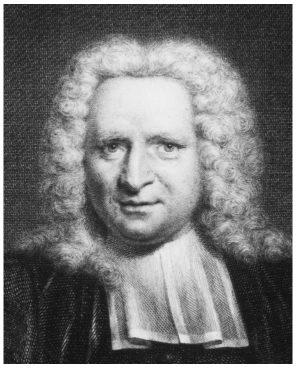
That was a mild foretaste of what was to come. In the span of only five years electricity was promoted from an obscure phenomenon to the most fashionable "science". What took place was a veritable mania to build "electrical machines", ever larger glass globes, no longer rubbed by hand but by small leather cushions. The faster these globes or disks were turned, the more electricity they produced, so they were spun with the help of ever larger wheels and belts

The movement started in Germany and one of the busiest demonstrators during this period was Georg Mathias Bose, a professor at Wittenberg. Bose was a born showman. In one of his famous demonstrations he insulated an entire dinner table and connected it to an electrical machine hidden in the next room. After the guests had sat down he gave a signal to his assistant who operated the machine with all his force. The surprised guests had sparks flying at them as they touched the silverware and the metal dishes and cups [6].

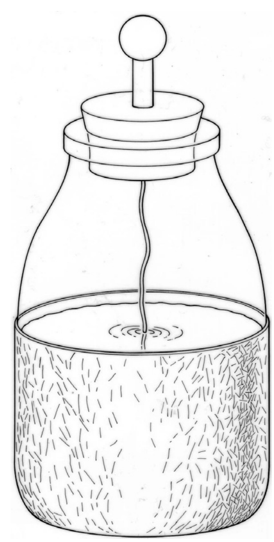
As a climax he placed a "pretty young maiden" on an insulated stand, connected her to the machine and invited the young men among his guests to kiss her. Some of the brash young kissers thought they had their teeth knocked out (no mention is made of the teeth of the young lady). Professor Bose published his experiments in three small volumes of Latin poetry, strange pieces of literature reeking of self-admiration [1].

Bose also administered a shock to 20 soldiers holding hands and later bragged that he could do this to an entire army.

Bose and his contemporaries generated sparks of considerable length, which we now know, corresponds to voltages in excess of 50,000 volts. This is far above the 110 or 220 volts in houses, which is quite capable of killing a person. So why weren't these people killed? They were lucky that these electrical friction machines were very inefficient power generators; they produced a high voltage alright but, as soon as this voltage was applied to the human body it collapsed to a harmless level.


Pieter van Musschenbroek

In **1746** Pieter van Musschenbroek, a professor of experimental physics at Leyden (or Leiden) in Holland, tried to draw "electrical fire" from water in a glass jar. Musschenbroek had an acquaintance, a lawyer named Andreas Cunnaeus, who amused himself by visiting Musschenbroek's laboratory and dabbling in electrical experiments. Cunnaeus tried the same experiment and, when he grabbed the outside of the jar with one hand and touched the conductor immersed in the water with the other, he received a tremendous shock. He showed the experiment to Musschenbroek, who repeated it with a larger jar. The shock Musschenbroek received was so stunning that he thought he "was done for". Hours later he was still shaken and vowed that nothing could make him try the experiment again [6]. For anyone who thinks that lawyers have never contributed anything to mankind, here is a clear-cut case of at least one lawyer who did. It is ironic that this case, too, was a painful experience.


The Leyden Jar: It stored electricity, which made the shock almost lethal. But nobody knew why or how.

Musschenbroek sent a letter explaining his experiments to his correspondent at the French Academy and soon the "Leyden Jar" was in fashion, with metal foil around its outside replacing the hand. Every electrical experimenter worth his salt built one and started shocking everybody in sight. Among the experiences they reported were nose bleeding, temporary paralysis, concussions and convulsions. One gallant experimenter observed that his wife was unable to walk after he had asked her to touch the Leyden jar.

Musschenbroek believed that the electricity was in the water inside the jar, and that the larger the volume of the water the greater the shock. What he or Cunnaeus had in fact discovered was what is now called the capacitor. The electricity (or better: electrical charge) is temporarily stored not in the water but in the *wall*. The electrons generated by rubbing of the glass accumulate on one side of the wall or the other and wait there until they find a path to flow out of the capacitor again (e.g. through the human body), in great strength and all at once. In this way the delivered power becomes larger, and shocking people more fun.

And none provided more fun than Abbé Jean Antoine Nollet. He was not really an Abbé, though. He had studied theology but, before becoming a priest, switched to physics. Nevertheless he wore the garb of a priest and always used the title.

Nollet had connections at court. Louis XV invited him to demonstrate this new electric marvel at Versailles. Nollet had 180 of the King's soldiers join hands in a circle and then applied the Leyden jar to one of them. To the great joy of the king and his court the soldiers simultaneously leaped into the air. Louis liked the demonstration so much that he had it repeated in Paris, this time with 700 Carthusian monks [1].

These frivolous demonstrations depict the state of electricity in 1747. Electricity had become a more interesting effect than magnetism, but both were still only on the level of parlor tricks; with an electric demonstration anyone could become the life of a party.