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SPARKS WILL FLY

STATIC ELECTRICITY

We see spiders, flies, or ants entombed and preserved forever in amber, a more than royal tomb.

—SIR FRANCIS BACON

Copenhagen, Denmark, is an eye-catching city with bold architecture complementing natural beauty. But if you perform an internet search for images of Copenhagen, most of the hits will show colorful photographs taken from just a single vantage point: the dockside view at Nyhavn harbor. At Nyhavn, a seventeenth-century waterfront docking area and now popular entertainment district, many vividly colored buildings and boats line both sides of its narrow waterway. On a sunny day with a blue sky, it is unquestionably the most photogenic location in a city full of photogenic locations. Yet, the most beautiful things in Nyhavn cannot be seen in any of these photographs.

Nyhavn's stunning treasures are housed in a small, white building on the extreme far left, out of frame for most pictures of the harbor. The treasures are literally jewels, and they are on display in the House of Amber, a combination jewelry store and amber museum.[1] The three-story building itself is historic, dating to 1606, but its contents are prehistoric, with some amber pieces estimated to be 30–50 million years old. As I enter the House of Amber, a young professional woman, smartly dressed, introduces herself as Birgitte Niclasen and welcomes me. She works in the House of Amber's human resources and special projects section, and she offers to give me a tour of the museum's amber collection.

Niclasen knows a lot about amber, the national gemstone of Denmark. She explains that amber is fossilized sap from prehistoric pine trees and is found in various parts of the world, but particularly in the Baltic Sea region because of the vast prehistoric conifer forests that existed in this area. Amber, with a density only slightly heavier than water, is remarkably light. As such, it easily was washed into prehistoric rivers, where it was carried out to sea. For this reason, amber often can be found on beaches in areas that were once prehistoric river estuaries. In fact, much of the world's amber stockpiles simply were picked up from beaches by professional or amateur collectors. The collectors know which stretches of shoreline are most likely to yield amber, and they visit them after every storm in the hope that the storm will have dislodged more amber from the sea floor and washed new deposits onto the beach.

Amber is famous for having *inclusions*, which are imbedded small objects—often insects—frozen in time. The insects were trapped in sticky tree sap that ultimately solidified and fossilized to become amber.[2] High-quality inclusions increase the amber's ornamental value and frequently end up in some of the finest jewelry. Niclasen shows me the museum's best examples of amber pieces with insect inclusions. She notes that such inclusions are typically not pristine; rather, the insects are often damaged or have misshapen appendages. Perfect insect inclusions are rare, making them tremendously valuable for jewelry. Jewelry with inclusions of animals larger than the size of insects is extremely rare, and most such pieces are fakes. The fakes are modern-day animals simply imbedded in amber-colored synthetic resins. Niclasen tells the story of a woman visitor to the museum who showed off a pendent that appeared to have a perfect inclusion of a small snake. The woman was so proud of her "amber" pendant that Niclasen didn't have the heart to tell her it was undoubtedly a fake. Unfortunately, the woman probably

FIG 1.1. Amber. Although valued since antiquity as a gemstone, amber is actually fossilized tree resin that is millions of years old. Different types of amber vary in appearance, but Baltic amber (shown here), the most common variety, is typically clear or translucent. When polished, impurities called inclusions can sometimes be seen. The inclusions are often insects (such as the ant shown here) that were trapped in the thick liquid resin before it solidified. (Photo © Anders L. Damgaard; www.amber-inclusions.dk)

had paid a lot of money for her treasure, but her naïveté is understandable. Hawkers of fake amber have deceived even financially shrewd people. Most famously, J. P. Morgan, a wealthy nineteenth-century American financier and banker, once paid $100,000 ($2,900,000 in 2020 dollars) for an amber collection whose most precious piece had an inclusion of a frog. When he donated the collection to the American

Museum of Natural History in New York, the curators quickly recognized that the prized amber piece with the frog inclusion was actually a fake.[3]

Fortunately, there are several chemical means to identify fake amber from the real stuff. Unfortunately, most of them require a small sample of the amber for analysis and thus are modestly destructive to the piece in question.[4] There is a nondestructive method, though. Niclasen remarks, "The easiest way to identify a fake is simply to rub the suspect amber with a woolen cloth and see if the rubbed amber can move small dust particles." If it is real amber, you can electrify it by rubbing it in this way. That is, the rubbing will cause the amber to take on static electric properties: it will attract small particles, and it may even produce an electrical spark you can feel. In fact, amber's electrical properties make it unique among gemstones and enhance its appeal.[5]

All amber is beautiful, and people have likely been adorning themselves with it for as long as there have been people. Archaeologists have found amber pendants dating from 12,000 BC, which was just at the tail end of the last Ice Age.[6] Yet, the appeal of amber jewelry to primitive peoples went well beyond simply its beautiful appearance. Amber was also known to be magical. People who wore amber jewelry would often feel it give off shocks and could see it attract particles of soil or small seeds after being rubbed with wool.[7] No wonder all sorts of mystical qualities were attributed to amber!

Humans have a propensity to immediately apply all new discoveries of natural phenomena toward the treatment of their ailments. We will see this recurring pattern time and again throughout the book. Amber was no different.

The first recorded medical treatments with amber come from the ancient Greeks, but such practices probably started much earlier. The Greeks sought to utilize the attractive forces of amber to fight disease. They massaged the bodies of sick people, rubbing pain-afflicted areas with amber stones in the hope that amber's attractive forces would pull the pain out of their bodies. Later, the Romans employed amber as both a disease treatment and a disease preventative. Pliny the Elder (23–79 AD), the great Roman naturalist and naval commander who was killed at Pompeii by the eruption of Mount Vesuvius, recommended wearing amber around the neck to ward off throat diseases and mental disorders.

Powdered amber later found its way into various medicines and potions, and many people claimed to have benefited from its healing powers. As late as the sixteenth century, the famous Swiss physician Paracelsus recommended amber as "a noble medicine for the head, stomach, intestines and other sinews complaints."[8] Whether anything more than a placebo effect was at play is quite doubtful. But even a placebo can have clinical value.[9]

Apart from the attractive forces coming from rubbed amber, the stone also could produce sparks. Both the attractive forces and the sparks required the amber to be rubbed, suggesting the two phenomena were somehow related and produced in the same way. But unlike its attractive forces, amber's sparks could be felt and seen. And sometimes the feeling was strong enough to be quite unpleasant. What was the nature of these sparks and were they good or bad for the body? Was the pain level of the sparks a consequence of the attractive forces? The sparks raised many questions.

Before going any further, we should stop here and define exactly what we mean by a *spark*. People are sometimes sloppy with how they use the term.

The modern English word *spark* is thought to come from the Old English word *spearca*, meaning "a glowing or fiery particle thrown off."

The origin of the word is probably extremely old, since the production of heat sparks is one of the most evident consequences of burning wood or smacking two stones together—things that even cave people did regularly. Because sparks can burn skin and eyes, people were careful when dealing with this menacing phenomenon. So it seems likely there would have been a word for such a ubiquitous hazard even in very primitive lexicons.

But the use of the term *spark* in connection with electrical events came much later, when people started to recognize that the shocks they sometimes felt when they touched objects, like amber, were typically accompanied by very faint flashes of light at the exact point of contact. Since they looked similar to the sparks from the fires and stones, and they were also similarly painful to the touch, they were given the same name. But such sparks are, in fact, quite different.

The sparks from fires and stones are really just flying fiery particles produced by rapid burning or intense friction. In contrast, the sparks that produce the shocking sensation from amber are due, as we shall soon see, to electricity rather than heat. And the sensation they produce isn't a burn but a direct stimulation of the body's nerves by the electricity. So the fact that electrical sparks could interact with the body and produce a physical sensation was appreciated at the very moment of their discovery. It is the electrical spark that concerns us here.

As time progressed, it gradually became apparent that other substances behaved similarly to amber. If you rubbed them, you could likewise produce attractive forces and sparks. As such, these dual properties that could be produced by rubbing different materials together were called "electrical" properties, derived from the Latin word *electricus*, meaning "amber-like."

The gradual realization that different combinations of paired materials could be rubbed together to produce electrical properties, and the appreciation that there were patterns, orders, and rules as to which material of the rubbed pair would become electrified was a breakthrough.

It opened the door for the systematic study of electrical properties, and moved electricity from the dominion of mysticism into the realm of science.

Most people today will confidently tell you electricity is a current of electrons, and they may even volunteer that an electron has a negative charge. Beyond that, if you challenge them to define what they mean by "electron" and "charge," they probably will start stammering because these are extremely difficult concepts to grasp, even for physicists. If you press them on what they mean by "current," however, their spirits will brighten, because everyone thinks they know what a current is: it is the pattern of flow of a fluid (like water) or a gas (like air).

Since electrons flow in currents, exploring electricity as you might investigate currents of water could result in some very important and highly comprehensible insight. This is exactly what the first scientific investigators of electricity did. And they did so with no knowledge of electrons. They just imagined electric currents to be equivalent to water currents, and they simply thought electricity to be a current of some invisible fluid. For the most part, this approach worked and people learned much by thinking of electricity as a current of an invisible fluid.

Of course, electricity isn't really an invisible fluid, so if you take this model too literally and start trying to find the invisible fluid, you will be doomed to failure. Michael Faraday, the brilliant nineteenth-century scientist who would transform our understanding of electricity, knew this well.[10] In 1821, he admonished his colleagues: "Those who consider electricity as a fluid, or as two fluids, conceive that a current or currents of electricity are passing through the wire during the whole time [that it remains connected to a battery]. . . . There are many arguments in favor of the materiality of electricity, and but few against it; but still it is only a supposition; and it will be well to remember . . . that we have no proof of the materiality of electricity, or of the existence of any [fluid flow] through the wire."[11]

Notwithstanding Faraday's admonition, "electrical fluid" is a good place to start if we want to understand electrical principles because there are many parallels between electric currents and water currents. So that's what we'll do here; we'll begin our exploration of electricity by focusing on its behavior as a current, and we'll worry about the exact physical nature of the imaginary "fluid" that comprises electrical current later.

Of course, almost everyone knows the famous eighteenth-century American printer, inventor, colonial statesman, and scientist, Benjamin Franklin, is very important to the history of electricity, and that he once flew a kite in a lightning storm to demonstrate such storms were electrical. But his accomplishments as an electricity scientist wouldn't have been diminished even if he had never flown his kite. The kite stunt turned out to be a double-edged sword for Franklin's image. Rather than being a scientific discovery, it was really just a demonstration of electrical principles he already understood better than anyone else.[12] Franklin proved his electrical knowledge by dramatically tempting fate with a kite, and he received outsized attention for it. The kite makes an interesting story, and I promise we'll discuss it in some detail. For now, however, let's focus on Franklin's experiments that showed electricity to behave like a fluid. That was his true insight.

In Franklin's day, the only technique to produce electricity was to rub materials together, as we have just discussed. Producing electricity in this way leaves the electricity localized on the surface of the object being rubbed. Since this type of electricity remains localized and isn't moving in currents, we call it *static*, meaning unchanging or fixed in position. But if static electricity is provided a route to go elsewhere, it will cease being static and start to flow, thereby producing a current, like water being syphoned from a bowl. In the bowl, the water is static, but if provided a route through the syphon, the water flows in a downhill current, with gravity providing the required force. Once we have such a current, we have something we can measure . . . and study. The flow of the water allows us to deduce the properties of water, such as its weight, its density, its resistance, its speed, its pressure, etc. Similarly, through the study of electrical current, we can begin to understand electricity.

There is a limit to how much electricity one can generate by rubbing amber by hand, so people sought alternatives. Common glass can substitute for amber when it is rubbed with silk. The major appeal of glass was that it was relatively cheap and could readily be formed into any desired shape and size. This led to the production of static electricity–producing machines based on rotating a glass rod, cylinder, or sphere against a piece of silk. The rotation usually was achieved with a simple hand crank.[13] It was these static electricity machines that first caught Franklin's attention.

Franklin reported he had first become interested in electricity when he attended a demonstration in Philadelphia given by a man whom he referred to simply as "Dr. Spence." We aren't exactly sure who Dr. Spence was, but he was most likely Archibald Spencer. A man by such a name had run an advertisement that appeared in Franklin's *Pennsylvania Gazette* in April of 1744. The announcement promoted a series of lectures to be given by Archibald Spencer on the topic of "Experimental Philosophy," and it instructed interested parties to register for the lecture series and pick up their *Catalogue of Experiments* at the Philadelphia Post Office. (Spencer apparently was moving from city to city with his electrical demonstrations, because a similar advertisement promoting demonstrations in Boston had appeared in a newspaper there a few months earlier.) Since Franklin owned the newspaper that published the advertisement, and he was, at the time, postmaster of Philadelphia, it seems highly likely that Franklin was aware of Spencer's lecture series and decided to attend.

Apparently, Spencer's Experimental Philosophy lectures contained a number of static electricity demonstrations to entertain his audience, one of which was called the Flying Boy demonstration.[14] This particular demonstration had become the main attraction for the many traveling electricity performances that were captivating upper-crust society at the time. People found the demonstration noteworthy because it showed that electrical phenomena could be produced apart from a machine. Stephen Gray, a distinguished British scientist, debuted the Flying Boy in 1729.[15] The demonstration has been described in detail by him and others, so we know exactly how it worked.

"Flying Boy" really was a misnomer. No boy ever flew. Rather, the demonstration involved a boy being suspended by silk ribbons from the ceiling, facedown in a prone position—a simulated "flying" posture. Then a glass static electricity generator was used to electrify the boy's bare feet. An open book was then put on the floor beneath the boy's face, and he was asked to turn the page. The boy waved his finger across the book and the page turned without his touching it! That was what astounded the audience.[16] How did the boy turn the page without touching it?

Of course, the page could have been turned without any touching simply by rubbing a glass rod to electrify it and give it attractive forces, and then waving the rod itself across the book. So the page turning alone wasn't any cause for excitement. The interesting part was that the electricity generated with the static electricity generator was being transferred *to the boy's body*, such that his whole body had become electrified, just as if his body were an electrified glass rod. And if the page turning didn't convince an audience member about the boy truly being electrified, one could just touch the boy's body and receive the same type of shock that resulted from touching an electrified glass rod.[17]

It turns out the "flying boy" part of the performance wasn't merely theatrics; it was essential to the demonstration's success. The boy needed to be electrically isolated in order for his body to become electrified. If there had been a way for the electricity to move from the boy to the ground, it would quickly enter the ground and dissipate. But air and silk are poor conductors of electricity. (*Conductors* are materials

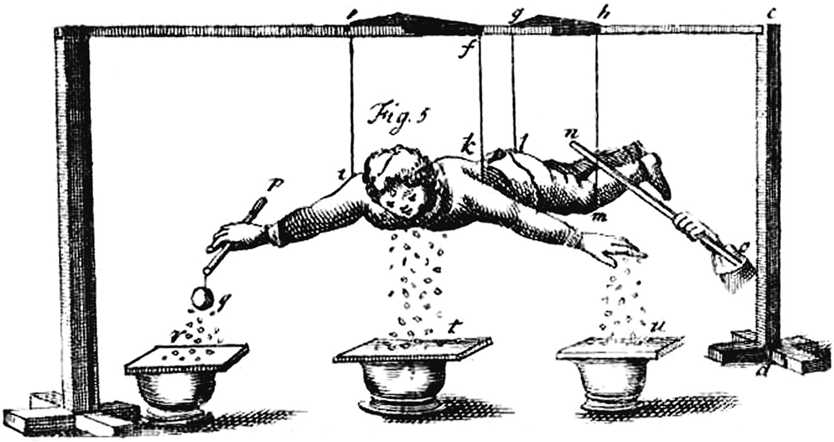

FIG. 1.2. The Flying Boy. The ability of the human body to conduct electricity and hold a static charge was first demonstrated by British scientist Stephen Gray using a boy suspended in a prone ("flying") position by means of electrically insulating silk ribbons. The boy, whose body was isolated from the ground, could be electrically charged by transferring electricity to him through a glass rod that had been precharged with static electricity. Once charged, the boy was able to turn book pages without touching them and attract small pieces of paper or feathers to his fingers, due to the attractive forces of his electrified body. Although the demonstration was originally done purely as part of Gray's scientific investigations, modified versions of the Flying Boy soon became the main attraction at traveling static electricity shows that toured the American colonies in the mid-1700s to entertain the general public, and through which Benjamin Franklin first became acquainted with the mysterious properties of electricity. This historical image depicts the Flying Boy demonstration as originally performed by Gray around 1730. (Science Source)

through which electricity can pass, while *insulators* are materials through which it doesn't easily flow.) By suspending the boy in the air with silk, the electricity in the boy's body had nowhere to go, so it remained stationary (static) in the boy's body. Why a boy and not a girl? No reason; girls work just as well. Why a boy and not a man? Probably because men are too heavy to easily suspend with silk ribbons, and boys worked for less pay.

Traveling static electricity performances like Spencer's were typically offered only during the colder months of the year. Not because there were fewer other amusements during the winter, and not because the performers wanted to have their summers off. Rather, the static electricity performances didn't happen in the summer because the electrical demonstrations didn't work during the summer, for reasons nobody knew. We now know the reason is because the warm air of summer is typically very humid, and moist air is the enemy of static electricity. It is difficult to electrify an object when the air is humid, and once electrified, the object tends to lose its electricity quickly because water in the air bleeds the electricity away. Summer months, being humid, thwart all attempts to play with (or study) static electricity. So, April of 1744 must have been very near the closing of Spence's electricity demonstration season. Franklin, therefore, would have seen one of Spencer's last shows of the season. Spencer wouldn't be returning to his show circuit until fall.

Franklin was astounded by Spencer's electricity show, and he became obsessed with learning more about electricity. He had several friends and colleagues with whom he regularly corresponded about scientific matters. He soon started asking them what they knew about these electricity performances, and he began speculating as to exactly how electricity worked.

What he found was that many people had been studying such electrical marvels for a long time, but a universal theory that explained the various electrical effects still seemed a long way off.[18] One reason was that there were technical obstacles to studying electricity. In addition to the humidity problem, there was no easy way to measure electricity. It also was hard to produce large amounts by just rubbing objects together, and it remained localized for only a few minutes; that is, it couldn't be stored. These crude static electricity generators also produced highly variable results, and measuring the amount of electricity by gauging the pain intensity from an electrical shock wasn't reliable either.

But timing is everything. Franklin had the good fortune to become interested in electricity at just the perfect time. While he was watching Spencer's electricity demonstrations in Philadelphia, Pieter van Musschenbroek, working in Leyden, Germany, was in the process of conquering the electricity storage problem.[19] Musschenbroek invented a very simple device—something anyone could make—that was capable of storing very large amounts of electricity in a simple glass jar, just as one might store water. This discovery revolutionized electricity research, because it allowed the relatively modest amounts of electricity produced by the hand-operated electrostatic generators to be collected and stored in jars for an extended period of time. Need a little electricity? Just take a jar of it off the shelf. Need a lot of electricity? Gather a bunch of jars and connect them together.[20]

With the arrival of what was commonly known as the *Leyden jar*—Franklin often called it "Musschenbroek's wonderful bottle"—electricity demonstrations took a completely new turn. They went from electrifying a single boy to electrifying a chain of men!

In April 1747, just three years after Franklin had seen Spencer's fairly tame electricity demonstration in Philadelphia, Jean-Antoine Nollet, a French cleric and scientist, performed his own electricity demonstration for King Louis XV of France.[21] He had 180 men from the king's Royal Guard stand in line holding hands. He then had the soldier at one end of the line use his free hand to touch the top of a fully electrified Leyden jar. Instantly, all 180 men in line reeled from the strong shock they felt. The king was impressed.

If a series of 180 men could be shocked, how many more? Nollet staged an even larger spectacle. As his day job was running a monastery, he was able to recruit Carthusian monks to make an even longer hand-to-hand chain. Since monks were more common then than they are now, Nollet was able to gather a group of 700. Results were the same; all 700 monks received a jolting shock. No, that Flying Boy demonstration wasn't going to impress anyone anymore.

Nollet offered a scientific explanation for his results. He proposed that electrical transmissions between people were achieved by currents of two competing fluids—he called them "affluent" and "effluent" currents—that moved among human bodies by means of tiny body pores, too small to be seen. This two-fluid electrical theory gained some traction among scientists, because two different electrical fluids might somehow explain why pairs of electrified objects sometimes attracted each other and sometimes repelled each other. The explanation for the alternative repulsive and attractive properties of electrified objects might be explained if currents from two different types of fluids were electrifying them. However, other scientists had a problem with the theory because all the men in the chain seemed to be shocked simultaneously, and it was difficult to imagine fluids flowing through body pores could move so quickly. Nevertheless, the two-fluid theory would persist until replaced by Franklin's alternative one-fluid theory, which was appealing because it not only accounted for the movement of electricity between human bodies but also provided a working model of how the Leyden jar worked.

Imagine a wide-mouth glass jar, like a mayonnaise jar, with a plastic lid. Cover the outside of the glass jar with aluminum foil and line the inside with aluminum foil, making sure the outside foil has no physical contact with the inside foil. Put the lid back on the jar, punch a hole in the lid, and run a metal wire from the inside foil out through the hole, protruding just a few inches. Now, either place the jar on the ground or run another wire from the outside foil to the ground.[22] You have just made yourself a Leyden jar, ready to be electrified.[23]

To fill the jar with electricity, rub a glass rod with silk to electrify the rod, and then touch the wire protruding from the top of the jar. The electricity from the glass rod will flow into the aluminum foil lining the inside of the jar. Repeat. With each repetition, more and more electricity goes into the jar. As the jar becomes filled with electricity, electrical "pressure" builds up in the jar, just as pressure would build up if we were forcing air into the jar. The inside electricity would like to flow to the outside foil, escape to the ground, and thus relieve the pressure, but the glass is blocking its flow, so that cannot happen. The electricity just sits there, statically, waiting until an opportunity for escape presents itself. And that's exactly what happens if a person should touch the wire on the jar's top. The electricity escapes by going into the person's body, down through his feet, and into the ground. He briefly feels the shock of the passing electricity. Then it's gone, and the jar has lost all of its stored electricity.

Now suppose the man who touches the wire is standing on an insulator (or wearing nonconducting shoes), which blocks the electricity's route to the ground. In that case, we have the equivalent of the Flying Boy. The electricity enters the man's body, but it has nowhere to go, so it stays statically in the man's body, waiting to escape his body by another route. Touch the man, and it goes into you. Make a chain of men holding hands, and it will go through all of them, searching for a way to the ground. If one of the men in the chain happens to be barefoot, the route to the ground is found and men farther down the chain are spared the shock.

This is what's happening with a Leyden jar. The electricity is getting stuck inside with nowhere to go. The electrical "pressure" level in the jar is what we call the *voltage,* and it represents the electrical force difference between the inside of the jar and the outside of the jar. We'll be hearing a lot more about voltage as we proceed with our story. We'll get to that soon. But first, I had promised to tell the true story behind Franklin's kite.

It doesn't take a genius to realize that lightning looks like an enormous spark in the sky, so the notion that lightning storms are electrical wasn't particularly novel. The idea had been around long before Franklin arrived on the scene. It further seemed obvious to most people that sparks so big should represent a lot of electricity stored in storm clouds, most likely of exactly the same type produced by static electricity generators but on a much grander scale. Franklin articulated the case for lightning being an electrical phenomenon in 1749:

> Electrical fluid [electricity] agrees with lightning in these particulars: 1. Giving light. 2. Colour of the light. 3. Crooked direction. 4. Swift motion. 5. Being conducted by metals. 6. Crack or noise in exploding. 7. Subsisting in water or ice. 8. Rending [tearing apart] bodies as it

> passes through. 9. Destroying animals. 10. Melting metals. 11. Firing inflammable substances. 12. Sulphureous smells. . . . [We further know that] electrical fluid is attracted by points. We do not know whether this property is in lightning. But since they agree in all particulars wherein we can already compare them, is it not possible that they agree likewise in this? Let the experiment be made.[24]

In 1750, Franklin went on to publicly propose a specific experiment to explore the alleged electrical nature of lightning. In effect, it amounted to conducting the Flying Boy demonstration using lightning as the source of electricity, with two major differences in the experimental design: 1) the boy suspended from insulating silk ribbons was replaced with a man standing on an insulated platform [a stand with glass peg legs]; 2) the electrification of the body would be achieved not by touching the feet with an electrified glass rod, but rather by having the platform the man was standing on attached to a long *pointed* iron rod reaching 30 feet into the sky.[25] Franklin believed it essential that the rod be pointed, since it had been established that static electricity was attracted most strongly to pointed metal objects.

The idea was that the experiment would be performed at the top of a church steeple or other very high location during a thunderstorm, so that the pointed iron rod would draw electricity from the clouds and electrify the man, just as electricity from the rubbed glass rod had electrified the boy.

To be clear, Franklin didn't believe there would be an actual lightning strike to the iron rod. Rather, he believed the iron rod would simply bleed the cloud of its stored static electricity, as one might bleed the pressure from a shaken bottle of soda by slowly unscrewing the cap. But he realized some people might think it irresponsible to subject a person to such a lightning risk. So he suggested an alternative experimental design, where a grounded wire would be brought close enough to the iron rod to elicit a visual electrical spark as evidence of the rod's electrification by the passing cloud, thus eliminating the need for an electrified human to be part of the experiment.

Franklin was also concerned that it probably would be raining when weather conditions were ripe for conducting the experiment. So he specified that it should be conducted within a small wooden hut to protect everything from getting wet. Only the iron rod would protrude from the hut, into the sky. Because of the need for the hut, Franklin's proposal is often called the Sentry Box experiment.

Franklin published his Sentry Box idea and then waited for an opportune time to actually conduct the experiment. But the logistics were complicated. A church congregation needed to volunteer its steeple, a 30-foot pointed iron rod needed to be made, a sentry box needed to be constructed, etc. At some point in the process, Franklin decided that maybe a kite and a Leyden jar was all he really needed. Franklin reasoned that if his hypothesis about the electricity being in clouds was true, he should be able to capture some of the storm's electricity in a Leyden jar with just the use of a kite to get the electricity from the cloud. So that's what Franklin attempted to do with his kite; he sought to fill a Leyden jar with electricity captured from the sky.

His modified experimental design was to fly a kite, with a thin metal wire pointing up from its top, near the clouds during a thunderstorm. He hoped the kite's wire would allow him to bleed off some of the static electricity he believed to be trapped in the cloud. His expectation was that the cloud's electricity would flow down the wet kite string and into a Leyden jar. Conveniently, the wetness of the string would actually improve its electrical conduction. But how would he prevent himself from being electrocuted in the process? After all, wouldn't the electricity just travel from the string, through his body, and into the ground, perhaps shocking him to death in the process?

Franklin's idea was to insulate himself from the kite in way similar to the way the Flying Boy was electrically insulated from the ground: with a silk ribbon. He didn't directly hold the kite string in his hand. He held a silk ribbon that was tied to a door key. The kite string, in turn, was likewise tied to the same door key. In this way, the electricity in the kite would pass down the kite string only as far as the key, where it would accumulate because it couldn't pass through the silk ribbon into Franklin's hand on its way to the ground. The key could then be touched to the top wire of a Leyden jar, and electricity would flow from the key into the jar. As an added safety precaution, Franklin planned to stand within a rain shelter while he flew the kite to keep both himself and the silk ribbon dry, since water conducts electricity.[26] If he or the ribbon got wet, the electricity would have an alternative route, going through his body to the ground, thus jeopardizing his experiment and threatening his life. But if everything went according to plan, Franklin then would have captured some of the storm's electricity in the jar.

Franklin assembled his experimental materials and awaited a thunderstorm. The opportunity came in June 1752 when a storm descended upon Philadelphia. Franklin grabbed his kite and headed out to catch some electricity.

His modified kite went aloft just as planned, and Franklin started to realize the experiment was working when he saw the kite string's fibers beginning to stick straight out, just as static electricity can make the hairs on your head stand out. In his exuberance, he unwisely risked touching the key to his knuckle to confirm it would deliver an electrical shock. It did. Then he touched the key to the Leyden jar. He had imprisoned lightning in a jar!

There are a number of circumstantial reasons why some people came to doubt Franklin's account of the kite story. But most of the criticisms have been dispelled in recent years by historians who have fleshed out the details of the story and found them to be credible.[27] The general academic consensus now is that Franklin's account checks out; he performed the kite experiment as he claimed and when he claimed: June of 1752.

Ironically, at the time Franklin performed his kite experiment, a group of scientists in France had already been successful in performing his Sentry Box experiment. The French performed their experiment exactly as Franklin had previously specified. They had achieved their success one month before Franklin flew his kite, but Franklin was unaware of it. News traveled slowly at the time. Franklin didn't learn about the successful French experiment until a couple of months later. But it was of no concern to Franklin that he had been scooped. He just appreciated that his idea had been independently validated.[28]

One of the early criticisms of Franklin's claim had been that, if he actually had done the experiment, how did he live to tell about it?

Lightning kills! Everyone knows that. Russian scientist Georg Wilhelm Richmann was one such victim.[29] One year after Franklin's kite experiment, Richmann was in St. Petersburg using a metal rod to reproduce the Sentry Box experiment. He was trying to assess the electricity buildup in the rod, possibly by touching it with his hand, when the rod was abruptly and violently struck by lightning, instantly killing him. The electrical jolt was so powerful that it also knocked his companion down and split a nearby door frame. Up until then, Richmann actually had been a pioneer in the study of electricity. He was nearly as famous for his electrical studies as Franklin was at the time. But Richmann was as unlucky as Franklin had been lucky. We now remember Franklin as the first man to extract electricity from a storm, while Richmann's legacy is that he was the first person in history to die from an electricity experiment. Fate is cruel.

But maybe the difference between the fate of the two men wasn't just luck. Franklin had understood the problem of having your body "grounded" (i.e., connected to the ground) while conducting electrical experiments, and he took precautions, like the insulating silk ribbon, to prevent the electricity from passing through his body into the ground. Perhaps Richmann was more careless. We'll never know. But one thing is clear: *do not* try either man's lightning experiment at home. You likely won't enjoy Franklin's good luck.

Franklin's work with lightning didn't stop with his kite. He would do much more, as we shall soon see. But the kite experiment allowed him to establish that lightning behaves just like static electricity *because it is static electricity*. This, in turn, implied that the discovery of the fundamental physical laws that ruled static electricity's behavior would be applicable to lightning's behavior as well, and that realization had some very important implications.

Because static electricity moves from one place to another like a current of water and exhibits a type of pressure (voltage) when confined to Leyden jars, it isn't hard to understand why many people believed static electricity to be composed of some type of invisible fluid.[30] That seemed to be a logical conclusion. What people wondered about, however, was whether static electricity comprises just one type of fluid or two.

As mentioned already, the reason the two-fluid model came up was that electricity exhibited both attractive and repulsive properties. Could one fluid both attract and repel itself? That seemed incredible. It was easier to believe there were two different fluids, each repellent to itself but attracted by the other (or vice versa).[31] But Franklin had another idea. And his idea would hold up in substance, if not in detail, until the present day.

Franklin believed there was only one electrical fluid that sought to spread itself equally among all materials. In his own words: "We suppose . . . that electrical [fluid] is a common element, of which everyone . . . has his equal share."[32] In other words, the normal state of affairs is that the concentration of the electrical fluid among solid materials is the same; that is, it is constant. Rubbing two objects together means actually scraping the fluid from one of the objects onto the other. Franklin claimed the object that lost fluid was now fluid deficient, which he termed *negatively charged*. In contrast, the object that gained the electrical fluid was thus in fluid excess, so he called it *positively charged*. In Franklin's view, the attractive forces between electrified objects had to do with negatively charged objects trying to get their fluid back from positively charged objects. Thus, negative objects are attracted to positive objects because they are trying to redistribute the charge. In contrast, when two objects with the same charge are placed together, the effect is to exacerbate the charge distribution problem rather than relieve it, so the objects tend to repel each other.[33] It may be worth reading this paragraph again to fully absorb it, because this single-fluid theory of Franklin's reveals a fundamental truth of electricity. It is not correct in detail. There is no actual fluid, and the redistribution of matter actually moves in the direction opposite to the way he proposed (i.e., the charge usually moves from negative to positive rather than from positive to negative). Nevertheless, his perception of electricity was so insightful and provided such a useful model of how electricity behaves that we are still using Franklin's electrical terminology today.[34]

All these things are on my mind as I'm shown the beautiful collection of amber art and jewelry at the House of Amber. How can it be that one material teaches us so much about life? Its physical properties enable it to entrap and freeze life-forms in place for millions of years, and its clarity allows modern humans to actually see those entrapped inclusions and study their anatomy, telling us much about prehistoric animals and the evolution of species.[35] In addition, amber's physical properties revealed electricity to humankind and allowed us to perceive the invisible electrical world that is all around us, permeating our bodies and, as we shall see, enabling life itself to exist.

Yes, amber is an amazing gem that can do some very impressive stuff. In fact, I'm so impressed that I can't bring myself to leave the House of Amber without buying a souvenir. I have a wedding anniversary coming up. Could it be that amber is the traditional gemstone for our anniversary year? I check the internet. Nope . . . our anniversary year's gemstone is emerald. How boring! An emerald just won't do. So I find the most beautiful amber pendant I can afford and purchase it as an anniversary gift for my wife. Emeralds be damned! It would be hard to find an anniversary gemstone of more significance, or with a better backstory, than amber.

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