Nature and Science

Lightning

by *John Sedgwick*

ONE JUNE DAY IN 1978 in the ancient Mayan city of Chichén Itzá in Mexico's Yucatán, a storm blew up, scattering leaves across the grass by the massive stone temples. Dennis Puleston, an American archaeologist, was visiting the site that day with his two young sons. When the rain started to fall and the first thunderclaps began to rumble through the jungle, Puleston suggested that the three climb up to a small enclosure crowning the tallest temple, a hundred-foot pyramid dedicated to Kukulcán, the god of the winds, to watch the storm.

Puleston's ten-year-old son didn't want to go. He'd heard the villagers never went up there because the place was sacred. Besides, weren't there murals inside of priests cutting out people's hearts to offer to Kukulcán? Puleston told his son not to worry: that was just superstition. He started up the ninety steps to the summit, and reluctantly, his sons followed. At the top, Puleston ducked under the stone roof held up by four snarling jaguars—Mayan symbols of mystery—and peered out over the jungle. As his sons watched horrified, the sky burst open with a blaze of light; there was a tremendous crack, as if the very air were being torn apart, and suddenly their father lay dead, killed by a lightning bolt.

The god of the winds had claimed another victim.

What could be more awesome and spectacular than a burst of lightning on a summer afternoon? The sky goes dark, the air grows chill. Then, out of nowhere, there is a burst of blinding light and a deafening roar, and the world is awash in a torrent of water. No wonder the Mayans thought it the work of the gods.

Scientists are no less impressed. "It's the scariest and most spectacular thing I know," says Martin Uman, professor of electrical engineering at the University of Florida and author of several books on lightning. "Sometimes the more you know about something the less interesting it is," Uman goes on. "But with lightning, it just gets better and better."

As Uman and other researchers have discovered, the bolts that pierce the air are actually channels of pulsing electric energy two inches across. They may be as short as two hundred feet or as long as twenty miles. They may be forked, branched, beaded, or ribboned. In the glimmering instant it takes for lightning to strike, the electricity heats up the surrounding air to a scorching 30,000°C, five times the temperature of the surface of the sun. Hitting a tree, the blast instantly sets the sap boiling so fiercely the tree just bursts apart. It has been known to blow open ten-foot craters in the ground and split huge boulders in two. The lightning strike zips through the air at ninety thousand miles per second, nearly half the speed of light. (At that clip, it's impossible to see what special high-speed cameras have shown—that the bolt is actually traveling from the ground up to the clouds.) And it produces enough light to illuminate the countryside for miles around. Although three quarters of the bolt's energy is used up in heat, enough remains to deliver a full 125 million volts of electricity to earth.

With one hundred lightning bolts blasting the earth every second—that's eight million a day—lightning provides more than twice the voltage put out by all the United States' electric generators combined. (Unfortunately, no one has found a way to harness this now-you-see-it-now-you-don't energy source.) The *Apollo XI* astronauts returning from their pioneer voyage to the moon were astonished at one point to see both sides of the earth lit up—one by the steady glare of sunlight, the other by a vast network of lightning flashes.

Physicists speculate that this electrical bombardment may well have figured in the creation of life. Laboratory experiments have shown that powerful electrical jolts, like those produced by lightning, are capable of breaking down the four gases that formed the world's primordial atmosphere—methane, ammonia, hydrogen, and water vapor—to produce amino acids, the building blocks of living organisms. Later on, lightning certainly sustained early man by providing his only source of fire. Even now, lightning alone is responsible for maintaining the earth's negative charge, crucial for the production of nitrogen, which is an essential ingredient for the growth of most plants. Without lightning to replenish the supply, all of the earth's charge would drift off into the upper atmosphere in less than an hour.

But lightning gives, and it takes away. Lightning starts more than three quarters of the forest fires in the United States, accounting for the destruction of more than 30 million dollars' worth of marketable timber every year. It also blasts 20 million dollars' worth of other property. Lightning is the major cause of power blowouts in this country as well, bursting transformers with its sudden surges of power. (It is blamed for the twenty-five-hour New York City blackout of 1977.) Lightning's capriciousness poses other hazards besides, such as nearly short-circuiting one moon-bound *Apollo* space capsule a few moments after blastoff with two strikes to the command

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module. Lightning was one thing the National Aeronautics and Space Administration officials didn't think of. "They really were on the block after that," chuckled Professor Uman. Since then, twenty lightning research groups have been invited down to Cape Kennedy for consultation.

But, the biggest threat of all is the threat to human life. On average, one hundred eighty Americans are killed by lightning every year, archaeologist Puleston being just one example. That's more than the death toll of tornadoes, hurricanes, blizzards, or any other weather formation. Lightning kills by paralyzing the heart with its blast of current—so powerful it often blows off one shoe as it departs. Four victims out of five are male, because males spend more time outside—golfing, camping, fishing, working. As more women venture into the great outdoors, equal opportunity should level off the ratio.

Because of all that current—ten thousand times the amount used in the electric chair—no one who is hit directly by a lightning bolt will live to tell about it. If hit by lightning that has mostly spent itself on a nearby house, or rock, or tree, a person probably will. Just ask Roy C. "Dooms" Sullivan, a sixty-six-year old former ranger in Virginia's Shenandoah National Park. Dubbed the Human Lightning Rod, Dooms has been "struck" no less than seven times by lightning, a Guinness World Record.

"Number two, number five, and number seven—those were the worst," says Sullivan. Number two (1969) only singed his eyebrows. But number five (1973), striking him as he stepped out of a truck, was livelier. "It set my hat and hair on fire," he said at the time. "Then it went down my left arm and leg, knocked off my shoe, and crossed over to my other leg. It also set my underwear on fire." Dooms had to douse himself with a water bucket to put all the fires out. Number seven (1977) flattened him while he was fishing, searing his head and shoulders and sending him to the hospital for four days—the only time he'd ever been laid up by lightning. "That last one was pretty hot," he observes.

One restaurant in the Shenandoah Valley refuses to let Dooms onto the premises during thunderstorms, but the ex-ranger doesn't think lightning will strike him again. Why? "Seven is my lucky number."

As the ancient Greeks explained it, Hephaestus forged the lightning bolts on his anvil, giving them to Zeus to hurl at his enemies. Zeus was supposedly so pleased with his new weapon that he gave the smith his daughter Aphrodite in return. (The idea of lightning bolt as weapon survives; it is pictured in the American eagle's talons on the back of the one-dollar bill.) Norsemen believed lightning was created by Thor hurling his magic hammer down from the sky. Even today the Bantu people of Africa hold it is the streaking flight of the divine thunderbird.

Aristotle, unimpressed by the mythological explanation, postulated in the fourth century B.C. that lightning was a hot "exhalation" from the sphere of fire in the nether regions of the sky. In the Middle Ages it was assumed that lightning passed down a long invisible tube of air from the clouds. Nothing wrong with that. The trouble was that as a preventative measure bell ringers were dispatched to their belfries in hopes that the clanging might break up the lightning paths. (That's why bells of the period bear the inscription *Fulgara frango*—"I break up the lightning.") Since church steeples were among the tallest objects around, the ringers' job had clear occupational hazards. In one thirty-year period, more than a hundred bell ringers were electrocuted.

But Europe didn't learn. Gunpowder was stored in what was normally the safest place in town—the church vaults. In the town of Brescia, Italy, a hundred tons of gunpowder were deposited in the crypt of the lofty Church of Saint Navarene, but there was a serious flaw in this scheme. A lightning storm that summer blew several thousand Brescians—plus a good portion of Brescia—to kingdom come. The disaster was in fact doubly tragic, for by this time Benjamin Franklin had invented the lightning rod, which would have prevented the calamity.

Franklin had toyed with a hand-cranked electrical generator for several years and noted that the long jagged sparks it produced bore a remarkable similarity to lightning. In typical fashion, he made a list of twelve common characteristics, including—number nine—the observation that both destroyed animals, for one afternoon on a picnic he had zapped a turkey to impress his friends.

To test his hypothesis, Franklin sent up his celebrated kite during a thunderstorm in the fall of 1752, dangling a key from the earthward end of the string. Contrary to legend, lightning did not strike the kite to set the key glowing. If it had, more than just the key would have lit up. (A few years later a Professor Richmann, seeking to duplicate Franklin's experiment, was fatally sizzled in just this fashion.) All that happened was that Franklin noticed a few loose strands of the kite string bristling as they had in the presence of electricity that was generated by the hand crank. Franklin drew off some of this charge to store in a primitive capacitor, the Leyden jar. Sure enough, the lightning performed exactly as did the "electrical fluid" produced by the crank. Lightning was electricity.

Franklin's kite was only the beginning of modern science's frontal assault on the mysteries of the upper atmosphere. Other scientists sent up more kites higher into the clouds. Some intrepid researchers even rode balloons into the sky to examine the source of the thunderbolts first hand. (Remarkably, no fatalities were reported.) Later, down on the ground, physicists uncovered the charged particles that compose the atom—in particular the key figure in the lightning process, the electron. Later still, a British physicist, Charles Boys, developed a camera with a revolving lens capable of capturing the fleeting image of the lightning bolt. Or so he thought. The poor man lugged the bulky instrument all around England by train for thirty years without ever obtaining a single clear print. That honor fell to colleagues in South America, where lightning is plentiful, who modified the Boys camera. The brilliant researcher Charles Steinmetz constructed an apparatus for Westinghouse that could generate lightning-like bolts fifty feet long to test methods for protecting the company's power lines. (He had become particularly interested in the subject after lightning blasted the work table in his vacation cabin.) In 1945 even the U.S. Air Force got into the act with Thunderstorm Project, which involved sending fighter planes weighing almost fifteen tons into the thunderhead to obtain wind velocity data.

Now, finally, the god of the winds has yielded some of his secrets.

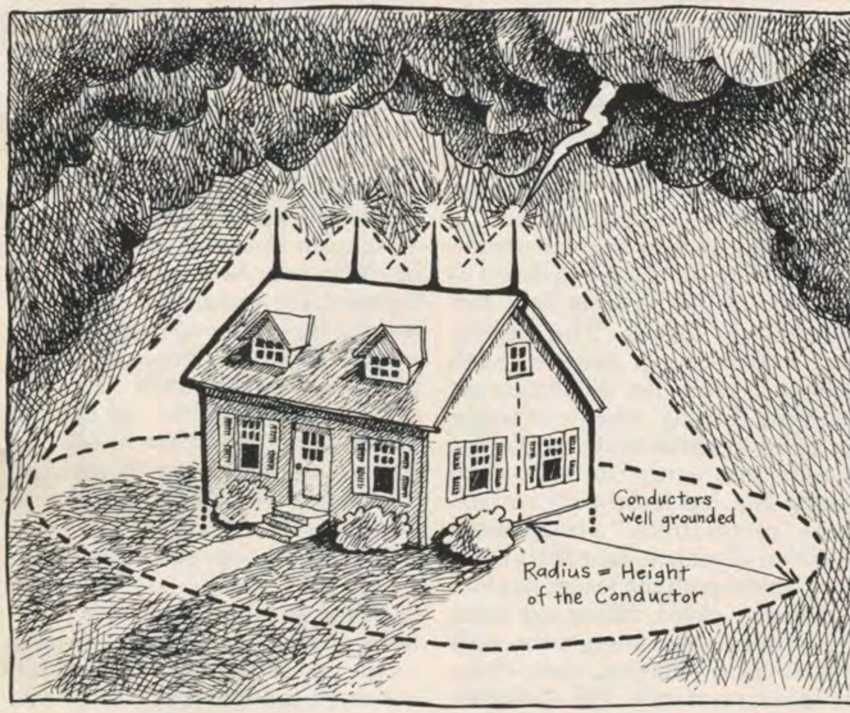
Think of the earth and sky as two oppositely charged metal plates. The earth, for reasons we will get to in a moment, maintains a steady surplus of electrons that leaves it charged at three hundred thousand negative volts compared to the sky, in particular to that region of the sky forty miles up, the ionosphere, which is full of electrically charged ions. The air, which separates these two plates, is normally a poor electric conductor, but it breaks down in the face of the colossal voltage involved, about fifty volts a foot. (This means, incidentally, that your head has about two hundred fifty volts compared to your feet—depending on your height—but you don't feel anything because of the minuscule current involved.) In normal, fair weather conditions, electrons are continually drifting off into the clouds, dissipating the earth's charge. Either they emigrate on the backs of evaporating water droplets, or they are discharged from any sharp object—blades of grass, tips of branches, telephone poles—which, because of their configuration, squirt the electrons into the air.

But the earth and sky form a closed circuit; none of the electrons are lost permanently, for there is another force to be reckoned with—lightning. Lightning bolts resupply earth's charge 125 million volts at a time.

How does a thundercloud get so charged up? No one knows for sure. As one professor of atmospheric electricity put it, "There are fourteen major workers in the field and fourteen major theories." Most of them, however, involve some version of the idea that as the water (or ice) particles are blown about in the swirling currents of the thundercloud, slamming into one another, electrical charges are exchanged, one particle ending up positive, the other negative. These newly charged particles then migrate to align themselves with the cloud's basic electric field—positive charge going to the top, negative charge to the bottom. The field intensifies; the process repeats; the field intensifies still more. Finally the negatively charged cloud base accumulates a whopping potential of up to a billion volts. This is enough to overcome the air's resistance and, since like charges repel, force the earth's fickle electrons to change directions, actually driving them back through the same sharp objects—grass, branches, poles—through which they had attempted to exit in the first place.

If the field is particularly intense, the electrons actually glow as they gather about these points, producing a strange but harmless blue effulgence known as Saint Elmo's fire, named after the patron saint of sailors. The "fire," which sailors knew often preceded a lightning flash, was taken—rather optimistically—as a sign of the saint's protecting presence. During storms the fire can sometimes be seen flaring off the tops of skyscrapers such as the Empire State Building. Mountain climbers near summits often find themselves glowing with it. Biblical scholars speculate that Saint Elmo's fire might explain Moses' vision of the burning bush that flamed without being consumed. Eerily, the fire sometimes clings to cattle out on the plains, transforming, as one rancher put it, "every steer into a devil with flaming horns."

This "point discharge," as Saint Elmo's fire is mistakenly called (since electrons are not departing,



MARGOT APPLE

The Cone of Protection

WITH ALL THIS WHITE-HOT DANGER flashing around your house, you might want to consider some protection. The most prominent and reliable form is as old as the knowledge of lightning's electrical nature itself—Ben Franklin's lightning rods.

They've changed little since Franklin's time. Usually made of copper, the rods thrust up sharp points at intervals on the roof of a house, run down the outside walls, and are imbedded several feet into the ground. Properly constructed and installed, they offer nearly total protection from lightning damage.

Even though the rods' effectiveness has been proved time and again, it wasn't clear for a long while just what they did. Did they reduce the chances of a house being struck by dissipating the thundercloud's electrical charge, as Franklin himself thought? Or did they, in fact, attract the lightning bolts, but then channel them harmlessly along the conductors to the ground?

The answer is that the tips of the rods *do* discharge electrons—you can see the weird blue glow of Saint Elmo's fire around them during a thunderstorm—making them more enticing to a strike. But, happily, this just means that the lightning is all the more likely to hit the rods instead of your roof. The rods transmit the charge painlessly to the ground.

Lightning seeks the shortest route to ground voltage. Since the lightning rods are wired to the ground, they maintain ground voltage even while they stand on rooftops hundreds of feet in the air and so make an ideal target for lightning as it plunges down from the sky. The lightning will actually divert its strike in midair to get at them. The area the lightning passes up is the shape of a cone—the "cone of protection" in industry parlance—whose radius is equal to the height of the rod. Properly installed, the rods shelter your entire house under these conic umbrellas.

Unfortunately, the protection doesn't come cheap. The current price of installing copper lightning rods on an average-sized four-bedroom house is $600. Aluminum rods are somewhat cheaper, but they are slightly less conductive. Although insurance companies offer 15 per cent discounts on property insurance to farms that have installed lightning rods, they don't give the same deal to private residences.

It is not recommended that the homeowner try to cut costs by installing the rods himself. As Wally Akerman of the American Lightning Rod Company in Dover, New Hampshire, says: "A bad system is even worse than none at all." It attracts the lightning, but doesn't protect you from it. Also, it is best to use materials certified by the Underwriters Laboratory.

Are the rods worth it? That depends on whether your house is going to be hit by lightning, obviously. The incidence of strikes increases nationally to the south and east, meaning the Northeast is relatively lightning-free. However, there are hot spots around, such as Washington, New Hampshire, which according to Akerman has been hit so often every house in town has rods. Kurt Lochman at the Franklin Lightning Rod Company in Reading, Massachusetts, recommends the protection for houses near water—lakes, ponds, an artesian well, even a swamp can bring the lightning raining down on you, he says. Exposed houses in a field, say, or on high ground are also vulnerable. Tall trees around your house, on the other hand, can serve as lightning rods themselves and save you $600, as long as they don't fall on your house when they get hit.

But strange things can happen. In Connecticut recently, lightning hit a tall pine in front of a house, traveled down the trunk, through the roots, into the house water pipes, up the plumbing, and into the kitchen sink where it smashed a stack of dinner plates. With lightning, you can't be too careful. J.S.

but returning), is one way the thundercloud restores the earth's electron supply. The other is more dramatic—in a lightning burst. As it happens, only 20 per cent of all strikes actually reach the ground (the rest flash within the cloud or from one cloud to another), but to us earthlings, the cloud-to-ground strikes are the most important. Here, in a nutshell, is what happens. [For the full story—on this and other topics—see Peter Viemeister's *The Lightning Book*.] As the thundercloud's charge drives electrons into the earth, it creates a positive charge on the earth's surface, a charge that the negatively charged bottom of the thundercloud finds very attractive. When the thundercloud's potential reaches the vicinity of a billion volts, the air can hold it off no longer. The charge spills out from the cloud in what's called "stepped leaders," a faint latticework of angular streamers, too faint for the eye to detect in the face of the blinding light that immediately follows. The zig-zagging leaders sweep down to earth cautiously, as if they didn't dare get too close. Finally, when one comes wriggling to within thirty yards of the ground, the earth can take it no longer and lets loose with a mammoth "return stroke," a tremendous eruption of radiant light that shoots back up the path the leader has broken to the cloud, filling out some side channels and wrong turns on its way, to form a blazing, many-channeled stream of light. This is what we see. At 30,000°C, the lightning splits open the air to create a massive shock wave—the roar, crack, and rumble of thunder. That is what we hear. Usually the cloud then responds with another spurt of energy, this time a "dart leader" that zips back down the lightning path, provoking another tremendous convulsion. Then there might be another dart leader and another return stroke. And another and another, producing as many as forty flashes. But they happen so rapidly that they appear as no more than a quick flickering in the lightning shaft.

THE GOD OF THE WINDS, however, still retains some of his secrets. One phenomenon in particular leaves researchers utterly baffled. Consider this:

Kim Fadiman, a young mountaineer, was up on New Hampshire's Mount Washington with a group of friends several winters ago. They had been waiting out a blizzard for three days in a cabin near the peak; their only recreation was square dancing on the icy floor of the hut. Eager for a diversion, the six raced outside when a freak lightning storm broke out over the mountains. To their amazement, they discovered that the whole area was charged with a strange blue flame—Saint Elmo's fire. Besides glowing on branches, it flared from their fingers, their hair, even the tips of their noses. It spurted from their ice axes, and the group immediately split up to duel with these bizarre rays. "The glow gave little sense of electricity when it touched you," Fadiman explains. Suddenly they heard a loud hiss "like the buzzing of a swarm of bees" coming from the roof of the cabin. Everyone looked up to see a glowing reddish orange ball about the size of a pumpkin hovering on the cabin's lightning rod. As they watched, astounded, the fireball flew straight up into the sky for several seconds until, several hundred feet up, it exploded—*blam!* Fadiman says that even the most experienced climber among them said, when he saw the flaming orb and heard it explode, "You could have made me believe in any religion."

What the group saw was ball lightning. Only recently have scientists accepted its existence, having previously chalked it up to blurred vision on the part of the observer, the result of being blinded by a lightning flash. But they still have no idea what it is. From reports, ball lightning varies between the size of a golf ball and a basketball. It's generally a fiery orange or red—and often emits a loud buzz. It seems to have a fondness for the indoors, sometimes sliding down chimneys, passing through screens, even slipping between cracks to get inside, where it hovers at about chest height for a few seconds or drifts by in the air. One ball glided down the aisle of a BOAC prop plane. After about five seconds the balls disappear, often with a bang, leaving behind a vague smell of sulfur. Weird stuff. Some people say the balls are UFOs. Who knows? Maybe they are.

If, however, you are outdoors in a lightning storm, don't look for alien beings, take precautions. Lightning normally strikes the tallest object, because that provides the shortest path to the ground. In an open field,