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Understanding voltage: Ground current lab exercise for lightning education

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Abstract: This lab demonstration shows an experiential approach to teach non-experts the relationship between probe distance and voltage in ground current events. This is a fundamental aspect of the very definition of voltage that can help average citizens make smarter choices regarding lightning safety. Common materials are used to send a one Joule, one Hertz pulse through a bed of damp sand. A pulsed volt meter is used to show the mathematical relationship between probe separation and voltage, then participants will do an exercise to reinforce the pattern of greater voltage at greater separation, reinforcing the point to keep their bodies from touching two different conductors when at risk of electrical shock from lightning. This concept is generalizable to all electricity.

Twenty years ago lightning experts assumed that direct strikes were the primary cause of lightning-caused injuries to humans. Athletes were told to crouch to reduce their chances of being struck, without being told to leave the open field. Theoretically, this crouching made sense because a lower height compared to surroundings reduced the chances of generating an upward streamer from your body. Practically, this no longer makes sense because of simpler priorities in lightning risk reduction and better data on lightning injury mechanisms. But the last generation was taught this approach to risk reduction and it will take a long time to bust this myth we created.

1993 Lightning brochure showing the lightning crouch

The lightning position is an important technique for reducing risk of injury from lightning. Twenty two million Americans recreate far from modern buildings or vehicles and this technique can help them reduce risks. People who are in the protection of modern buildings would benefit from understanding how electrical potential (voltage) works so they understand why they should avoid contact with conductors during a thunderstorm. This lab exercise helps people understand why certain techniques can reduce risks from lightning.

It is critical that we use clear language when discussing the lightning position. The *lightning position* is an important risk reduction technique: its effectiveness is arguable in many circumstances, but it is not arguable that we need to eliminate the words crouch and safety from lightning education. The *lightning crouch* is history: we should only use that term to refer to the old technique we used to teach. The name specifies the importance of getting lower to the ground, which is both incorrect and a distraction. We should avoid the phrase *lightning safety position*, because the word safety infers complete safety from harm, whereas the lightning position merely reduces some of the risks. If lightning educators want to discuss this position, they should discuss the lightning position without cluttering the conversation with language that is both old-fashioned and incorrect.

Ground current is the leading injury mechanism for lightning-caused human fatalities (Cooper & Holle, 2008). This should drive the advice we give people to avoid injury from lightning, whether they are in a remote location or waiting out a storm in their car. It helps people to understand why they need to minimize their footprint on the ground, and it is especially helpful to physically practice the responses we expect them to do under stressful circumstances.

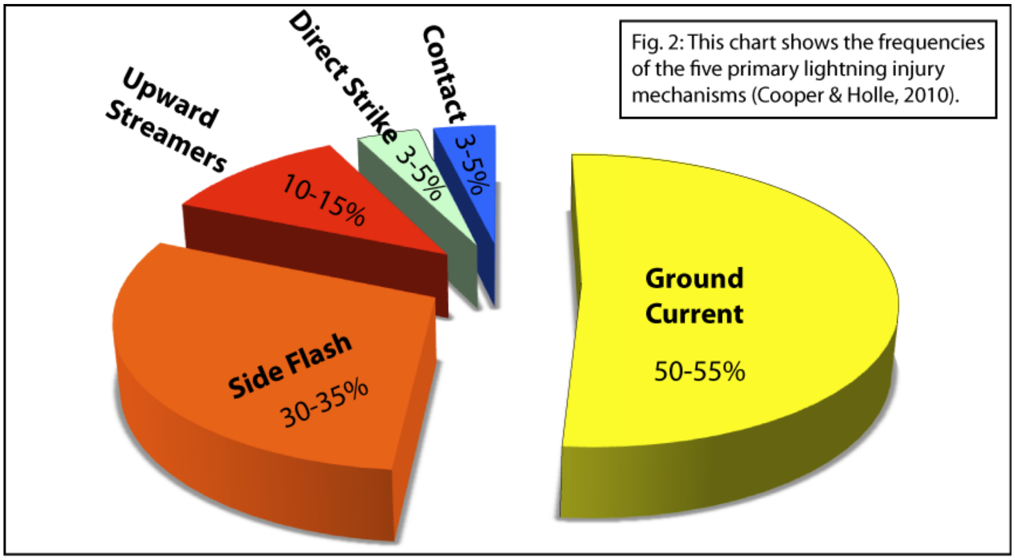
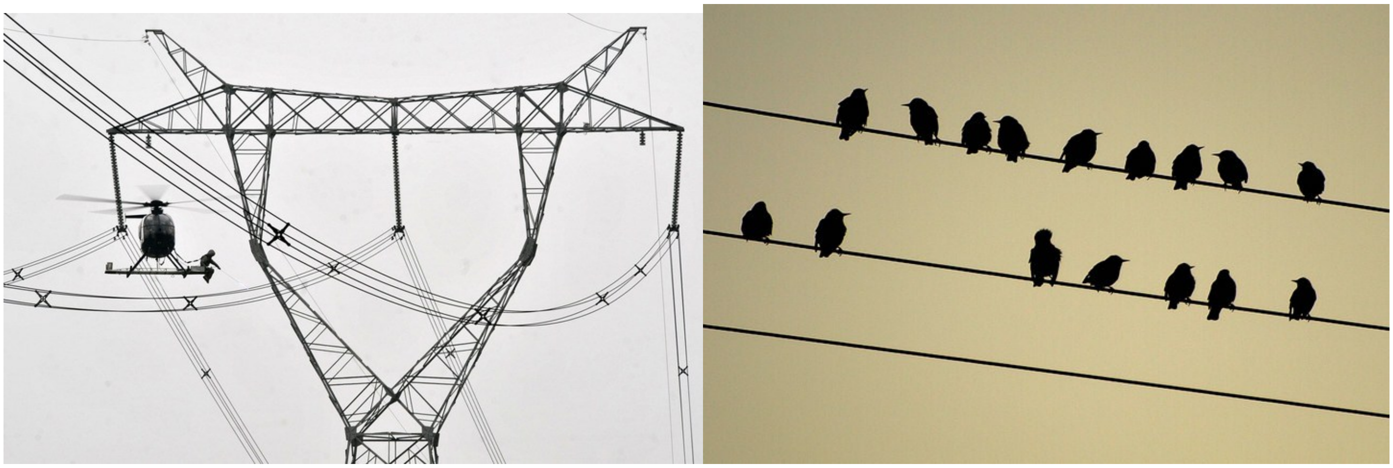


Fig. 2: This chart shows the frequencies of the five primary lightning injury mechanisms (Cooper & Holle, 2010).

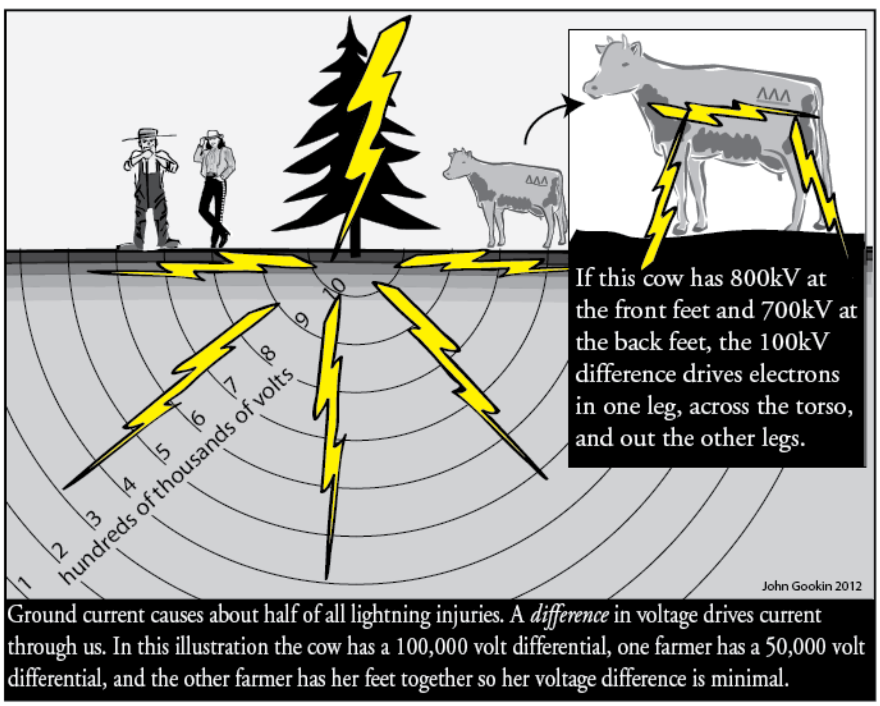
Ground current causes roughly half of all human fatalities. Contact injuries also use this mechanism of different voltages driving current.

Ground current is electrical current driven by voltage differences. High voltage alone doesn't injure humans. High voltage is a problem if the person is also touching a grounded object because then the voltage difference drives current through the body. We can see this effect every day by looking at birds sitting on power lines. In a more extreme case, utility workers routinely work on live high voltage power lines from helicopters.



High voltage causes no harm by itself. This utility worker does maintenance on live high voltage power lines. As long as the helicopter doesn't touch anything of a different voltage, the worker can handle the high voltage lines, because a difference in voltage is what drives current. The birds on wires are fine as long as they don't touch one of the other wires at the same time.

In the attached diagram, lightning strikes a tree, causing the highest voltage at the tree and less and less voltage as the current dissipates through the ground. This generalized diagram is based on measurements at UFL of roughly 100KV difference per meter. This diagram shows why livestock are much more prone to ground current issues than humans, because their feet are naturally so far apart. The wider the exposure on the ground, the more voltage difference drives current through the body. People who stand up and have their feet together have minimal exposure to ground current. People who lay down on the ground have maximum exposure to ground current.



Ground current causes about half of all lightning injuries. A *difference* in voltage drives current through us. In this illustration the cow has a 100,000 volt differential, one farmer has a 50,000 volt differential, and the other farmer has her feet together so her voltage difference is minimal.

Fig X: Ground current is driven by the voltage difference between one spot on the ground and another. The further apart our ground contacts, the greater the voltage difference, hence the greater the current flowing through our bodies.

People often seek shelter from the rain during thunderstorms, but many of these rain shelters offer no protection from lightning. These people should go get in their cars or get inside modern buildings with walls. But many people don’t have these options. Indeed, worldwide, most people who die from lightning are at home in buildings that lack the Faraday cage effect from modern plumbing and wiring. If there is any chance of a lightning strike nearby, there are things people can do to reduce the effects of ground current.

Three people were in this tent when lightning struck nearby. The two people standing survived and the person lying down was killed by ground current. (NOAA photo by Steve Hodanish)

This lab exercise provides cognitive understanding of the ground current mechanism, biofeedback for certain behaviors, and repetitive practice that the military trainers have found to be especially helpful for learning immediate action drills to be applied in stressful circumstances.

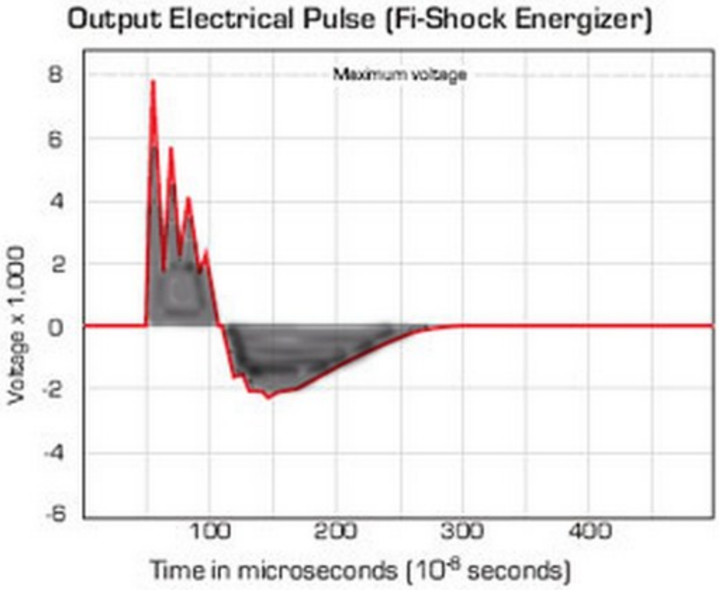
Ground current lab exercise

SAFETY BRIEFING

This lab exercise uses discharges of electricity sent through a three-meter long resistor made from damp sand to emulate the ground current effect from a lightning strike. The one-joule pulse is generated by an electric fence energizer. This safety briefing is based on electric fence technology which is standardized for human use by Underwriter’s Lab. These instructions cannot be generalized to the use of other power sources. The ground current effect is non-linear so more powerful energizers should not be used in this application.

Electric fences provide risks to human health but the risks are generally much easier to mitigate than other common hazards like playing sports or driving automobiles. There are many types of electric fence energizers: this lab exercise uses an energizer with an output rating of one joule per stored pulse. A joule is just a unit of measure for how many electrons are stored then discharged, so it accounts for the three dimensions of an electrical pulse which are voltage, amperage, and time. A joule meter easily shows that this lab exercise exposes students to one tenth of the pulse generated, but some students intentionally touch the bare wires so this safety briefing is based on the worst-case scenario of a one joule pulse touching a person’s hands.

Finally, education that involves any sort of risks should use “challenge by choice” where the student chooses to participate. Be very clear that if you spread your hands too far apart the shock may be painful. If some people choose to not participate, don’t twist their arms. In most cases, but not all, the people who initially don’t want to participate change their mind when they see how much fun the other students have with this exercise. The others may have very personal reasons to not participate and we shouldn’t add social pressure that makes them even more uncomfortable. They can just watch but they won’t learn the lifelong lessons that only come from physical practice.



An oscilloscope shows the wave form of a pulse from an electric fence energizer. A joule meter measures the three dimensions of voltage (wave height), amperage (wave depth, not shown here), and time to calculate how many electrons are in each pulse. This spike explains why the standard measure for electrical fence energizers is joules per stored pulse and not just peak voltage. (Waveform courtesy Ted Etter, USDA MTDC)

Cardiologists use 100-200 Joule pulses of electricity for defibrillation of a heart, so a one-joule pulse is not a safety concern for humans, with a few exceptions:
1) People with pacemakers should stay away from electric fences.
2) Keep electricity away from our brains. About two dairy farmers die from electric fences each year worldwide, but they are typically standing in wet muck, have 10-20 joule energizers, and they bump hot wires with their heads. At least one baby died with their head stuck in an electric fence. So, don't let anyone play with the energizer recklessly.

MATERIALS
You need an **electric fence energizer** in the range of 0.5 to 1.0 joules per stored pulse. You need to understand that the energizer needs a complete circuit from hot to ground for the static pulses to work right. If this complete circuit concept doesn't seem simple to you, you may not be the right person to set up this lab exercise.

You need a **volt meter** made specifically for electric fences. It needs to read out numbers, not use blinking lights to give rough estimates of voltages. They sell these at farm supply stores where they sell the fence energizers. Volts are not the ultimate measure of electric fence performance, but voltmeters are a cheap and simple tool that most farmers use for measuring how well their electric fence is performing.

You can use any sort of decent **insulated wire** (like 12 ga. Romex) to connect your fence energizer to the ends of the gutter. Cut two pieces about seven to ten inches long each. Scrape one inch bare on one end and two to three inches bare on the other end of each wire. Just bury the long bared ends of the wires in the damp sand and fasten the short bared ends to the energizer. You will need a way to fasten the wire to the gutter ends, by either wrapping the end with a box hitch or using plastic twine.

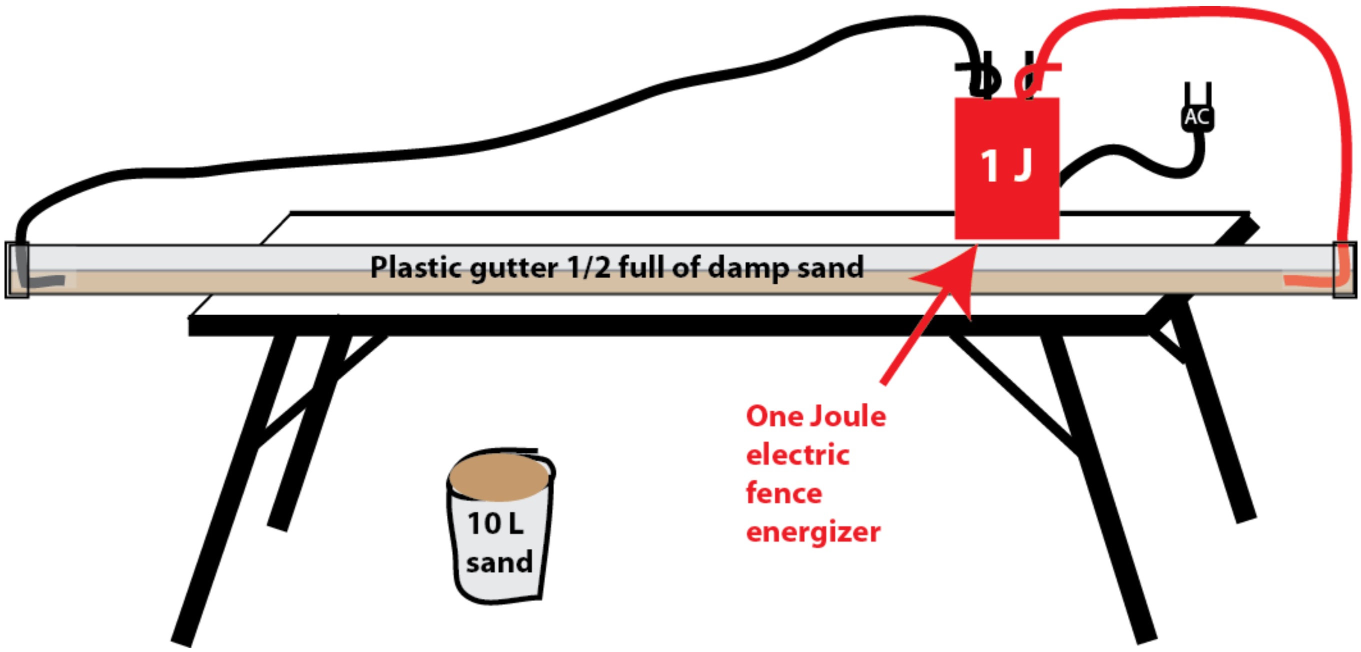
Your **10-inch long plastic gutter (with two end caps)** needs to be half-filled with washed **sand**. It takes about two gallons of sand to do this. The sand needs to be two to four inches deep in the plastic gutter, then pour enough water on it to make it damp but not wet. Some sand conducts electricity better than other sand. Finer sand conducts better. Sand with salt, metals, or dirt in it conducts better, sometimes too well. A small plastic

shovel helps spread the sand then put it back in your bucket when you leave.

If you accidentally use salted sand (for sanding the ice on sidewalks and highways) you will have to keep fingers a few inches apart to do the experiment: just use one hand and spread your fingers wider and closer. Avoid salted sand because it makes it too easy for some students to get a strong negative stimulus.

TUNING THE GROUND CURRENT SIMULATOR

Turn your energizer on. Use your volt meter and test the voltage at a foot apart. Put the tester's ground at one place in the sand and put the other lead a foot away from it, also in the sand. It should read well under 1,000 volts. (If you don't get enough voltage difference, you may need to add more water to help the sand conduct electricity better.) Now put the test leads closer and closer until you get about 200 volts. With this low amperage, that's a good amount of electricity to start with. If you can use one hand, place fingers at the distance for 200 volts and see if it tingles. If it is too hot for comfort, put your fingers closer. If you can barely feel it, spread your fingers farther apart. Figure out the threshold between no feeling of the electricity and a slight tingle because you want your students to start with this very slight sensation, so they get the point that if you are close enough together with your feet on the ground, the voltage is the same, hence you won't get much voltage. Test this before asking students to participate, then turn the energizer off until you want to begin the lab exercise. If some students arrive early and you are ready, feel free to have some of the students play with the experiment so they get a feel for how probe (finger) distance correlates with voltage difference (pain).



This lab exercise uses a plastic gutter filled with damp sand, powered by a one joule per pulse electric fence energizer.

LAB EXERCISE

Show some of the above photos and explain how ground current works. This should take five to fifteen minutes depending on depth. One of the most important concepts to explain is that voltage is a measure of the electrical *potential* between two points. We can't measure voltage unless we use something else like the ground for a voltage reference. Indeed, the local earth ground is a common reference for voltage measurements.

Turn the energizer on. Use the voltmeter to demonstrate the concept that just touching one place shows zero volts of electrical potential, but when we contact two different places we can get measurements of electrical potential. Show how the voltage increases the further you separate the probes. Place them wider and closer, reading off the voltage reading. Repetition is important so they see the clear pattern.

Demonstrate with your own hands how you get closer together and don't feel much, then as you get wider apart you feel a stronger tingling with each pulse. Again, repetition is important to clarify and reinforce the relationship between probe distance and current. It is not enough to tell students that you want them to go wider then closer at least three times: you need to show them what this looks like as you do it.

Now have students practice. Many students can do this at the same time, but be sure nobody bumps anyone else because their probe separation will be from the furthest extremes of each person's fingers.

If students are having fun with this, encourage them to do team contact, where they hold hands and a person on each end touches the sand. Start with the same probe separation that individuals were using or they may get a shocking experience they didn't expect.

Good teachers can often make learning fun for people of all ages. If young people are involved with this lab exercise you might see why certain types of adolescent males dominate accident statistics in many fields. Supervision is important because you want people to actively play with this electricity without being reckless, and sometimes there is a fine line between the two.

Using both sides of the gutter, six people can do the lab exercise at the same time. Watch these three students do individual and team exercises on Youtube.

OPTIOINAL: Faraday Cage demo
A device that looks like a miniature house can be made by cutting and folding wire mesh. The model in the photo was made out of hardware cloth by a local sheet metal business. Set the device in the damp sand. Bury the bottom of the wire in the sand well enough to stabilize it in the gutter. Use the voltmeter to show no voltage difference inside of the "house," then demo with your fingers, then let students feel that there is ground current outside of the house but not inside of the house. Ask them why they think this works. Ask advanced students why some human made structures provide this Faraday Cage effect while others don't.

A simple cage made out of wire mesh can be placed in the gutter to show the Faraday Cage effect. This one has a sheet metal roof with rolled edges, to look more like a house.

WRAP-UP

Ask students to demonstrate safer and less safe ways to hang out if they are in a building or vehicle during a thunderstorm. Again, repetition helps reinforce what you want them to remember ten years from now. If these are backcountry users, discuss the lightning position with their feet together, but be clear that it this only helps a tiny amount compared to the safe options available in the frontcountry.

Summary

This lab exercise helps students understand the concept of voltage as applied to ground current, specifically the correlation between probe distance and current strength when near a lightning strike. Ideally, this should help people understand lightning risk reduction techniques. The physical practice is meant to provide rehearsal of procedures so students recall what to do in stressful circumstances.