

## **Electric shock**

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Resources and methods for learning about these subjects (list a few here, in preparation for your research):

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### Question 1

It is sometimes said regarding electrical safety that, "It's not the *voltage* that will hurt you, it's the *current*." Why then are there signs reading **Danger: High Voltage** near electrical substations and on large pieces of electrical equipment, rather than signs reading **Danger: High Current**?

file 00004

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### Answer 1

Yes, it is electric *current* that does the damage when enough of it passes through a body, but current exists only when there is sufficient *voltage* to push it through that body's *resistance*. Thus, there is no shock hazard when there is too little voltage present to force dangerous levels of current through a human body.

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### Notes 1

Ask students how this question relates to *Ohm's Law*. If they don't know what Ohm's Law is yet, this is a really good place to begin exploring!

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## Question 2

Why is this sign a joke?



file 00066

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## Answer 2

Electrical *resistance* is not hazardous in the least. In fact, the more resistance there is, the less chance there is for electrons to flow, thus minimizing shock hazard.

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## Notes 2

A joke it may be, but still a fun one to play. Hang a large sign saying "Danger: high resistance" over the entrance to the electrical lab and watch the responses of the uninitiated!

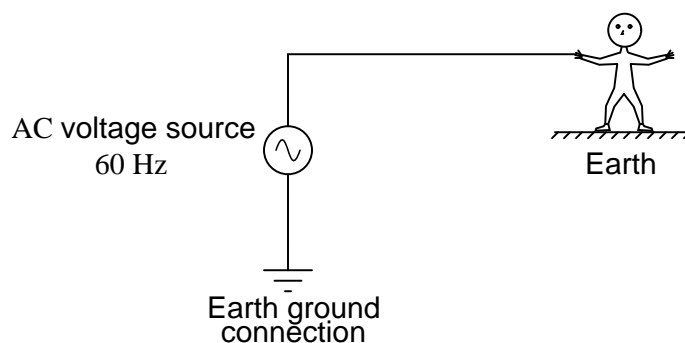
### Question 3

An American researcher named Charles Dalziel performed experiments with both human and animal subjects to determine the effects of electric currents on the body. A table showing his research data is presented here:

<i>Bodily effect</i>	<i>Gender</i>	<i>DC</i>	<i>60 Hz AC</i>	<i>10 kHz AC</i>
Slight sensation at point(s) of contact	Men	1 mA	0.4 mA	7 mA
	Women	0.6 mA	0.3 mA	5 mA
Threshold of bodily perception	Men	5.2 mA	1.1 mA	12 mA
	Women	3.5 mA	0.7 mA	8 mA
Pain, with voluntary muscle control maintained	Men	62 mA	9 mA	55 mA
	Women	41 mA	6 mA	37 mA
Pain, with loss of voluntary muscle control	Men	76 mA	16 mA	75 mA
	Women	51 mA	10.5 mA	50 mA
Severe pain, difficulty breathing	Men	90 mA	23 mA	94 mA
	Women	60 mA	15 mA	63 mA
Possible heart fibrillation after three seconds	Men	500 mA	100 mA	
	Women	500 mA	100 mA	

**Important Note:** *Dalziel's human test subjects were men and women in good health, with no known heart conditions or any other abnormalities that would have compromised their safety. In other words, these data points represent best-case scenarios, and do not necessarily reflect the risk to persons in poorer states of health.*

Assuming a skin contact resistance of  $600\ \Omega$  for a sweaty hand,  $1000\ \Omega$  of resistance for foot-to-ground contact,  $50\ \Omega$  internal body resistance,  $70\ \Omega$  of resistance through the soil from the person's location to the earth ground point, and a male victim, calculate the amount of voltage necessary to achieve each of the listed shock conditions (threshold of perception, pain, etc.) for the following circuit:



file 01703

- Slight sensation at point(s) of contact: **0.69 volts**
- Threshold of bodily perception: **1.9 volts**
- Pain, with voluntary muscle control maintained: **15.5 volts**
- Pain, with loss of voluntary muscle control: **27.5 volts**
- Severe pain and difficulty breathing: **39.6 volts**
- Possible heart fibrillation after three seconds: **172 volts**

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Notes 3

Not only does this question introduce students to the various levels of shock current necessary to induce deleterious effects in the (healthy) human body, but it also serves as a good exercise for Ohm's Law, and for introducing (or reviewing) the concept of series resistances.

For the morbidly curious, Charles Dalziel's experimentation conducted at the University of California (Berkeley) began with a state grant to investigate the bodily effects of sub-lethal electric current. His testing method was as follows: healthy male and female volunteer subjects were asked to hold a copper wire in one hand and place their other hand on a round, brass plate. A voltage was then applied between the wire and the plate, causing electrons to flow through the subject's arms and chest. The current was stopped, then resumed at a higher level. The goal here was to see how much current the subject could tolerate and still keep their hand pressed against the brass plate. When this threshold was reached, laboratory assistants forcefully held the subject's hand in contact with the plate and the current was again increased. The subject was asked to release the wire they were holding, to see at what current level involuntary muscle contraction (tetanus) prevented them from doing so. For each subject the experiment was conducted using DC and also AC at various frequencies. Over two dozen human volunteers were tested, and later studies on heart fibrillation were conducted using animal subjects.

Given that Dalziel tested subjects for the effects of a hand-to-hand shock current path, his data does not precisely match the scenario I show in the schematic diagram (hand-to-foot). Therefore, the calculated voltages for various hand-to-foot shock conditions are *approximate only*.

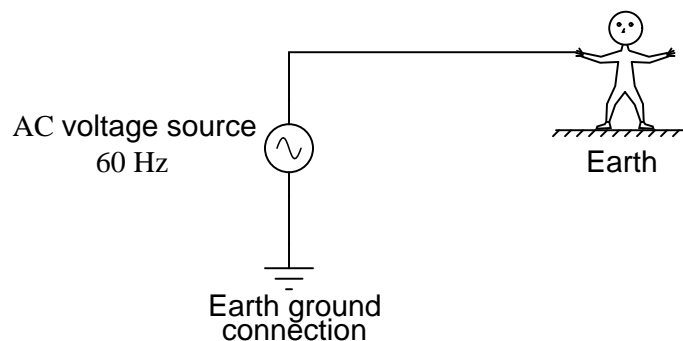
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**Important Note:** *Dalziel's human test subjects were men and women in good health, with no known heart conditions or any other abnormalities that would have compromised their safety. In other words, these data points represent best-case scenarios, and do not necessarily reflect the risk to persons in poorer states of health.*

Assuming a wire-to-hand contact resistance of  $1500\ \Omega$ ,  $4400\ \Omega$  of resistance for foot-to-ground contact,  $50\ \Omega$  internal body resistance,  $200\ \Omega$  of resistance through the soil from the person's location to the earth ground point, and a female victim, calculate the amount of voltage necessary to achieve each of the listed shock conditions (threshold of perception, pain, etc.) for the following circuit:



file 03246

- Slight sensation at point(s) of contact: **1.85 volts**
- Threshold of bodily perception: **4.3 volts**
- Pain, with voluntary muscle control maintained: **36.9 volts**
- Pain, with loss of voluntary muscle control: **64.6 volts**
- Severe pain and difficulty breathing: **92.3 volts**
- Possible heart fibrillation after three seconds: **615 volts**

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Notes 4

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#### Question 5

All other factors being equal, which possesses a greater potential for inducing harmful electric shock, DC electricity or AC electricity at a frequency of 60 Hertz? Be sure to back up your answer with research data!

file 03289

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#### Answer 5

From a perspective of inducing electric shock, AC has been experimentally proven to possess greater hazard than DC (all other factors being equal). See the research of Charles Dalziel for supporting data.

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#### Notes 5

A common misconception is that DC is more capable of delivering a harmful electric shock than AC, all other factors being equal. In fact, this is something I used to teach myself (because I had heard it numerous times from others) before I discovered the research of Charles Dalziel. One of the explanations used to support the myth of DC being more dangerous is that DC has the ability to cause muscle tetanus more readily than AC. However, at 60 Hertz, the reversals of polarity occur so quickly that no human muscle could relax fast enough to enable a shock victim to release a "hot" wire anyway, so that fact that AC stops multiple times per second is of no benefit to the victim.

Do not be surprised if some students react unfavorably to the answer given here! The myth that DC is more dangerous than AC is so prevalent, especially among people who have a little background knowledge of the subject, that to counter it is to invite dispute. This is why I included the condition of supporting any answer by research data in the question.

This just goes to show that there are many misconceptions about electricity that are passed from person to person as "common knowledge" which have little or no grounding in fact (lightning never strikes twice in the same spot, electricity takes the least path of resistance, high current is more dangerous than high voltage, etc., etc.). The study of electricity and electronics is science, and in science experimental data is our sole authority. One of the most important lessons to be learned in science is that human beings have a propensity to believe things which are not true, and some will continue to defend false beliefs even in the face of conclusive evidence.



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Question 6

Using Ohm's Law, explain why personal protective equipment such as insulating gloves and boots help reduce the risk of electric shock.

file 00302

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Answer 6

Such personal protective equipment serves the purpose of increasing electrical resistance in the shock path.

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Notes 6

Ohm's Law has many applications, and electrical safety is just one of them. I have found that the topic of safety is an excellent venue for highlighting certain (otherwise abstract) physical principles. Not only is the topic interesting, but it is of great personal importance, and so student attention is very easy to attain and hold in discussion.

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#### Question 7

The ignition system in a spark-ignition automobile engine produces voltages in the range of tens of thousands of volts: greater than the voltage levels typically used to distribute electric power through neighborhoods. Although this is capable of producing very painful electric shocks, the actual shock *hazard* it poses to a person is minimal. Why is this?

file 00006

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#### Answer 7

Automotive ignition systems pose little direct shock hazard because of two factors: the *resistance* intrinsic to the high voltage circuit limits current to a fairly low value even without the resistance of a person's body in the circuit; and the high voltage pulse lasts only a brief moment in time.

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#### Notes 7

This is not to say that ignition systems pose no hazard, though. One of the main hazards is the reaction a shock produces in a person: namely, the jerking of limbs which could be dangerous in the proximity of moving parts. Emphasize that hazards may often be indirect: that something in itself may not be enough to hurt you, but your body's reaction to that something is what poses the greater threat.

An example of this general principle is an allergic reaction. The threat here is the body's over-reaction to an allergen, not the allergen itself!

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#### Question 8

If you scuff your feet across a carpeted surface on a dry day, you will produce an electric potential resulting from a static electric charge that may range in the order of tens of thousands of volts! Can this pose a danger to you, at least in principle?

file 00005

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#### Answer 8

Static electric charges rarely pose any shock hazard, because the actual charge quantity (measured in *coulombs*) is so small that the resulting current upon discharge can only last a very brief moment in time.

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#### Notes 8

This question is a good starting point for a discussion on *time* as a variable in determining electric shock hazard. There is more to determining hazard to the human body than a simple assessment of volts, amps, and ohms!

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#### Question 9

In the late 1700's, an Italian professor of anatomy, Luigi Galvani, discovered that the leg muscles of a recently deceased frog could be made to twitch when subjected to an electric current. What phenomenon is suggested by Galvani's discovery? In other words, what does this tell us about the operation of muscle fibers in living creatures? More importantly, what practical importance does this have for people working near electric circuits?

file 00223

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#### Answer 9

Essentially, muscle fibers are "activated" by electrical signals. I'll let you figure out what practical importance this effect has for you!

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#### Notes 9

This question presents an excellent opportunity to discuss one of the important aspects of electrical safety: involuntary muscle contraction.

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#### Question 10

Suppose the foot-ground contact resistance of a person standing barefoot is  $3\text{ k}\Omega$ , the contact resistance between a person's hand and a held wire is  $10\text{ k}\Omega$ , and the person's hand-to-foot internal body resistance is  $500\text{ }\Omega$ . How much danger would a person be in, given these conditions, if the voltage between the wire they were holding and the ground they were standing on was 120 volts, 60 Hz alternating current?

file 00305

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#### Answer 10

According to research done by Charles F. Dalziel, the amount of current that would go through this individual would be sufficient to cause pain, but not enough to cause loss of voluntary muscle control.

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#### Notes 10

This question is not only a practical exercise of Ohm's Law, but also a stimulus for researching shock current levels and their effects on the human body. Be sure pursue a line of questioning here during discussion time to explore the effects of electric current on the human body for a wide range of currents. In other words, don't just leave the answer at "causes pain, but muscle control maintained," but rather use this time to investigate what levels of current cause more (and less) serious effects on the human body.

Also, be sure to point out that the health of the individual being shocked is important to consider. Dalziel's work was based on healthy individuals, who had been medically screened for this testing. A person in ill health may not fare as well in the same scenario.

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### Question 11

Suppose you are an electrician, and you need to disconnect the power conductors from a large electric motor. What steps should you take to ensure no shock hazard exists prior to touching the bare conductors?  
file 00301

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### Answer 11

- Turn the motor off (using the start/stop switch).
- Shut off the circuit breaker (or disconnect switch) providing electrical power to the motor.
- Lock and tag the circuit breaker (or disconnect switch) so no one else will turn it on in your absence.
- Check the operation of a voltmeter by connecting it to a known source of voltage.
- Check for the presence of voltage at the conductor terminations with a voltmeter.
- Re-check the operation of a voltmeter by connecting it to a known source of voltage.
- As a final step, touch the bare conductor with the *back* of your right hand, before touching it in any other way.

Follow-up questions:

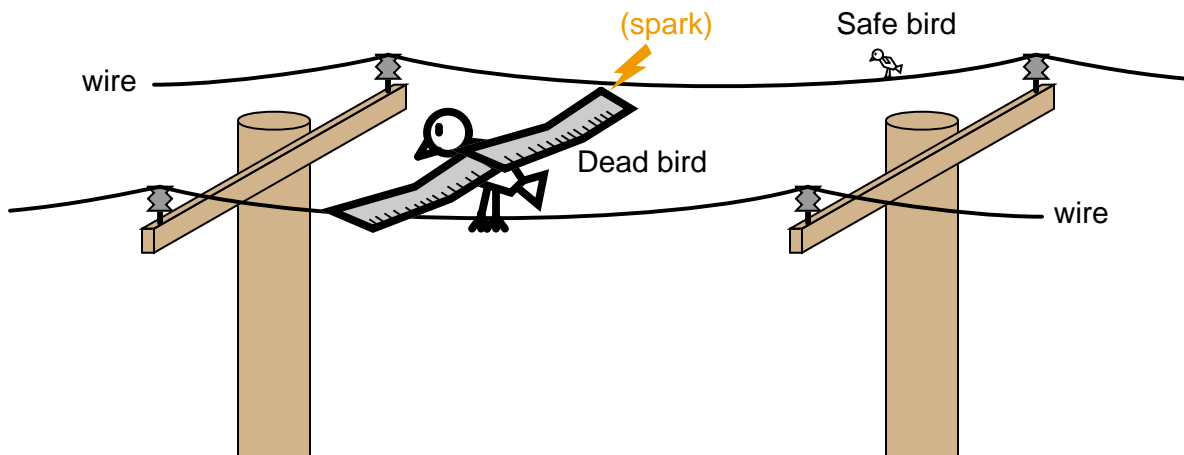
- Why check the voltmeter both before and after testing for voltage at the motor connections?
  - Why touch the conductor with the back of your hand? What does it matter which side of your hand should touch the bare conductor?
  - Why use your right hand? Why not your left?
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### Notes 11

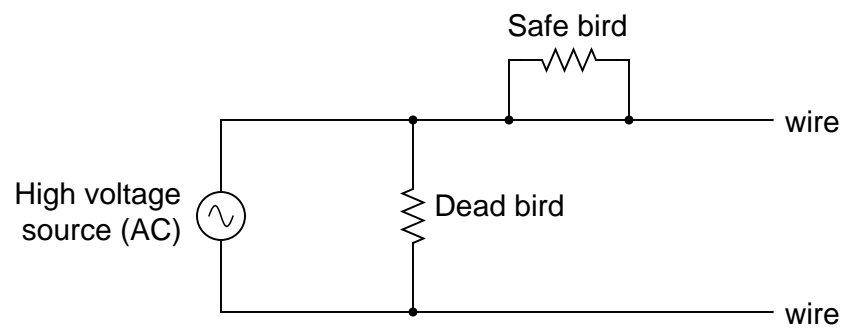
A lot of electrical safety principles are covered in this one question. Be sure to spend adequate time with the follow-up questions, to be sure students understand exactly why the given steps are necessary to ensure safety.

### Question 12

Explain why birds do not get shocked when they perch on a power line, even if both of their feet touch the wire. Explain why birds become electrocuted if their wings bridge between two different power conductors:



For a schematic view of both scenarios, see this diagram:



file 01704

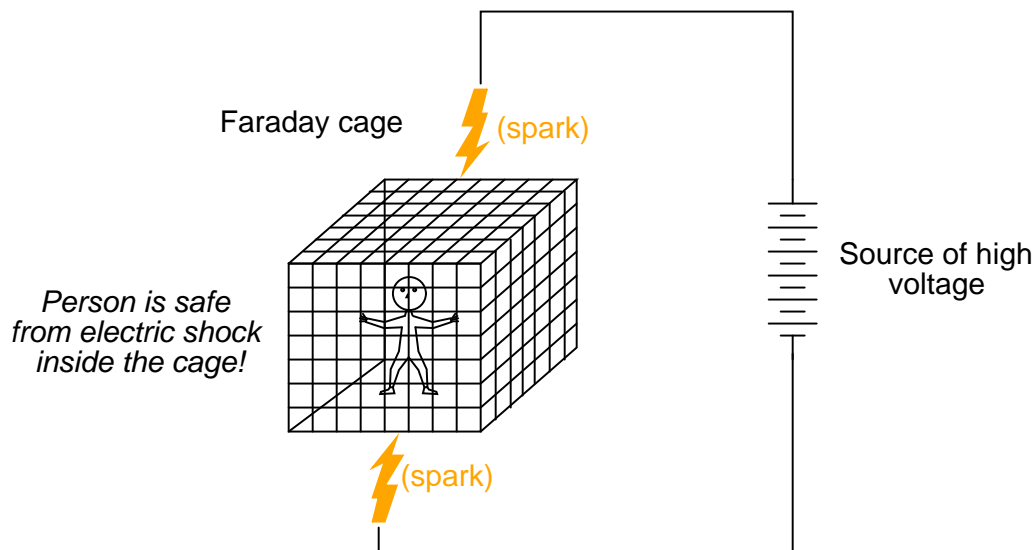
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## Answer 12

Perhaps the easiest way to explain the relative danger of these two scenarios is by way of voltage. The "safe" bird will not be shocked because there is negligible voltage between its feet (both feet resting on the same wire). Points connected directly together with low-resistance (conductive) wire are said to be *electrically common*, and should never have appreciable voltage between them.

The dead bird got that way because there is full source voltage between the two points of contact (each wing-tip touching a different wire).

Follow-up question: a safety device called a *Faraday cage* protects anyone inside from electrical shock. A Faraday cage is nothing more than a cage made of closely-spaced metal bars (or alternatively, made of metal wire mesh):



Explain how the principle of electrically common points protects the person inside the Faraday cage from being shocked by the outside source of high voltage. Discuss how this principle might apply to metal-frame automobiles and aircraft.

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## Notes 12

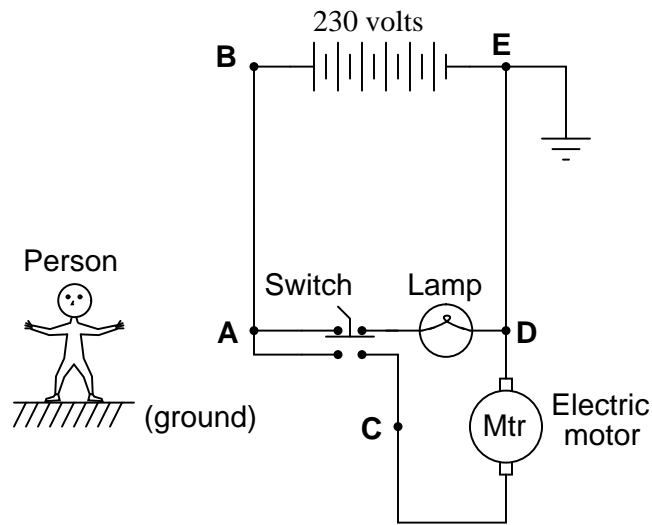
Very vivid demonstrations have been performed with Van de Graaff generators and Tesla coils showing the protective nature of a Faraday cage. When students understand that substantial voltage cannot exist between electrically common points (at least at frequencies below RF!), not only are they prepared to understand the purpose of safety grounding in electrical systems, but they are also equipped with an extremely important concept for use in electrical troubleshooting.



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### Question 13

Determine whether or not a shock hazard exists for a person standing on the ground, by touching any one of the points labeled in this circuit:



- Point "A"
- Point "B"
- Point "C"
- Point "D"
- Point "E"

file 00303

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### Answer 13

- Point "A" *dangerous to touch*
- Point "B" *dangerous to touch*
- Point "C" *dangerous to touch when motor is turned on*
- Point "D" *safe to touch*
- Point "E" *safe to touch*

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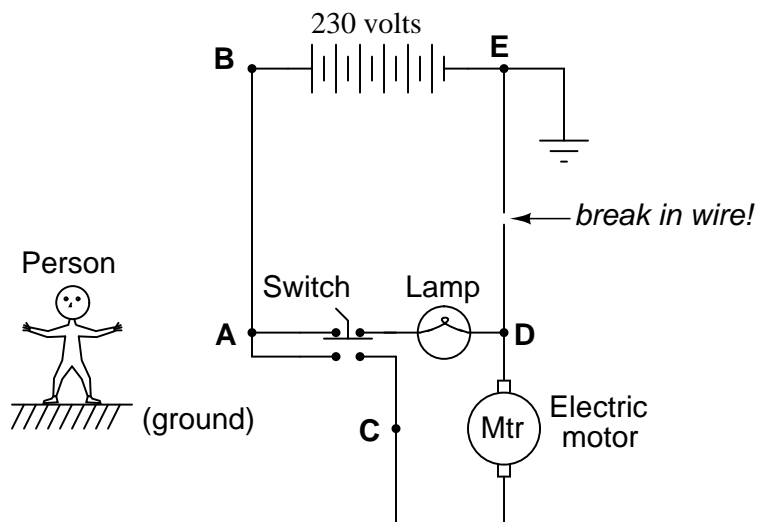
### Notes 13

One suggestion for approaching this question is to ask your students to identify which of the power source conductors is "hot" and which one is "neutral," then identify which points in the circuit are electrically common to either one or the other source conductors.

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### Question 14

Determine whether or not a shock hazard exists for a person standing on the ground, by touching any one of the points labeled in this faulted circuit:



- Point "A"
- Point "B"
- Point "C"
- Point "D"
- Point "E"

file 00304

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### Answer 14

- Point "A" *dangerous to touch*
- Point "B" *dangerous to touch*
- Point "C" *dangerous to touch*
- Point "D" *dangerous to touch*
- Point "E" *safe to touch*

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### Notes 14

The purpose of this question is to get students to realize that safe conditions may turn into unsafe conditions in a circuit, given certain wiring failures!

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Question 15

What sort of immediate medical attention does a victim of severe electrical shock require? Explain why this attention is necessary.

file 00300

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Answer 15

Cardio-pulmonary resuscitation (CPR).

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Notes 15

In truth, CPR is not the only attention a victim of electrical shock may require, but it is of primary importance. Discuss with your students some of the effects of electricity on the human body, and the various kinds of injuries that electricity may inflict upon it.

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### Question 16

The following recommendations came from a flyer published by an electric power utility. Read and comment on their instructions regarding downed power lines:

*Assume any downed line is an energized power line. If a power line falls on your car while you are driving, slowly drive on until you are completely clear of the line (but do not drive over it). If your car is immobilized, stay in it until help arrives. Call for help from a cell phone if you have one.*

*If you need to escape from a vehicle, such as for a car fire, jump clear of the car. Electricity is not only traveling through the vehicle, but may also be traveling in the ground around the area. Keep your arms crossed over your chest while you jump, and both feet together. Do NOT touch the vehicle and the ground at the same time. Once you land on the ground, shuffle clear of the area, keeping both feet together, on the ground, and touching at all times. Continue shuffling until you're at least 30 feet from the accident site.*

Why do you suppose the following actions were recommended?

- Do not drive over a downed power line.
- Stay in the car if possible.
- Do not touch the car and the ground at the same time.
- Shuffle away from the car (rather than walk), with both feet together.

file 02911

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### Answer 16

These are all interesting points to consider as a group. I'll let you figure out possible answers to these questions together in class.

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### Notes 16

The italicized text was taken directly from Puget Sound Energy's April 2005 "Energywise" mail flyer. The points brought up were, I thought, very appropriate for discussion of electrical safety and theory. Personally, I question the suggestion of shuffling on both feet. I would suspect that running full-speed, where only one foot touches the ground at a time, and where you would leave the dangerous area faster, would be the safest option. I would be very interested to see if there is any scientific test data available on this subject!

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## Question 17

Briefly answer the following safety questions:

- What does electric current do to muscle tissue?
- What can electric current do to motor muscles (fingers, arms, legs)?
- What can electric current do to heart and lungs?
- Why should you use one hand while working on live power circuits? Which hand?
- Why is water dangerous when working around electric power?
- Why is metal jewelry dangerous to wear when working on electric circuits?
- What kinds of tools are best for working on live power circuits?
- What kind of immediate medical attention does an electric shock victim require?
- What footwear is appropriate when working around electric power?
- What footwear is **not** appropriate when working around electric power?

file 01702

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## Answer 17

- What does electric current do to muscle tissue? *Electric current causes muscles to contract.*
- What can electric current do to motor muscles (fingers, arms, legs)? *It may cause them to involuntarily contract.*
- What can electric current do to heart and lungs? *Paralyze them.*
- Why should you use one hand while working on live power circuits? *To minimize the danger of an across-the-chest path for electric current.* Which hand? *The right, because the heart is more vulnerable to shock current going through the left-hand side of the chest.*
- Why is water dangerous when working around electric power? *It lowers the resistance of porous substances, including human skin.*
- Why is metal jewelry dangerous to wear when working on electric circuits? *Because the metal pieces optimize contact between your skin and an exposed power conductor, or between two power conductors.*
- What kinds of tools are best for working on live power circuits? *Tools with electrically-insulated handles.*
- What kind of immediate medical attention does an electric shock victim require? *CPR if they are not breathing or their heart is not beating.*
- What footwear is appropriate when working around electric power? *Closed-toed work boots or shoes with good, thick, insulating soles.*
- What footwear is **not** appropriate when working around electric power? *Sandals, flip-flops, or other shoes exposing the skin.*

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## Notes 17

The safety concern of jewelry worn around electric circuits is not limited to high voltages where shock is possible. It is also a concern around low-voltage circuits where high current through a ring or bracelet (caused by bridging two conductors with the jewelry) can cause the jewelry to heat up and burn the skin.