Electrical Safety in ECE Laboratories

Dr. Kurt Kosbar
ECE Associate Chair for Laboratories
227 Emerson Electric Company Hall
Missouri University of Science and Technology
Rolla, MO 65409-0040
Phone: (573) 341-4894 (voice only)
kosbar@mst.edu
Emergency Procedures for Electric Shock

• Stay calm, stay focused
• Do not become the second victim, while trying to help the first victim
• Stop the current flow
• Call 911
• Provide first aid, and CPR if appropriate
• Assist first responders
ECE Lab Safety Quiz

• Study on-line safety manual (lab TA will make this available)
• Take a 10 question, multiple choice quiz
• Must get 90% or 100% to pass the quiz
• Can take the quiz up to 3 times
• After 3 failures, you must meet with ECE Associate Chair for Labs
• Bring copies of your three quizzes, and how you answered them, with you to the meeting
• May be given another chance to take the quiz, or removed from the lab for your safety, and the safety of others
Electrical Hazards

• Electricity can cause injuries in a number of ways
• Electrical Shock
  • This is when an external source of electrical energy forces a current through someone’s body.
  • The term “electrocution” is only used when the shock is fatal.
• Heat / Burns / Fire
  • High levels of electric current can easily melt metal
  • Rings and other forms of jewelry are often good conductors
  • High temperatures in electrical wiring may start structure fires
Electrical Hazards

• Extremely High Temperatures / Arc Flash
  • If an electric circuit produces an arc, it can create temperatures up to 19 000 degrees Celsius.
  • By comparison, the surface of the sun is less than 6 000 degrees Celsius.
  • Heat energy radiates out from an arc flash, injuring people who never came into physical contact with the circuit

• Blast / Explosion / Shrapnel
  • The rapid and extreme heating during an arc flash event may cause the air or other material nearby to rapidly expand, causing an explosion
  • The blast of the explosion may cause injury all by itself
  • Even if the blast is not a problem, the shrapnel (small bits of flying, hot metal) may cause injury
Electrical Hazards

• Ultraviolet Radiation
  • Electric arcs produce large amounts of ultraviolet light
  • Human eyes cannot detect UV light, so it is difficult to determine how much of it is striking our bodies
  • UV light can permanently damage eyesight, and cause severe “sunburn” on skin

• Sparks
  • Small electric arcs routinely occur when mechanical contacts open and close
  • Even when they arcs produce very little heat, they still create very high temperatures in a small area
  • These small arcs may ignite flammable materials
Electrical Hazards

• Electrostatic Discharge
  • People and objects routinely develop high voltages through common movement
  • These voltages may damage electronic components, and create sparks

• Surprise
  • A small shock, arc, etc. may not itself injure someone, but it may startle or surprise them
  • A person’s reaction to the surprise may cause them to quickly react, in a way that causes far greater injury.
Your Responsibilities

• Learn how to identify electrical hazards
• Educate yourself on safety protocols and standards
• Behave in a way that keeps yourself, and others, safe
• Operate equipment in a safe manner
• Design equipment so it can be used safely
• Caution those you see acting in an unsafe manner, and if necessary report violations of safety standards
• Provide appropriate aid in emergency situations
Electrical Shock

• Electric current can interact with a person’s body in a variety of ways
• It can be difficult to predict the severity of one’s injury from an electric shock
• Current levels as low as 100 mA (0.1 amps) can be fatal
• Yet some people have survived being struck by lightning multiple times, at current levels probably above 10 kA (10 000 amps).
• Never the less, the level of current passing though a person’s body is the best single indicator of how likely they are to be injured
Electrical Shock

• Under 1 mA
  • Perfectly safe
  • Causes no sensation of pain
  • Causes no injury
  • No need to prevent people from experiencing this level of current

• 1 mA
  • Triggers nervous system, causing a person to feel a pain or tingling sensation
  • Pain will go away as soon as current is removed
  • Does not cause permanent damage – at least not directly
  • Is a hazard, because it may startle someone, and their reaction may cause greater injury
  • You must design equipment so people will not be exposed to currents above 1 mA
Electrical Shock

• 10 mA
  • Causes significant pain
  • Can cause muscles to involuntarily contract (muscle paralysis)
  • Person receiving the shock cannot command their muscles to release
  • Can cause a person’s hand to continue to grab a wire, even though they don’t want to
  • The shock victim may not be able to breathe normally
  • The shock victim may not be able to talk
  • When working with high voltages, do not stop talking to someone because you are mad at them. This is not only inappropriate for social reasons, but they may fail to notice if you are receiving a shock which is prohibiting you from speaking.
  • In response to the stress, a person’s body will probably start sweating. This salt water on the skin can easily decrease their resistance, and take the current to a higher level
  • Once current is removed, the person can recover, but may have muscle cramps
  • Substantial risk that the current will not hold at this level, but increase to fatal levels.
Electrical Shock

• 100 mA
  • Potentially lethal
  • This creates a medical emergency which requires immediate attention
  • Shock victim will not immediately die, but may within the next few minutes
  • Interferes with operation of the heart
  • May cause V-fib (ventricular fibrillation). This is an abnormal beating of the heart, where it fails to circulate blood.
  • Victim may stay in V-fib, even after current is removed
  • After a few minutes of V-fib, the victim will die.
  • CPR (cardiopulmonary resuscitation) can keep a person in V-fib alive, and may even allow their heart to return to normal function.
  • CPR may keep the victim alive long enough for emergency medical teams to arrive on site, and take over
  • A device known as an AED (automated external defibrillator) can be used, even by untrained individuals, to get the victim out of V-fib.
Electrical Shock

• Over 100 mA
  • Potentially lethal
  • V-fib is sometimes avoided (AED devices intentionally apply more than 100 mA of current)
  • Even if it is somewhat less lethal than 100 mA, never intentionally expose yourself or others to these high level currents.
  • Severe burns become possible, and increasingly likely as current increases
  • Burns can be extremely difficult for medical professionals to identify and diagnose, as they can occur deep inside one’s body
  • At high levels of current, burns can easily be fatal – even if victim survives initial shock
Electrical Shock

• Summary
  • Under 1 mA
    • Safe, no pain, no muscle contractions, no heart problems, victims unaware current is passing through their bodies
  • 1 mA
    • Mild pain, no muscle contractions, no heart problems, surprise factor biggest problem
  • 10 mA
    • Significant pain, muscle paralysis, no heart problems, causes sweating that often increases current to higher level
  • 100 mA
    • Extreme pain, muscle paralysis, serious heart problems such as V-fib, potentially fatal
  • Over 100 mA
    • Extreme pain, muscle paralysis, may or may not have serious heart problems, severe burns, potentially fatal
Voltage / Current Relationship

• Many electrical sources produce reasonably constant voltages
• To determine the shock hazard, must determine current level the voltage can cause
• To first order approximation, Ohm’s law is useful
  • $V = I \cdot R$
  • $V =$ voltage in volts
  • $I =$ current in amperes
  • $R =$ resistance in ohms
• Electrically, a human body looks like a mass of salt water (a good conductor) surrounded by skin (a good insulator).
• Electrical resistance of a human body varies considerably with the precise condition of the person’s skin
Voltage / Current Relationship

• If a person’s skin is damaged, it provides little electrical insulation.
• A person with damaged skin may have a resistance in the range of only 500 ohms.
• Skin damage includes
  • Small cuts, like paper cuts
  • Blisters
  • Burns
  • Sweat and other liquids on the skin
• A low-level electric shock may stimulate a person’s body to produce sweat, quickly lowering the resistance of their skin. High level shock may produce burns, also quickly lowering skin resistance.
• Evolution has taught our bodies to get ready to run or fight when stressed – unfortunately this is exactly the wrong response for electric shock.
Voltage / Current Relationship

• If a person’s skin is undamaged and dry, it is a pretty good insulator

• Undamaged dry skin may provide a resistance of 500 kilohms

• Thick calluses caused by physical labor tend to increase resistance even more, into the megaohm range.

• Since skin resistance can vary by a factor of 1000 or more (500 ohms to 500 kilohms), current can also vary by a factor of 1000 or more
Voltage / Current Relationship - Example

• Alice accidentally comes into contact with a conductor energized to 120 volts. She has dry, healthy, skin. Approximately $120 / 500,000 = 0.24$ mA of current flows through her body. She does not feel this, and in fact is unaware she even touched the conductor. She may even tell Bob it is safe to touch the wire, because it does not appear to be electrically energized.

• Bob has a paper cut on his skin. When he contacts the conductor, approximately $120 / 500 = 240$ mA passes through his body. He experiences extreme pain, his muscles suddenly contract pushing involuntarily throwing himself across the room, and his heart goes into V-fib. Bob dies.
Voltage / Current - Rule of Thumb

• Circuits with voltages under 50 volts are generally considered safe, at least from electric shock hazards. That is because 50 volts / 500 ohms is 100 mA, the threshold for fatal electric shocks.

• Do not intentionally come into contact with 50 volts, or any other voltage. However you will routinely see people working on circuits powered by 3 volts, 5 volts and 12 volts, without taking any significant precautions to prevent electric shock.

• 120 VAC and higher voltages are clearly unsafe to handle

• Voltage is not the only hazard. Circuits that can produce substantial amounts of current, even at low voltages, can cause serious injury.
Frequency and Electric Shock

• While current level is the best single indicator of the severity of electric shock, other factors such as the frequency of the voltage will also influence the level of injury.

• While there are good reasons to use frequencies in the range of 50-60 Hz for long-distance power transmission, it is unfortunately more dangerous than DC or higher frequencies.

• Very high frequencies tend to flow only along a surface of a conductor, because of something known as the skin effect. This means high frequency radio signals tend to cause skin burns more than heart damage.
EM Radiation Hazards

• In the MHz and GHz range, it is reasonably easy to create powerful electromagnetic waves. These are also known as radio waves, microwaves, and millimeter waves.

• These waves can cause injury, even if one does not physically contact the circuit.

• Just as in a microwave oven, these waves can heat body tissue, and injure them.

• Eyes and some reproductive organs are particularly sensitive to this type of heating.

• Do not enter an area where high power radio, microwave, millimeter wave, cell phone, radar, or similar transmitters are operating.

• There should be “non ionizing radiation” warning signs near high power transmitters. Do not enter those areas unless the transmitters have been powered down.
Optical Hazards

• Optical communication systems use infrared light.
• Human eyes cannot see infrared light, but can be damaged by it.
• Never stare into a fiber-optic cable, or laser light source. Even if the cable/laser appears dark, your eyes may receive a damaging dose of infrared light.
• Arcs, such as those produced by arc welders, produce substantial amounts of ultraviolet light.
• Human eyes cannot see UV light, but can be damaged by it.
• Never stare at an arc welder arc, even from a great distance. If you happen to see one by accident, quickly look away. If you are producing an arc, wear proper eye protection, and shield the arc in a way that bystanders cannot easily view it.
• UV light from arc welders can cause sun burns, and possibly skin cancer. Arc welders need to protect their skin from the light of the arc.
Heat / Burns / Fire

• High currents can create substantial amounts of heat as they pass through conductors.

• Do not wear jewelry such as rings and watches when working on electrical equipment. They often are good conductors, and large currents can easily flow through them.

• A conventional 12 volt automobile battery can easily produce 500 amps of current. If a ring on your finger comes across a battery, it can create 12 volts x 500 amps = 6 kW of power. This is as much power as an electric arc welder produces. Your ring will quickly heat to the point it becomes molten metal, and seriously injure your hand.
Heat / Burns / Fire

• Electrical wiring in the walls of buildings will generate heat when electricity passes through them.
• If enough current flows through the wire, it can become hot enough to ignite the material in the wall.
• Insulation may melt off of a hot wire, causing a short circuit, and an arc fault that creates higher temperatures yet.
• The wiring in structures is always protected by fuse, or circuit breaker, which will stop current flow if it rises to a level which is unsafe for the wire to accommodate.
• The wiring to a common residential, office, and laboratory 120 VAC convenience outlet is protected by a 15 amp or 20 amp fuse or circuit breaker.
• Note that 0.1 amps is a potentially fatal electric shock. A a 15 or 20 amp circuit breaker provides no protection against electric shock. They exist only to protect against fires, not electric shock.
Ground Faults

• The term “fault” means current is flowing in an unintentional way.

• A common form of electric shock is known as a ground fault, or a line-to-ground fault, or a hot-to-ground fault.

• The earth conducts electricity reasonably well.

• Utility companies intentionally connect one of their conductors to the earth. The conductor attached to the earth is known as the “neutral” wire. The conductor not attached to the earth is known as “line” or “hot”.

• Modern convenience outlets have three wires, hot, neutral and ground. As the name implies, the ground wire is connected to the earth. In a properly wired building, the neutral and ground wires are connected to each other where they enter the building, and should be within a few volts of each other throughout the structure.
Ground Faults

• It is common for a person to be unintentionally electrically connected to the ground.

• If a person should be able to safely touch the ground wire of a convenience outlet.

• If a person accidentally comes into contact the neutral line, they should receive little if any electric shock. However you should never intentionally touch the neutral line, or allow others to touch it. Not all buildings are wired properly. Sometimes what should be the neutral connection has been accidentally wired as the hot line.

• People can receive a potentially fatal electric shock if they are at ground voltage, and come into contact with the hot line.
Ground Faults

• Sometimes electrical equipment is contained inside a metal case, which a user is expected to touch.

• The metal case should be electrically insulated from both hot and neutral lines.

• The metal case should be electrically connected to the ground wire.

• If the insulation inside the equipment fails, the hot line may touch the case. Hopefully, it will find a low-resistance path to earth ground, causing so much current to flow the fuse or circuit-breaker will activate, and shut off the current.

• Do not touch a metal cased instrument if the case is not connected to the earth ground connection. A failure of insulation inside the equipment may raise the case to the hot voltage, causing a ground fault when you touch it.
Ground Faults

• Some electrical equipment uses only the hot and neutral wires, and does not use the earth ground connection.

• This equipment must be “double insulated”. This means there are two independent layers of insulation between the hot wire, and the case of the equipment (or any part of the equipment a user is likely to touch).

• The hope is that if one layer of insulation fails, the other will still be intact.

• Obviously significant damage to the equipment may cause both layers to fail. Do not use damaged equipment.
Ground Faults

• Some convenience outlets are protected by GFCI, ground fault circuit interrupters. These are also known as GFI.

• The devices constantly compare the current leaving the hot connection and the current returning through the neutral connection. As long as they match, the GFCI lets the current flow.

• If the GFCI detects an imbalance of even a few mA, it will shut off the current.

• A GFCI provides some protection against ground faults, and can shut off current before it rises to the level of causing serious injury.

• GFCI offer no protection from a hot-to-neutral fault

• GFCI sometimes fail, so they should be tested regularly, and should never be intentionally activated. Never intentionally touch a hot conductor, trusting the GFCI to save your life.
Avoiding Faults

• When working around high voltages, it is a good idea to keep your non-dominant hand in a pocket if you can, and work with only one hand. This will reduce the chance the hand you are not currently watching will contact an energized conductor. It also makes it less likely you will have a fault current go in one arm and out the other.

• Try to avoid having a low resistance path from your body to the earth. Do not work in bare feet. Do not intentionally “ground” yourself with a wire, or by touching an object that you know is at ground potential.

• To avoid electrostatic discharge, it is sometimes desirable to intentionally put your body at the same voltage of the earth. This should be done with a specially designed “wrist ground strap”. These devices attach your wrist to the earth though a one megaohm resistor. The resistor will limit fault currents to safe levels. So not simply tie a wire from your wrist to ground.
Avoiding Faults

• Do not reach into an area unless you can clearly see what you are doing.

• Ensure there is always sufficient lighting to allow you to clearly see the work area.
Avoiding Faults

• When working on equipment, perform tasks in this order
  1. Remove the power source
  2. If other people can easily reconnect the power, lock the switch in the off position, and place a tag on it so others know you are working on the circuit. This is called lock-out tag-out.
  3. Discharge any components which store energy, such as capacitors.
  4. Make connections in the circuit, from circuit to load, and from test equipment to the circuit.
  5. Double check all connections you touched, to make sure they are mechanically sound (are unlikely to come apart or move).
  6. Double check all connections you touched, to make sure they are electrically sound (have low resistance)
  7. Remove any lock you put on the power source, and check it to see if anyone else has a lock or tag on it.
  8. Stand clear of the circuit, and make sure others are aware it is about to be energized.
  9. Connect the power source.
Using Switches

• A mechanical switch should produce almost no heat, and generate no arcs, when it is in the fully-open or fully-closed position.

• A switch that is warm to the touch may be damaged. Discontinue using it, and have it inspected and/or replaced.

• A switch that does not move smoothly, has a loose lever, or does not hold itself firmly in the open and closed positions should be inspected and/or replaced.

• Never repair a switch. If it is defective, replace it with a new one.
Using Switches

• When a switch is moving between the open and closed position, an arc may be produced internally.

• The switch is designed to tolerate the arc, and extinguish it, provided it is being moved quickly between the open and closed position.

• The arc of DC current is more difficult to extinguish than AC current. For that reason, switches may have a lower “rating” (maximum safe current level) for DC power, than for AC power.

• Never move a switch slowly.

• Never pause between the open and closed positions when moving a switch.

• Always grab a switch handle firmly, and move it quickly between the open and closed position, without pausing in between.
Using Circuit Breakers

• A circuit breaker looks like a switch, but has some different properties.
• There are three positions the lever can be in: on, tripped, and off.
• The tripped position is between on and off.
• To remove power, push the circuit breaker lever to the off position, regardless of which position it was in previously.
• To restore power, first push the circuit breaker lever to the off position, then push it to the on position.
• If the breaker measures an excessive amount of current, an internal spring will cause the lever to move from on to tripped, without human intervention.
• Like a switch, always move the handle quickly. Do not move it slowly, and do not stop half way between the off and on positions.
• Do not manually move a circuit breaker between the off and on position on a daily basis. A circuit breaker has a limited number of on/off cycles it can tolerate, before it must be replaced. It is not designed to be used as frequently as a common disconnect switch.
Mechanical Hazards

• Some laboratories expose students to rotating machines, which creates mechanical hazards.

• Nearly all rotating machines used in the department require specialized training. Do not operate the machine unless, and until, you receive such training.

• All rotating shafts, pulleys, belts, chains, etc. should be protected by guards. Do not energize the machine unless all guards are in place.

• Do not wear loose clothing or jewelry while operating rotating machines.

• Never touch, or place a tool against, a rotating object. Deenergize the equipment, and wait for the shaft, chuck, pulley, etc. to stop moving, before touching it. Do not slow the rotation by placing your hand against it.

• If the machine generates chips (such as a saw, drill, mill, lathe, etc.) wear safety goggles.
Emergency Preparedness

• Lean about safety procedures and protective equipment
• Learn how to provide first aid
• Learn how to perform CPR
• Obtain proper equipment for the job at hand
• Obtain necessary personal protective equipment and first aid supplies
• Have a phone, or some other way to call for help. Know the number to dial for first responders
• Learn the address of your location, to give to first responders. Locate emergency exits.
• Do not work alone
• Know how to quickly deenergize equipment
• Learn the names of the people you are working with
Emergency Procedures

• If you receive an electric shock, do the following:

• Stay calm, stay focused
  • Many people have survived electric shocks, many without serious injury
  • Rapid movements, such as jerking your arm away very quickly, may cause you to throw it into a conductor which will give you a bigger shock, knock you off a ladder, etc.

• Stop the current flow
  • If you know where the current is entering your body, and you can move that part of your body, do so quickly – but not violently.
  • If you can’t move your body or the conductor, try to shut off the current with an electrical switch.

• Alert others
  • Notify those working with you that you have received a shock
  • Consider seeing a medical professional
Emergency Procedures

• If you see someone getting an electric shock

• Stay safe
  • Your #1 priority, even in this situation, is to keep yourself safe
  • Yes, you are morally obligated to offer assistance. But you are not obligated to put yourself in harm’s way to do it.
  • If your actions result in you getting an electric shock also, you will be of no help to the other person. In fact, you may distract people because they have to now help you.

• Stop the current flow
  • The severity of the person’s injuries may increase in a matter of seconds.
  • Stop the current flow before taking other actions (like calling for help, or providing first aid)
  • If a switch is nearby that will shut off power, use it.
  • If this is in a laboratory, hopefully you learned the location of power shut-off switches before you started working
  • If it is impractical to shut off the power source, try to move the person using a non-conducting object like a wooden broom handle.
  • If you can’t shut off the current, and cannot move the person, seek help from others.
Emergency Procedures

• Call 911
  • As soon as you stop the current flowing though a person’s body, call 911 to report the emergency.
  • If you are the only person present to render aid, call 911 before starting first aid such as CPR. You cannot do CPR for very long before you will become exhausted. It is important to get an ambulance en-route to your location, so by the time you are exhausted, help has arrived.
  • If there are two or more people who are available to render aid one person should call 911, while the others provide first aid.
  • If nobody else is giving orders, take charge. Assign one person the job of calling 911, and make sure they are held accountable for doing it. You can say something like “You, in the blue shirt. Go call 911, then come back here and tell me what they said to do.”
  • Do not simply say “somebody call 911”. Chances are nobody will. Make sure one person has been directed to do it, and let them know they are expected to return and prove to you they did.
Emergency Procedures

• Provide first aid, such as CPR (if appropriate)
  • After you stop the current flow, and somebody is calling 911, provide first aid.
  • Hopefully you have received some training on first aid and CPR. If you do, now is the time to use that training.
  • It is safe to touch a person who just experienced an electric shock. Once you have stopped the current from flowing, there is no longer a risk that you will get a shock from them.
  • If the person is not conscious, and does not appear to be breathing, consider using an AED if one is available. These devices will have simple directions on their cover, and can safely and reasonably be used by people who have no prior training.
  • It is reasonable to worry that your first aid actions may cause more harm than good. Be aware that Missouri, and many other states, have “Good Samaritan Laws”. These laws say a person cannot be held legally liable for a bad first aid decision, if they made it in good faith, and they are not a medical professional such as a doctor, nurse, etc.
Emergency Procedures

• Assist Emergency Personnel
  • If there are multiple people available to help, send one person to the main building entrance. Have them waive their arms to attract the attention of emergency personnel when they arrive, and lead them to the scene of the accident.
  • Stay on the scene, even after first responders arrive. They may need you to answer questions about what happened, and may need assistance to evacuate the injured
  • Leave the area only after first responders have either all left, or have told you your assistance is no longer needed.
Emergency Procedures for Electric Shock

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• Assist first responders