

Fire Investigation: Electrical Systems

FI: ES-Student Manual

3rd Edition, 1st Printing-June 2026



FEMA

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June 2024

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Acronyms

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ACKNOWLEDGMENTS

The development of any National Fire Academy (NFA) course is a complex process aimed at providing students with the best possible learning opportunity we can deliver. There are many players in course development, each of whom plays an equally important part in its success. We want to extend our heartfelt thanks to everyone who participated in making this quality product.

Sincerely,

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COURSE GOAL

The goal of the “Fire Investigation: Electrical Systems” (FI: ES) course is to provide students with a basic knowledge of electricity, electrical circuits and distribution systems, common electrical faults and failures, the National Fire Protection Association (NFPA) guidelines, and the National Electrical Code® (NEC). This course provides hands-on experience in a controlled environment to allow students the opportunity to apply theory and practice through hands-on basic circuit wiring, creation of artifacts and analysis of fire-induced failures, and evaluation of compromised components and conductors.

AUDIENCE, SCOPE AND COURSE PURPOSE

The target audience for FI: ES is aspiring or current fire investigators. Priority is given to full-time personnel with current fire investigation and/or code enforcement responsibility.

This five-day specialized course addresses the critical skills essential to the effective investigation and evaluation of fires involving potential electrical fire causes. This course uses current techniques, practices, protocols, and standards to assist investigators in the evaluation of electrical systems and associated components. Students will be provided with a basic knowledge of electricity, electrical circuits and distribution systems, and common electrical faults and failures. Students will develop a working knowledge of the NEC and how it applies to fire investigations.

Students will learn to apply arc mapping theory that will effectively assist in fire origin determination. Students will demonstrate a general knowledge of electricity by building electrical circuits and systems through a series of instructor-led, hands-on practical activities.

The purpose of this course is to provide students with the tools to evaluate and recognize common electrical faults and failures of electrical components, systems, circuits and common household appliances.

GRADING METHODOLOGY

A minimum total score of 80 is required for successful completion of this course. The total course score is derived from the graded activities and final exam. The weighting of evaluation methods below will be electronically calculated within Blackboard.

Evaluation Method	Percent of Final Grade
Over-Current Protection Device Recognition Quiz	30%
Circuit Build-Out Activity	50%
Final Exam	20%

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SCHEDULE

DAY 1	DAY 2	DAY 3
Introduction Activity 1-1: Electrical Questions Unit 1: Basic Electricity	Unit 5: Electrical Service Equipment Activity 5.1: Over-Current Protection Device Identification Quiz Unit 6: Typical Circuit Components Unit 7: Building an Electrical Service	Unit 8: Circuit Protection Methods and Devices Activity 8.1: Over-Current Protection Device Identification Quiz Unit 9: Circuit Breaker Issues Unit 10: High-Resistance Connections
<i>Lunch</i>	<i>Lunch</i>	<i>Lunch</i>
Unit 2: Scene Safety Activity 2.1: Identify Test Points Unit 3: Ohm's Law and Joule's Law Activity 3.1: Ohm's Law and Joule's Law Calculations Activity 3.2: Hypothesis Testing Unit 4: Electrical Power Delivery	Unit 7: Building an Electrical Service (cont'd) Activity 7.1: Preparing Basic Electrical Drawings Activity 7.2: Circuit Build-Out	Unit 10: High-Resistance Connections Case Study Unit 11: Evaluate the Components Activity 11.1: Identifying Poor Electrical Workmanship Activity 11.2: Black Box Experiment

FIRE INVESTIGATION: ELECTRICAL SYSTEMS

DAY 4	DAY 5
Unit 12: Arc Mapping	Unit 13: Appliance Failures
	Activity 13.1: Appliance Modification
<i>Lunch</i>	<i>Lunch</i>
Unit 12: Arc Mapping (cont'd)	Final Exam
Activity 12.1: Ohm's Wall	Evaluations
Activity 12.2: Artifact Identification	Certificates

*Activity length is subject to the number of instructors and the skillset of the students; therefore, flexibility has been built into the schedule and is at the discretion of the instructor.

GRADING RUBRIC

GRADING RUBRIC: CIRCUIT BUILD-OUT ACTIVITY

Name	
Panel #	

Content Area	Unsatisfactory 0	Satisfactory 1	Good 2	Score Activity
Workmanship	Unable to recognize or explain the potential effects of poor workmanship (i.e., poor wire connections, incorrect installations, and fire hazards).	Able to explain the effects of poor workmanship and offer solutions or correct such findings (i.e., incorrect use of conductors, neutral and phase conductors both white, multiple wires on a receptacle, improper grounding etc.).	Meets all satisfactory criteria and is able to identify and recognize potential poor workmanship before energizing the circuit.	
Functionality	Circuit does not operate correctly; unable to resolve issues without instructor assistance.	All circuits operate for jobs 1–7 on the first attempt; able to identify and resolve the problem without instructor assistance.	Meets all satisfactory criteria and is able to explain what makes a circuit work (functionality of a three- and four-way switch).	
Task	Given a specific wiring job, is unable to identify which cables and conductors are energized.	Able to identify which cables and conductors are energized given a specific switch or circuit configuration. Uses the appropriate color for each wire.	Meets all satisfactory criteria and can explain the relevance of energized cables and conductors as related to arc mapping.	
Safety	• Puts themselves or others in danger. • Unable to identify critical test points of service entrance equipment. • Unable to use test equipment to verify the presence or absence of electricity.	Identifies all critical test points of service entrance equipment and correctly/safely uses testing equipment to verify the presence or absence of electricity.	Meets all satisfactory criteria and is able to verbally explain the consequences of using faulty or unlisted test equipment.	

TOTAL SCORE: _____

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FIREFIGHTER CODE OF ETHICS

Background

The Fire Service is a noble calling, one which is founded on mutual respect and trust between firefighters and the citizens they serve. To ensure the continuing integrity of the Fire Service, the highest standards of ethical conduct must be maintained at all times.

Developed in response to the publication of the Fire Service Reputation Management White Paper, the purpose of this National Firefighter Code of Ethics is to establish criteria that encourages fire service personnel to promote a culture of ethical integrity and high standards of professionalism in our field. The broad scope of this recommended Code of Ethics is intended to mitigate and negate situations that may result in embarrassment and waning of public support for what has historically been a highly respected profession.

Ethics comes from the Greek word *ethos*, meaning character. Character is not necessarily defined by how a person behaves when conditions are optimal and life is good. It is easy to take the high road when the path is paved and obstacles are few or non-existent. Character is also defined by decisions made under pressure, when no one is looking, when the road contains land mines, and the way is obscured. As members of the Fire Service, we share a responsibility to project an ethical character of professionalism, integrity, compassion, loyalty and honesty in all that we do, all of the time.

We need to accept this ethics challenge and be truly willing to maintain a culture that is consistent with the expectations outlined in this document. By doing so, we can create a legacy that validates and sustains the distinguished Fire Service institution, and at the same time ensure that we leave the Fire Service in better condition than when we arrived.



FIREFIGHTER CODE OF ETHICS

I understand that I have the responsibility to conduct myself in a manner that reflects proper ethical behavior and integrity. In so doing, I will help foster a continuing positive public perception of the fire service. Therefore, I pledge the following...

- Always conduct myself, on and off duty, in a manner that reflects positively on myself, my department and the fire service in general.
- Accept responsibility for my actions and for the consequences of my actions.
- Support the concept of fairness and the value of diverse thoughts and opinions.
- Avoid situations that would adversely affect the credibility or public perception of the fire service profession.
- Be truthful and honest at all times and report instances of cheating or other dishonest acts that compromise the integrity of the fire service.
- Conduct my personal affairs in a manner that does not improperly influence the performance of my duties, or bring discredit to my organization.
- Be respectful and conscious of each member's safety and welfare.
- Recognize that I serve in a position of public trust that requires stewardship in the honest and efficient use of publicly owned resources, including uniforms, facilities, vehicles and equipment and that these are protected from misuse and theft.
- Exercise professionalism, competence, respect and loyalty in the performance of my duties and use information, confidential or otherwise, gained by virtue of my position, only to benefit those I am entrusted to serve.
- Avoid financial investments, outside employment, outside business interests or activities that conflict with or are enhanced by my official position or have the potential to create the perception of impropriety.
- Never propose or accept personal rewards, special privileges, benefits, advancement, honors or gifts that may create a conflict of interest, or the appearance thereof.
- Never engage in activities involving alcohol or other substance use or abuse that can impair my mental state or the performance of my duties and compromise safety.
- Never discriminate on the basis of race, religion, color, creed, age, marital status, national origin, ancestry, gender, sexual preference, medical condition or handicap.
- Never harass, intimidate or threaten fellow members of the service or the public and stop or report the actions of other firefighters who engage in such behaviors.
- Responsibly use social networking, electronic communications, or other media technology opportunities in a manner that does not discredit, dishonor or embarrass my organization, the fire service and the public. I also understand that failure to resolve or report inappropriate use of this media equates to condoning this behavior.

Developed by the National Society of Executive Fire Officers

A Student Guide to End-of-course Evaluations

Say What You Mean ...

Ten Things You Can Do to Improve the National Fire Academy

The National Fire Academy takes its course evaluations very seriously. Your comments and suggestions enable us to improve your learning experience.

Unfortunately, we often get end-of-course comments like these that are vague and, therefore, not actionable. We know you are trying to keep your answers short, but the more specific you can be, the better we can respond.

Actual quotes from student evaluations:	Examples of specific, actionable comments that would help us improve the course:
1 "Update the materials."	- The (ABC) fire video is out-of-date because of the dangerous tactics it demonstrates. The available (XYZ) video shows current practices. - The student manual references building codes that are 12 years old.
2 "We want an advanced class in (fill in the blank)."	- We would like a class that enables us to calculate energy transfer rates resulting from exposure fires. - We would like a class that provides one-on-one workplace harassment counseling practice exercises.
3 "More activities."	- An activity where students can physically measure the area of sprinkler coverage would improve understanding of the concept. - Not all students were able to fill all ICS positions in the exercises. Add more exercises so all students can participate.
4 "A longer course."	- The class should be increased by one hour per day to enable all students to participate in exercises. - The class should be increased by two days so that all group presentations can be peer evaluated and have written abstracts.
5 "Readable plans."	- The plans should be enlarged to 11 by 17 and provided with an accurate scale. - My plan set was blurry, which caused the dotted lines to be interpreted as solid lines.
6 "Better student guide organization," "manual did not coincide with slides."	- The slide sequence in Unit 4 did not align with the content in the student manual from slides 4-16 through 4-21. - The instructor added slides in Unit 4 that were not in my student manual.
7 "Dry in spots."	- The instructor/activity should have used student group activities rather than lecture to explain Maslow's Hierarchy. - Create a pre-course reading on symbiotic personal relationships rather than trying to lecture on them in class.
8 "More visual aids."	- The text description of V-patterns did not provide three-dimensional views. More photographs or drawings would help me imagine the pattern. - There was a video clip on NBC News (date) that summarized the topic very well.
9 "Re-evaluate pre-course assignments."	- The pre-course assignments were not discussed or referenced in class. Either connect them to the course content or delete them. - The pre-course assignments on ICS could be reduced to a one-page job aid rather than a 25-page reading.
10 "A better understanding of NIMS."	- The instructor did not explain the connection between NIMS and ICS. - The student manual needs an illustrated guide to NIMS.

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UNIT 1: BASIC ELECTRICITY

TERMINAL OBJECTIVE

The students will be able to:

- 1.1 *Apply and demonstrate electrical theory to include current, voltage and power.*

ENABLING OBJECTIVES

The students will be able to:

- 1.1 *Apply the National Fire Protection Association (NFPA) Scientific Method guidelines to a fire investigation.*
 - 1.2 *Introduce and define electrical terminology.*
 - 1.3 *Demonstrate application of basic electrical concepts.*
-

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TERMINAL OBJECTIVE

Apply and demonstrate electrical theory to include current, voltage and power.

Slide 1-2

ENABLING OBJECTIVES

- 1.1 Apply the National Fire Protection Association (NFPA) Scientific Method guidelines to a fire investigation.
- 1.2 Introduce and define electrical terminology.
- 1.3 Demonstrate application of basic electrical concepts.

Slide 1-3

I. BASIC ELECTRICITY FOR FIRE INVESTIGATORS

BASIC ELECTRICITY FOR FIRE INVESTIGATORS

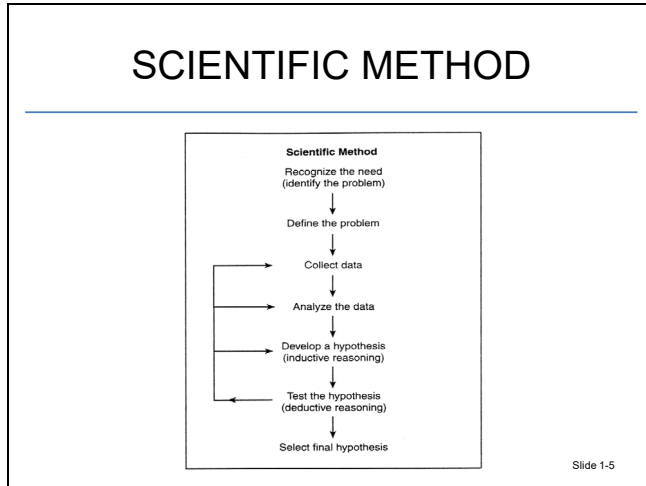
NFPA 1033, Section 4.1.7 states that fire investigators should have basic knowledge of electricity and electrical systems.

As a reminder, the National Electrical Code® (NEC) is commercial guidance for electrical installations.

Slide 1-4

A. Overview.

1. As an investigator, knowledge in various fields is critical to the successful determination of fire origin and cause. National Fire Protection Association (NFPA) 1033, *Standard for Professional Qualifications for Fire Investigator*, states that fire investigators should have basic knowledge of electricity and electrical systems.
2. The National Electrical Code® (NEC) is commercial guidance for electrical installations, and building codes pertaining to electricity are generally based on information contained in the NEC. While an electrical installation may be compliant with NEC guidelines, electrical failures in the installation could still cause a fire. For example, a loose connection may develop into a high-resistance connection (HRC), providing a competent ignition source. As a fire investigator, you need to be able to conduct the investigation and determine whether the origin and cause of a fire was electrical. Investigators should also be able to document the electrical system using the appropriate terminology and references. This unit will provide a basic overview of electricity, electrical terminology, and common trade names used in the electrical field. Each subsequent unit will build on this unit.



B. Scientific Method: A fire investigation should follow the Scientific Method, as outlined in NFPA 921, *Guide for Fire and Explosion Investigations*. The steps of the Scientific Method are as follows (NFPA 921, 2024, Section 4.3): recognize the need, define the problem, collect data, analyze the data, develop hypotheses, test the hypotheses, and select a final hypothesis.

1. Recognize the need: First, one should determine that a problem exists. In the case of fire investigation, a fire or explosion has occurred, and the cause should be determined and listed so that future similar incidents can be prevented.
2. Define the problem: Usually the problem is defined by the need to determine where and how the fire started, which will make possible prevention of future fires and identify responsible people or products.
3. Collect the data.
 - a. Facts about the fire incident are collected by observation, experiment, or other data-gathering means.
 - b. Investigators rely on four things to determine the area of origin: witness statements, fire patterns, fire dynamics and arc mapping. These sources of information, along with numerous other sources, provide the data for the data collection segment of the Scientific Method.
 - c. This type of data is called empirical data. Empirical data are based on observation, experimentation and experience. The data collection is not confined to the physical fire scene; follow-up investigation, laboratory testing and results, and literature review are all included. Sometimes the mindset during an investigation is that it is completed when the investigator leaves the scene. However, consideration should always be given to conducting follow-up investigation.

4. Analyze the data: All empirical data collected during the investigation are evaluated and reviewed. Inductive reasoning is used; this relies on specific observations and follow-up investigation to form a possible hypothesis or hypotheses, rather than on speculation.
5. Develop hypotheses.
 - a. A scenario or hypothesis is developed using all data collected during the investigation. The scenario should strive to match the physical findings and supporting investigation. It is possible to have more than one.
 - b. If there are unanswered questions regarding a hypothesis, whether from fire behavior, witness statements, or follow-up investigation, further analysis is required to identify the reason for the discrepancy. If the hypothesis does not match the facts, then another hypothesis must be considered and developed.
6. Test the hypotheses.
 - a. Using deductive reasoning, which accounts for specific experimental results, the hypothesis is tested. Frequently, the test is conducted by consideration of expected fire behavior from a suspected area of origin. Another test routinely conducted by investigators involves considering what the fire scene would look like if the origin was in another location.
 - b. The test for cause involves identifying ignition potentials in the area of origin and then systematically considering the ability of each source to be the cause for the fire. If all causes cannot be eliminated, the cause may be determined to be probable, possible or undetermined. These determinations will be relative to the likelihood of one potential ignition source being the cause as opposed to another potential ignition source.
 - c. Avoid making assumptions: Until data have been collected, no specific hypothesis can be reasonably formed or tested. Remember, the purpose is to **disprove** the hypothesis during the testing phase.
7. Select final hypothesis: Once the systematic investigation is completed using the Scientific Method — incorporating empirical data and inductive and deductive reasoning — and a scenario accounting for origin and cause is developed, tested, and confirmed, a final hypothesis can be determined to be the correct scenario.

II. ORIGIN AND CAUSE

ORIGIN FIRST ... THEN CAUSE

Most important task of a fire investigator is first to identify the origin; sometimes this may also be the most difficult.

Only after the investigator has identified origin can they begin the task of cause determination.

Investigators are much more likely to determine cause when they have correctly identified the origin first.

Slide 1-6

- A. In the field of fire investigation, it is essential to determine the origin first and then the cause. The most important and imperative task of a fire investigator is to identify the origin; sometimes this step may also be the most difficult. Only after the investigator has identified the origin can they begin the task of determining the cause.

HOW DO FIRE INVESTIGATORS ARRIVE AT THE ORIGIN?

NFPA 921, Section 18.1.2.

Determination of the origin of the fire involves the coordination of information derived from one or more of the following:

- Witness Information. The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire.

Slide 1-7

- B. How fire investigators determine the origin of a fire:

1. As fire investigators apply the Scientific Method to determine origin, they use information derived from witnesses' statements, fire patterns, and fire dynamics. One of the methods of fire patterns analysis we will focus on in this course is arc mapping. Arc mapping is defined as identifying and documenting a fire pattern derived from the identification of arc sites used to aid in determining the area of fire origin or spread (NFPA 921, 2024, Section 3.3.11). Arc mapping may also be referred to "arc fault mapping" or "arc fault survey."

HOW DO FIRE INVESTIGATORS ARRIVE AT THE ORIGIN? (cont'd.)

- Fire Patterns. The visible or measurable physical changes, or identifiable shapes, formed by a fire effect or group of fire effects (NFPA 921, 2024, Section 3.3.81). One of the methods of fire patterns analysis we will focus on in this course is **arc mapping**.
- Arc Mapping. Identifying and documenting a fire pattern derived from the identification of arc sites used to aid in determining the area of fire origin or spread. (NFPA 921, 2024, Section 3.3.11).

Slide 1-8

HOW DO FIRE INVESTIGATORS ARRIVE AT THE ORIGIN? (cont'd.)

- Fire Dynamics. The detailed study of how chemistry, fire science, and the engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior.

Slide 1-9

2. It is important that the fire investigator ensures that arc mapping is viewed as only a piece of the puzzle, not as the sole determinant. While arc mapping might lead one to believe a fire started in a certain location, other information from witnesses or burn patterns could tell a different story.

III. WHAT IS ELECTRICITY?

WHAT IS ELECTRICITY?

The physical phenomena arising from the behavior of electrons and protons that is caused by the attraction of particles with opposite charges and the repulsion of particles with the same charge.

Electric current used or regarded as a source of power.

Excerpted from The American Heritage Dictionary of the English Language, Third Edition Copyright © 1992 by Houghton Mifflin Company.

Slide 1-10

- A. Electricity is the flow of electrons from one point to another. While electricity cannot be seen, its effects can be. We see this every day, whether it be in the illumination from a desk lamp, the movement of a motor, or lightning across the sky. The flow of electricity is classified in one of two ways: alternating current (AC) or direct current (DC). In the following slides, the difference between AC and DC will be discussed. It is important to know the difference because the two types of electrical current can act differently with various circuit components.

DIRECT CURRENT (DC)

Direct current.

- Mechanically or chemically generated.
- Chemical = batteries or photovoltaic.
- Mechanical = generator with rectification.
- Electrons flow in one direction only, from negative to positive.
- Usage can be identified by positive and negative terminals on equipment.

Slide 1-11

- B. DC.

1. DC is the continuous flow of electrons from one point to another. DC is a one-way flow, from negative to positive. The negative/positive aspect of DC flow is called polarity. Polarity can be seen by looking at the positive and negative terminals on a car battery. The presence of a positive terminal (cathode) and a negative terminal (anode) in an acidic solution causes electricity to flow from one terminal to the other.

2. DC can be generated from a chemical process, such as in common household and car batteries, or from the photovoltaic process, such as when sunlight strikes a particular chemical composition found in solar cells. In certain applications, DC can be generated mechanically, but the process includes an electrical function called rectification, whereby the AC produced by the mechanical generator is converted into DC.

DIRECT CURRENT (DC) (cont'd.)

Most recognized form is as a battery, found in power supplies, DC generators.



In some industrial applications DC is used for numerous operations.

Slide 1-12

3. DC is transferred more quickly in smaller applications, as it is easier to create from batteries, small plug-in power supplies, and, in certain situations, a DC generator. However, it should be noted that DC may be present in certain industrial settings, particularly as it relates to communication and control circuits. Most energized rail subway systems operate on DC systems.

ALTERNATING CURRENT (AC)

Alternating current:

- Mechanically generated.
- Electrons reverse flow many times a second; a complete change of direction is called a cycle; the number of cycles per second is the frequency (measured in hertz, or Hz).
- Ungrounded (hot) and grounded (neutral) terminals on equipment.
- Voltages can be changed with transformers.

Slide 1-13

C. AC.

1. As the name implies, AC alternates direction of flow. As a result, there are typically no positive and negative terminals as with DC power sources, such as batteries. Conductors are designated as hot or grounded, commonly referred to as the neutral. The hot, or ungrounded, conductor is the source of AC. It is through the neutral, or grounded, conductor that this current flow is returned to the distribution system. And while this seems like a linear, one-way flow, you can think of that current as pulsating back and forth as it flows through the system.
2. One complete change of direction is called a cycle. The number of times direction changes, or the number of cycles per second, is referred to as a frequency. The unit of measurement for one cycle per second is a hertz (Hz). In the United States, AC power is delivered at 60 Hz, meaning that in one second the flow of current reverses itself completely 60 times. Globally, you will also find household power delivered at 50 Hz.
3. A major benefit of AC is that its voltage level can easily be increased or decreased by a device called a transformer.

ALTERNATING CURRENT (AC)
(cont'd.)

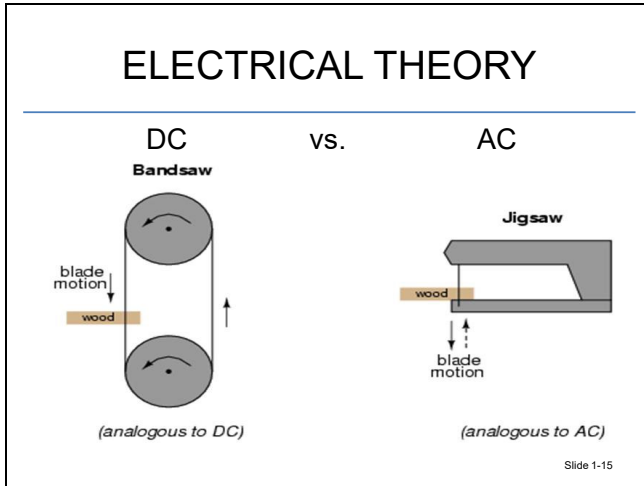
Found predominantly
in structures.

Voltages of 120, 240,
208, 277, 480 volts.



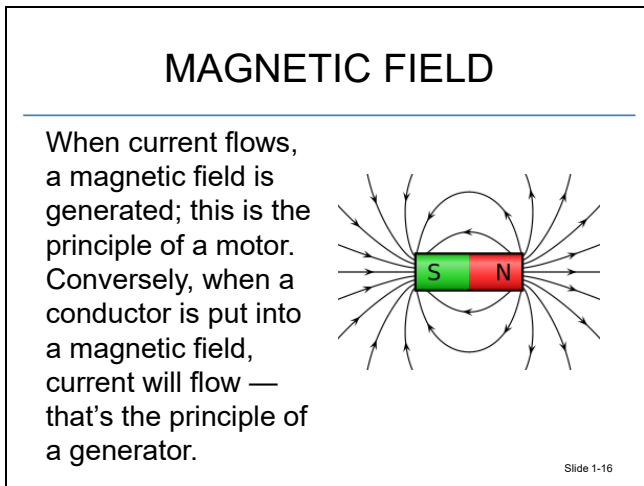
Slide 1-14

4. AC is prominent in the home, industry, and distribution systems of the United States. There are also AC applications in place in certain rail systems other than the energized rail subway. In the home, we are accustomed to seeing voltage levels of 120 and 240 volts (V), whereas in industrial settings voltages of 208, 240, 277, and 480 are common. It is typical to see voltages in the utility's distribution system reach magnitudes of 765,000 V.



D. Electrical theory: As a means of visualizing what the flow of current would look like through a conductor, consider two common saws, the bandsaw and the jigsaw, as they cut the same size piece of wood.

1. A bandsaw represents DC flow. The blade of the bandsaw moves continuously in one direction.
2. The jigsaw represents AC flow. In this case, the blade is reversing its direction many times a second.

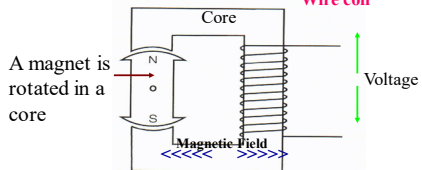


E. Magnetic fields.

1. The flow of current through a conductor generates a magnetic field. Various factors determine the strength and behavior of that magnetic field. For example, a straight conductor generates a weak magnetic field, whereas a coiled conductor will create a stronger field, especially if the conductor is wound around an iron core. ACs and DCs create different magnetic fields. It is this difference that allows AC to be produced at the output of a transformer, where DC would produce no output.

2. The principle of generating a magnetic field from a conductor underlies the creation of an electric motor. The principle of introducing a conductor into a magnetic field underlies the creation of a generator, as well as a transformer.

WHAT CAUSES THE ELECTRONS TO MOVE: MAGNETISM



A magnet is rotated in a core

Core

Wire coil

Magnetic Field

Voltage

As the magnet is rotated it creates a field in the core. This field is strongest as the magnet is aligned vertically as shown. When the magnet is rotated to horizontal the field is decreasing to zero. The field reverses and increases as the magnet continues to rotate. This increasing, decreasing, and reversing field creates a voltage potential in the coil. The voltage waveform is a sine wave; this is how AC or alternating current is generated.

Slide 1-17

F. What causes the electrons to move?

1. The visual on the slide is a basic representation of a generator. In this scenario, the rotation of the magnet would create a changing magnetic field in the circular core. That magnetic field in the core and in the windings of the conductor wrapped around the core would induce an Electromotive Force (EMF), or voltage, in the conductor.
2. As shown in this static diagram with the north pole at the top, and during rotation, there would be a peak voltage across the conductors at that point. As the shaft rotates to 90 degrees, the voltage drops to zero as the magnet becomes perpendicular to the core opening. As the shaft continues to rotate toward 180 degrees, the voltage again increases. Then, at the point at which the shaft is precisely at 180 degrees, the voltage is at its opposite polarity peak. As the shaft continues rotating toward 270 degrees, the voltage drops to zero as the magnet again becomes perpendicular to the core opening. As the magnet continues back to 0 degrees, the voltage begins to peak again as it completes one 360-degree revolution. The graphical representation of this voltage output is a sine wave.
3. The speed of the motion of the shaft determines the frequency of the sine wave. Every rotation of the shaft creates one cycle. Generally speaking, without considering variances in windings and the amount of poles, a two-pole generator as shown in the visual would have an operating speed of 3,600 revolutions per minute (RPM) to create the 60 Hz AC power we see in the household ($3,600 \text{ RPM} = 60 \text{ revolutions per second} = 60 \text{ Hz}$; in Europe, the figure is 50 Hz).

ATOMIC THEORY

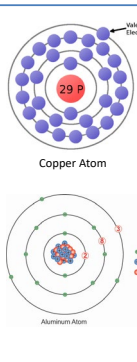
All matter is made of atoms.
 Protons + neutrons = nucleus.
 Electrons form valence rings around nucleus.
 # of electrons = # of protons.
 Outer valence ring has 1–8 electrons.
 1–3 electrons in outer ring = unstable/conductor.
 Examples: silver, copper, gold, aluminum.
 6–8 electrons in outer ring = stable/insulator.
 Examples: wood, glass, plastics.

Slide 1-18

G. Atomic theory.

1. All matter is made up of atoms, and all atoms have an outer valence ring, which contains between one and eight electrons.
2. For current to flow, the imparted energy must move **all** of the valence electrons at once. The fewer valence electrons there are, the easier it is for that energy to move them.
3. Most electrical conductors have one to three electrons in the valence ring. While two materials might have the same number of valence electrons, the overall electrical conductivity of one of the materials may make it a better conductor than the other. For example, gold and copper each have one valence electron, but copper is a better conductor. Gold is often used in the contacts of electrical connections because it does not oxidize as easily as copper does, and it helps to keep the connection at a low resistance.

ATOMIC THEORY (cont'd.)



More valence electrons in the outer ring = more stability.

More stability = Less conductive.

Copper atom has **1** valence electron.

Aluminum atom has **3** valence electrons.

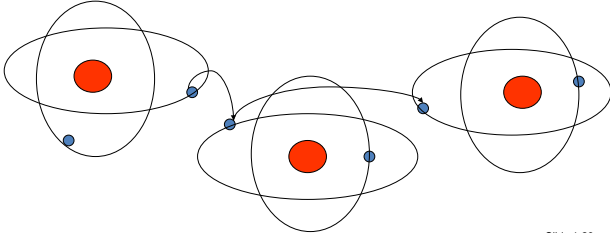
Aluminum takes 3 times as much energy to move those free electrons as copper. This is why aluminum conductors, when used, need to be larger than copper to carry the same amount of current.

Slide 1-19

4. Copper has only one valence electron, whereas aluminum has three. In simple terms, this means that aluminum is a more stable atom, and as such it takes three times the energy to move those three valence electrons in an aluminum atom as to move the one valence electron in a copper atom.
5. This is why the resistance of aluminum is higher than that of copper, and why aluminum conductors must be physically larger than copper conductors to carry the same current load.
6. Graphics in the slide show the atomic structure of copper and aluminum.
7. The moving electrons in a conductor are what creates electricity!

ATOMIC THEORY (cont'd.)

When ring is unstable, electrons will bump other electrons from other similar atoms, causing an electron flow ... Electricity!



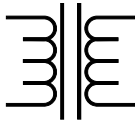
Slide 1-20

8. Graphic in the slide depicts the valence electron of an atom moving from one atom to another.

TRANSFORMERS

Used to step AC voltage up or down.

AC can be rectified to act like DC and supply one-way current.



DC voltage can be increased or decreased, but not with a transformer.

Slide 1-21

- H. Transformers: The change of current direction in AC causes a magnetic field to be created and then to collapse. This change in the magnetic field induces a current in the other set of windings. The number of windings is a factor in the change in voltage. The secondary side of the transformer is the output side, with resulting voltage that is either increased (stepped up) or decreased (stepped down).

VOLT

"The unit of electrical pressure (electromotive force) represented by the symbol 'E'; the difference in potential required to make a current of one ampere flow through a resistance of one ohm" (*NFPA 921, 2024, Section 3.3.209*).

E = volts.

The symbol for volts is commonly written as V.

Its hydraulic counterpart is pressure, or PSI.

Slide 1-22

I. Voltage.

1. As previously mentioned, fire investigation is rooted in science. As such, basic knowledge of electrical terminology is critical because it can help investigators reach a conclusion that they may have to defend in court. Knowledge of common electrical terms can also attest to or ruin an investigator's credibility. The first term we will review is voltage. We discussed the fact that a generator will produce voltage across the conductors, but what does voltage mean? By definition, voltage is the electrical pressure that moves the electrons through the conductor.
2. Voltage is also referred to in the electrical engineering field as EMF. It is the difference in potential and the difference in potential energy that causes current flow. This is why the electrical symbol for voltage in mathematic equations is E.
3. Knowing the voltage for which a particular system is designed is analogous to knowing the water pressure limits of a particular hose. A hose designed to handle 60 pounds per square inch (psi) of pressure could certainly fail if water were being pumped through it at 300 psi.
4. Similarly, for the electrical analogue, a residential wiring circuit is designed to operate at either 120 or 240 volts, depending on the appliance. If a 7,000 V primary line falls across a residential service drop 240/120 Volts Alternating Current (VAC) (volts of AC), that increased electrical pressure is likely to cause a failure of wiring or appliances in the house, causing a fire. Dropping a primary line onto a secondary, or the neutral, is called a hot-cross fault.

AMPERE

"The unit of electric current that is equivalent to a flow of one coulomb per second" (*NFPA 921, 2024, Section 3.3.7*).

I = ampere or amp.

The symbol for amperage is commonly written as A.

Its hydraulic counterpart is gallons per minute (gpm).

Slide 1-23

J. Amperes.

1. Current is the rate at which electrons flow through a conductor. It is determined by measuring the amount of electrons flowing past a single point in one second.
2. It is the flow of electrons that causes magnetic fields, as well as causing heat in electrical circuits when met by resistance. Symbolically, current is written as the letter I. The unit of measurement is an ampere, commonly referred to as an amp.
3. It should be noted that a coulomb is a measurement of the amount of electrons present. To put it in the context of the hydraulic analogue, a coulomb is like a gallon, whereas an ampere is equivalent to gallons per minute (gpm). The former is a measurement of amount and the latter is a measurement of the rate of flow of that amount.
4. Just as understanding voltage is important to the investigator, so too is understanding current. An amount of current that exceeds the design limits of a conductor becomes problematic. A point will be reached at which a conductor will not be able to handle the heat generated by the flow of current. When determining factors for fire causation, it is imperative that the investigator understand the effects of current flow, as well as the effects of excessive current flow, or overload.

RESISTANCE

This is the opposition to current flow.
Measured in ohms.
Symbol for ohms is Greek letter omega.

R or Ω

Its hydraulic counterpart is friction loss but
not all aspects of friction loss are identical.

Slide 1-24

K. Resistance.

1. Resistance in electrical circuits can be intentional and part of circuit design, or unintentional and a potential source of heat. The book definition of resistance is opposition to current flow. It is measured in ohms and is symbolized by an R or the Greek letter omega (Ω). You may also come across the term “impedance,” found only in AC circuits, which takes into consideration the power factor of the circuit. From an investigator’s standpoint, impedance and resistance can be considered the same.
2. Resistance varies from friction loss in that resistance is not affected by the physical arrangement of the conductor, whereas friction loss is.

RESISTANCE (cont’d.)

- When current flows through any resistance, heat is always generated.
- Every conductor offers some resistance.
- Every splice/connection in a circuit creates some resistance.
- Excessive resistance can create high temperatures.

Slide 1-25

3. When current flows through any resistance, heat is always generated. Every conductor offers some resistance. Every splice/connection in a circuit creates some resistance. Excessive resistance can create high temperatures.

WATT

“Unit of power, or rate of work, equal to one joule per second, or the rate of work represented by a current of one ampere under the potential of one volt” (*NFPA 921, 2024, Section 3.3.210*).

For the purposes of this class:

- Watts (W) = volts (V) x amps (A).
- Watts commonly written as W.

Slide 1-26

- L. Watt: A power rating is found on almost every electrical appliance we come in contact with. Power, or wattage, is the measure of the rate at which work is done. Electrical power is defined as a product of voltage and current values, and is measured in watts (W) — for example, a 60 W lightbulb or a 1,200 W hair dryer. The combined power ratings of appliances on an individual circuit can give the investigator a clue as to whether or not a circuit or an extension cord may have been overloaded, assuming the appliances were all turned on at the same time. The combined power rating on a circuit, for which we know the nominal voltage, will allow us to determine how much current was flowing.

HORSEPOWER

Horsepower can be calculated from a wattage rating by dividing the watts by 746, and horsepower can be converted to watts by multiplying the HP rating by 746.

For example:

- A 0.5-HP motor will use approximately 373 W.
- A motor rated at 3000 W is approximately 4 HP.

Slide 1-27

- M. Horsepower is an extension of wattage in that it is also a measurement of power. Scottish engineer James Watt adopted it in the late 18th century as a way to compare the power of steam to that of horses. For the electrical investigator, the standard remains important, as electrical motors are still rated in terms of horsepower. Knowing the horsepower rating will allow us to determine the power rating in wattage. This, in turn, will allow investigators to make other calculations, as will be described in Unit 2: Ohm’s Law and Joule’s Law.

AMPACITY

“The maximum current, in amperes, that a conductor can carry continuously under the conditions of use without exceeding its temperature rating” (*NFPA 921, 2024, Section 3.3.6*).

Slide 1-28

N. Ampacity.

1. The ampacity (ampere capacity) depends upon conductor resistance, type of insulation or enclosure, and ambient temperature, as discussed here. Two examples: four separate 12-American Wire Gauge (AWG) conductors running in a conduit rated for only two conductors would affect the ampacity of those conductors, because they would be unable to dissipate heat out of the conduit. As a result, each of those separate 12-gauge conductors, normally rated to carry 20 amps, would have a derated ampacity of 12 amps because of the space restriction of the overfilled conduit not being able to dissipate heat.

AMPACITY (cont'd.)

The maximum current a conductor carries continuously varies with the conditions of use, as well as with the temperature rating of the conductor's insulation. For example, ambient temperature is a factor of capacity rating and use.

Slide 1-29

2. Example: Knob-and-tube wiring in older houses was meant to be run in open spaces. As the need for energy efficiency grew, and homeowners were pumping more insulation into attics, the old circuit conductors ended up covered in insulation and unable to dissipate heat, ultimately causing failure or fires.

3. Another example: A conductor with insulation rated at 60 °C maximum, and installed near a furnace where the ambient temperature is continuously maintained at 60 °C, technically has no current-carrying capacity. Any current flowing through the conductor will raise its temperature above the 60 °C insulation rating. Therefore, the calculated ampacity of the 60 °C conductor, regardless of its AWG size, is zero.

FREQUENCY

The number of times the flow of AC electricity reverses itself in the span of one second.

Frequency is measured in Hertz (Hz).

In the U.S., the system frequency is 60 Hz.

Foreign countries use 50-Hz systems.

Slide 1-30

- O. Frequency is the number of times per second AC completes a “back-and-forth” cycle; that is going from zero volts to a peak positive polarity, back to zero, to a peak negative polarity, and then back to zero volts.

OVER-CURRENT PROTECTION DEVICES

Devices that are designed and installed to protect circuit components from exceeding a specific amperage value.

Often referred to and written as OCPD.

Slide 1-31

- P. Over-current protection devices (OCPDs): The foremost examples of OCPDs are fuses and circuit breakers in the home panel. Both are designed to interrupt (open) a circuit when the current exceeds the allowable limit. This limit is based upon wire size and code derived from the NEC.

CONDUCTORS

Materials that allow current to flow freely with minimal resistance.

Copper and aluminum are two of the most recognized types.

Both are used in electrical systems.

Gold and silver are also used, but usually only at points of contact.

Slide 1-32

- Q. Conductors are materials that allow current to flow freely with minimal resistance. Copper and aluminum are two of the most widely recognized and widely used conductors. Examples of conductors you would see at an investigation include wiring in the walls of a home, service drops from a pole to a house, and service connections from the meters to the main electrical panel. In addition, materials we normally do not associate with being conductors can conduct electricity, depending on conditions. Examples: Sufficiently high voltage can cause air to break down and conduct electricity. Dirt and carbon can cause nonconductive materials to become conductors. Increased salinity of water makes the water a better conductor.

SERVICE EQUIPMENT

“The necessary equipment, consisting of a circuit breaker(s) or switch(es) and fuse(s) and their accessories, connected to the serving utility and intended to constitute the main control and disconnect of the serving utility” (NFPA 70 (NEC), 2023, Article 100).

Slide 1-33

- R. Service equipment: “The necessary equipment, consisting of a circuit breaker(s) or switch(es) and fuse(s) and their accessories, connected to the serving utility and intended to constitute the main control and disconnect of the serving utility” (NFPA 70 (NEC), 2023, Article 100).

For investigation documentation purposes, the service equipment is the first equipment installed on the load side of the metering equipment. In a typical residence this can be a simple disconnect switch/breaker on the outside of the structure, or the main breaker/panel located inside the structure.

FEEDER

“All circuit conductors between the service equipment, the source of a separately derived system, or other power supply source and the final branch-circuit overcurrent device” (*NFPA 70 (NEC), 2023, Article 100*).

Slide 1-34

- S. Feeder: “All circuit conductors between the service equipment, the source of a separately derived system, or other power supply source and the final branch-circuit overcurrent device” (*NFPA 70 (NEC), 2023, Article 100*).

For investigation purposes, a feeder is the conductor between the service equipment and any subpanels in a structure.

BRANCH CIRCUIT CONDUCTOR

“The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s)” (*NFPA 70 (NEC), 2023, Article 100*).

Slide 1-35

- T. Branch circuit conductors: “The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s)” (*NFPA 70 (NEC), 2023, Article 100*).

Branch circuit conductors are the conductors that run from the OCPD to the point at which the branch circuit conductors are used.

GROUNDING CONDUCTOR

“A system or circuit conductor that is intentionally grounded” (*NFPA 70 (NEC), 2023, Article 100*).

The neutral conductor of a typical AC electrical system is referred to as a grounded conductor because it is bonded to the grounding system at the service entrance.

Slide 1-36

- U. Grounded conductor: “A system or circuit conductor that is intentionally grounded” (*NFPA 70 (NEC), 2023, Article 100*).

An important point to remember here from the earlier slides about AC and DC is that, unlike DC, AC does not have a constant polarity. So while we may be accustomed to seeing positive and negative terminals or conductors in a DC system, AC systems generally contain a grounded conductor, often called the neutral, and ungrounded or hot conductor(s).

EQUIPMENT GROUNDING CONDUCTOR

The “conductive path(s) that is part of an effective ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both” (*NFPA 70 (NEC), 2023, Article 100*).

Slide 1-37

- V. Equipment grounding conductor (EGC).

1. EGC is the “conductive path(s) that is part of an effective ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both” (*NFPA 70 (NEC), 2023, Article 100*).

2. The EGC is also what we refer to as the ground wire. While the EGC is connected to the system's grounding conductor, it is important to realize that the EGC is not designed to carry current normally. The EGC is a safety mechanism. It allows for the voltage to be shunted to the grounding connector instead of to, or through, a person. An easily recognized example is the common household plug and receptacle. Typically, devices with no conductive exterior components only have two blade plugs, for example, a table lamp. Here an EGC is not used. A washing machine, however, will have three prongs. The third prong on the bottom connects the metal components of the washing machine to the grounding conductor of the system via the EGC.

GROUNDING ELECTRODE

"A conducting object through which a direct connection to earth is established" (*NFPA 70 (NEC), 2023, Article 100*).

Examples of grounding electrodes are ground rods, and rebar encased in concrete in direct contact with the earth.

Slide 1-38

3. Grounding electrode: A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system (*NFPA 70 (NEC), 2023, Article 100*).
4. An example of why this is important:
- a. A new washing machine with a metal housing has experienced an internal fault in which the hot wire has made contact with the metal frame. The EGC allows this voltage to be conducted back to the system grounding conductor. In most cases, this would carry enough fault current to immediately cause an OCPD to activate. This would prevent an individual from coming in contact with the dangerous voltage if they were to touch the metal housing of the washer. Even if the flow of current was not enough to trip an OCPD, the path back to the system grounding conductor would lower the risk of shock and electrocution to the individual touching the energized frame.

- b. In the example above, if the washing machine predated the code change and did not have an EGC connection, the dangerous voltage potential would remain on the metal housing. Instead of the voltage having a safe path to ground, if an individual were to touch the housing, they would be exposed to that voltage. If that person was also in contact with the ground — perhaps in bare feet and on a basement floor — that current would then flow through the individual and to ground.

GROUNDING ELECTRODE CONDUCTOR

“A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system” (*NFPA 70 (NEC), 2023, Article 100*).

Slide 1-39

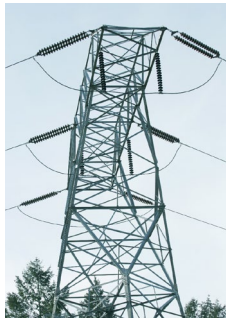
- W. The grounding electrode conductor is the conductor from the grounding electrode (i.e., ground rod) to the service equipment. Its size is based on the physical size of the largest service entrance conductor, not on any amperage ratings, per the NEC.

INSULATORS

They work oppositely to conductors; they oppose or stop the flow of current.

Insulators include glass, porcelain, air, and pure water.

However, a high enough voltage may defeat an insulator.



Slide 1-40

- X. Insulators are the opposite of conductors; they oppose or stop the flow of current. Some examples of insulators are glass, porcelain, air and pure water. While insulators are the opposite of conductors, a high enough voltage may defeat an insulator.

1. Air: Look at the distance lightning travels to reach the Earth.
2. Dirty insulators on pole tops can create a path for current flow.

ARC

“A high-temperature luminous electric discharge across a gap or through a medium such as charred insulation” (NFPA 921, 2024, Section 3.3.8).

Arcs have temperatures of 5000–7000°F. Static electricity and lightning are natural arcs.

It takes at least 350 V to bridge a small air gap (0.01mm/width of human hair).

4,500 V is needed to bridge a 1 mm gap.

Slide 1-41

Y. Arc.

1. Arcs are “a high-temperature luminous electric discharge across a gap or through a medium such as charred insulation” (NFPA 921, 2024, Section 3.3.8).
2. Arcs can occur between two conductors (parallel) as well as inline (series) in a conductor.
3. The second conductor can be a grounded surface, conductors in circuits other than the arcing conductor’s circuit, or a human being.

SPARK

“A moving particle of solid material that emits radiant energy due to either its temperature or the process of combustion on its surface” (NFPA 921, 2024, Section 3.3.187).

Sparks are much different from arcs; a spark is an incandescent particle, not an electrical discharge.

Sparks are much better ignition sources than arcs.



Slide 1-42

- Z. Spark: “A moving particle of solid material that emits radiant energy due to either its temperature or the process of combustion on its surface” (NFPA 921, 2024, Section 3.3.187).

Arc and spark are often incorrectly used interchangeably. However, they are completely different terms. An arc is the flow of electricity as discussed in the previous slide. And, while arcs are high-temperature, they differ from sparks per NFPA definition. That said, the normal operation of some equipment, as well as electrical failures, can create situations in which sparks are generated.

IV. EFFECTS OF ELECTRICITY

EFFECTS OF ELECTRICITY

The effects of current flowing can be seen by:

- Thermal action.
- Magnetism.
- Chemical reaction.
- Illumination.

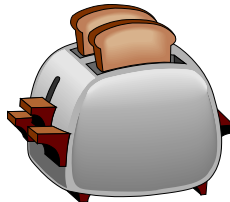
Slide 1-43

The effects of electricity include thermal action, magnetism, chemical reaction and illumination.

THERMAL ACTION

Heat caused by
flowing current
through a conductor.

Examples: stoves,
toaster, baseboard
heat, etc.



Slide 1-44

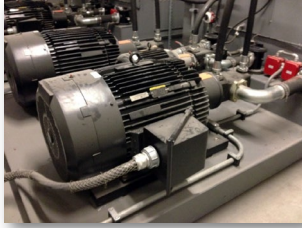
- A. Thermal action is heat caused by current flowing through a conductor. Examples of thermal action can be seen in stoves, toasters, baseboard heaters, etc.

MAGNETISM

Current flow produces a magnetic field.

Large enough field will produce heat.

Example: electric motors.



Slide 1-45

- B. Magnetism is the result of current flow that produces a magnetic field. A large enough field will produce heat. An example of this effect in use is electric motors.

CHEMICAL REACTION

Oxidation can occur at loose or improperly made connections.

Oxidation will increase resistance, which in turn increases the power dissipated at the oxidized connection.

Increased power dissipation = higher heat.

Higher heat = more oxidation.

Slide 1-46

- C. Chemical reaction: Improper connections can include inadequately tightened screws or connections or splicing of dissimilar metals, such as copper and aluminum (without the properly rated fittings made to do so). As these connections begin to oxidize, the resistance of the connection increases. As the current flows through that increased resistance, heat is generated. As the power is dissipated in the form of heat, the connections tend to oxidize more, and the problem continues until possible failure or fire.

ILLUMINATION

The light that can be seen from a glowing conductor.

Illumination can also be the result of a chemical process in the presence of electricity.

Slide 1-47

D. Illumination.

1. Illumination can be a function of heat or of a chemical reaction.
2. An incandescent bulb has a filament that heats up beyond glowing to the point that visible light is generated. This process is protected by the glass envelope of the bulb, and the vacuum in the bulb for bulbs rated greater than 25 W.
3. A light-emitting diode (LED) clock radio display is an example of a situation in which the electricity passing through the display causes a chemical reaction which emits visible light.

V. SUMMARY



SUMMARY



Review the National Fire Protection Association (NFPA) guidelines for applying the Scientific Method to a fire investigation.

Introduce and define electrical terminology.

Demonstrate application of basic electricity concepts.

Slide 1-48

UNIT 2: SCENE SAFETY

TERMINAL OBJECTIVE

The students will be able to:

- 2.1 *Evaluate safety methods, equipment, and techniques used to evaluate electrical systems.*

ENABLING OBJECTIVES

The students will be able to:

- 2.1 *Review safety equipment to use on a fire investigation scene.*
 - 2.2 *Demonstrate the ability to use multimeters and non-contact voltage testers.*
 - 2.3 *Demonstrate how to locate sources of power and safely test them for the presence of electricity.*
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TERMINAL OBJECTIVE

Evaluate safety methods, equipment, and techniques used to evaluate electrical systems.

Slide 2-2

ENABLING OBJECTIVES

- 2.1 Review safety equipment to use on a fire investigation scene.
- 2.2 Demonstrate the ability to use multimeters and non-contact voltage testers.
- 2.3 Demonstrate how to locate sources of power and safely test them for the presence of electricity.

Slide 2-3

I. SAFETY TIPS

SAFETY CONCERNS

- Safety is the number one concern.
- Make sure the circuit or system is de-energized.
- Do not pull meters.
- Check with a testing device before touching anything.
- Lockout/tagout if applicable.

Slide 2-4

A. General considerations.

1. Safety is the number one concern.
2. Make sure the circuit or system is de-energized.
 - a. It is important for the investigator to remember that until they verify with test equipment that the electrical system under investigation is de-energized, the assumption should always be that the circuit is live and dangerous.
 - b. Electricity can take multiple routes through a building. For example, an open neutral fault in a home's electrical system can cause line voltages to be present on the braided sheath conductor on a cable TV coax. The utility company is one of the best resources to ensure that a structure is de-energized. Even so, illegal hookups, do-it-yourself (DIY), and other installations can cause voltage to be present where least expected; therefore, the investigator should use test equipment on any circuit under examination.
3. Check with a testing device before touching anything.
4. Lockout/tagout if applicable: When de-energizing a circuit for examination, the investigator must ensure that the disconnect is properly tagged or locked out. If it is left untagged, a well-intentioned individual could come behind the investigator and re-energize the circuit, not realizing that it was intentionally de-energized. This could create the potential for injury or death.

5. Electrical scene safety is further compounded by the inherent challenges of any fire scene. Debris can be conductive in nature, and water is a challenge when dealing with electricity. As mentioned earlier, electricity can take nontraditional paths into and through a structure.
6. Knowing the voltages that could be present in a structure is equally important. In industrial settings where three-phase voltages of 480 Volts Alternating Current (VAC) and above could be present, an investigator would not have to make contact with a conductor to get a shock because arc distance in air, sometimes called air gap arcing, can cause a shock hazard at higher voltages.

SAFETY

Verify mechanical separation.

- Service conductor drip loops cut the utility transformer fuse cutouts open.

Use a non-contact voltage tester.

- Check each conductor for the presence of voltage.

Slide 2-5

SAFETY – CHECK IT

Conduct voltage checks using a multimeter.

- Check each conductor for the presence of voltage.
- Test each phase to neutral, ground, and to other phases.

Lockout/tagout as necessary.

Slide 2-6

B. Steps to ensure your safety.

1. If any of the initial steps indicate the presence of voltage, stop the investigation and find out why! Remedy the situation and repeat the entire testing process before continuing. Never operate on a scene that is energized!

2. Remember that a pulled meter is never a guarantee of disconnection, and the utility-side conductors might still be energized.

II. TESTING AND EQUIPMENT

TESTING AND EQUIPMENT

- Ensure that the circuit is de-energized.
- Take proper precautions if the circuit cannot be de-energized.
- Use non-contact voltage testers.
 - Meters.
 - Analog (needle and scale).
 - Digital (numeric LCD display).
- Neon bulb testers – **DO NOT USE!!**

Slide 2-7

A. Testing.

1. Ensure that the circuit is de-energized: Mechanical disconnect and separation is the first step in ensuring that a circuit is de-energized. This should always be verified with test equipment on each and every circuit undergoing testing.

VOLTAGE TEST EQUIPMENT



Slide 2-8

2. Take proper precautions if the circuit cannot be de-energized.

WARNING

Removing a breaker panel cover should be a two-person process.

Cover panels can be heavy and unwieldy.

Panel covers will tend to stay in place until the last retaining screw is loosened, and then they can pivot and fall, hanging on that last screw until the weight balances.

Slide 2-9

3. Use precautions when accessing breaker panels for testing.
 - a. Document the position of the breaker handles before attempting to remove the panel cover.

WARNING (cont'd.)

Again, removing a breaker panel cover should be a two-person process.

This action can dislodge potentially energized breakers from the bus bar and move breaker handles from their original positions.

One person should firmly hold the panel in place until all screws are removed by the other person, and then both people should carefully remove the panel straight outward.

Slide 2-10

- b. Removing the breaker panel cover to check for voltages can be a tricky process. Panel covers can be surprisingly heavy and awkward to remove. They will tend to fall into an angled position, hanging by the last screw that is loosened, if care is not taken in removing the cover. A pivoting or swinging action on the last screw can easily dislodge breakers from the bus bar or move breaker handles from the position they were in before the cover removal attempt.

B. Equipment.

NON-CONTACT VOLTAGE
TESTER

Test on a known good
circuit before every
use.

Be aware of your
tester's detectable
voltage range!



Slide 2-11

1. The non-contact voltage tester indicates the presence of voltage on a circuit under test. This indication is delivered with a light or audible indication, or both. The non-contact tester affords the investigator the cushion of not having to make a physical connection to the circuit under test. Although the non-contact tester is reliable, it is important to know that it should be tested on a known good circuit before every use. Keep in mind the challenge this test might present to the investigator on the fire scene when power has been disconnected.

NON-CONTACT VOLTAGE
TESTER (cont'd.)

Luminary voltage tester:

- Tip lights up, or some models add a buzz or beep sound.
- Inexpensive and reliable.
- Can be used to check any type of energized alternating current (AC) circuit.
- No voltage amount is indicated; only the presence of voltage is detected.



Slide 2-12

- a. Luminary voltage tester.
 - Tip lights up, or some models add a buzz or beep sound.
 - Inexpensive and reliable.

- Can be used to check any type of energized alternating current (AC) circuit.
- No voltage amount is indicated; only the presence of voltage is detected.

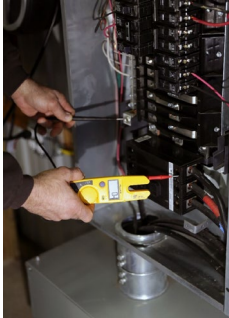
b. Audible voltage tester.

DIGITAL MULTIMETER (1 of 3)

Check the main service entrance conductors.

Start with one lead on the neutral or ground conductor first, and then the other lead to the phase conductor.

No voltage present.



Slide 2-13

2. Meters.

a. Analog (needle and scale).

b. Digital (numeric liquid-crystal display (LCD)).

- The digital multimeter offers the investigator increased functionality. Most meters can measure voltage (AC and direct current (DC)), current, and resistance or continuity.
- When checking voltages, it is safest to make contact with one of the test leads to a point of no potential to earth/ground first, such as a grounded surface or neutral. This is done to minimize the voltage potential from the remaining test lead tip to ground.

DIGITAL MULTIMETER (2 of 3)

Meter leads across two of the three total phase conductors at the panel box.

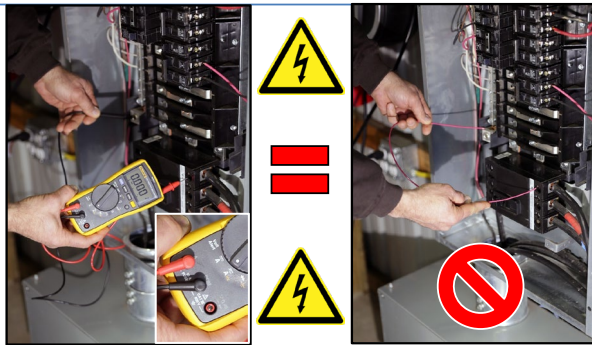
No voltage present.



Slide 2-14

- In the photo, the investigator is verifying the absence of voltage from Line 1 (L1) to neutral of a three-phase system.
- An investigator must check each phase conductor to neutral/ground, and then each phase against the other phases to check a system completely. Remember that, with three-phase systems, it is possible to have only one of the three phases energized. Check “everything to everything” to be safe!

DIGITAL MULTIMETER (3 of 3)



Slide 2-15

- In the photo, the investigator is verifying the absence of voltage from L1 to Line 2 (L2) of a three-phase system.
- When using multimeters that have multiple test lead ports, it is **critical** to make sure that the test leads are in the correct function ports before attempting to make a measurement.

- By virtue of its operational design, when a multimeter is placed in current measuring mode, and the leads are in the appropriate function ports for that mode (Amps and COMmon), the meter essentially becomes a jumper wire.
 - An investigator attempting to measure across two points for the presence of voltage while a meter is in the amps measurement mode is the equivalent of shorting those two points with a piece of wire. With well-designed meters, if voltage is present, this will simply blow a fuse inside the meter.
 - Remember that with a “dead short,” the current draw through the circuit (the multimeter in this case) might be hundreds, if not thousands, of amps. Similar damage or risks can also occur if applying voltage to the test leads while the meter is in Ohms or continuity mode.
3. Neon bulb testers: Although neon bulb testers can indicate the presence of voltage, the testers can be dangerous because there may not be enough voltage for the bulb to light, but there still may be enough to harm or injure the investigator. In other words, depending on the tester design, voltage can be as high as 90 VAC.

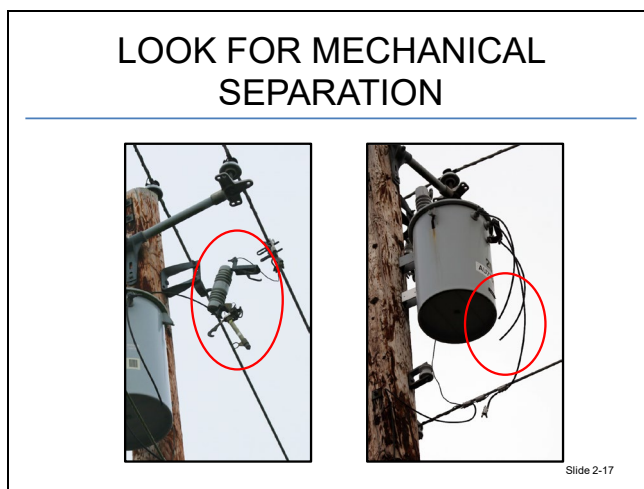


C. Personal protective equipment (PPE).

1. The slide provides some examples of PPE.
2. At a minimum, the investigator should have eye protection, hand protection, a lockout/tagout device and voltage test equipment.

3. Every voltage test device has different capabilities and limitations. An investigator needs to ensure that they are properly trained and comfortable using their specific test equipment.
4. Conductive jewelry should not be worn while working around electrical equipment. The natural reaction from electric shock is to reactively jerk or pull away from the points of contact. If worn, and if such jewelry were to make contact with other energized components during this reaction or otherwise, the results could be devastating.

III. MECHANICAL SEPARATION



- A. Look for mechanical separation.
1. This can be accomplished by the service feed or loops being physically cut, or by opening the fuses inline from the utility to the structure. It is important to note that this is a job for the utility company to perform. There is no over-current protection on the upstream utility side.
 2. An investigator should always look to disconnect power from the source and work their way in toward the structure or circuit in question. The photo on the left shows that the utility fuse cutout has been opened, and the photo on the right shows that the conductor loops have been cut.

CHECK FOR ALTERNATIVE POWER SOURCES



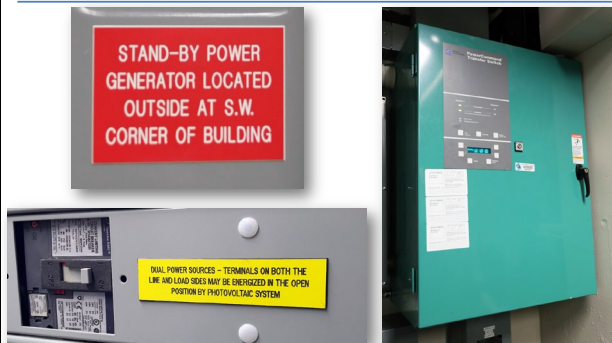
Slide 2-18

B. Check for alternative power sources.

1. The slide provides an example of an alternative power source: a generator.
2. Consider consumer or end-user uninterruptible power supply (UPS)/battery backup systems that may be present at the scene.
3. Backup or alternative power sources can be manual or automatic. They are in the distribution circuit between the utility and the structure.

Example: Do not assume that because the service loops are cut that the building is de-energized, as the building could be energized by an alternative power source, such as a backup generator or solar panels.

CHECK FOR ALTERNATIVE POWER SOURCES (cont'd.)



Slide 2-19

4. Test every time. Do not assume that the mechanical separation has de-energized the structure or circuit.

5. The presence of an automatic transfer switch or the presence of informational labels are clues that an alternative power supply is on the premises.

ACTIVITY 2.1

Identify Test Points

Purpose

Identify voltage test points on various panels.

Direction

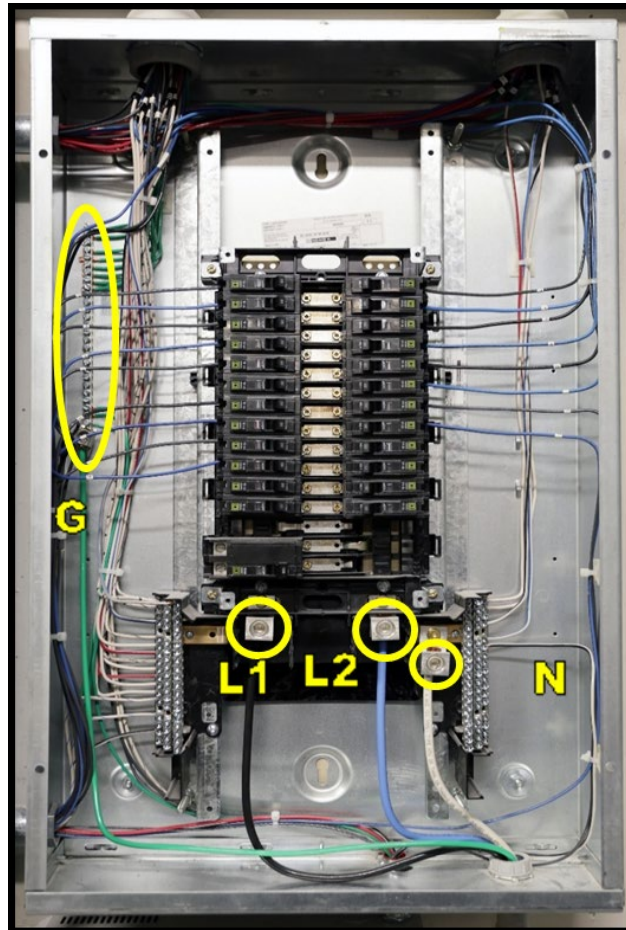
Working in your table group, use the provided worksheets to identify all essential test point locations and combinations.

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ACTIVITY 2.1 (cont'd)

Identify Test Points Answer Sheet

PICTURE 1



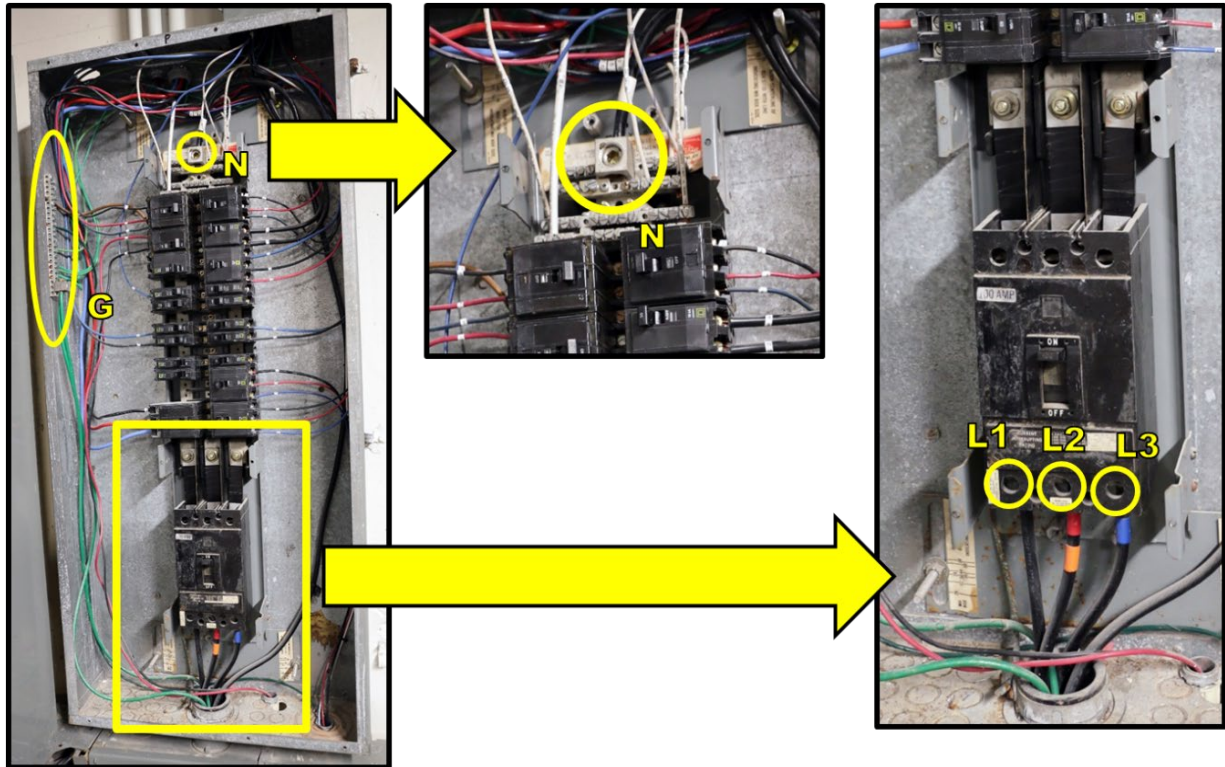
Identify and label the test points and terminals on the photo.

What are the points to test on this panel? (Answers should be in the “from ____ to ____” format.)

Does it have a main breaker? Yes or No

Type of panel: _____

PICTURE 2



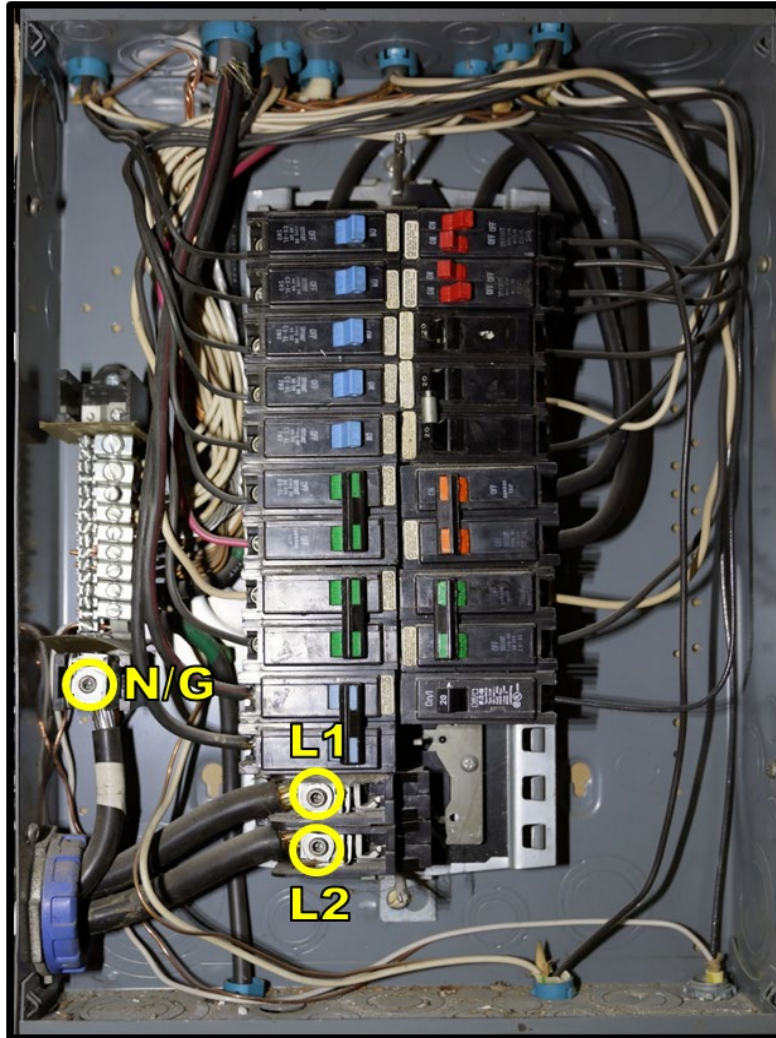
Identify and label the test points and terminals on the photo.

What are the points to test on this panel? (Answers should be in the “from ____ to ____” format.)

Type of panel: _____

Does it have a main breaker? Yes or No

PICTURE 3



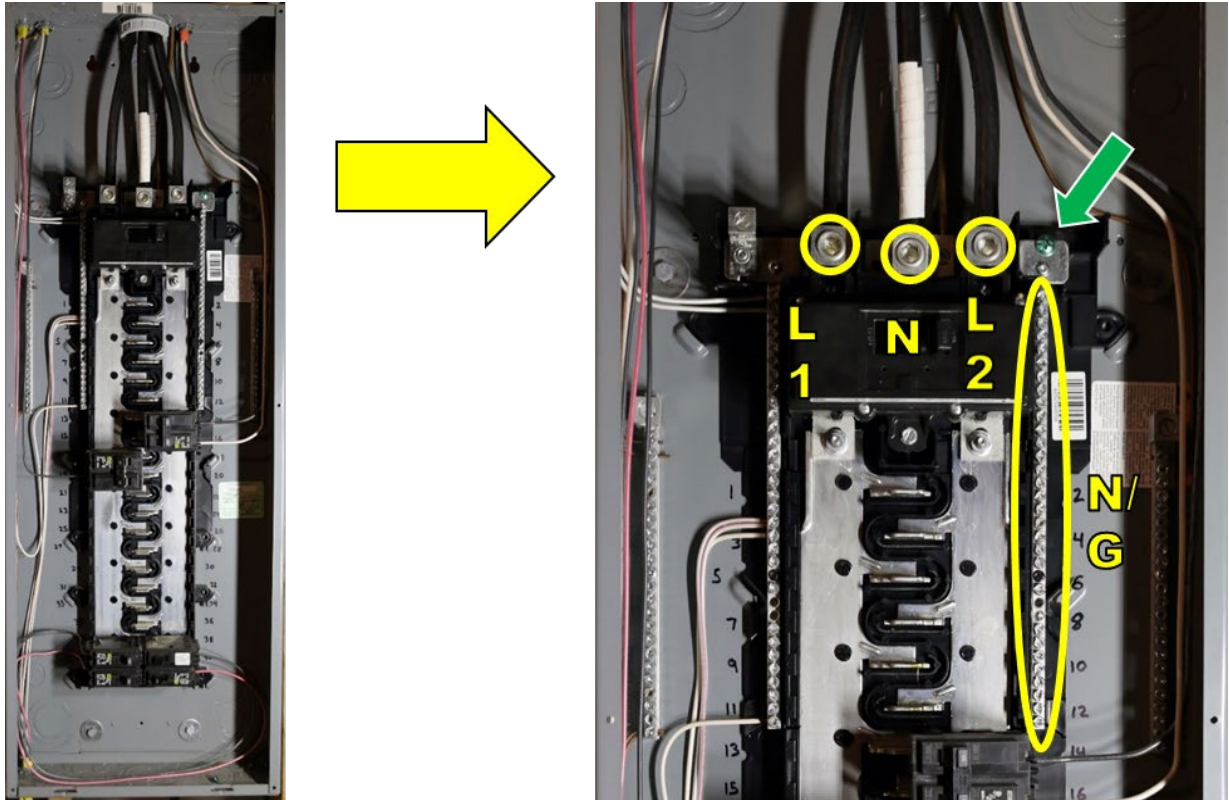
Identify and label the test points and terminals on the photo.

What are the points to test on this panel? (Answers should be in the “from ____ to ____” format.)

Type of panel: _____

Does it have a main breaker? Yes or No

PICTURE 4

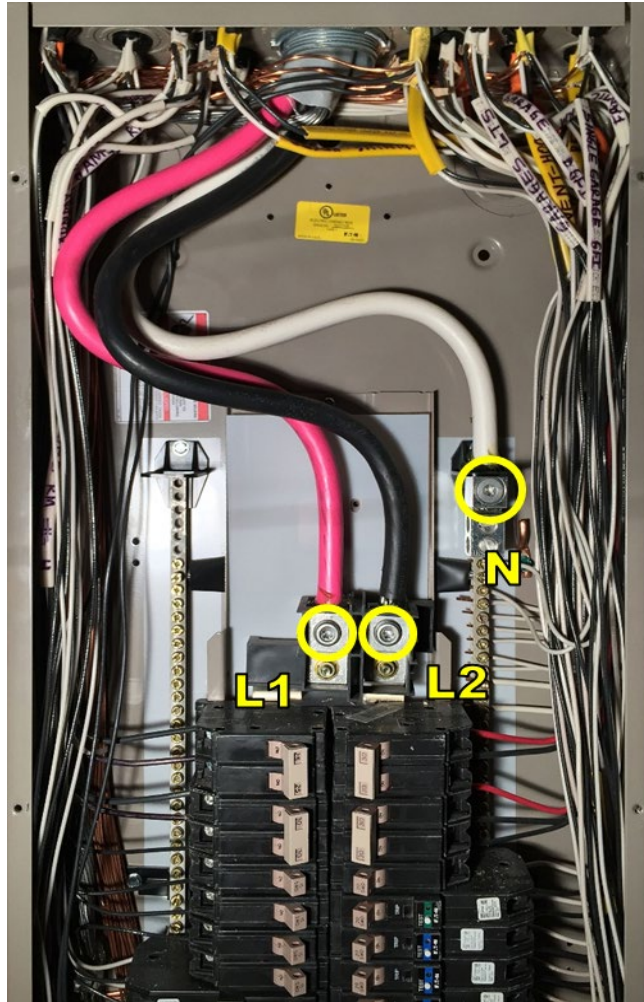


Identify and label the test points and terminals on the photo.

What are the points to test on this panel? (Answers should be in the “from ____ to ____” format.)

Type of panel: _____

Does it have a main breaker? Yes or No

PICTURE 5

Identify and label the test points and terminals on the photo.

What are the points to test on this panel? (Answers should be in the “from ____ to ____” format.)

Type of panel: _____

Does it have a main breaker? Yes or No

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IV. SUMMARY



SUMMARY

Review safety equipment to use on a fire investigation scene.

Demonstrate the ability to use multimeters and non-contact voltage testers.

Demonstrate and identify how to locate sources of power and safely test them for the presence of electricity.

Slide 2-21

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UNIT 3: OHM'S LAW AND JOULE'S LAW

TERMINAL OBJECTIVE

The students will be able to:

- 3.1 *Use Ohm's and Joule's laws to calculate unknown values.*

ENABLING OBJECTIVES

The students will be able to:

- 3.1 *Define Ohm's and Joule's laws.*
- 3.2 *Calculate wattage, voltage, power, resistance and amperage to determine missing values using the application of Ohm's and Joule's laws.*
- 3.3 *Analyze the operation of simple electrical circuits using Ohm's and Joule's laws.*
-

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TERMINAL OBJECTIVE

Use Ohm's and Joule's laws to calculate unknown values.

Slide 3-2

ENABLING OBJECTIVES

- 3.1 Define Ohm's and Joule's laws.
- 3.2 Calculate wattage, voltage, power, resistance and amperage to determine missing values using the application of Ohm's and Joule's laws.
- 3.3 Analyze the operation of simple electrical circuits using Ohm's and Joule's laws.

Slide 3-3

I. OHM'S LAW

OHM'S LAW

- Ohm's law is named after Georg Simon Ohm (1787–1854).
- Ohm's law is made up of three mathematical equations that show the relationship among voltage, current, and resistance.

Slide 3-4

A. Definition.

1. The scientific expression of Ohm's law is: The amount of current flowing in a circuit made up of pure resistance is directly proportional to the Electromotive Forces (EMFs) impressed on the circuit and inversely proportional to the total resistance of the circuit. The most important thing for an investigator to know is that Ohm's law, named after German physicist Georg Simon Ohm, shows the relationship among voltage, current and resistance. In the previous unit, we defined voltage, current and resistance. Now comes the point at which we will apply those definitions.
2. In the course of conducting an investigation, the fire investigator is often left with the task of recreating that which has been damaged and/or made unavailable because of fire damage. In Unit 1: Basic Electricity, we discussed basic terms related to electricity: voltage, current, resistance and power in watts. An investigator will often need to have values for one of these measurements without having the information at hand. Understanding these relationships will be of great use to an investigator needing to find other circuit values. Ohm's law is important to understand because it can help an investigator determine how much load was on a circuit/conductor, and it can help determine whether a potential overload existed at the time of a fire.

B. Example.

1. Imagine a huge water tank high on a hill filled with thousands of gallons of water. The difference between the pressure of water at the top of the tank and the pressure of the water that comes out of a pipe connected at the bottom can be thought of as potential voltage. Now, what is current? In the water tank example, the amount of flow is determined by the pressure (voltage) of the water through the pipes leading to a faucet. The term “current” refers to the quantity, volume or intensity of electrical flow, as opposed to voltage, which refers to the force or pressure causing the current flow.
2. What is resistance? Resistance is the size of the water pipes and the size of the faucet. The larger the pipe and the faucet (the lower the resistance), the more water comes out. The smaller the pipe and faucet (the greater the resistance), the less water comes out. This can be thought of as resistance to the flow of the water current.
3. The point is that all three of these terms — voltage, current and resistance — directly interact in Ohm’s law. If two of the values are known, the missing value can be easily calculated.

OHM’S LAW CALCULATIONS

- Can be used to determine load on the circuit.
- Can prove whether overload condition existed on circuit or circuit components.
- Can model what was occurring in the circuit provided you have proper input data.
 - i.e., resistance, voltage, wattage, etc.

Slide 3-5

- C. Ohm’s law calculations: An investigator must determine what may or may not have happened in a circuit. One way to determine whether an overload existed is to make the appropriate calculations using Ohm’s law.

OHM'S LAW BASICS

$$E = I \times R$$

E is voltage (Electromotive Force (EMF)) measured in volts.

I is current measured in amperes.

R is resistance measured in ohms.

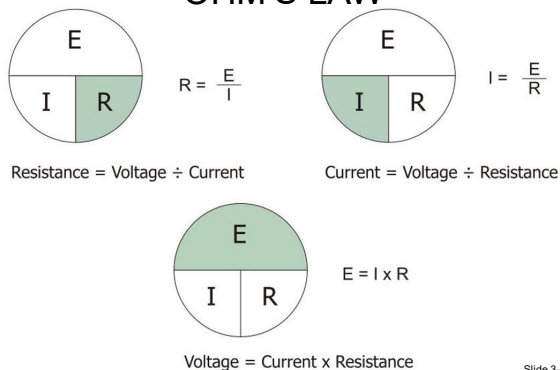
- $E = I \times R$
(Voltage = current multiplied by resistance).
- $R = E / I$
(Resistance = voltage divided by current).
- $I = E / R$
(Current = voltage divided by resistance).

Slide 3-6

D. Ohm's law basics.

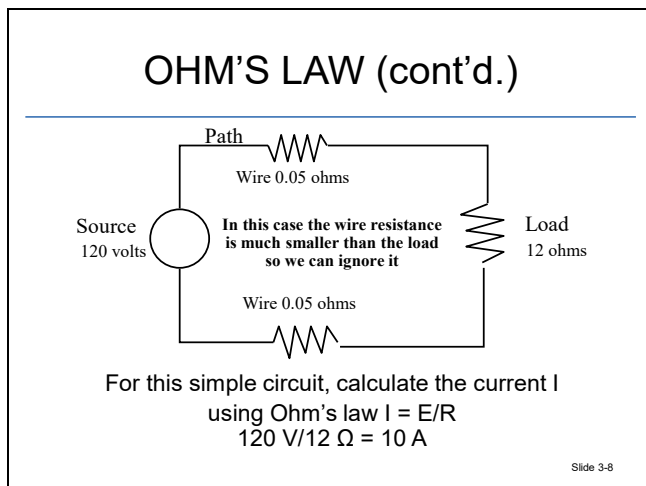
1. Remember the water tank example.
2. In the following equations:
 - a. E is EMF measured in volts (V) (the size of the water tank).
 - b. I is current measured in amperes (related to the amount of water flowing through the pipes and faucet).
 - c. R is resistance measured in ohms (Ω) (related to the size of the pipes and faucet).
 - d. $E = I \times R$ (voltage = current multiplied by resistance).
 - e. $R = E/I$ (resistance = voltage divided by current).
 - f. $I = E/R$ (current = voltage divided by resistance).

VISUAL REPRESENTATION OHM'S LAW



E. Visual representation of Ohm's law.

1. Find the voltage in a circuit: If the circuit has a current of 2 amperes and a resistance of 1 Ω (these are the two known quantities), then, according to Ohm's law and the formulas above, voltage equals current multiplied by resistance: $E = 2 \text{ amperes} \times 1 \Omega = 2 \text{ V}$.
2. To find the current in the same circuit example above, knowing only the voltage and resistance: $I = 2 \text{ V} \text{ divided by the resistance } 1 \Omega = 2 \text{ amperes}$.
3. Remember:
 - a. To find the voltage (E):
 - $[E = I \times R] \text{ E (V) = I (amps) } \times \text{ R } (\Omega)$.
 - b. To find the current (I):
 - $[I = E \div R] \text{ I (amps) = E (V) } \div \text{ R } (\Omega)$.
 - c. To find the resistance (R):
 - $[R = E \div I] \text{ R } (\Omega) = \text{ E (V) } \div \text{ I (amps)}$.



F. Representation of typical branch circuit.

1. This visual shows a representation of a typical branch circuit in the household. The 120 V source is representative of the main panel, and the top and bottom wires in the diagram are the run of Romex[®] or other conductors to a wall outlet. Note that while the conductor does have inherent resistance, in most applications it is so negligible as not to affect the calculation significantly.

2. The $12\ \Omega$ load on the right could represent an appliance plugged into a receptacle. Knowing that the appliance has a resistance of $12\ \Omega$, and that it was plugged into a 120 V branch circuit, the investigator can determine that the current draw of the appliance on that circuit was 10 amps. In this scenario, with proper installation and barring any other failure, this would be viewed as a normally operating branch circuit and would not be cause for alarm.

II. JOULE'S LAW

JOULE'S LAW

James Prescott Joule (1818–1889) formulated a relationship between the heat generated in a conductor and the voltage across and the current through that conductor.

Slide 3-9

A. Definition.

1. Joule's law is a mathematical description of the rate at which resistance in a circuit converts electrical energy into heat energy. The English physicist James Prescott Joule discovered that the amount of heat per second that develops in a wire carrying a current, known as a Joule or 1 watt, is equal to the electrical resistance of the wire multiplied by the current ($I = E \times R$). Heat is generated by current flowing through resistance.
2. Typically, wattage is the measurement by which electric appliances are rated.
3. By using a combination of Ohm's law and Joule's law, if two values are known, an investigator can calculate all of the circuit variables.

JOULE'S LAW CALCULATIONS

Joule's law states that power (in watts) equals voltage multiplied by the current.

$$I \text{ (current)} = P \text{ (watts)} / E \text{ (volts)}$$

$$P \text{ (watts)} = I \text{ (current)} \times E \text{ (volts)}$$

$$E \text{ (volts)} = P \text{ (watts)} / I \text{ (current)}$$

For example, if you know you have an 1800-watt appliance plugged into a 120-volt branch circuit, you could use $I = P/E$ to calculate amps.

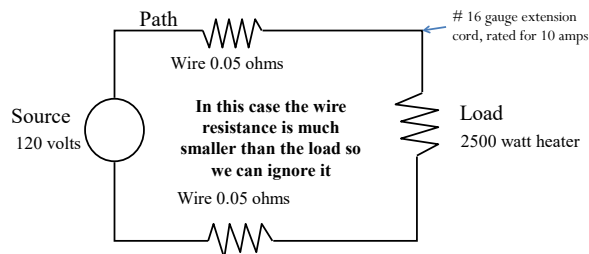
$$1800 \text{ watts} / 120 \text{ volts} = 15 \text{ amps}$$

Slide 3-10

B. Joule's law calculations.

1. Joule's law states that power (in watts (W)) equals voltage multiplied by the current.
2. Slide illustrates that an 1800 W appliance plugged into a 120 V branch circuit has a 15-amp current draw.
3. To determine the resistance of the appliance, use Ohm's law formula $R = E/I$ to determine that the appliance had a resistance of 8Ω .

VISUAL REPRESENTATION JOULE'S LAW



For this simple circuit, calculate the current I
using Joule's law $I = P/E$
 $2500 \text{ W} / 120 \text{ V} = 20.8 \text{ amps}$

Slide 3-11

C. Visual representation of Joule's law.

1. By using a schematic diagram similar to that of the Ohm's law scenario, the investigator can make a determination about what may have happened with this circuit.

2. A 2,500 W space heater was plugged into a branch circuit via a 16-gauge extension cord. Using Joule's law, the investigator can determine that the heater rated at 2,500 W plugged into a 120 V branch circuit would have a current draw of 20.8 amps. This shows that there was an overload on the 16-gauge extension cord, which is rated to carry 13 amps safely when used properly. The 20.8-amp load is not a significant overload on 12-American Wire Gauge (AWG) premises wiring, and would probably not trip a standard 20-amp breaker.
3. In this case, it was determined that an energized space heater was plugged into a 16 AWG extension cord to reach the receptacle. Per the National Electrical Code® (NEC), a 16 AWG conductor is rated to carry no more than 13 amperes, as mentioned above. As a result, the 20.8-amp draw of the heater would have overloaded the 16 AWG extension cord.

OHM'S LAW AND JOULE'S LAW

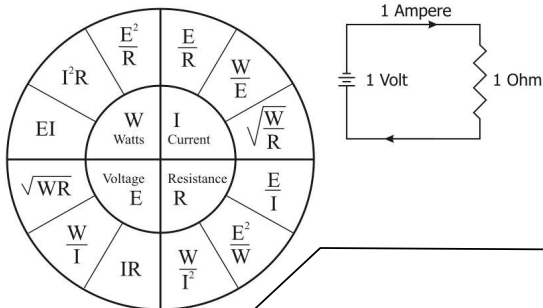
Ohm's and Joule's laws:

- Mathematical equations that calculate voltage, wattage, current, and resistance in electrical circuits.
- A model of what is happening in the circuit.

Slide 3-12

- D. Ohm's law and Joule's law: Based on two known values, the investigator will be able to model what occurred in that circuit. The investigator can then determine if the model is consistent with normal operation, or shows a condition that could prove to be a factor in fire cause.

WATT'S WHEEL



Slide 3-13

E. Watt's Wheel: On the slide is a graphical representation of the combination of Ohm's law and Joule's law. The inner circle is divided into quadrants and labeled for the value you want to find. For example, use the upper-left quadrant to determine the wattage by performing simple mathematical operations on the two known values. Determine the wattage by:

1. Multiplying the voltage and current.
2. Multiplying the current squared by the resistance.
3. Dividing the voltage squared by the resistance.

III. CALCULATING MISSING RATINGS

CALCULATING MISSING RATINGS
(1 of 5)



Slide 3-14

A. Clothes washer example.

The photo shows the label from a clothes washer, but the label does not show watts. We can calculate W using Joule's law:

1. $P = I \times E$.
2. $P = 10 \text{ (amps)} \times 120 \text{ (V)}$.
3. $P = 1,200 \text{ W}$.

CALCULATING MISSING RATINGS (2 of 5)

Model No. TO 1332BD, 120V~60HZ 1150W

Slide 3-15

- B. Toaster example: This shows the information printed on the bottom of a toaster oven, but the information does not provide the amperage. We can calculate the missing amps figure with Joule's law:

1. $I \text{ (amps)} = P/E.$
2. $I = 1,150 \text{ (W)}/120 \text{ (V)}.$
3. $I = 9.58 \text{ amps}.$

CALCULATING MISSING RATINGS (3 of 5)



Slide 3-16

- C. Lightbulb example: Slide shows a lightbulb. We can calculate the amps with Joule's law:

1. $I \text{ (amps)} = P/E.$
2. $I = 75 \text{ (W)}/120 \text{ (V)}.$
3. $I = 0.625 \text{ amps}.$

CALCULATING MISSING RATINGS (4 of 5)

MODEL	597CND42-B	DO	N/A
FACTORY CHARGED	R-22		
COOLING CAPACITY	3.69 TONS		
POWER SUPPLY	208/230 V		
PERFORMANCE RATINGS			
230V	18.7 HP		
208V	17.0 HP		
199V	15.0 HP		
187V	13.0 HP		
175V	11.0 HP		
163V	9.0 HP		
151V	7.0 HP		
139V	5.0 HP		
127V	3.0 HP		
115V	1.0 HP		
103V	0.5 HP		
91V	0.2 HP		
79V	0.1 HP		
67V	0.05 HP		
55V	0.02 HP		
43V	0.01 HP		
31V	0.005 HP		
19V	0.002 HP		
7V	0.001 HP		
0V	0.000 HP		

Slide 3-17

D. Air conditioning unit example.

- It may be challenging to find relevant ratings for an appliance or a piece of equipment and may require additional research.

CALCULATING MISSING RATINGS (5 of 5)

120/240 V	60 HZ	5600 W	24 A	3 WIRE
120/240 V	60 HZ	5600 W	24 A	3 WIRE
120/208 V	60 HZ	4400 W	22 A	3 WIRE
120/200 V	60 HZ	4400 W	22 A	3 WIRE
FUSE: 30 A				
48N9				
LISTED E9527				

Slide 3-18

- This clothes dryer label shows all relevant information, even the size of the breaker (fuse) that should be installed in the circuit.
- Notice the amperage and wattage ratings change when the operating voltage changes.

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ACTIVITY 3.1

Ohm's Law and Joule's Law Calculations

Purpose

Calculate wattage and amperage to determine missing components in single- and three-phase alternating current (AC) circuits.

Direction

Use Handout 3-1: Ohm's Law and Joule's Law Calculations Worksheet to practice applying Ohm's and Joule's laws.

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ACTIVITY 3.2

Hypothesis Testing

Purpose

Test a hypothesis (Scientific Method step 7) by analyzing the scenario below, using National Fire Protection Association (NFPA) 921, *Guide for Fire and Explosion Investigations*, to determine whether or not the given hypothesis is correct.

Directions

1. Read the scenario below, and use NFPA 921 to determine whether or not the hypothesis provided is correct.
2. Provide the correct NFPA 921 numerical section reference and reasoning to support your answer.

Scenario

Fire Investigator Stapleton conducts a fire origin and cause investigation at a residential structure. The fire origin investigation is focused on the basement, which was based on witness statements, fire dynamics, and fire patterns. Stapleton continues to collect fire-scene data, evaluate the electrical system, and conduct arc mapping. Stapleton notes that the electrical system is single-phase 120/240 V. He identifies an 18 AWG extension cord rated for 10 amps plugged into a wall directly in the area where he believes the fire originated (next to a trash can filled with combustible materials). Stapleton identifies that two 1,200 W space heaters are plugged into the extension cord. The owner had stated that the heaters ran all the time because of moisture in the basement. Stapleton examines the breaker panel and identifies that the circuit is protected by a 20-amp breaker. With this information, Stapleton believes that the fire was caused by an overloaded extension cord, which ignited available common combustible materials. Stapleton classifies the fire as accidental. Do you agree with Stapleton's findings?

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IV. SUMMARY



SUMMARY

- Define Ohm's and Joule's laws.
- Calculate wattage, voltage, power, resistance, and amperage to determine missing values using the application of Ohm's and Joule's laws.
- Analyze the operation of simple electrical circuits using Ohm's and Joule's laws to calculate unknown values.

Slide 3-21

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UNIT 4:

ELECTRICAL POWER DELIVERY

TERMINAL OBJECTIVE

The students will be able to:

- 4.1 *Distinguish among the theories and physics of electrical systems to determine their relevance in a fire investigation.*

ENABLING OBJECTIVES

The students will be able to:

- 4.1 *Explain how electricity arrives at a structure and is delivered from the transformer to the load center.*
 - 4.2 *Illustrate transformer theory, including types of transformers, voltage/current relationship, and application.*
 - 4.3 *Differentiate between single-phase and three-phase power systems.*
 - 4.4 *Apply the concepts of open neutral and alternate flow paths.*
-

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TERMINAL OBJECTIVE

Distinguish among the theories and physics of electrical systems to determine their relevance in a fire investigation.

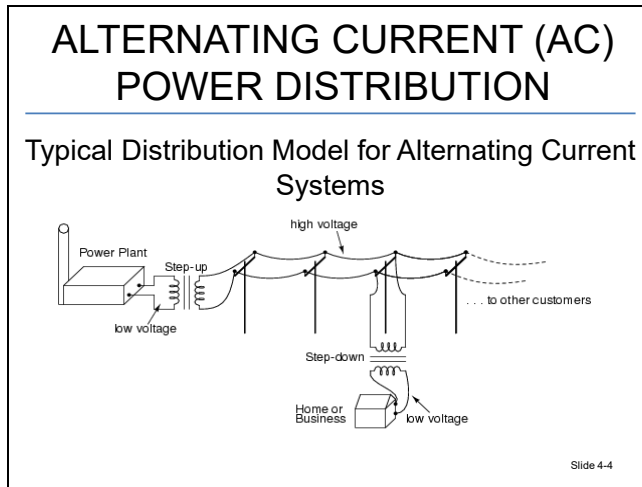
Slide 4-2

ENABLING OBJECTIVES

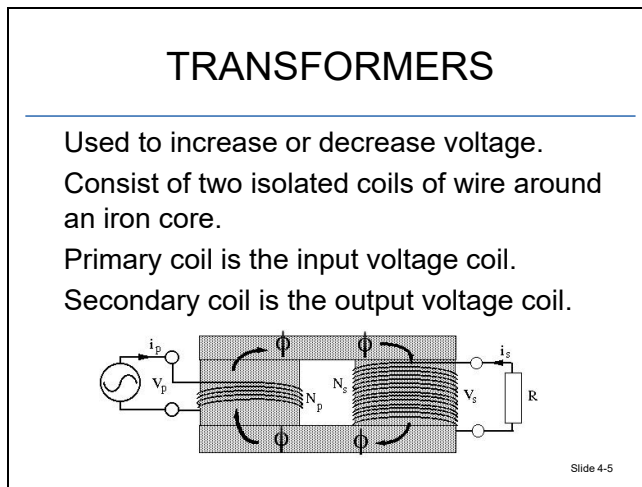
- 4.1 Explain how electricity arrives at a structure and is delivered from the transformer to the load center.
- 4.2 Illustrate transformer theory, including types of transformers, voltage/current relationship, and application.
- 4.3 Differentiate between single-phase and three-phase power systems.
- 4.4 Apply the concepts of open neutral and alternate flow paths.

Slide 4-3

I. ALTERNATING CURRENT POWER DISTRIBUTION

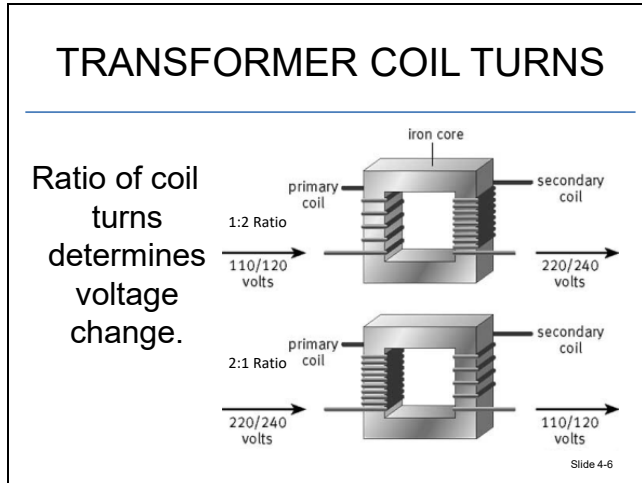


- A. Distribution model: The graphic shows a typical distribution model for alternating current (AC) systems.

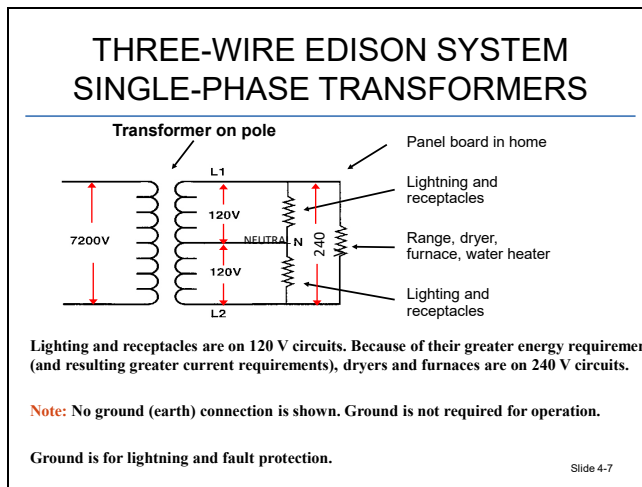


- B. Transformers.

1. The electrical distribution system is a series of “closed-loop” generation systems. Remember that electricity flows in a loop back to the source from which it was created. This slide shows three separate “loops” or systems: the power generation plant, the distribution network, and ultimately the transformer at the consumer’s premises.
2. Transformers can be found at fire scenes. For utility distribution purposes, they may be mounted on a power pole or located at or below ground level. The purpose of a transformer is to use the magnetic effects of current flow to change the voltage level, a change typically referred to as step-up or step-down. Electricity is applied to the primary winding, and the magnetic field created by that current flow induces a voltage potential through magnetism in the secondary winding.



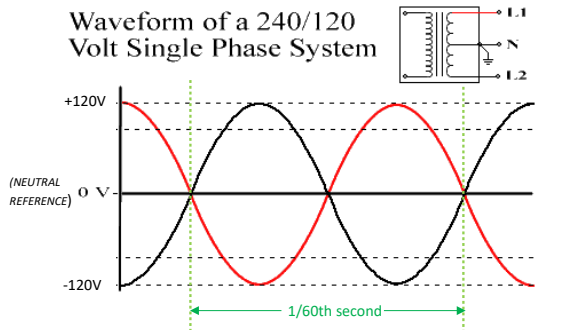
- C. Coil turns: The diagram illustrates that the ratio of coil turns determines voltage change. High-voltage/low-amperage primary power is transformed into low-voltage/high-amperage secondary power, the level of which is determined by the ratio of primary to secondary coils within the transformer. For example, with a 2:1 ratio transformer, for every two volts (V) of voltage applied to the primary side coil, one V is available on the secondary side.



- D. Three-Wire Edison system: The graphic shows a diagram of a typical Three-Wire Edison System, which supplies residential structures with a voltage of 240/120, and is also known as a split-phase system. The transformer that supplies residential voltage can be viewed simply as two windings in one container — a primary and a secondary winding. The utility provides 7,200 V to the primary winding, and the secondary winding, low-voltage side, provides the dual voltage of 240/120. This is accomplished by the neutral reference point/connection, which is at the mechanical center of the secondary winding. There is zero voltage potential at the neutral.

SINGLE- VS. THREE-PHASE SINGLE-PHASE POWER

Waveform of a 240/120
Volt Single Phase System

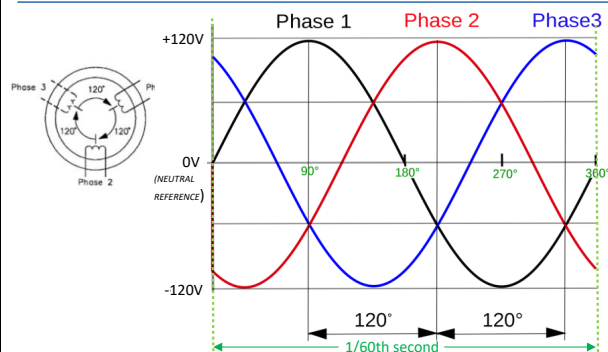


Slide 4-8

E. Single-phase power.

1. Split-phase power is not two-phase electricity. The single phase is split so that the peak waveforms of the two phases — Line 1-Line 2 (L1-L2) — occur 180° from each other. Their zero-voltage points occur at the same place.
2. The graphic illustrates the voltage waveform of a single-phase system. The time in the slide represents the change of voltage within $1/60$ th of a second, or one cycle. This is 60 hertz (Hz), or a 60-cycle AC system. The waveforms represent the change in voltage of each leg of a 240/120 transformer. At the peak of its cycle, the voltage of each leg of the transformer (L1 and L2) relative to neutral is approximately 120 V, either positive or negative voltage depending on the polarity of the magnetic field that created the flow. 240 V are derived in this system from the difference in potential of the two waveforms at their peaks, relative to each other.

SINGLE- VS. THREE-PHASE THREE-PHASE POWER



Slide 4-9

F. Three-phase power.

1. Three-phase power is simply three single-phase waveforms, in which the timing of the generation of the phases is 120° apart. The term “ 120° apart” refers to the position in the rotation of the magnetic field of the phase’s winding. In this graphic, 120 V is used as reference voltage simply for comparison to the single-phase system on the previous slide; three-phase systems will usually be higher-peak voltages.

THREE-PHASE POWER

Used in larger occupancies where lighting and motor loads are greater than in a residential occupancy.

Motors are less costly and run more efficiently.

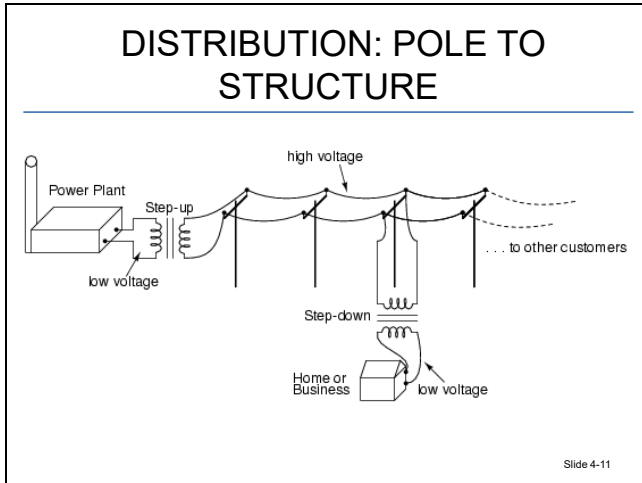
Common three-phase system voltages are:
120 V/240 V/208 V and 277 V/480 V.

Slide 4-10

2. Since three-phase power provides three voltage values, it is more efficient due to the greater continuity of the delivery of power. Commercial and industrial occupancies use mainly three-phase power. The voltages encountered will be 208/120, 277/480 Wye system, 120/240/208 on an open delta system; 208 voltage on an open delta is between phase B and neutral. Higher voltages in three-phase systems allow for use of smaller conductors due to the lower amperage draws in comparison to a single-phase system.

Example: Ten 100 W lighting fixtures connected to a 277 V light circuit would draw 3.6 amps (Ohm’s law). The same lighting fixtures connected to a 120 V lighting circuit would draw 8.3 amps (Ohm’s law). Lower voltage equals higher current and vice versa. Residential buildings would not benefit sufficiently from the advantages of three-phase power to justify the equipment and installation costs.

3. Three-phase power, by the nature of its higher voltages, also provides the potential for higher amounts of energy dissipation in the event of a fault. By using Ohm’s law and increasing the E (voltage) portion of the formula from 120 to 480, we can see numerically how the same resistance (remember: short circuits are almost zero resistance) will draw four times the current and resultant energy at 480 V than it does at 120 V.



II. ELECTRICAL SERVICE

ELECTRICAL SERVICE

- Starts at utilities demarcation point – service point.
- Two classifications or types: overhead and underground.
- Includes metering equipment.
- Includes premises grounding systems.
- May include a breaker panel with individual branch circuit over-current protection devices.

Slide 4-12

A. Overview.

1. In this context, the term “electrical service” describes the components that are associated with the electrical system within the structure, which typically include conductors, metering equipment, and over-current protection. The electrical service begins at the connection point of the utility company’s conductors to the consumer’s equipment.

The point of connection is known as the service point or point of attachment. An overhead electric service (service drop) connects the weather head attached to the structure. An underground service (service lateral) connects directly in the meter base or service equipment. Local utility responsibility may vary at this point of connection.

2. The service entrance is the point at which grounding electrodes are installed and bonded to the incoming electrical system. The grounding portion of an electrical system does not need to be present for a system to function correctly; its purpose is fault and lightning protection. Grounding is for life safety.
3. Once electricity has reached the building, it must be distributed within the structure to its points of use. This is done through a series of main disconnect switches and breaker panels, with installed over-current protection devices (OCPDs) for each branch circuit in the structure.
4. An investigator must be able to identify and correctly document the various portions of an electrical system. At points in an investigation, such as arc mapping, an investigator must be able to understand and identify exactly where the electricity is coming from and where it is going. Personal safety, which is paramount, requires ensuring that electricity has been disconnected prior to an investigation.

PRIMARY POWER-POLE-MOUNTED FUSES



Slide 4-13

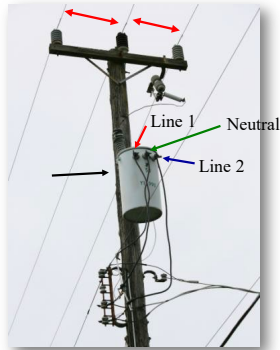
B. Primary power-pole-mounted fuses.

1. Primary power fuses are in series with the conductor that feeds the high-voltage primary power to the transformer. They protect the utility company equipment/conductors from failures or faults on the primary side of the transformer.
2. The photo on the left shows a typical fuseholder in the “closed” or “on” position. The photo on the right shows a fuseholder in the “open” or “off” position. Fuseholders of this type are also referred to as cutouts. The utility company may state that power was “disconnected at the cutout”; this is what they are referring to.

SINGLE-PHASE POWER-POLE

Distribution voltages are usually 4800–14400 volts

A transformer is provided to step the voltage down to safer voltages



Slide 4-14

C. Single-phase power.

1. The slide shows a picture of single-phase service. Single-phase services will have only one transformer connected to only one of the high-voltage lines, which takes that one phase and steps it down to a lower-voltage single phase.
2. The two red arrows at the top of the photo indicate the distribution voltages between the conductors, which are typically between 4,800 and 14,400 V. The red and blue arrows indicate where L1 and L2 voltage legs are tapped off the transformer. The green arrow shows the neutral tap of the transformer winding.

THREE-PHASE POWER

The graphic depicts a three-phase 120/240 V system with a 208 V to ground high leg. The two transformers are indicative of this delta transformer configuration.



Slide 3-15

D. Three-phase power.

1. Three-phase systems may have one, two or three transformers connected. The transformers are connected to two or more phases of the high-voltage primary power. The two-transformer setup shown here has voltage potentials of 120, 208, and 240 V. Notice that each transformer has its own over-current protection in the form of a fusible link between the primary power conductor and the transformer. It is possible in this arrangement for one of the two fuses to be blown or disconnected; therefore, voltage potential may still exist in the structure.

THREE-PHASE POWER- TRANSFORMER

Three transformers are indicative of this Wye transformer configuration.



Slide 4-16

2. A typical three-phase power transformer setup. Notice that the transformers are independent of each other, and each is individually fused and connected to one of the three phases of high-voltage primary power conductors overhead.

THREE-PHASE POWER – SINGLE CAN

The graphic depicts a three-phase, larger single-can transformer. Remember, one transformer doesn't always indicate a single-phase system.

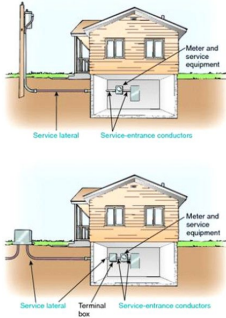


Slide 4-17

3. Three-phase systems in some areas may be supplied by a larger single can that houses the three separate windings of the transformer within a single enclosure. These three-phase systems and transformers can be identified by the presence of a conductor lead from each of the three high-voltage lines being connected to three insulated terminals on the transformer. Do not assume a single transformer always means a single-phase system. If in doubt about the type of system, contact the utility company for assistance.

**SERVICE-ENTRANCE
CONDUCTORS, UNDERGROUND
SYSTEM**

The service conductors between the terminals of the service equipment and the point of connection to the service lateral.



The diagram illustrates two scenarios for service-entrance conductors in an underground system. The top scenario shows a house with a meter and service equipment. A service lateral runs from the ground to the meter, and service-entrance conductors run from the meter to the service equipment. The bottom scenario shows a house with a meter and service equipment. A service lateral runs from the ground to a terminal box, and service-entrance conductors run from the terminal box to the service equipment. Labels include 'Service lateral', 'Service-entrance conductors', and 'Meter and service equipment'. Slide 4-18

- E. Service-entrance conductors, underground system: The service-entrance conductors of an underground system can originate from a pole-mounted transformer or a pad-mounted transformer. Both types of installation are subject to open neutral failures from physical damage, high-resistance connections (HRCs), or corrosion.

ELECTRICITY DISTRIBUTION

A pad-mounted transformer can be single- or three-phase and accompanied by underground lateral.



The photograph shows a pad-mounted transformer, which is a large, box-like unit mounted on a concrete pad. It is surrounded by vegetation. A utility pole with wires is visible in the background. Slide 4-19

- F. Electricity distribution.
1. Pad-mounted transformers have primary power fed from underground laterals associated with a buried underground distribution (BUD) system. Transformers can be fed from underground or aerial (pole to riser, then underground to transformer).

2. Transformers can also be located underground in vaults or inside structures in dedicated vault rooms.

ELECTRICITY DISTRIBUTION-TRANSFORMERS

Step-down or step-up transformers:

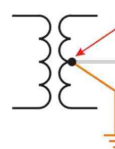
- Can be located almost anywhere.
- Transform voltages for use by building electrical components.



Slide 4-20

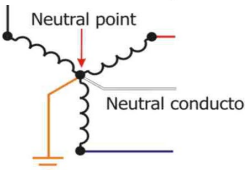
3. Three-phase systems that are 480/277 V systems will use step-down transformers to lower the voltage for nominal 120 V circuits (office equipment, receptacles, etc.). Transformer locations may vary throughout the structure.

NEUTRAL CONDUCTOR AND NEUTRAL POINT

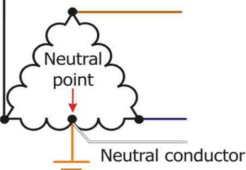


Neutral point of an electrical system.
Neutral conductor.

The terms **neutral conductor** and **neutral point** have been defined in Article 100 of the NEC. Rules throughout the NEC have been revised to clarify when the word **neutral** refers to the neutral conductor of a system or circuit and when the term refers to the neutral point of a system.



Neutral point
Neutral conductor



Neutral point
Neutral conductor

Graphic: <https://www.iaei.org/>

Slide 4-21

G. Neutral conductor and neutral point.

1. The neutral conductor, or grounded conductor, is a return path for current back to a transformer. It is referred to as the grounded conductor because it is bonded to the grounding system at the service entrance equipment. The wiring diagram here illustrates the point at which a neutral conductor connects to the neutral point of single- and three-phase transformer arrangements.
2. Identification of a neutral conductor is white (120/208/240 V systems) or natural gray (480/277 V systems).

III. SUMMARY



SUMMARY

- Explain how electricity arrives at a structure and is delivered from the transformer to the distribution panel.
- Introduce transformer theory, including types of transformers, voltage/current relationship, and application, and describe the basic electrical distribution system to ensure individual and equipment safety.
- Differentiate between single- and three-phase power systems.
- Illustrate the concept of an open neutral and describe the resultant current flow paths and the implications of current flowing through those alternate paths.

Slide 4-22

UNIT 5: ELECTRICAL SERVICE EQUIPMENT

TERMINAL OBJECTIVE

The students will be able to:

- 5.1 *Apply the fundamentals of electric utility system operations, including generation, transmission, distribution, and typical electrical service supplies to buildings and facilities.*

ENABLING OBJECTIVES

The students will be able to:

- 5.1 *Describe the function and purpose of electrical service equipment.*
 - 5.2 *Identify and differentiate the types of installed electrical service equipment used and the potential failures within those systems.*
-

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TERMINAL OBJECTIVE

Apply the fundamentals of electric utility system operations, including generation, transmission, distribution, and typical electrical service supplies to buildings and facilities.

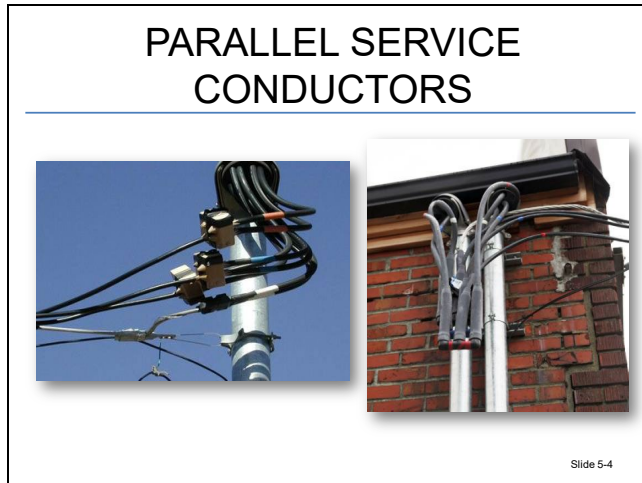
Slide 5-2

ENABLING OBJECTIVES

- 5.1 Describe the function and purpose of electrical service equipment.
- 5.2 Identify and differentiate the types of installed electrical service equipment used and the potential failures within those systems.

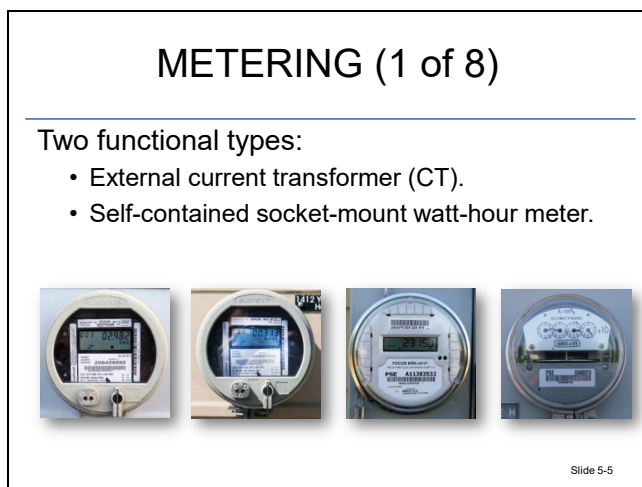
Slide 5-3

I. PARALLEL SERVICE CONDUCTORS



- A. There are service entrance installations that have two smaller conductors running parallel in place of one larger conductor; this is done for ease of installation. The conductors split the current load between them. This arrangement may also be used to feed two separate meters from a single service drop.
- B. If one of the parallel conductors fails, the remaining conductor could become overloaded.

II. METERING



- A. Types of meters.
1. The utility company measures the consumer's use of electricity with meters. Standard watt-hour meters or current transformer (CT) meters are used. Standard and CT are the two types of meters, and each one has variations.

2. CT and standard watt-hour meters have a similar external appearance, but the two types function completely differently. Either type can be a modern electronic version or the old “wheel-and-clock-dial” version.

METERING (2 of 8)

External CT metering:

- Can also be found in a cabinet enclosure.
- Used when service is greater than 400 amps.



Slide 5-6

3. External CT metering (also known as CT metering) uses coils that surround each of the current-carrying conductors to measure the amount of magnetic flux created by current flowing through the circuit, and then converts that value into a usable figure of watt-hours for billing purposes.
4. Electrical service of 400 amps and greater (single- or three-phase) will use external CT metering.
5. The photo on the slide shows the CT metering coils mounted on the pole at the service point where the service conductors go through the coils and the smaller wires run to the CT meter base.

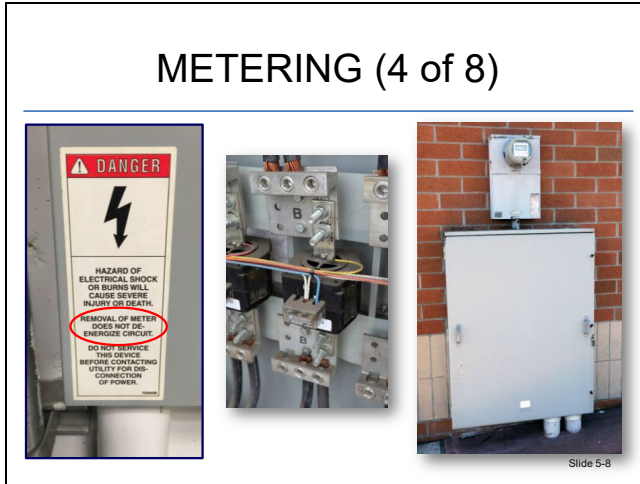
METERING (3 of 8)



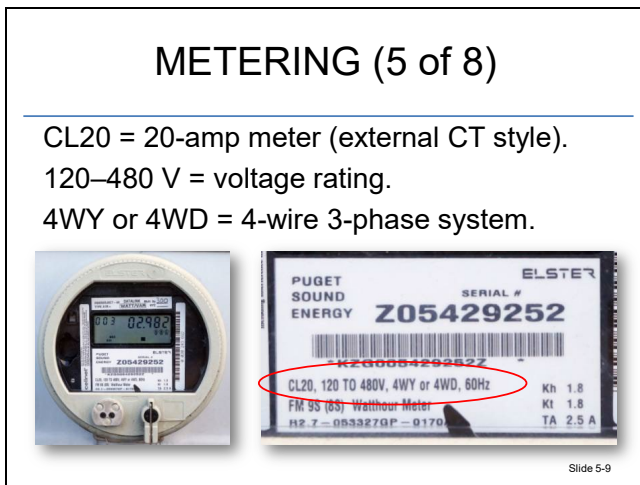
Cabinet-based CT metering

Slide 5-7

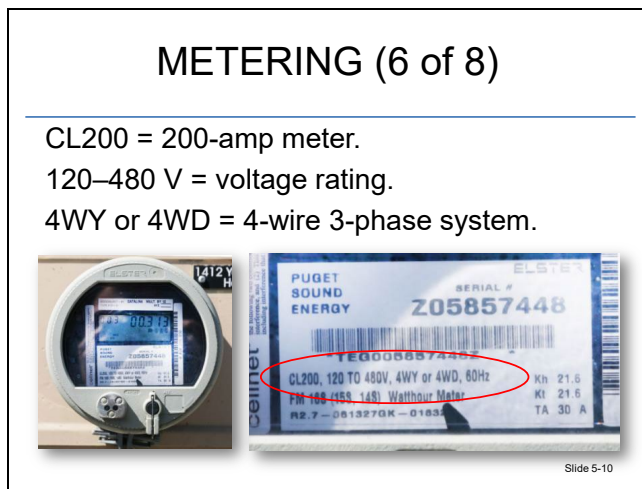
6. The photos on the slide show the CT coils mounted inside enclosures. The enclosure may be located inside or outside the structure. This type of setup will be found between the utility company's connection and the building's service equipment. Seeing this type of equipment should tell an investigator that high amperage power is present at the scene, and that power cannot be disconnected by simply removing the meter. The photo on the left shows the CT coils in a three-phase system; the photo on the right shows the CT coils in a single-phase residential system. Note: Only the current-carrying conductors are metered, not the neutral.



7. By design, external CT meters are not in series with the load path and do not break that circuit path if they are removed; all that removing this type of meter does is stop the measurement of the power being used.
8. Safety point: Removing an external CT-type meter will not de-energize the circuit/structure.



9. The slide shows an example of how to interpret information on meter labeling (three-phase, external CT type).
10. Meters will have labeling on them indicating their ampacity rating, voltage rating, and the type of system (single- or three-phase) they are designed to use.
11. With the meter on the slide, CL20 denotes that it is a 20-amp-capacity meter. Why only 20 amps? The corresponding current generated by the external CT coils is proportionally lower — hence only a 20 amp rating — and the lower the current, the smaller conductors and conduit that lead to a CT meter-base enclosure. This low amperage rating is indicative of an external CT metering setup. 120 volts (V) to 480 V indicates the voltage rating, and 4WY or 4WD means that the meter is for use on a 4-Wire Delta or 4-Wire Wye (Y-shaped) three-phase-type system.



B. Self-contained socket-mount watt-hour meter.

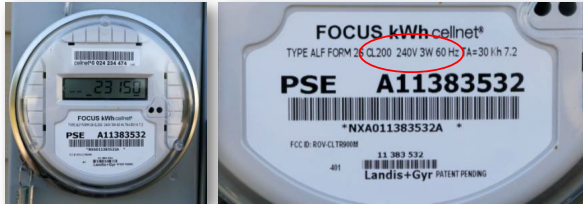
1. Example of how to interpret information on meter labeling (three-phase, self-contained type).
2. With this meter on the slide, CL200 shows that it is a 200-amp-capacity meter, 120 V to 480 V indicates the voltage rating (anything over 240 V is usually indicative of three-phase power), and the 4WY or 4WD shows that the meter is for use on a 4-Wire Delta or 4-Wire Wye (Y) three-phase-type system.
3. Note that this meter is externally identical to an external CT-style meter; the only difference is the labeling.

METERING (7 of 8)

CL200 = 200-amp meter.

240 V = voltage rating.

3W = 3-wire single-phase Edison system.



Slide 5-11

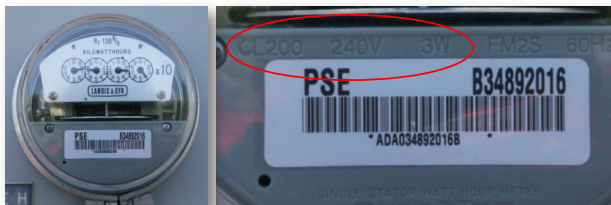
4. Example of how to interpret information on meter labeling (single-phase, self-contained type).
5. With the meter on the slide, CL200 shows that it is a 200-amp-capacity meter, 240 V indicates the maximum voltage on the system, and 3W shows that the meter is for use on a 3-Wire 240/120 V system.

METERING (8 of 8)

CL200 = 200-amp meter.

240 V = voltage rating.

3W = 3-wire single-phase Edison system.



Slide 5-12

6. With the meter on the slide, CL200 again denotes that it is a 200-amp-capacity meter, 240 V indicates the maximum voltage on the system, and 3W shows that the meter is for use on a 3-Wire 240/120 V system.
7. Both single- and three-phase, and both self-contained and external CT-type meters, can also come in this old-fashioned wheel-and-clock-dial version. Do not make system-type assumptions based on the appearance of the meter!
8. Different manufacturers will label their products in their own methods/locations, but the information will be the same.
9. Knowing the type of system that is present on a scene is crucial.

TYPICAL UNDERGROUND METER BASE

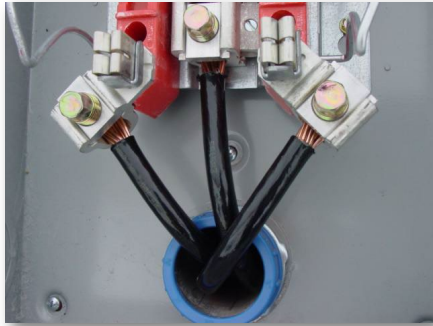


Slide 5-13

C. Typical meter base.

1. A standard socket-mount watt-hour meter is in series with the load path and becomes part of the circuit when in place. As such, it is subject to high current loads, and the connection points are potential points of high resistance and/or failure.
2. Meter bases for socket-mount watt-hour meters will usually have the line-side utility connected to the top lugs, and the load-side feeding power to the structure from the bottom lugs in both underground or overhead services.
3. Safety note: Does removing a standard, self-contained-type socket-mount meter de-energize a structure? In a perfect world, yes. But there is always a possibility that other sources of power may be connected on the load side, such as emergency standby generators, uninterruptible power supply (UPS) battery backup systems, cross-connections to separate still-energized systems (as in strip malls with multiple occupancies), or even illegal power taps that bypass the meter completely.
4. Firefighters or investigators should not remove a meter as a form of utility control. Using meter removal as a primary form of utility control potentially subjects the meter and the meter base to conditions for which it was not designed (breaking under load) and potentially exposes personnel to electric shock. If the meter base is deteriorated, it could fall apart during meter removal. It could potentially short to ground or another conductor with no over-current protection to interrupt that short circuit.
5. Removing meters is in violation of National Fire Protection Association (NFPA) 1500™, *Standard on Fire Department Occupational Safety and Health Program*, Section 8.5.15.3, which states “Fire department personnel shall not be permitted to move or cut electrical meters” (NFPA, 2013).

METER-BASE CONNECTION



Slide 5-14

- D. Meter-base connection: Anywhere there is a connection, there is a potential for failure, be it caused by human error during installation, loose connections, corrosion/oxidation, or mechanical failure.

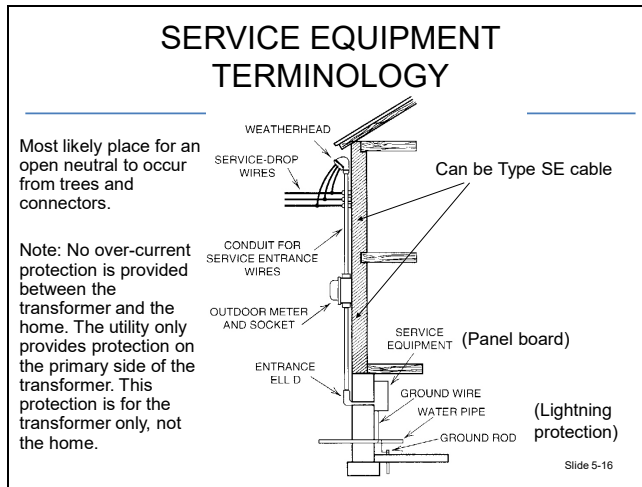
BOOTED METER



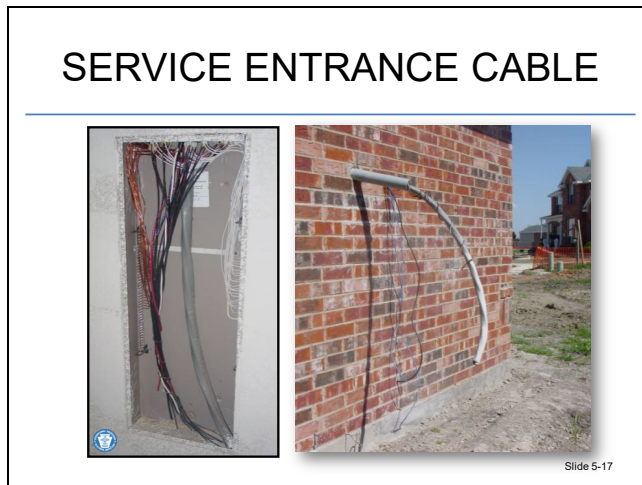
Slide 5-15

- E. Booted meter: Utility companies may “boot” a meter of a nonpaying customer to prevent further electricity consumption or as a means of control in multifamily occupancies. These plastic insulators prevent the terminals of the meter from making contact with the meter socket base. They are not visible from the outside when the meter is reinstalled. If these boots are in place, and no other source of electricity is present, then electricity can preliminarily be eliminated as a cause.

III. SERVICE EQUIPMENT

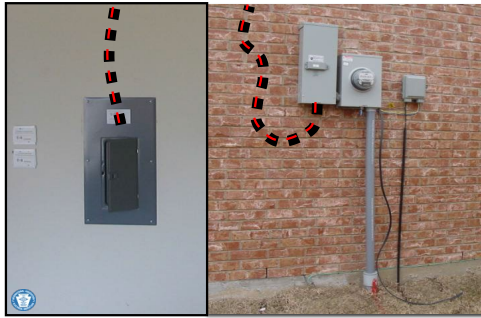


- A. Terminology: The slide illustrates the typical components and arrangement of residential service equipment. There is no over-current protection for the service entrance conductors, the metering equipment, or the conductors up to the point of the first service disconnect, typically the main breaker. This means that an electrical failure/short circuit in any of these portions will not be stopped by the primary power cutout/fuse at the pole. That over-current protection is for the utility company to protect from problems with the transformer itself. Short circuits in these portions of the system result in high currents for prolonged durations that can lead to excessive damage. This damage can affect the metallic enclosures/conduits and other conductors.



- B. Service entrance cable: The slide shows an example of a service entrance cable from a yet-to-be-installed meter base to a breaker panel. In most residential installations, the section of conductors/cable from the meter base to the breaker panel has no overcurrent protection.

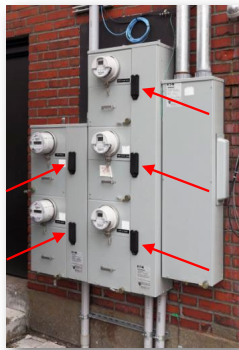
SERVICE ENTRANCE EQUIPMENT



Slide 5-18

- C. Service entrance equipment: On the slide, the breaker panel is a greater distance from the meter base than the code allows, so the service entrance conductors are first run to an enclosure with an over-current protection device (OCPD) (which becomes the service entrance equipment by definition), and the conductors/cable to the breaker panel are then afforded over-current protection.

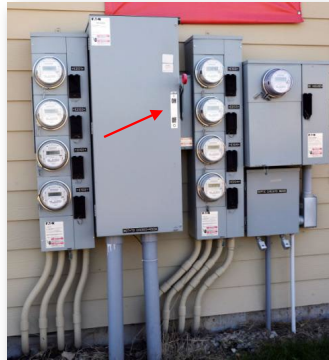
SERVICE DISCONNECTS (1 of 3)



Slide 5-19

- D. Service disconnects.
1. With multiunit structures, such as apartments or strip malls, main disconnect switches will be installed for each metered unit in a single location. This is done so that over-current protection can be provided to the conductors that run to each unit's breaker panel from the meter. The National Electrical Code® (NEC) requires that power to a building must be able to be completely disconnected with no more than "six throws of the handle," and in this case there are five handles. Be aware though that the NEC definition of a building may not be what the fire service would consider a building. A fire wall(s) within a structure creates separate sections that will be considered separate buildings by the fire service.

SERVICE DISCONNECTS (2 of 3)



Slide 5-20

2. More than six throws of the handle would be needed to disconnect this building. This slide illustrates a single main disconnect switch.
3. Whenever you are using any point of disconnect, especially those that are remotely located, use a lockout/tagout system to prevent the scene from being re-energized.

SERVICE DISCONNECTS (3 of 3)

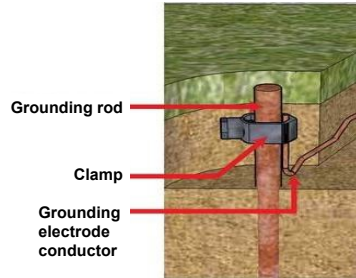


Slide 5-21

4. Remember, a lockout/tagout system is a system in which a source of energy (electrical, mechanical, etc.) is specifically controlled. In this situation, it could be as simple as a lock (to which the investigator holds the key), locking the switch in the OFF position with a note attached that indicates why it is off, contact information, etc.

GROUNDING ELECTRODE

A conducting object through which a direct connection to earth is established.



Slide 5-22

E. Grounding electrode.

1. A grounding system is not necessary for electrical operation; its purpose is to provide safety from overvoltage and lightning. In a properly installed and operating system, the grounding system carries no current and stands by idle.
2. The grounding conductor can become a current-carrying conductor in the event of an open neutral on either the customer or the utility side.
3. The grounding electrode is typically a ground rod, or a set of ground rods driven into the earth, but can also consist of a buried metallic plate and may be bonded to other objects, such as metal structural components, concrete-encased steel rebar, etc.

GROUND ROD

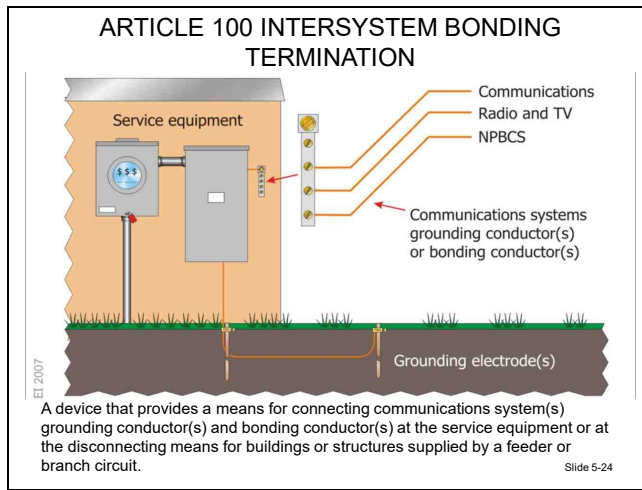


Photo: IAEI Archives

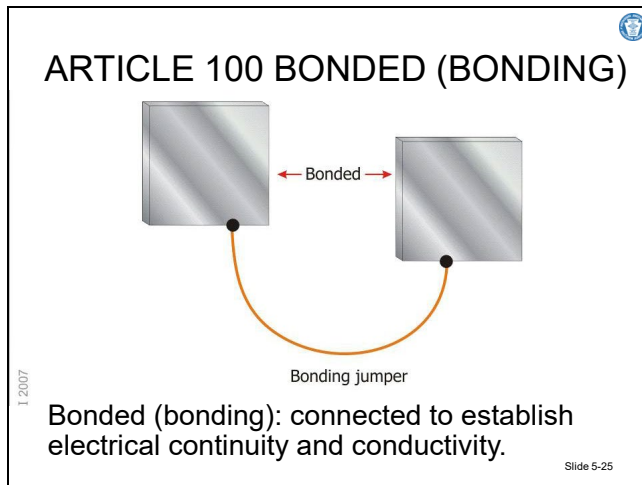
Slide 5-23

F. Ground rod.

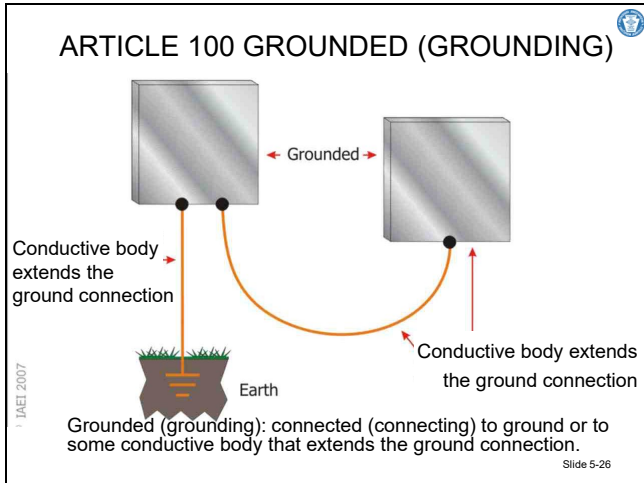
1. The slide shows an example of a typical ground rod connection. If this connection is loose, the grounding system becomes compromised, and electricity will use other paths.



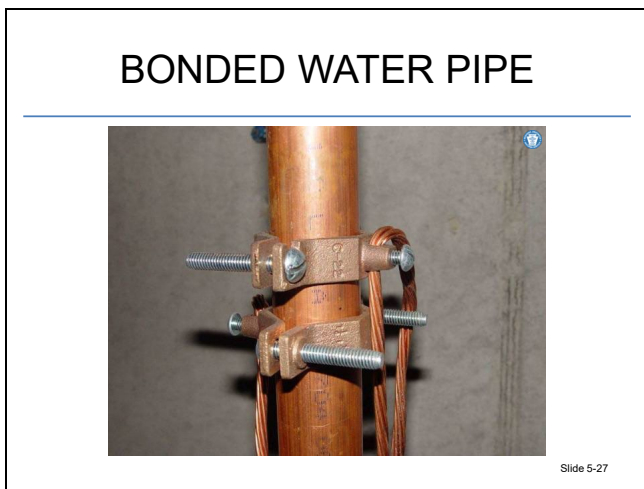
2. Utilities, such as telephone and cable TV, also electrically bond their systems to the structure's grounding electrode. As a result, they also may become alternative current paths in the event of an open neutral.



- G. Bonding is conducted to establish electrical continuity and conductivity. Bonding can be any form of solid electrical connection. It can be a jumper wire, two enclosures bolted together tightly, properly installed types of conduit, etc.



- H. Grounding is the continuous pathway between conductive items to the grounding system. If a connection is poorly bonded, it can become a high-resistance connection (HRC). HRCs can become sources of heat, while at the same time contributing to the inability of an OCPD to operate. Items can be **grounded** by virtue of being **bonded** to other grounded items.



- I. Bonded water pipe: The slide shows how metallic water pipes can be bonded. This building's copper-water-pipe system is bonded to the grounding system by clamps, which ensure that the copper water pipe is at the same potential as the ground.

SERVICE PANELS

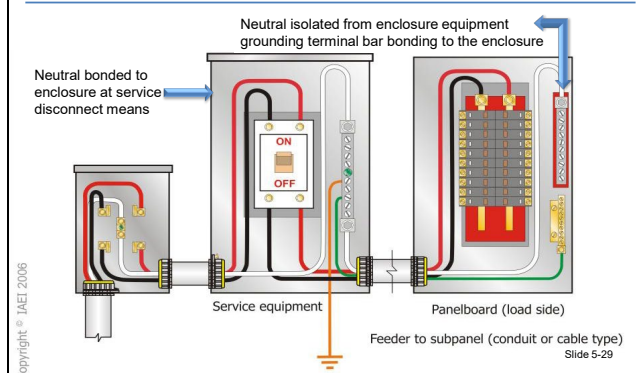
Service panels are fuses, circuit breakers, or a combination of both; they provide over-current protection for building and branch circuits.



Slide 5-28

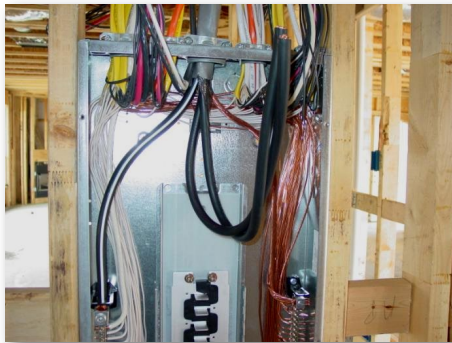
- J. Service panels: From our metering equipment, the service conductors are brought into a service panel, commonly referred to as a breaker panel. The equipment shown in the slide contains the OCPDs for the circuits within the structure. It can also be a combination of breakers and fuses.

SEPARATE NEUTRALS AND GROUNDS



- K. Separate neutrals and grounds: Service equipment is equipment that contains the first disconnect on the load side of the meter and is the only location where the neutral conductor and the grounding electrode conductor are bonded together. Other panels connected downstream of this point are referred to as subpanels, and differ in that the neutral and ground conductors are not bonded together; they are electrically isolated from each other.

OPEN NEUTRAL FAILURES

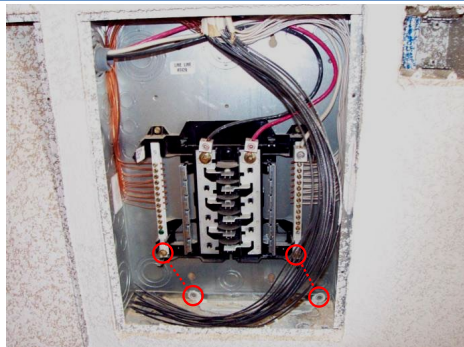


Slide 5-30

L. Open neutral failures.

1. The slide is a photo that shows that if the neutral conductor for a subpanel fails, all the circuits and connected equipment downstream of that panel are subject to open-neutral failure issues. This reinforces the idea that open neutral problems can occur at places other than the service entrance equipment or utility connection.

OPEN NEUTRAL FAILURES (cont'd.)



Slide 5-31

2. The slide is a photo showing how the panel has been converted to a subpanel by separation of neutrals and ground wires, by the removal of the jumper between the two terminal bars. The terminal bars are the point at which the ground wire and neutral conductor for each circuit terminate.

IV. SUMMARY



SUMMARY

- Explain how electricity arrives at a structure and how it is delivered from the transformer to the distribution panel.
- Introduce transformer theory, including types of transformers, voltage/current relationship, and application, and describe the basic electrical distribution system to ensure individual and equipment safety.

Slide 5-32

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UNIT 6: TYPICAL CIRCUIT COMPONENTS

TERMINAL OBJECTIVE

The students will be able to:

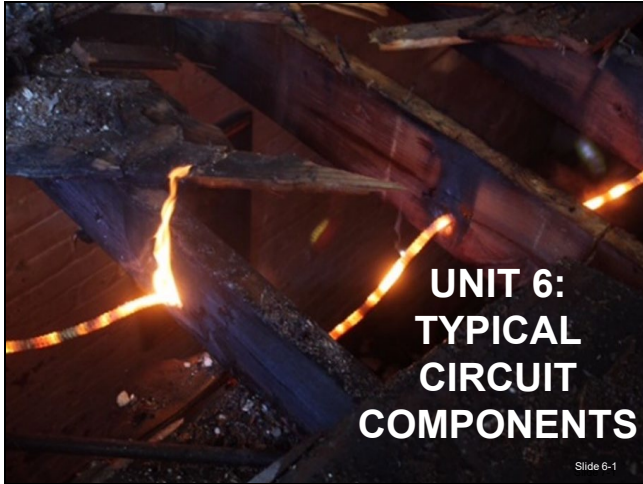
- 6.1 *Demonstrate knowledge of branch circuit components and installation methods.*

ENABLING OBJECTIVES

The students will be able to:

- 6.1 *Accurately distinguish between wiring methods and system components.*
- 6.2 *Explain common electrical issues with fixtures and installation.*
-

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TERMINAL OBJECTIVE

Demonstrate knowledge of branch circuit components and installation methods.

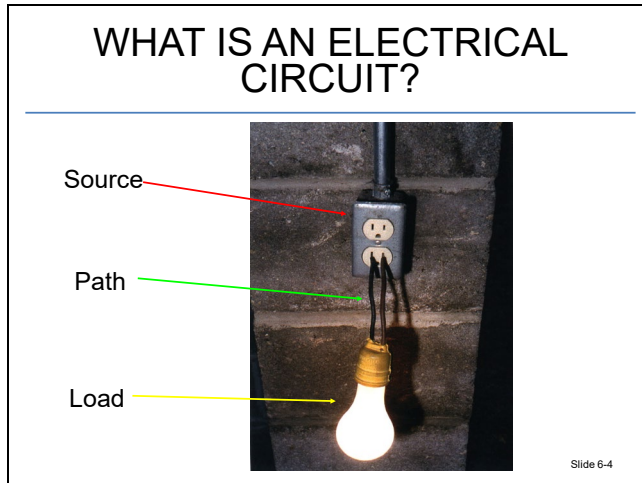
Slide 6-2

ENABLING OBJECTIVES

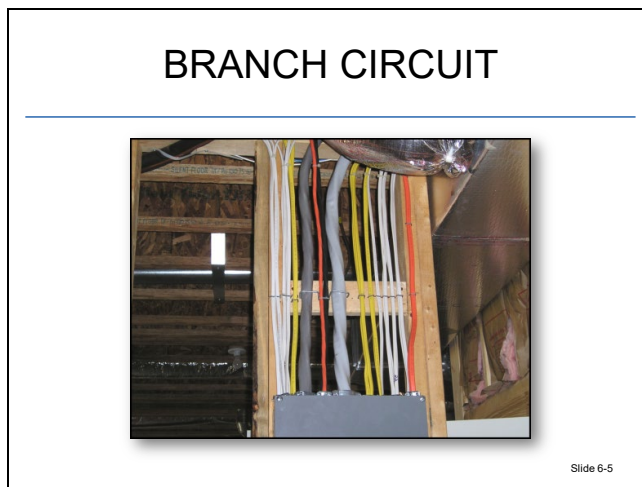
- 6.1 Accurately distinguish between wiring methods and system components.
- 6.2 Explain common electrical issues with fixtures and installation.

Slide 6-3

I. WHAT IS AN ELECTRICAL CIRCUIT?

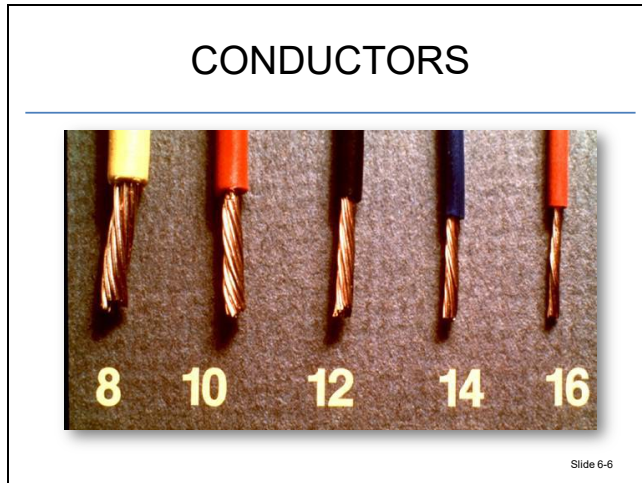


- A. Overview: The slide displays an electrical circuit. A circuit consists of a source, whether it is a battery, solar cells, a utility company, a generator, etc.; a path, which is usually intended conductors, such as wire, but can be any path that conducts electricity, including the human body; and a load, which is anything that uses electricity (from a high-resistance heating element to a low-resistance short circuit).



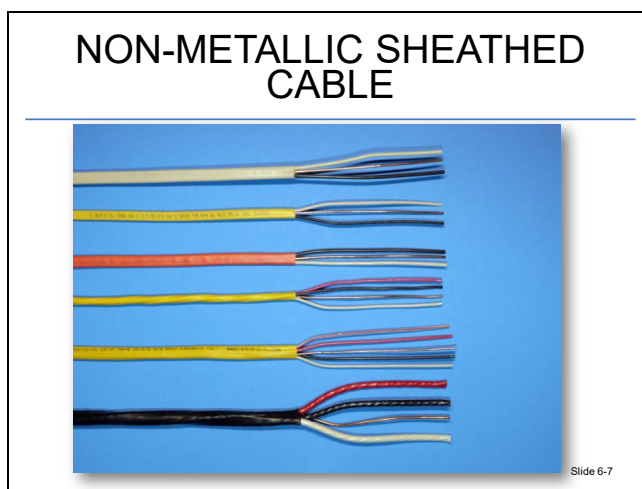
- B. A branch circuit, like the one shown on the slide, is made up of the circuit conductors between the final over-current device protecting the circuit (circuit breaker or fuse) and the outlets (point of use within a structure) (National Fire Protection Association (NFPA) 70[®], *National Electrical Code*[®] (NEC), 2023, Article 100).

II. CONDUCTORS



Types: Whether a conductor is solid or stranded, its ampacity is based upon its American Wire Gauge (AWG) size. The larger the number, the smaller the wire. The AWG number was based upon the number of dies that base solid copper material had to be pulled through to reduce its size. Stranded wire retains the original AWG wire size scheme, but is made up of smaller, individual conductors, allowing for greater flexibility of the wire.

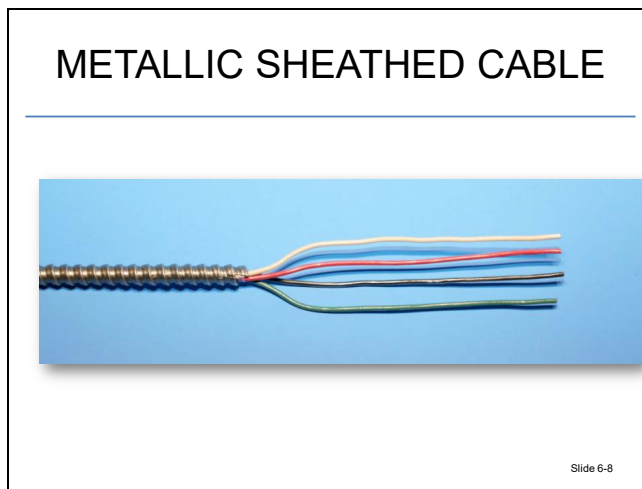
III. CABLES



A. Non-metallic sheathed cable (NMC) — Article 334.

1. The slide shows an illustration of an NMC.
2. The most common type of conductor assembly you will come across in residential applications is NMC, commonly referred to by the trade name, Romex®.

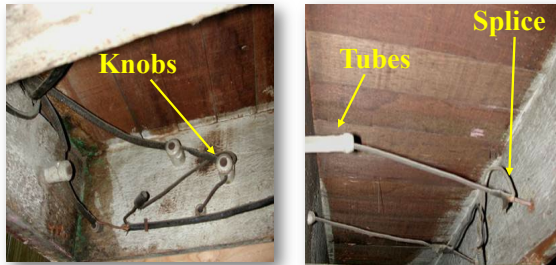
3. NMC comes in various conductor numbers and AWG sizes. The external sheath color will vary. In 2001, manufacturers began using a nonmandatory sheathing color-coding system to help identify the conductor size; white being 14, yellow being 12, and orange being 10. Prior to this change, most NMC sheathing for 14 through 10 AWG was white, so if it is white, the conductor size cannot be determined by color alone.
4. All conductors (wires) and cables will be marked with their conductor size, quantity (if a cable assembly), insulation type and insulation rating.
5. NMC will indicate the size and number of insulated conductors within the cable on the outer sheath. For example, “12/2” indicates two 12 AWG conductors. Newer NMC will always have a ground wire, but it is not listed in the conductor count. However, NMC did not always have a ground conductor. In fact, it was not required until the 2005 edition of NFPA 70! Therefore, you cannot always assume that NMC will have a ground conductor.



B. Metallic sheathed cable (MC) — Article 330.

1. The slide shows an illustration of an aluminum spiral-braid jacket around conductors.
2. MC is most often found in commercial applications. It consists of an aluminum or steel spiral-braid jacket around the conductors. There have been several variations of this style of cable through the years. Type “AC” cable does not contain a ground wire; instead, it contains a bare-bonding wire that is used in conjunction with the sheathing and listed connectors to become the ground path. Type “MC” cable contains a separate ground wire, and the armor sheathing is not designed to be used for grounding purposes; it is for physical protection only.

KNOB-AND-TUBE WIRING



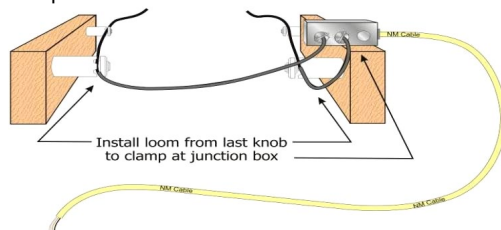
Slide 6-9

- C. Knob-and-tube wiring is also referred to as “open wiring” in Article 398 of the NEC, 2023 edition, which describes the conditions of use and installation. Article 394 of the NEC, 2023 edition, describes the conditions of use and installation of concealed knob-and-tube wiring.
1. The slide illustrates knob-and-tube wiring.
 2. Knob-and-tube wiring was the primary wiring system used until the 1930s and 1940s. The circuit wires were run separately from each other, attached to the structure with porcelain knobs, and run through joists and studs in tubes.
 3. Junctions and splices could be concealed within walls or ceilings, which is different from today’s code in which they must be accessible.
 4. Knob-and-tube wiring cannot be used in hollow spaces when surrounded by insulation because this would prevent heat dissipation, which the cable needs to maintain insulation integrity (NFPA 70 (NEC), 2023, Article 394.12). However, there are a few states that have made an exception to this requirement under certain conditions.

KNOB-AND-TUBE WIRING (cont'd.)

Junction box for extension of branch circuit by another wiring method.

Box and splices must be accessible.



Slide 6-10

5. Issues that arise with knob-and-tube wiring are related to expansion or modernization, concealed junctions or splices, and the inherent age of the materials used.
6. The insulation of knob-and-tube wiring was rubber; most installations of this type are now more than 70 years old, and the insulation has most likely become brittle due to degradation from heat and the environment.
 - a. Problems occur when the conductors are physically disturbed and the insulation breaks off or cracks, exposing the conductor.
 - This can occur as a result of something as simple as a homeowner replacing a receptacle.
 - b. Problems also occur when existing knob-and-tube installations are added onto during remodeling or expansion projects. Ideally, in any such project, knob-and-tube wiring would be replaced with modern NMC.
 - However, if knob-and-tube wiring is retained, there are requirements for how to interface with the existing wiring, as shown. “Loom,” or flexible replacement insulation material, must be installed to maintain conductor insulation — the original will most likely be damaged from movement during the modification — and the connection to new conductors must be made in an approved, accessible junction box. Arcing can occur from damaged insulation at points of entry to junction boxes, the original types of which were metallic.

CONDUCTORS (cont'd.)

Table B.310.15(B)(2)(1) Ampacities of Two or Three Insulated Conductors, Rated 6 Through 2000 Volts, Within an Overall Covering (Multiconductor Cables, in Free Air Based on Ambient Air Temperature of 30°C (86°F))

Size (AWG or kcmil)	Temperature Rating of Conductor (See Table B.310.15(B)(2)(1))						Size (AWG or kcmil)
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THWN, XHHW, ZW	Types THHN, THHW, THWN-2, RHH, RWU-2, USE-2, XHHW-2, ZW-2	Type TW	Types RHW, THHW, THWN, XHHW	Types THHN, THHW, THWN-2, RHH, RWU-2, USE-2, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
14	16**	18**	21**	—	—	—	14
12	20**	24**	27**	16**	18**	21**	12
10	27**	33**	36**	21**	25**	28**	10
8	36	43	48	28	33	37	8
6	48	58	65	38	45	51	6
4	66	79	89	51	61	69	4
3	76	90	102	59	70	79	3
2	84	105	119	69	83	93	2
1	102	121	137	80	95	106	1
150	121	143	163	94	113	127	150
250	138	166	186	108	129	146	250
350	156	189	214	124	147	167	350
400	167	203	233	147	176	197	400
250	205	245	276	160	192	217	250
300	234	281	317	185	221	250	300
350	255	305	345	202	242	273	350
400	274	328	371	218	261	295	400

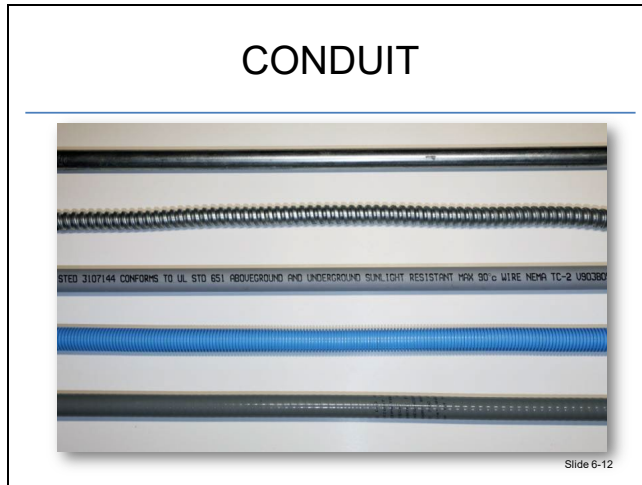
Slide 6-11

D. Conductors and ampacity ratings.

1. The table from the NEC on the slide shows the ampacity rating for common conductor types.

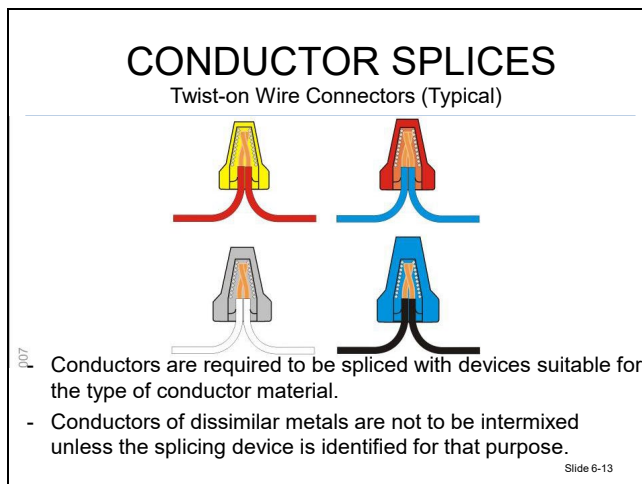
2. The asterisks next to the ratings for 14 and 10 AWG wire point to the following footnote that states that these size conductors are limited to a maximum amount for the over-current protection device (OCPD).

IV. CONDUIT

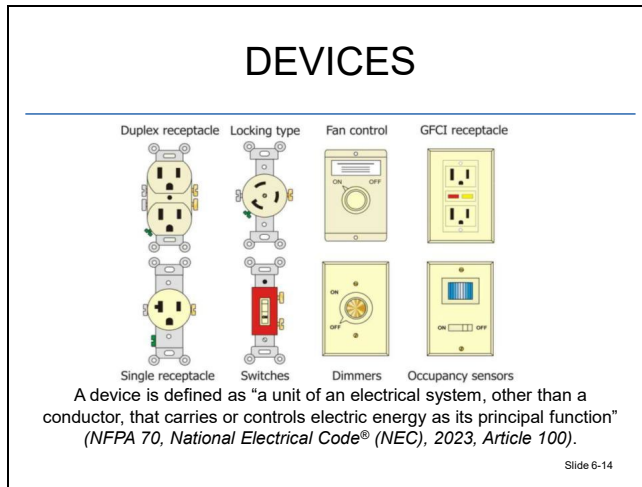


A. Overview.

1. The slide shows an illustration of various types of conduits.
2. A conduit is a type of raceway in which conductors can be run. It comes in metallic and non-metallic types, and in flexible and rigid versions. It can be found in residential, commercial and industrial applications.

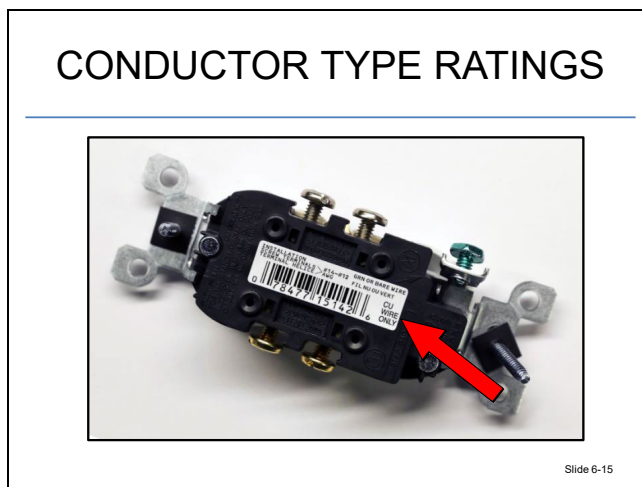


- B. Conductor splices must be of the correct type and size and installed correctly. Remember that every splice or termination of a conductor creates some resistance, which in turn creates heat. A properly selected and installed splice or termination reduces this resistance to a minimum, and as a result, the heat generated is also at a minimum and dissipates faster than it generates.

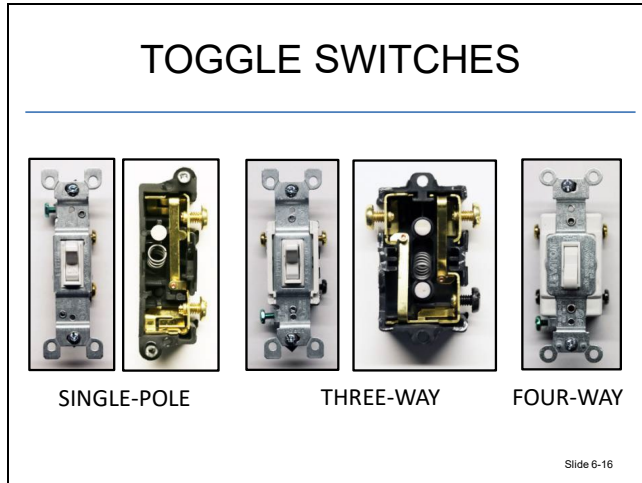


- C. A device is "an electrical system, other than a conductor, that carries or controls electric energy as its principle function" (NFPA 70, 2023, Article 100).

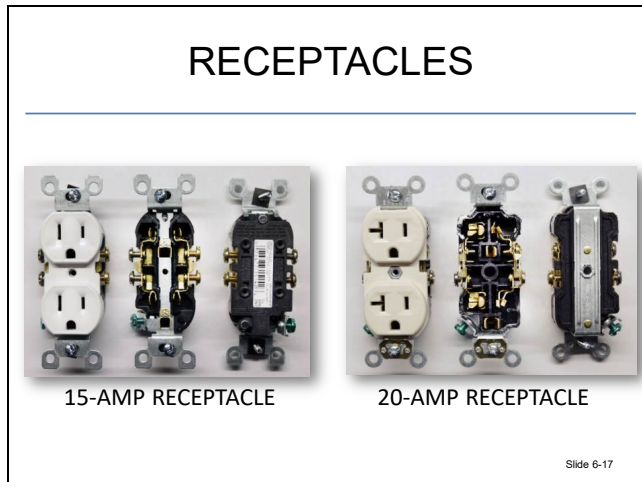
A device is almost everything that is installed within a junction box.



- D. Conductor type ratings: It is important that connectors and devices be connected to approved conductor types to avoid galvanic corrosion, which causes increased resistance and heat at the connection point. Connectors and devices will have markings to indicate which types of conductor materials are acceptable.



- E. Toggle switches are used to control the flow of electricity. They come in several configurations, but the most common are single-pole, three-way and four-way.



- F. Receptacles.
1. A receptacle is a contact device installed at the outlet for the connection of an outlet plug, or for the direct connection of electrical utilization equipment designed to mate with the corresponding contact device (NFPA 70, 2023, Article 100).
 2. Receptacles are the end-user interface of the electrical system. They come in numerous configurations of voltage, ampacity, single- and three-phase, and physical application designs.
 3. The most common receptacles found are duplex receptacles in 15- and 20-amp versions. Although they may appear similar from the front, their physical constructions differ.

4. The 20-amp receptacle shown has what is referred to as the “grounding strap” or “grounding yoke” mounted externally on the rear of the receptacle. This provides physical support to the outlets.

V. FIXTURES

RECESSED LIGHT FIXTURES

Two fixture types:

- IC – insulation contact.
- Non-IC – non-insulation contact.

Both may be listed as combination of styles, such as IC-AT, where “AT” refers to “air tight,” meaning that the fixture assembly is designed to prevent the movement of air through it for energy conservation purposes.

Slide 6-18

A. Recessed light fixtures.

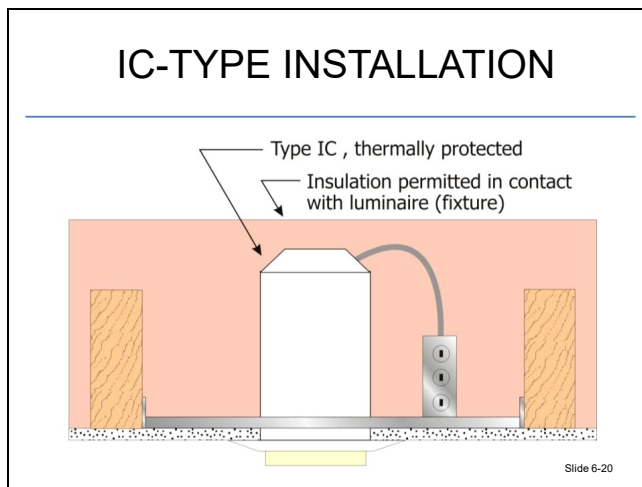
1. Two fixture types:
 - a. IC: insulation contact.
 - b. Non-IC: non-insulation contact.
2. Both may be listed as a combination of styles, such as IC-AT, where “AT” refers to “air tight,” meaning that the fixture assembly is designed to prevent the movement of air through it for energy conservation purposes.

RECESSED LIGHT FIXTURES (cont'd.)

Maximum wattage of a bulb is dependent on bulb style, trim type, and fixture type (IC vs. non-IC).

Slide 6-19

3. Maximum wattage of a bulb is dependent on bulb style, trim type, and fixture type (IC vs. non-IC).
4. All recessed lights manufactured after 1982 are required to have a thermal cutoff in the circuit that interrupts power if the temperature inside the housing exceeds 90 °C/194 °F.
5. The thermal cutoff helps to protect wiring from degradation caused by excess heat.
6. The following are signs of excess heat, usually caused by the use of a bulb whose wattage is too high for the trim/bulb combination, or by a non-IC fixture surrounded with insulation:
 - a. Thermal cutoff cycles the light on and off continuously.
 - b. Bulbs burn out prematurely or have a low life span.
 - c. Excess heat causes degradation, discoloring or deformation of trim pieces.
7. If light-emitting diode (LED) or compact fluorescent lights (CFLs) are used in place of standard incandescent bulbs, do not confuse equivalent wattage ratings used to compare lumen levels to incandescent bulbs with the actual electrical wattage used. The bulb itself will have a wattage listed on it, usually one-third to one-eighth of the equivalent wattage rating.



- B. IC-type fixture installation: The diagram shows the typical installation of an IC-type recessed light fixture completely covered with insulation.

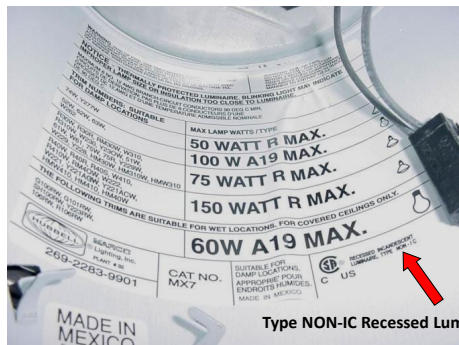
[illegible]

- [illegible]

Slide 6-22

- D. Recessed light fixtures.
1. A new design change in recessed light fixtures is the LED-only fixture. These fixtures are designed for use exclusively with low-wattage, low-heat-producing combination bulb/trim inserts. As such, they are lacking the thermal cutoff found in other recessed light fixtures. They have a unique plug-style connection in place of a standard lightbulb socket. They are also shallower, allowing a thicker insulation level above the fixture.

SAMPLE LABEL

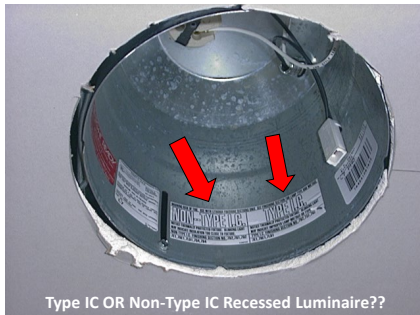


Type NON-IC Recessed Luminaire

Slide 6-23

2. A wattage/trim chart is usually affixed to the inside of the fixture or can, but falls off or is removed due to poor adhesion of the label. This label shows the maximum-wattage bulb that can be used with a bulb/trim combination. It is up to the end-user to determine the trim's model number, read the chart, and find the correct bulb type and wattage to use.

SAMPLE LABEL (cont'd.)



Type IC OR Non-Type IC Recessed Luminaire??

Slide 6-24

3. Challenges with reading the trim chart: With some particular fixture styles, an added challenge for the end-user is to determine what type of fixture it is — IC or non-IC — before the correct bulb specifications can be found. The slide displays a sample label reading “Non-Type IC” and “Type IC.”

INCORRECT INSTALLATION



Slide 6-25

4. Non-IC-type fixture.
 - a. The graphic shows an incorrectly installed non-IC-type fixture. Notice the paper in contact with the fixture.

INCORRECT INSTALLATION (cont'd.)



Slide 6-26

- b. The graphic shows another incorrectly installed fixture. Note that the top is pressed up against the oriented strand board sheathing.

VI. SUMMARY



SUMMARY

Accurately distinguish between wiring methods and system components.

Explain common electrical issues with fixtures and installation.

Slide 6-27

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UNIT 7: BUILDING AN ELECTRICAL SERVICE

TERMINAL OBJECTIVE

The students will be able to:

- 7.1 *Using knowledge of source, path and load, build a service entrance and connect the appropriate circuits.*

ENABLING OBJECTIVES

The students will be able to:

- 7.1 *Analyze the operation of simple electrical circuits.*
- 7.2 *Create wiring diagrams for simple electrical circuits.*
-

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TERMINAL OBJECTIVE

Using knowledge of source, path and load, build a service entrance and connect the appropriate circuits.

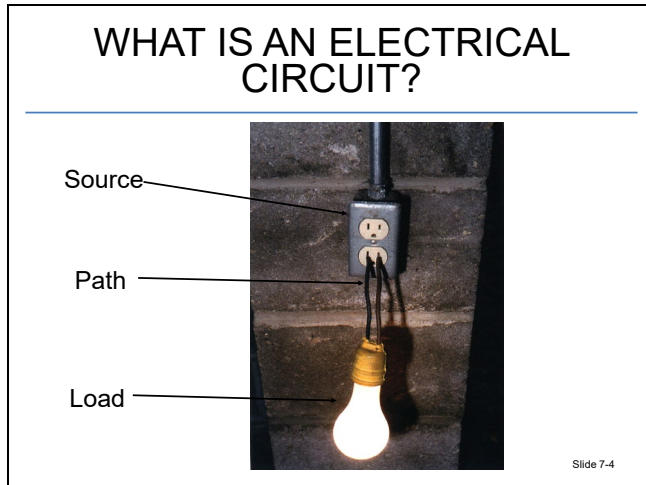
Slide 7-2

ENABLING OBJECTIVES

- 7.1 Analyze the operation of simple electrical circuits.
- 7.2 Create wiring diagrams for simple electrical circuits.

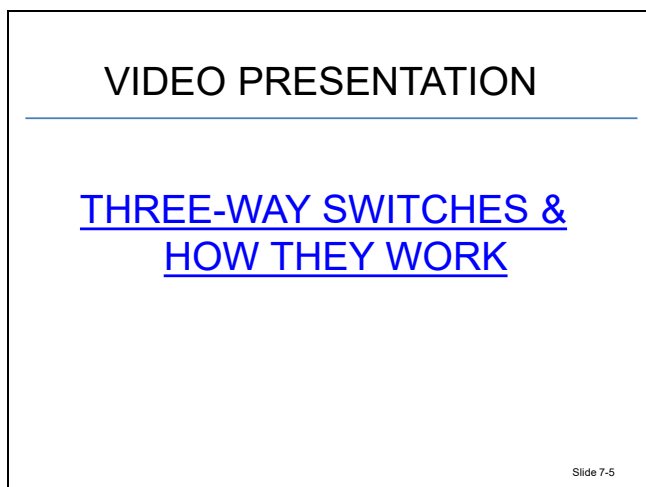
Slide 7-3

I. ELECTRICAL CIRCUIT



Definition: A circuit consists of a source, whether it is a battery, solar cells, a utility company, a generator, etc.; a path — usually intended conductors such as wire, but can be any path that conducts electricity, including the human body; and a load, which is anything that uses electricity, from a high-resistance heating element to a low-resistance short circuit.

II. DEMONSTRATION OF OPERATION



VIDEO PRESENTATION

HOW TO WIRE A 4 WAY
SWITCH

Slide 7-6

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ACTIVITY 7.1

Preparing Basic Electrical Drawings

Purpose

Use your understanding of “Source-Path-Load” that is required for any functional electrical circuit to create wiring diagrams for the given electrical circuits (i.e., “jobs”) listed on Handout 7-1: Wiring Statement Paper.

Materials

- Handout 7-1.
- Colored pens.
- Electrical Quick Reference Guide (Lowe’s handout).

Directions

1. Using Handout 7-1, read over the seven jobs.
2. Following the directions given by the instructor, draw out the individual conductors and connections necessary for each of the electrical circuits.
3. Color code your drawings as directed by your instructor.
4. Note: These completed circuit drawings will be used later in the course for you and your team to build real circuits.

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ACTIVITY 7.2

Circuit Build-Out

Purpose

Use your understanding of “Source-Path-Load” that is required for any functional electrical circuit to build the electrical circuits (i.e., “jobs”) listed below so that the circuits operate correctly.

Materials

The lab assistant will provide the materials; however, before starting the activity, students should confirm all materials and locate the appropriate supplies.

- Three breakers (one single pole, two three ways, and one four way).
- Five switches.
- Three receptacles (regular).
- One receptacle Ground Fault Circuit Interrupter (GFCI).
- Two light bulbs.
- Six plaster rings.
- One wire stripper.
- Tool pouch.
- Electrical tape.
- Wire connectors.
- 14-2 and 14-3 non-metallic sheathed cable (NMC).
- First-aid kit.

Safety Precautions

Students are required to wear safety glasses; to take appropriate measures to avoid physical hazards, such as sharp metal edges; and to take appropriate measures to avoid injury from using basic hand tools, such as screwdrivers, wire cutters and utility knives. After completing the service entrance build-out, the equipment can be energized only by and under the instructor’s direct supervision. Students must pay undivided attention to the task at hand and use caution during these times. Students must treat all conductors as if they were energized because they may truly be energized. Students must immediately report any injury to an instructor.

Directions

1. In your small group (two students per panelboard), create seven different circuits using the wiring jobs aid you created earlier.

2. Create the individual conductors and connections necessary for each of the electrical circuits.
3. After completing each job, ask the instructor to check your work by energizing the circuit before moving to the next job.
4. Upon completion of all seven jobs, strip the panelboard and clean up your workstation. Check the following:
 - a. Job 1: Test to see if the lights can turn on and off.
 - b. Job 2: Test random points to determine if there is electricity.
 - Load side of the meter.
 - Main circuit breaker.
 - c. Use multimeter measure voltage for:
 - Neutral to L1.
 - Neutral to L2.
 - L1 to L2.
5. After the circuit is energized for Job 3, use a GFCI tester to test if GFCI is wired correctly. If it doesn't work, check for an open neutral. Note: If not energized, the tester will not reset.
6. After the circuit is energized for Job 4, test to ensure that the three-way switch works.
7. After the circuit is energized for Job 5, test to ensure that the four-way switch works.
8. After the circuit is energized for Job 6, check to ensure that there is constant power to switch outlets.
9. After the circuit is energized for Job 7, test to ensure that two separate circuits work.

III. SUMMARY



SUMMARY

- Analyze the operation of simple electrical circuits.
- Create wiring diagrams for simple electrical circuits.

Slide 7-9

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UNIT 8: CIRCUIT PROTECTION METHODS AND DEVICES

TERMINAL OBJECTIVE

The students will be able to:

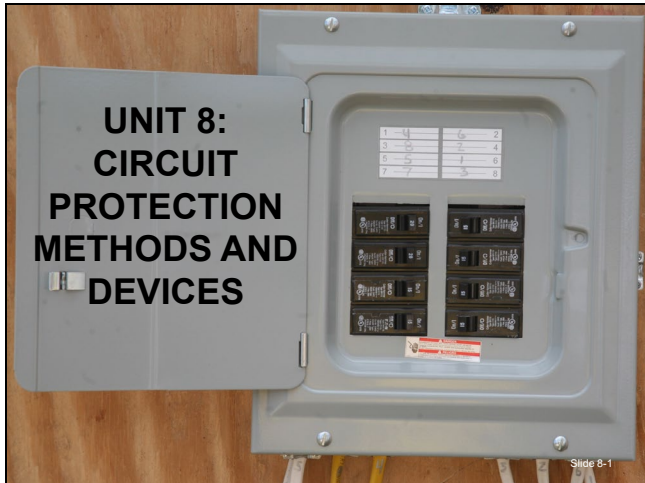
- 8.1 *Analyze the components of fuses and breakers to determine if the source of heat for ignition was the result of tampering or a failure.*

ENABLING OBJECTIVES

The students will be able to:

- 8.1 *Distinguish among the types, styles and function of an over-current protection device (OCPD).*
 - 8.2 *Interpret OCPD operation and principles, and associate them with a fire investigation.*
-

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TERMINAL OBJECTIVE

Analyze the components of fuses and breakers to determine if the source of heat for ignition was the result of tampering or a failure.

Slide 8-2

ENABLING OBJECTIVES

- 8.1 Distinguish among the types, styles and function of an over-current protection device (OCPD).
- 8.2 Interpret OCPD operation and principles, and associate them with a fire investigation.

Slide 8-3

I. FUSES

FUSES

Fuses are the original OCPD. The purpose of fuses is to protect the structural wiring from currents that exceed the capacity of the conductors used.



Slide 8-4

A. Fuses.

1. Fuses are the original over-current protection devices (OCPDs). Still in use today, they come in many different shapes, sizes and colors. But their underlying purpose is the same: to protect structural wiring from currents that exceed the capacity of the conductors used.
2. Fuses are not intended to protect against over-current in anything plugged into an outlet.

EDISON BASE

Edison Base (EB) screw-in fuses and breaker conversion adapter.

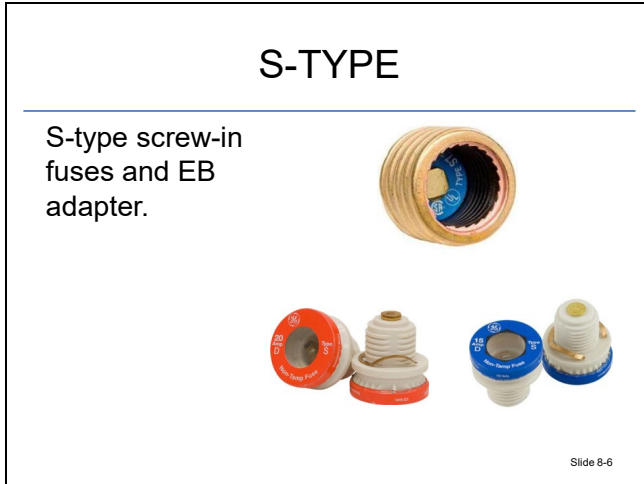


Slide 8-5

B. Edison Base (EB).

1. EB fuses were the first generation of screw-in fuses.
2. The main issue with this style of fuse is that they are all the same shape, size and thread pitch, no matter the amperage rating.

3. For example, a 30-amp fuse can be screwed into a 15-amp fuse socket with this design.
4. Screw-in replacement circuit breakers are also available.

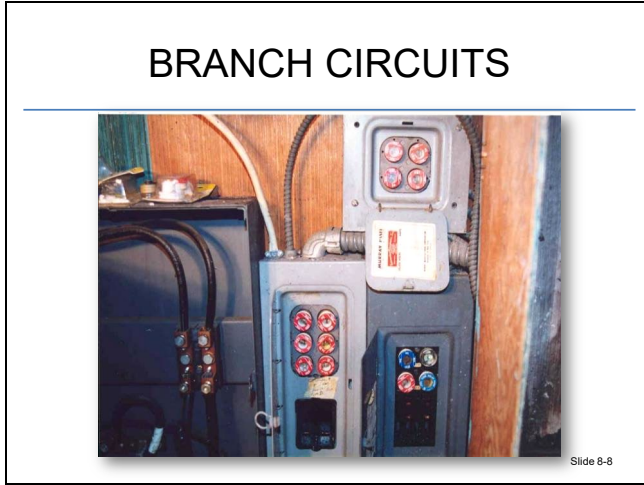


C. S-type.

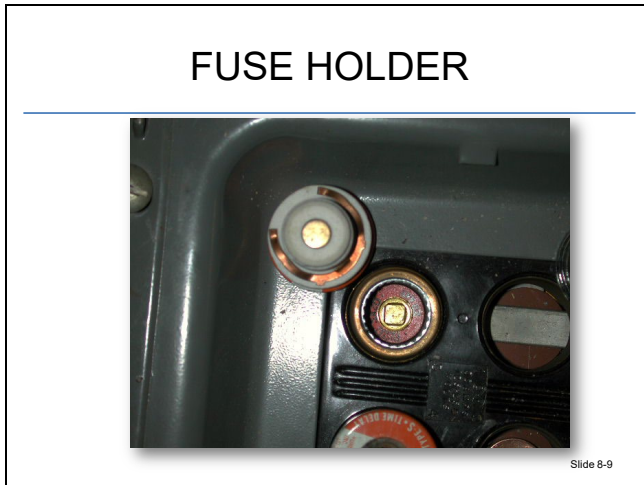
1. S-type fuses differ from each other in that the thread pitch of the base is different for each amperage rating; a 30-amp fuse will not physically fit into a 15-amp socket. Adapters are available to convert an EB fuse socket into an S-type fuse socket.
2. Either type of screw-in fuse is available in a maximum rating of 30 amps.



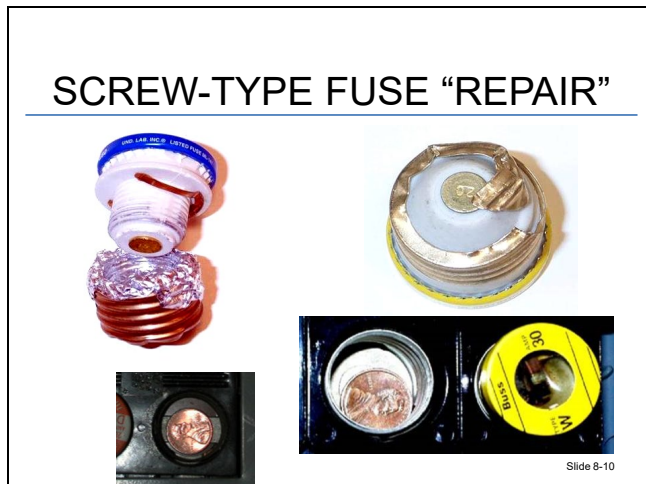
- D. Old-style service with fuses: Pull-outs (black modules with handles) serve as a method to disconnect the circuit and also hold the cartridge fuses that protect the structural wiring components of those circuits; in the case of the main breaker in this example, it protects the components of the panel that feed the fuse holders of the branch circuits.



- E. Branch circuits: The slide shows multiple branch circuits and potential failure points. Historically, a high-capacity residence rarely had more than eight branch circuits. As demands grew, so did the number of circuits needed. Panels were added onto panels, and then onto those other panels. Each addition brings its own set of connections and conductors that can fail.

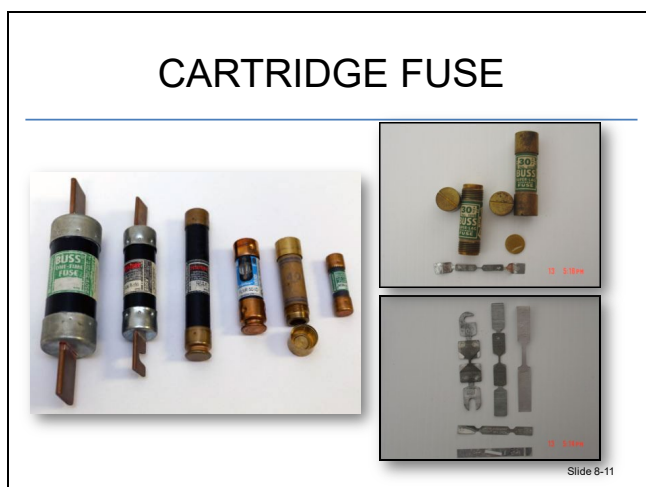


- F. Fuse holder: The slide shows a picture of a fuse holder that has been converted to an S-type screw-in fuse. Properly installed, the power feeds from the center contact first, through the fusing element, and then to the shell/threaded portion of the fuse.



G. Screw-type fuse “repair.”

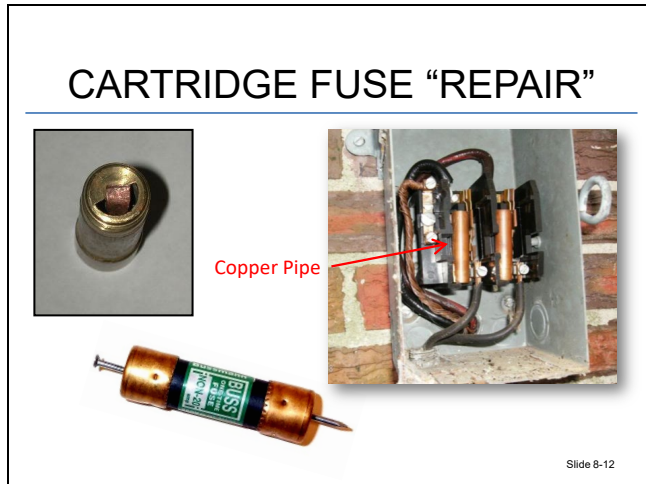
1. The slide shows a common type of inappropriate so-called repair.
2. A common fix was to place a penny at the back of the socket, and then screw the blown fuse back in to hold it in place.
3. Defeating the fuse can allow an issue or fault to continue — if this type of damaging repair is found, the question must be asked: What was the problem that caused the fuse to keep blowing?
4. Anything that comes in contact with the center contact and the shell portion of the socket will complete the circuit.



H. Cartridge fuse.

1. Cartridge fuses are generally used for higher amperages, although they can be found in a wide range of amperages.

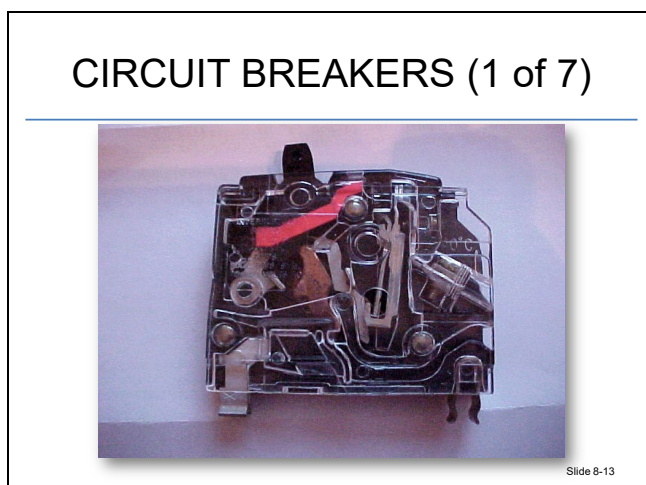
2. They come in all different sizes and configurations (barrel/blade connections); they are subject to human error (intentional or otherwise) in the selection of the correct amperage rating when they are installed or replaced.



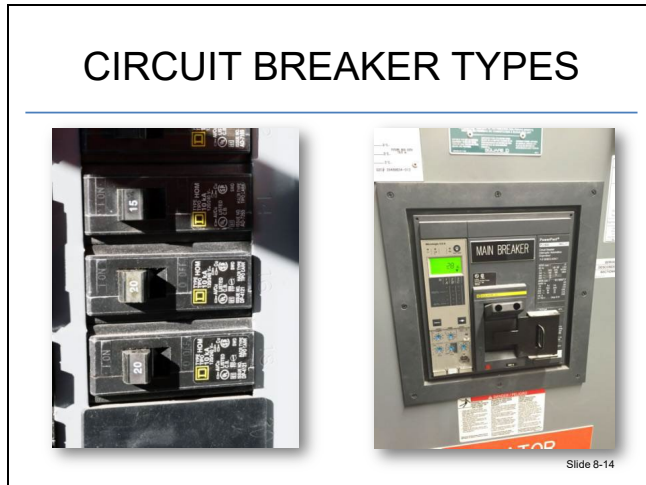
I. Cartridge fuse “repair.”

1. The slide shows an example of what a homeowner would call a repair, but it is actually a case of bypassing a safety component.
2. As with screw-in fuse sockets, anything that creates a path between the two socket contacts will complete the circuit and nullify any protection provided by the fuse.
3. If a fuse is blowing, there is a reason for it, and the fuse is doing its job.

II. OVER-CURRENT PROTECTION DEVICES OR CIRCUIT BREAKERS

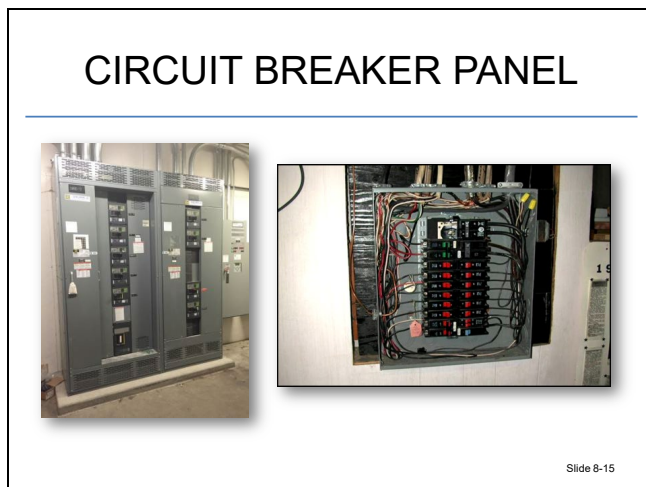


- A. The most common OCPD in use today is the circuit breaker.



- B. Circuit-breaker types.

1. The slide shows different styles of circuit breakers. Circuit breakers can vary in shape, size, color, appearance and functionality.
2. They can be as simple as the \$7 plug-in 20-amp standard breaker on the left, or as complex as the \$3,000 computer-controlled 800-amp breaker on the right.
3. Circuit breakers are intended to protect the components of the structural wiring system from over-current.



- C. Circuit-breaker panel.

1. Circuit-breaker panels can be found in every modern building. The one on the left can be found in commercial buildings, and the one on the right in residential properties. The important thing to remember is that no matter how simple or complex the breaker is, its purpose is the same.
2. They can range from large-capacity panels, such as that shown on the left with capacities of thousands of amps, to a standard residential breaker panel, seen on the right.

CIRCUIT BREAKERS (2 of 7)

Typical residential- and commercial-style circuit breakers operate on two trip mechanisms:

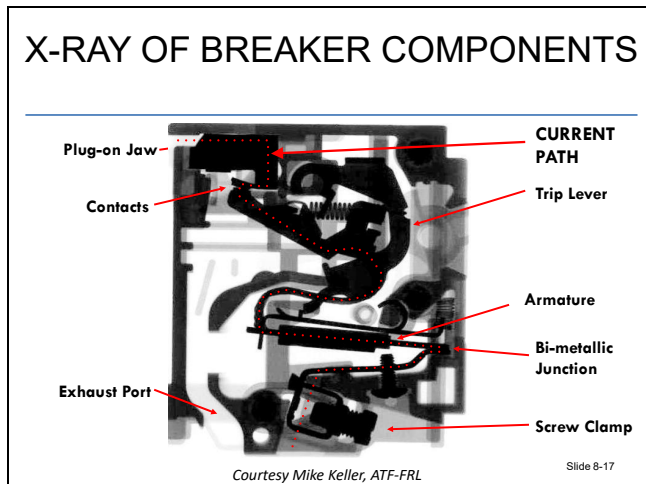
- Thermal (overloads).
- Magnetic (short circuits).

Circuit breakers are at rest in the OFF position, and are held in the ON position by a latching mechanism that is spring-loaded.

Slide 8-16

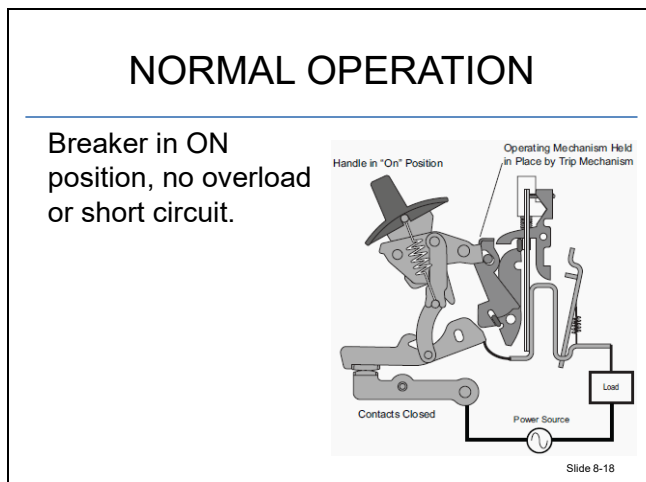
D. Circuit breakers.

1. Circuit breakers are at rest in the OFF position — like the uncocked hammer of a gun. When they are moved to the ON position, a spring-loaded latching mechanism is locked into place, ready to snap back quickly to the OFF position, opening the circuit quickly and minimizing the duration of the parting arc between the contacts.
2. Thermal circuit-breaker activation works like a thermostat: A bimetallic strip expands by heat created by a current passing through it; if and when it reaches a certain temperature and expansion point, it will cause the latching mechanism of the breaker to unlock or trip, at which point the spring will pull the contact lever into the OFF position, breaking the circuit.
3. Thermal protection sensitivity is affected by ambient temperatures: Higher ambient temperature = less time to trip; cooler ambient temperatures = more time to trip. Think of an outside combination meter/panel enclosure in Alaska. Because the bimetal is already “behind” in temperature, it will take longer to reach the trip point.
4. Magnetic activation uses the magnetic field created by a large instantaneous load (i.e., a short circuit) to activate the same mechanism that the thermal component moves, breaking the circuit.

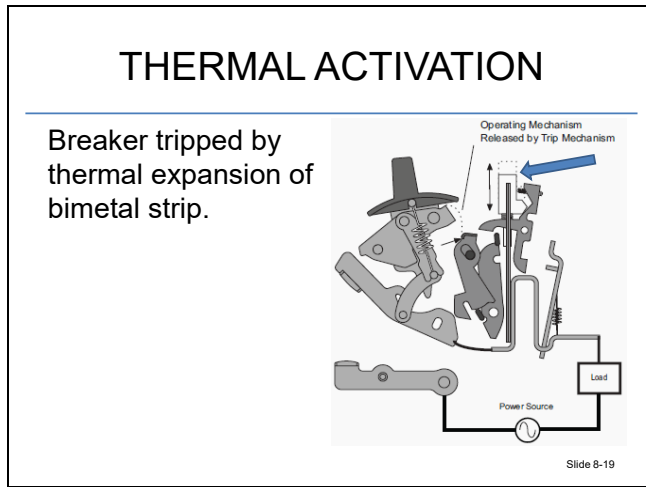


E. X-ray of breaker components.

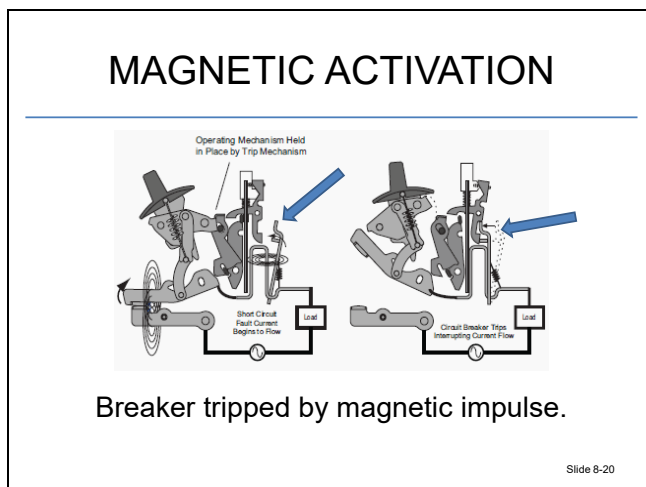
1. You can follow the flow path from the source, which is at the plug-on jaw at the top, through the conductive elements of the breaker, to the screw clamp at the bottom, where the conductor is connected.
2. Note the following definitions:
 - a. Plug-on jaw: where breaker connects to panel.
 - b. Contacts: the “switch” portion of the breaker that opens when the breaker trips or is turned off.
 - c. Exhaust port: a design feature of the breaker to direct the hot expanding gases created from the parting arc safely out of the breaker housing.
 - d. Armature: the magnetically activating portion of the breaker.
 - e. Bimetallic junction: the thermally activating portion of the breaker.



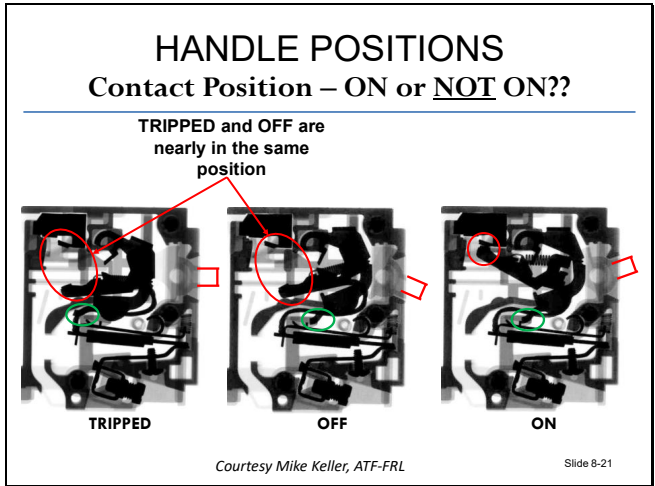
3. Normal operation: This graphic shows the positioning of a breaker in the ON position, in normal operating conditions.



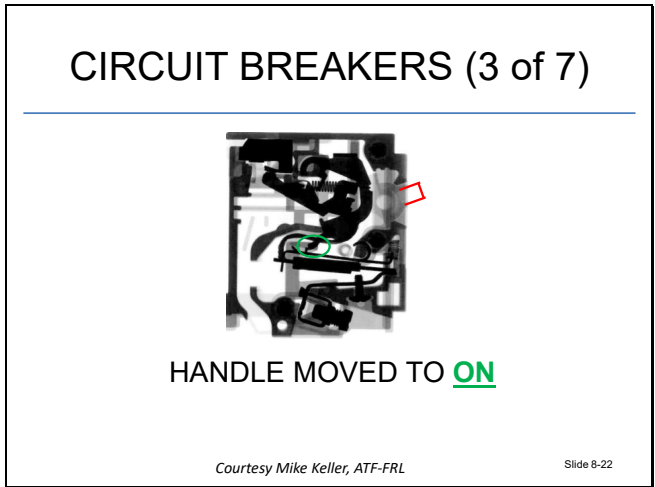
- F. Thermal activation: The slide shows a breaker during an overload condition; the bimetallic strip has expanded, causing the locking mechanism to release the trip lever and open the circuit.



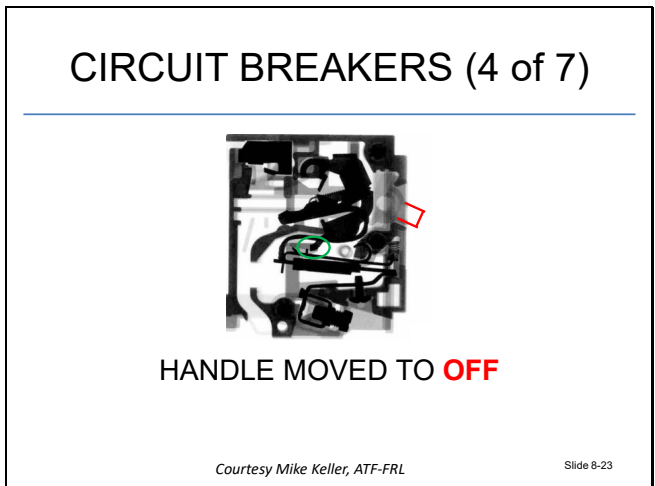
- G. Magnetic activation: The slide shows a breaker during a short-circuit condition; the large magnetic pulse draws the activating lever inward, which contacts the locking mechanism, releasing the trip lever and opening the circuit.



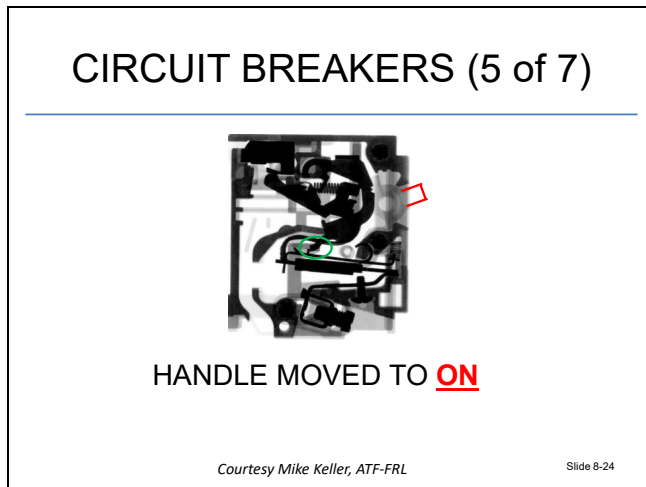
- [illegible]



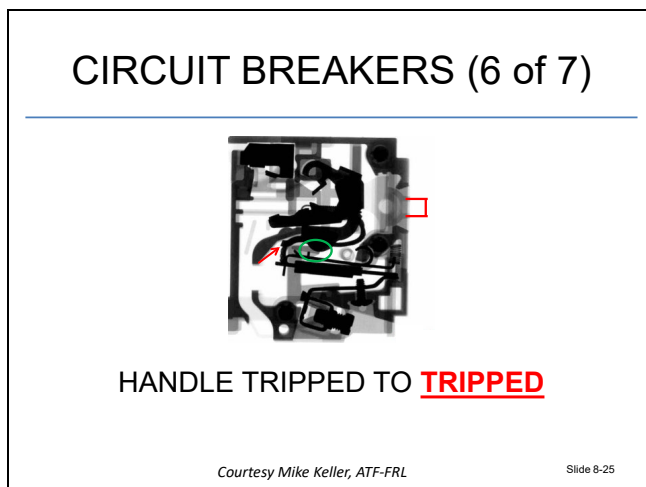
- [illegible]



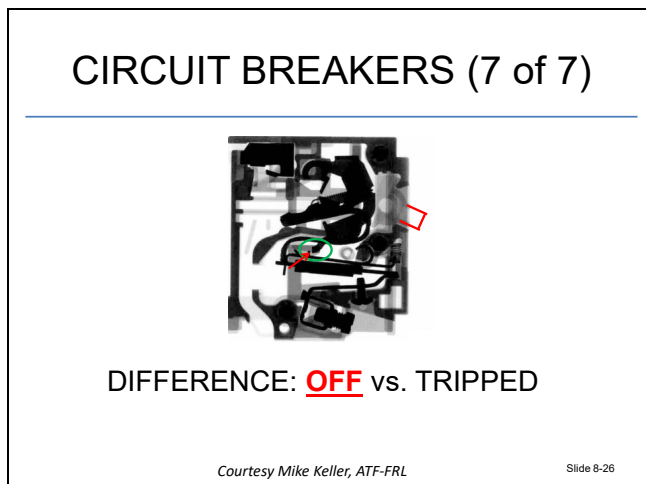
2. Mechanism in OFF position.



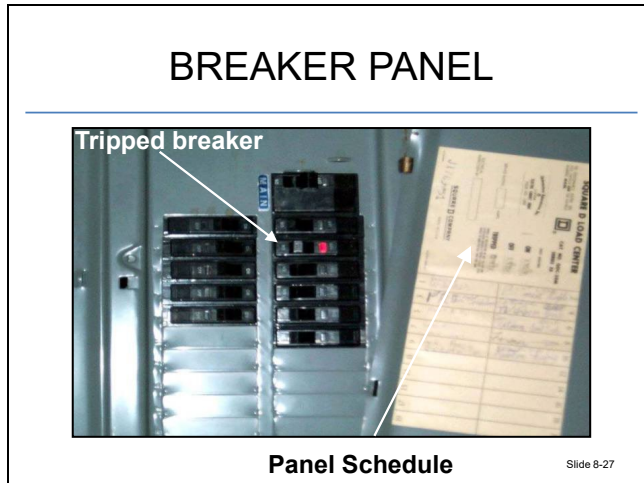
3. Mechanism in ON position.



4. Mechanism in TRIPPED position.

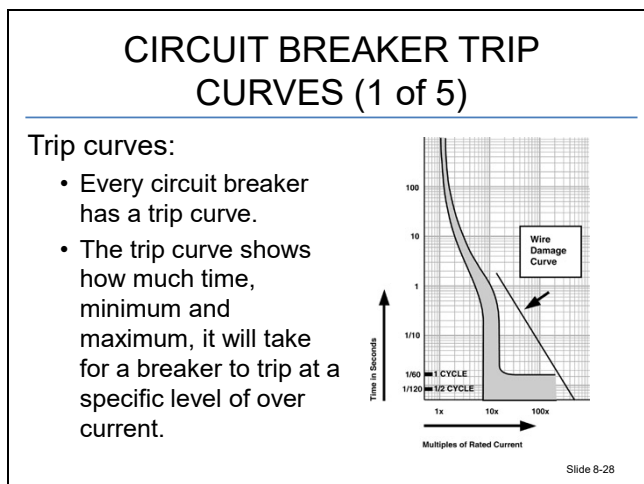


5. OFF vs. TRIPPED.



I. Breaker panel.

1. The slide shows a breaker panel schedule or legend. A breaker panel schedule or legend should identify what each circuit breaker controls. Note the TRIPPED breaker — some makes/models of breakers have indicators; others do not.
2. Trips can usually be identified by the handle position; TRIPPED will center the handle in most cases. However, some brands/models, such as Cutler Hammer (CH) and Federal Pacific breakers, will trip the handle to the OFF position. This is where X-rays can be used to determine whether the breaker was TRIPPED to OFF or turned OFF.



J. Circuit-breaker trip curves.

- [illegible]

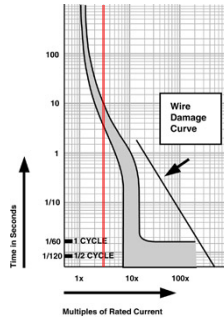
[illegible]

3. Most people think, for example, that if a 20-amp circuit breaker reaches a 21-amp level, it will trip instantaneously. As we can see by the trip curve, that is not necessarily the case. An over-current of twice a breaker's rated capacity can take up to 40 seconds to cause the breaker to trip. Properly installed and operating circuit breakers will protect the structural wiring as designed.

CIRCUIT BREAKER TRIP CURVES (4 of 5)

With this trip curve, a 20-amp breaker may take:

5 to 10
seconds to trip
at 60 amps.



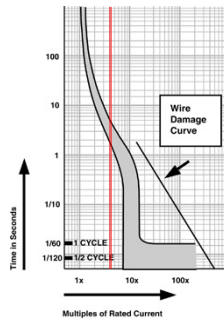
Slide 8-31

4. If we move the current multiplier line over to three times the rated current, we can see that the line now intersects at a lower portion of the time scale. In this case, the same 20-amp breaker now only takes five to 10 seconds to trip at 60 amps of overload.

CIRCUIT BREAKER TRIP CURVES (5 of 5)

With this trip curve, a 20-amp breaker may take:

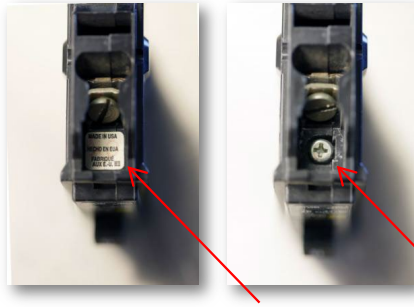
2 to 5 seconds
at 80 amps.



Slide 8-32

5. Now at four times the rated current, the breaker will trip between two and five seconds at 80 amps of overload.
6. If it is suspected that a breaker may not have tripped at an appropriate level, it can be sent to a testing laboratory to determine accurately the current level at which it does trip. For any type of laboratory testing, however, it is imperative that breakers be left in the position found and be removed and handled carefully.
7. We will conduct a lab activity demonstration showing that flowing 80 amps through a #12 American Wire Gauge (AWG) conductor, which is rated for 20 amps, takes significantly longer than five seconds to generate heat that causes damage to the conductor insulation.

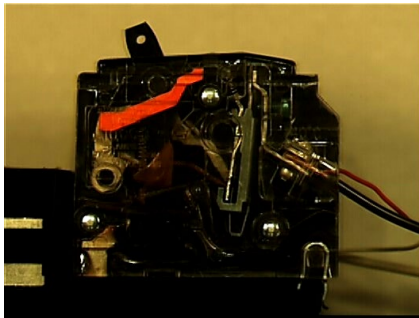
FACTORY ADJUSTMENT



Slide 8-33

- K. Factory adjustment: The slide shows a picture of an adjustment screw. There is an adjustment screw on breakers that allows for fine-tuning of the trip level at the factory. It can be tampered with, but the adjustment range is typically 10 percent up or down from the rated label current. With a 20-amp breaker, this means it could be adjusted to anywhere between 18 and 22 amps. Is an extra 2 amps going to make a difference, given the safety factors of conductors? Not likely.

CIRCUIT BREAKER OPEN IN SLOW MOTION-VIDEO



Slide 8-34

- L. Video presentation.
- M. Ground Fault Circuit Interrupter (GFCI) circuit breakers.

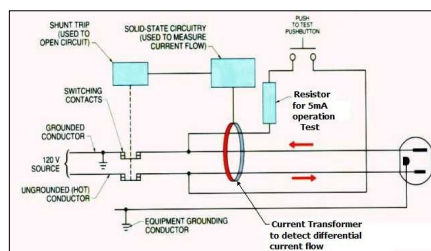
GFCI CIRCUIT BREAKERS



Slide 8-35

1. GFCI circuit breakers are another type of breaker that can be found in circuit breaker panels.
2. The basic thermal and magnetic trip principles function the same way as in a standard breaker, but there is added circuitry to monitor the flow of current going in and out of the circuit it protects.
3. The presence of a test button alone does not indicate that a breaker is a GFCI-type breaker; arc fault breakers also have a test button. There is no industry-standard test button color identification system, so that cannot be used as an indicator of type either.
4. The only way to tell the difference is to read the labeling on the breaker, which may be on a portion of the breaker hidden behind a panel cover.

GFCI CIRCUIT BREAKERS (cont'd.)



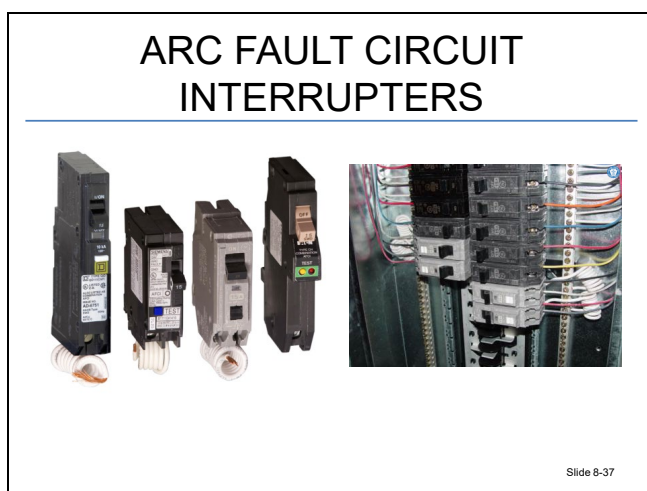
If current returning is not equal to current entering the circuit, that means it's finding another path to take.

Slide 8-36

5. GFCI breakers operate on the principle that the current entering a circuit must equal the current returning on that circuit.

6. If we monitor the two intended paths of a standard 120 V circuit, current flowing out on the hot/ungrounded conductor should equal the current returning on the neutral/grounded conductor.
7. If those are not equal, that means that current is returning to the source through an alternative path.
8. When that happens, the circuitry activates what is known as a “shunt-trip” mechanism that trips the same mechanism that the thermal and magnetic portions activate. This opens the circuit and stops the flow of current. GFCI breakers are designed to detect these current imbalances at levels as low as 5 milliamps.
9. GFCI breakers are designed and installed for safety purposes: to protect people from becoming an alternative path back to the source, or to prevent objects/surfaces that people may touch from becoming part of that path.
10. Because GFCI breakers need to be able to monitor the current returning on the neutral conductor, the circuit’s neutral conductor must be wired directly to the breaker itself; then a pigtail conductor from the breaker is connected to the neutral terminal bar.

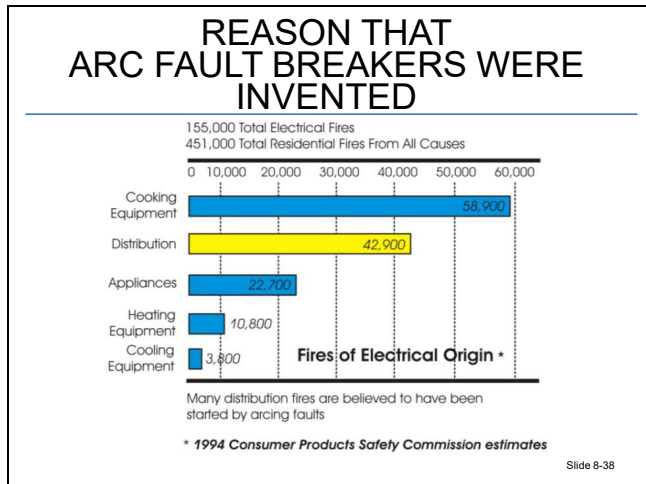
III. CIRCUIT INTERRUPTERS



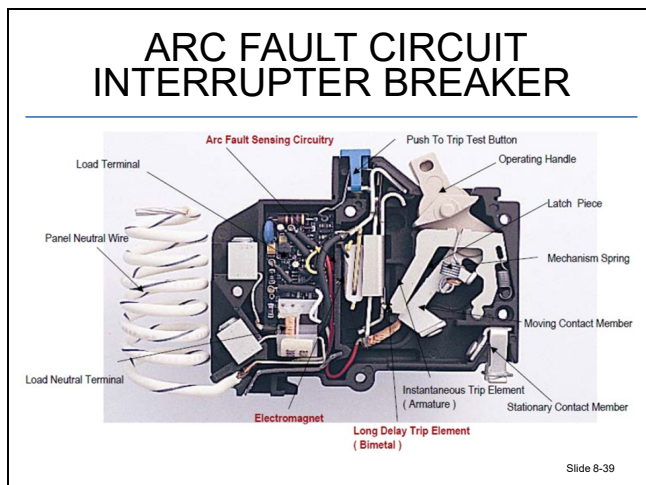
A. Arc Fault Circuit Interrupters (AFCIs).

1. The slide shows a picture of AFCI breakers, another type of circuit breaker.
2. Again, they have the same basic thermal/magnetic tripping functions as a standard breaker, but the additional circuitry of an AFCI breaker is designed to detect the changes in the voltage/current waveforms to determine whether an unwanted arc is occurring in the circuit.

3. They, too, have test buttons, and an external appearance similar to GFCI breakers.



4. The fire service — more specifically, the data extracted from National Fire Incident Reporting System (NFIRS) — reports where the cause of fires was indicated to have been arcing incidents within the structural wiring itself, and this is why AFCIs were invented.



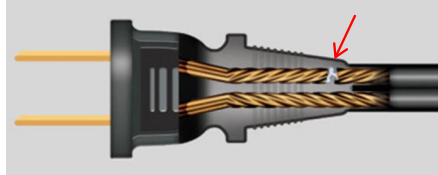
B. AFCI breaker internal components.

1. The slide shows an internal image of an AFCI breaker. The arc fault detection function of an AFCI circuit breaker operates by monitoring both the current and the voltage of a circuit.
2. When arcs occur, they cause brief periods (milliseconds) of high current and voltage changes. Voltage and current are monitored by the internal circuitry. When unwanted arcing conditions are detected, a shunt-trip mechanism is activated (as in the GFCI breaker), the circuit is opened, and current stops flowing.

ARC FAULT CIRCUIT INTERRUPTER BREAKER (cont'd.)

Modern Arc Fault Circuit Interrupter (AFCI) devices protect against two types of arcing:

Series arcing: Arcing between ends of the same conductor at a break.



Usually self-current-limiting; once conductor is severed, current flow and arcing stop.

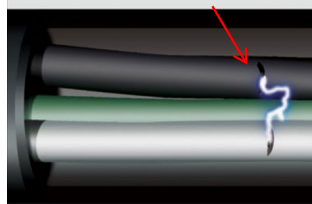
Slide 8-40

3. AFCI breakers help protect against two types of arcing. One of those types is called series arcing. This type of arcing occurs in series in the circuit, between two ends of the same conductor at a break. Because the arc is in series in the circuit, the magnitude of the arc is limited to the amount of current that load draws. These types of arcs are usually self-limiting in that once they burn out, the circuit is broken, and current stops flowing.

ARC FAULT CIRCUIT INTERRUPTER BREAKER (cont'd.)

Modern AFCI devices protect against two types of arcing:

Parallel arcing: Arcing between two conductors.

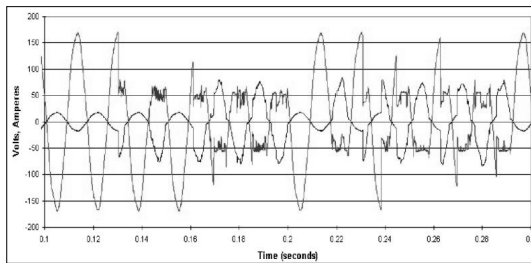


More damaging, more dangerous; limited only by breaker rating and available fault current.

Slide 8-41

4. The other type of arcing is known as parallel arcing. This occurs between an ungrounded conductor and another conductor, such as the neutral wire, ground wire, or another phase, and is limited only by the available fault current in the circuit and the over-current rating of the breaker. Use of extension cords increases the resistance in a circuit; this increased resistance can lower the current that is drawn by such an arc to a level such that the arcing activity will not exceed the trip curve conditions of a standard breaker, and the arcing activity can continue for long periods.

ARC FAULT CIRCUIT INTERRUPTER PROTECTION



Graph courtesy of 'The Arc-Fault Circuit Interrupter, An Emerging Product,' by George D. Gregory and Gary W. Scott, IEEE Transactions on Industry Applications, Vol. 34, No. 5, Sept/Oct. 1998, Publication 0093-9994/98

Slide 8-42

C. AFCI protection.

1. The circuitry of an AFCI breaker monitors the waveform of both the voltage and the current draw of the circuit.
2. When it sees activity that meets the algorithms for unwanted arc activity, the circuit breaker is tripped by the shunt mechanism, and current flow stops.

SHUNT-TRIP BREAKERS

Some breakers in industrial/commercial settings can be tripped remotely, usually for emergency shutoff purposes.

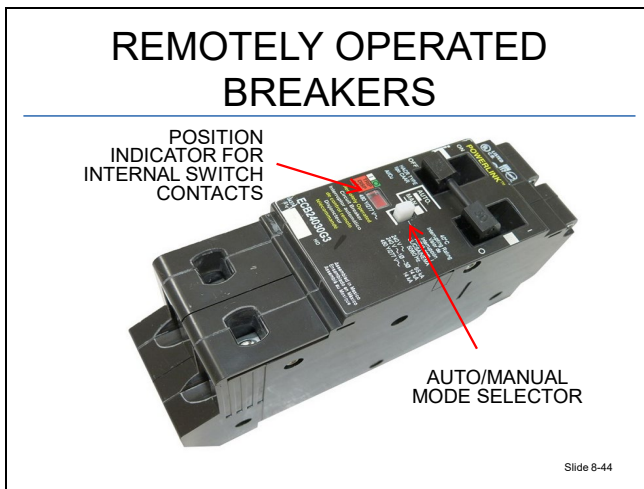


Slide 8-43

D. Shunt-trip breakers.

1. One feature available on circuit breakers is called a shunt-trip option, and it is usually installed in the breaker itself, although there are external options available.

2. Power required to activate the shunt-trip feature is usually external and independent of the breaker, and, as a result, the circuit that provides that voltage is subject to fire impingement with unintended activation — possibly remotely — regardless of the load on the breaker. These breakers can be identified in the panelboard by the presence of extra wires for the shunt-trip feature coming from the breaker — usually a smaller-gauge (16–18 AWG) wire. This means that it is possible to find a breaker in a panelboard that is tripped but was not overloaded or subjected to a short circuit. There is no way to determine, within the breaker itself, whether activation of the shunt-trip feature was the cause of the tripped breaker.
3. Supervisory control and data acquisition (SCADA) systems, if present, may record a shunt-trip input signal, especially in complex automated industrial systems. These control systems may be remotely located and undamaged by fire.



- E. Remotely operated breakers.
1. The slide shows a picture of a remotely operated circuit breaker (ROCB). With remotely operated breakers, an internal, electrically activated mechanism moves the contact mechanism inside the breaker to the ON or OFF position, without moving the handle.
 2. The external switch handle must be in the ON position for remote ON/OFF capability. ROCBs are similar in appearance to standard breakers when viewed from panel front. With these breakers, the external switch handle can be in the ON position, but internally the circuit can be OFF.
 3. An external/viewable indicator of the internal contact position is usually present. Under normal operating conditions, the internal contacts of an ROCB cannot be remotely moved to the ON position when the handle is in OFF or TRIPPED position. Power to operate the ON/OFF switch mechanism may be internal or external to breaker, and that mechanism conceivably could be activated multiple times in either direction (ON/OFF) due to fire impingement of remotely located control circuitry.

REMOTELY OPERATED BREAKERS (cont'd.)

Most commonly used for control of lighting circuits, but can be used for switching any load.



Slide 8-45

4. This picture shows what a typical ROCB panel looks like. The controlling circuitry can also be housed separately, and even remotely, from the panel.

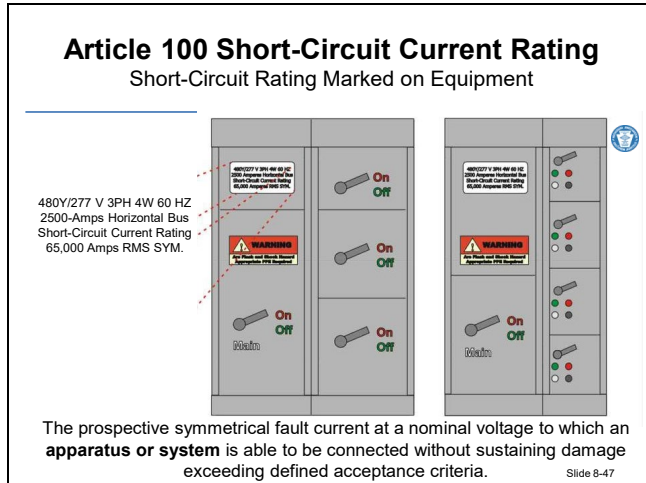
UNDERVOLTAGE RELEASE BREAKERS

Some breakers in industrial/commercial settings can also be configured to trip due to low-voltage situations, i.e., brownouts or undervoltage situations. This feature is known as an undervoltage release.

Prevent damage to equipment that may occur from operating at less than the designed voltage.

Slide 8-46

- F. Undervoltage release breakers: Some breakers in industrial/commercial settings can also be configured to trip due to low-voltage situations, i.e., brownouts or undervoltage situations. This feature is known as an undervoltage release, and the intention is to prevent damage to equipment that may occur from operating at less than the designed voltage. They have a panel-front appearance similar to standard breakers of the same type, and have a tripping mechanism similar to that of a shunt-trip breaker — the breaker handle will move to the TRIPPED position, giving a false indication that it tripped from overload or short circuit. One factor to consider is that the voltage loss or reduction that causes this tripping can be caused by fire-induced faults, or can occur if the structure is de-energized by the utility company.



- G. Article 100 short-circuit current (SCC) rating: All OCPDs are rated with an SCC rating. If we look back at our Ohm's law calculations, we know that a true short circuit can draw very high levels of current before the breaker trips, and it must break that circuit under that large current load. As we saw from the slow-motion video, that interruption causes a substantial arc and gas discharge — basically a mini-explosion of gases and pressure. The higher the current, the greater the energy in the arc. The SCC rating is the amount of current that a device can safely interrupt without damage to itself. If a higher-SCC-rated breaker is replaced with a lower-SCC-rated one, high current faults can cause issues in the panel (and possibly in nearby ignitable materials) if the breaker fails catastrophically when it trips.

ACTIVITY 8.1

Over-Current Protection Device Identification Quiz

Purpose

Evaluate OCPD recognition.

Directions

1. In a separate room/location, your instructors have placed a number of OCPDs onto a table.
2. You will be given 10-15 minutes to individually examine each type of OCPD and answer a preprinted quiz.
 - a. For questions 1-8, you will be required to identify the following information:
 - Brand/manufacturer.
 - Amperage rating.
 - Number of poles.
 - Rated operating voltage.
 - Mechanisms that will cause the breaker to trip (selecting all that apply).
 - b. For questions 9-12, students will be required to identify the following information:
 - Type of OCPD.
 - Amperage rating.
3. Once completed, you will turn the quiz in to instructors for grading.
4. The quiz will account for 30% of your final class grade.

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IV. SUMMARY



SUMMARY

- Distinguish among the types, styles and function of an OCPD.
- Interpret OCPD operation and principles, and associate them with a fire investigation.

Slide 8-49

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UNIT 9: CIRCUIT BREAKER ISSUES

TERMINAL OBJECTIVE

The students will be able to:

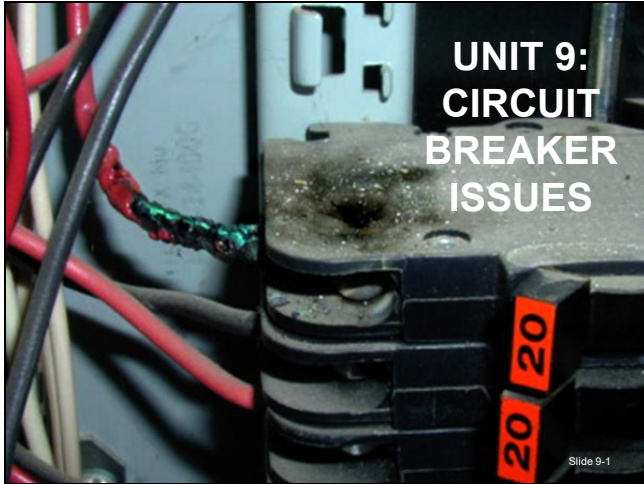
- 9.1 *Analyze the failure modes and limitations of over-current protection device (OCPD) types, styles and brands.*

ENABLING OBJECTIVES

The students will be able to:

- 9.1 *Compare and contrast known deficiencies and potential failure modes of specific circuit breaker types.*
- 9.2 *Differentiate between manufacturer styles, specifications and characteristics of circuit breakers.*
-

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TERMINAL OBJECTIVE

Analyze the failure modes and limitations of over-current protection device (OCPD) types, styles and brands.

Slide 9-2

ENABLING OBJECTIVES

- 9.1 Compare and contrast known deficiencies and potential failure modes of specific circuit breaker types.
- 9.2 Differentiate between manufacturer styles, specifications and characteristics of circuit breakers.

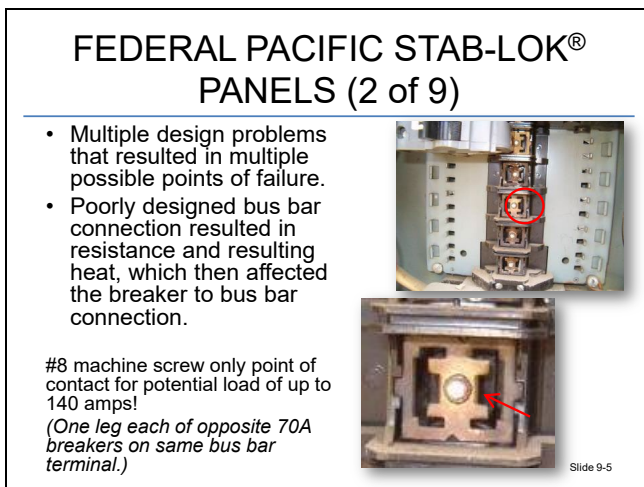
Slide 9-3

I. FEDERAL PACIFIC STAB-LOK® CIRCUIT BREAKERS

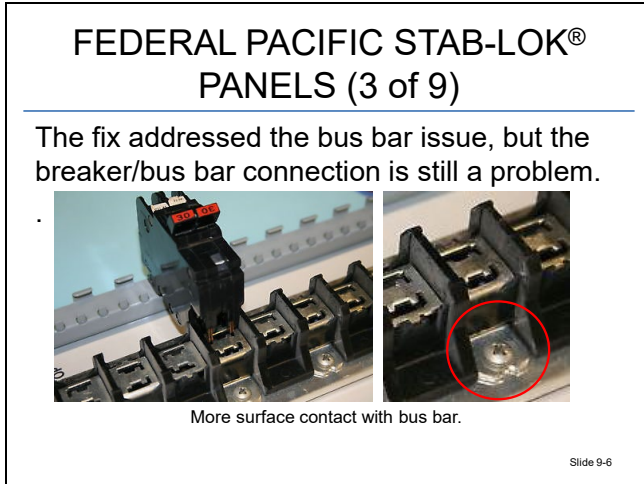


A. Federal Pacific Stab-Lok® panels.

1. When someone asks, “What’s a breaker panel type that has known problems?” the answer is usually, and correctly, Federal Pacific Electric (FPE) or Stab-Lok®. The Stab-Lok® series of FPE panels, like those shown on the slide, have had multiple issues that resulted in breaker and panel failures. Attempts to change the underlying design concepts did not fully address the issues. No recall was ever issued, and there are millions of FPE panels still in use today.
2. Stab-Lok® breakers differ from most breakers in that the operating handles move away from the center of the panel in the ON position, and they trip to the OFF position instead of the usual middle “tripped” position.



- B. Federal Pacific Stab-Lok[®] panel flaw: The first design flaw of FPE panels was that the contact plate where breakers connected to the distribution bus was held in place by a single steel machine screw through a standoff post holding the plate off of the bus bar. All of the current from the circuits connected to that particular plate, which could be as high as 140 amps, passed through the screw and post, and then passed through a small amount of contact area. This scenario caused excessive heat, which in turn caused failures of the connection points and potential damage to the breakers. Adding to the problem was the fact that different materials (aluminum, steel and copper) were used for the bus bar, standoff posts and contact plate.



- C. Federal Pacific Stab-Lok[®] panel flaw correction.
1. After identifying that there was an issue with the screw/post combination, a manufacturing change was made. The entire breaker/bus bar interface (contact plate) was combined into one piece, and it was mounted to the bus bar with a larger screw. By design, the one-piece plate interface made more surface contact with the bus bar. Note that this is a tandem 30-amp breaker, which means 60 amps could be drawn through the contact plate by those two breakers alone. Put two more 30-amp breakers on the other side, and the total is up to 120 amps through the single contact plate.
 2. Problems still remained in the design, in the way in which the breakers connected with the bus bar, and in the design of the breakers themselves.

FEDERAL PACIFIC STAB-LOK® PANELS (4 of 9)

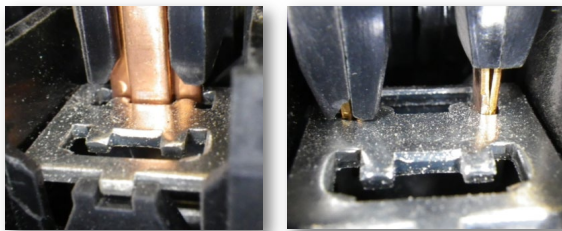
- Breaker tab connection at bus bar remains a problem.
- As a result, it is subject to loss of connection pressure, corrosion, and increased resistance and heat.



Slide 9-7

- D. Federal Pacific Stab-Lok® panels: Another issue with Stab-Lok® panels and their breakers is the breaker/contact plate connection. The tab design was physically weak and provided poor contact pressure, and some versions of Stab-Lok® breakers could inadvertently be installed incorrectly, causing a poor connection or damage to the breaker itself that was not readily apparent. Corrosion and overheating issues were a problem. In some panel versions, the entire bus bar assembly “floated” and was spring-loaded, so that it would press flush against the cover plate. This meant that every time a breaker was operated, the entire assembly was subject to movement. Breakers were often reported to be found so loose that they fell out when the panel cover was removed.

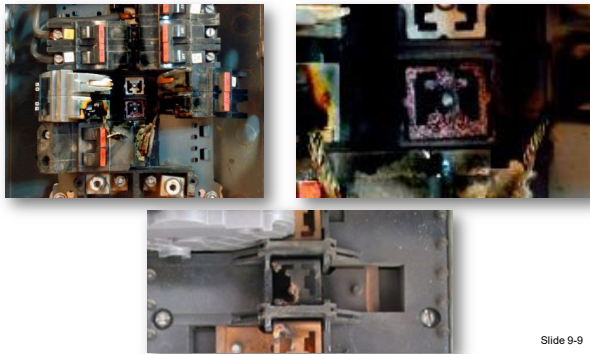
FEDERAL PACIFIC STAB-LOK® PANELS (5 of 9)



Slide 9-8

- E. Federal Pacific Stab-Lok® panel configuration: The photos show the different configurations of breaker tab and bus bar interfaces. The left photo shows how a full-size breaker connects, while the right photo shows two half-size breakers in one slot.

FEDERAL PACIFIC STAB-LOK®
PANELS (6 of 9)



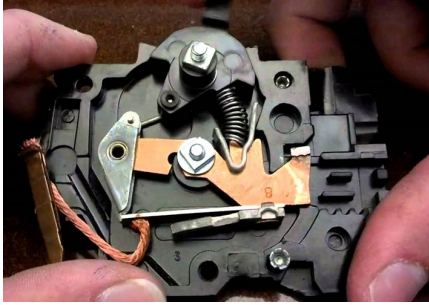
- F. Federal Pacific Stab-Lok® panel failures: The photos depict various Stab-Lok® panel failures.

FEDERAL PACIFIC STAB-LOK®
PANELS (7 of 9)



- G. Cover panel removal: Failed breakers can look the same as functional breakers from the panel front, as shown on the slide. This is why cover panel removal is an essential part of your electrical service documentation process.

FEDERAL PACIFIC STAB-LOK®
PANELS (8 of 9)



Slide 9-11

- H. Stab-Lok® breaker internal components: The internal components of Stab-Lok® breakers, shown on the slide, are minimal in quantity and design. Poor quality control during manufacturing contributed to problems.

FEDERAL PACIFIC STAB-LOK®
PANELS (9 of 9)

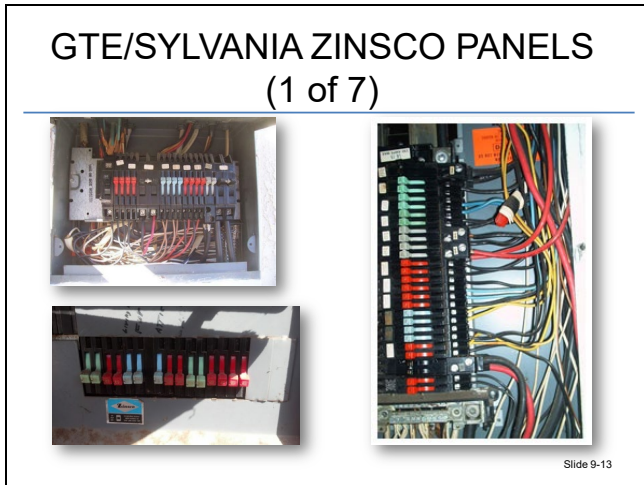
Double-pole breakers have a potential issue with the internal mechanism jamming when only one leg or side of the breaker trips – the other leg remains in the ON position and unable to trip at any current level, creating an obvious problem if there is an overcurrent situation.



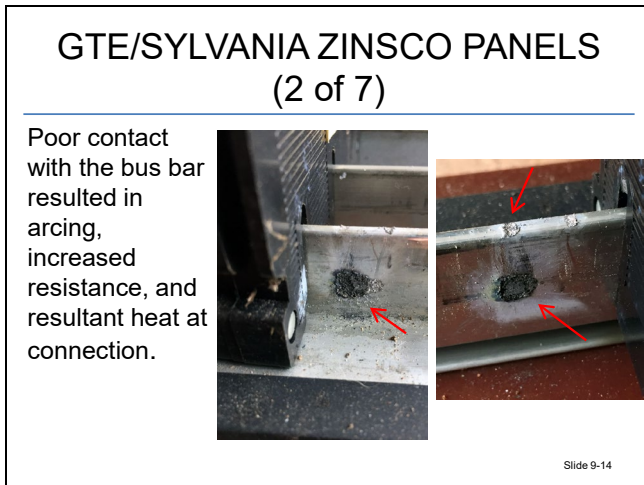
Slide 9-12

- I. Jammed double-pole breakers: A high failure rate is associated with double-pole breakers in conditions where only one leg of the breaker trips, and the second leg remains ON and jammed in that position; thus, the breaker is unable to trip at any over-current level. Take, for example, a normal household dryer that contains both 120-volt (V) and 240 V circuits on a 30-amp breaker. If an over-current on the 120 V circuit causes one side of the breaker to trip, and the other side remains jammed in the ON position, and the panel does not have a main, then the remaining operational circuits within the dryer will have **no** over-current protection downstream from the utility transformer. Basically, they are wired directly to that transformer outside the home, with no breaker in between to protect it.

II. GENERAL TELEPHONE AND ELECTRIC/SYLVANIA ZINSCO PANELS



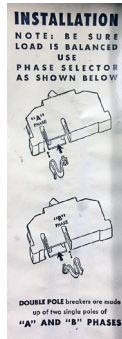
- A. General Telephone and Electric (GTE)/Sylvania Zinsco panels, like those on the slide, are another panel type that is documented to have problems. As with the Stab-Lok[®] panels, the issues arise at the breaker/bus bar interface. Also like the Stab-Lok[®] panels, no recall was ever issued, and millions remain installed and in use today.



- B. Flaws.
1. With Zinsco breakers, a poor connection at the bus bar and the bar clamp on the breaker resulted in arcing flaws.

GTE/SYLVANIA ZINSCO PANELS (3 of 7)

The phase choice for single-pole breakers was field-selectable, and the connection clamp was held in place by a machine screw placed into a thin strip of metal.

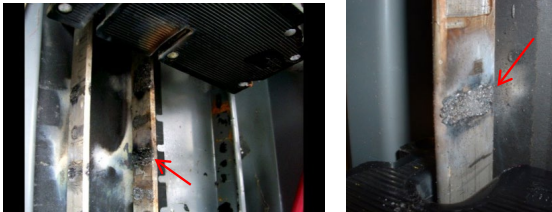


Slide 9-15

2. In single-pole versions of the breaker, the phase selection clamp was connected to the internals of the breaker by a tiny screw, which was easily stripped out or often not properly tightened. Remember that every connection, even a good one, creates some amount of heat. Poor connections create more heat, which may not dissipate faster than it is created, causing issues.

GTE/SYLVANIA ZINSCO PANELS (4 of 7)

The bus bar came in both aluminum and copper versions, but connection issues exist for both.



Slide 9-16

- C. Arcing damage: The photos show the damage caused by the arcing that occurs at loose connections in these panels. Arcing damage causes increased resistance, which causes more heat and makes the problem worse.

GTE/SYLVANIA ZINSCO PANELS
(5 of 7)



Slide 9-17

- D. Heat from poor breaker/bus bar connection: As shown on the slide, the heat created by a poor breaker/bus bar connection is conducted back into the internal components of the breaker and is also radiated to the housing. This unwanted heat causes damage to the breaker itself, potentially causing the breaker to trip at higher levels than desired, or possibly not trip at all.

GTE/SYLVANIA ZINSCO PANELS
(6 of 7)



Slide 9-18

- E. Heat damage: The photos show a closeup view of excessive heat damage to Zinsco breakers caused by a poor breaker/bus bar connection on the left, and a loose connection terminal on the right. When breakers are installed in a panel and sandwiched between other breakers, loss of integrity of the case (as shown in these photos) can cause pieces of the disintegrated case to drop inside the breaker, possibly blocking moving parts. This excessive heat also radiates to the breakers above and below it (if applicable), and can cause similar issues with those breakers.

GTE/SYLVANIA ZINSCO PANELS (7 of 7)

Breaker internal failure: may not trip at rated current (if at all), allowing failures to occur elsewhere.



Slide 9-19

- F. Breaker internal failure: Breakers that may have been damaged in the ways we have seen here on the slide are not necessarily the cause of a fire itself. If they fail to trip, they merely fail to protect the circuit or attached equipment from some other failure that caused the over-current in the first place. How far that failure progresses goes back to a question of where that failure occurred. Was it a competent ignition source? What was the first fuel that was ignited?

III. SUMMARY



SUMMARY



- Compare and contrast known deficiencies and potential failure modes of specific circuit breaker types.
- Differentiate between manufacturer styles, specifications and characteristics of circuit breakers.

Slide 9-20

UNIT 10: HIGH-RESISTANCE CONNECTIONS

TERMINAL OBJECTIVE

The students will be able to:

- 10.1 *Discern and evaluate electrical faults, failures, and associated high-resistance connection (HRC) characteristics.*

ENABLING OBJECTIVES

The students will be able to:

- 10.1 *Explain best practices for establishing a good connection.*
- 10.2 *Differentiate between arc damage and thermal impact to receptacle components.*
- 10.3 *Compare and contrast the damage effects to receptacles caused by fire exposure.*
- 10.4 *Differentiate the overheating characteristics for various materials, such as plastics and metals.*
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TERMINAL OBJECTIVE

Discern and evaluate electrical faults, failures, and associated high-resistance connection (HRC) characteristics.

Slide 10-2

ENABLING OBJECTIVES

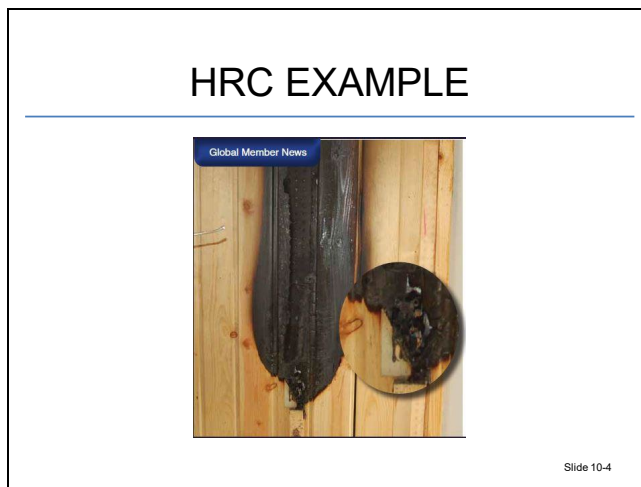
- 10.1 Explain best practices for establishing a good connection.
- 10.2 Differentiate between arc damage and thermal impact to receptacle components.
- 10.3 Compare and contrast the damage effects to receptacles caused by fire exposure.
- 10.4 Differentiate the overheating characteristics for various materials, such as plastics and metals.

Slide 10-3

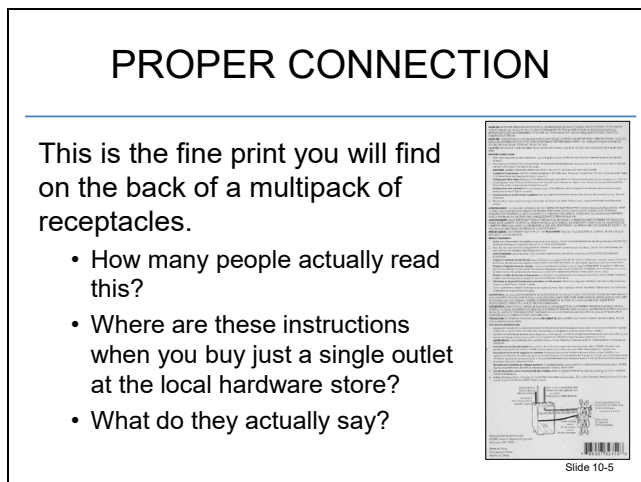
I. INTRODUCTION

A. Overview.

1. Can a receptacle, with nothing plugged into it, be the origin of a fire?
2. A high-resistance connection (HRC) results from a loose or poor connection in an electrical component that can cause heat to develop that is capable of starting a fire.
3. Safety devices, such as fuses and circuit breakers, even a Ground Fault Circuit Interrupter (GFCI), and/or Arc Fault Circuit Interrupter (AFCI), are unable to detect thermal rise and open the circuit.



- B. HRC example: This example illustrates a fire that occurred at an outlet without anything plugged into it. This outlet was located between the source and the load (the load was an outlet downstream, which had a high current draw). The loose connection in this outlet could not support the flow/draw.



- C. Proper connection: The manufacturers include specific installation instructions. Instructions for establishing a proper connection can typically be found in the fine print on the back of a multipack of receptacles.

SAMPLE WARNING LABEL

WARNING: IMPROPER WIRING OF ANY ELECTRICAL WIRING DEVICE CAN CAUSE SERIOUS INJURY OR DEATH. THESE WIRING DEVICES SHOULD BE INSTALLED ONLY BY AN ELECTRICIAN OR OTHER QUALIFIED PERSON IN ACCORDANCE WITH ALL APPROPRIATE CODES AND STANDARDS. IF YOU ARE NOT SURE ABOUT ANY PART OF THESE INSTRUCTIONS, CONSULT A QUALIFIED ELECTRICIAN.

WARNING: TO AVOID RISK OF FIRE OR SHOCK WHICH MAY RESULT IN SERIOUS INJURY OR DEATH TURN OFF POWER TO OUTLET BOX USING BREAKER OR FUSE AT THE SERVICE ENTRANCE. BEFORE WIRING VERIFY THAT POWER HAS BEEN REMOVED BY TESTING WITH A CIRCUIT TESTER AT THE OUTLET BOX.

CAUTION: THIS DEVICE IS FOR USE ONLY WITH COPPER OR COPPER CLAD WIRE. DO NOT USE THIS DEVICE WITH ALUMINUM WIRE.

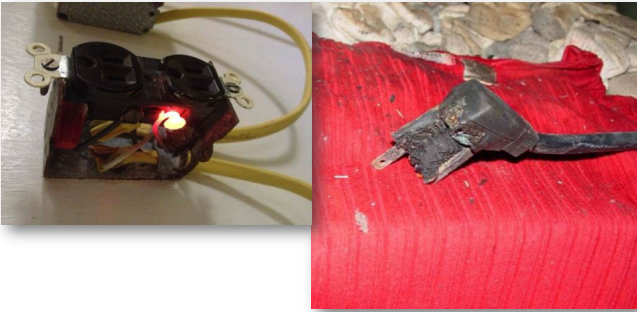
Installation instructions:

1. After removing power as described above, use strip gauge on back of outlet to strip all wires to desired length (if not already stripped).
2. Attach wires according to the diagram below. Be sure the wires are fastened securely either by the terminal screws or through the push-wire holes in the back of the outlet. **WARNING: loosely fastened wires may result in outlet failure and/or fire hazard.**
 - If using terminal screws:** Terminal screws accept up to #12 AWG wire. Wrap each stripped wire ¾ turn clockwise under heads of screws without overlapping and tighten securely.
 - If using push-wire holes:** Fully inset #14 AWG solid copper wire ONLY into the push-wire holes. Do not use push-wire holes for circuits greater than 15 amps. If outlet must be removed, insert screwdriver blade in the release slot and push it towards the front of the outlet, releasing wire. **Discard the outlet.**
 - If using back-wire method:** Back-wire accepts up to a #12 AWG wire. Insert stripped wire between external pressure plate clamp and terminal. Tighten securely.
3. **If using device as a split circuit receptacle:** Remove split circuit tab from between the Brass or Hot terminal screws. Wire the receptacle.
4. Mount outlet in box using mounting screws supplied. Attach wall plate. Restore power only when finished wiring the entire circuit.

Slide 10-6

II. LOOSE OR HIGH-RESISTANCE CONNECTIONS

LOOSE OR HIGH-RESISTANCE CONNECTIONS



Slide 10-7

Effects of loose or failed connections.

- A. The photos on the slide illustrate loose connections.
- B. Loose connections often create parting arcs as contact is made and broken when the connection is disturbed.
- C. Intermittent arc (current) passes through the air gap as the conductor is moved.



D. The photos on the slide show the effects of HRCs on receptacles.



E. HRCs can occur at any connection or splice, such as wire nuts, terminal blocks on appliances, etc.

III. CORRECT METHOD OF CONNECTION

DEMONSTRATION CONNECTIONS

- The freshly stripped end of the wire is wrapped two-thirds to three-quarters of the distance around the wire-binding screw post, as shown in Step A. The loop is made so that rotation of the screw during tightening will tend to wrap the wire around the post rather than unwrap it.

Step A: Strip insulation and wrap wire

Step B: Tighten screw to full contact

Step C: Complete installation
Slide 10-10

A. Proper connection demonstration.

- Wrap a newly stripped length of wire two-thirds to three-quarters of the distance around the wire-binding screw post, as shown in Step A. The loop is made so that the rotation of the screw during tightening will wrap around the post (rather than unwrap it).

DEMONSTRATION

- The screw is tightened until the wire is snugly in contact with the underside of the screw head and with the contact plate on the wiring device, as shown in Step B.

Step A: Strip insulation and wrap wire

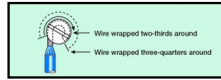
Step B: Tighten screw to full contact

Step C: Complete installation
Slide 10-11

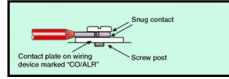
- Tighten the screw until the wire is snugly in contact with the underside of the screw head and with the contact plate on the wiring device, as shown in Step B.

DEMONSTRATION-TIGHTEN

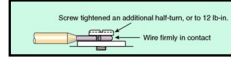
3. The screw is tightened an additional half-turn, thereby providing a firm connection, as shown in Step C. If a torque screwdriver is used, the screw is tightened to 12 to 15 in/lb.



Step A: Strip insulation and wrap wire



Step B: Tighten screw to full contact

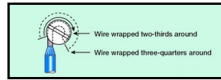


Step C: Complete installation
Slide 10-12

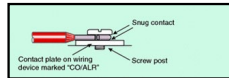
3. Tighten the screw an additional half-turn, thereby providing a firm connection, as shown in Step C. If a torque screwdriver is used, the screw is tightened to 12 to 15 in/lb.

DEMONSTRATION CORRECT CONNECTION

4. The wires should be positioned behind the wiring device to decrease the likelihood of the terminal screws loosening when the device is positioned into the outlet box.



Step A: Strip insulation and wrap wire



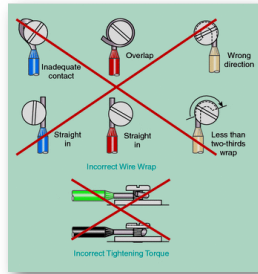
Step B: Tighten screw to full contact



Step C: Complete installation
Slide 10-13

4. Position the wires behind the receptacle to decrease the likelihood of the terminal screws loosening when the device is positioned into the outlet box.

IMPROPER CONNECTIONS

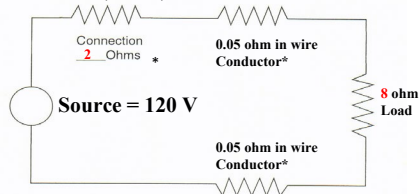


Slide 10-14

- B. Improper connections: Labeled 12-American Wire Gauge (AWG) or 10 AWG solid aluminum wire that does not bear the new aluminum wire label should only be used with wiring devices marked “CO/ALR” and connected in accordance with the manufacturer’s instructions.

HOW LOOSE CONNECTIONS CAUSE FIRES

Current of entire circuit (I) = $E / R = 120 \text{ V} / 10 \text{ ohms} = 12 \text{ amps}$
 Power (heat) generated at loose screw terminal = $I^2 \times R =$
 $(12 \times 12) \times 2 = 288 \text{ watts}$



*does not include small values of overall circuit resistance.

Slide 10-15

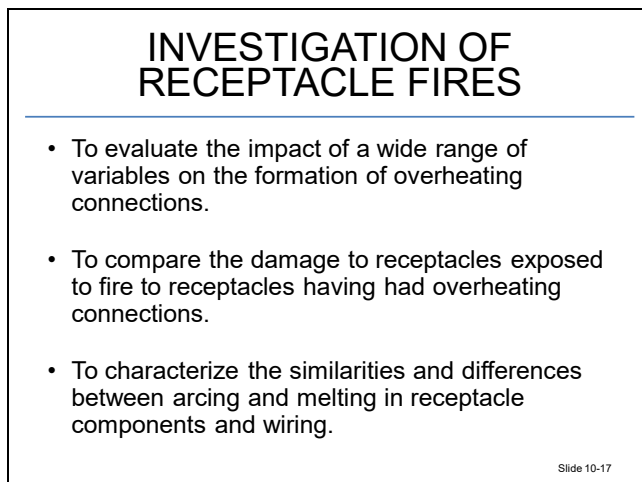
- C. How loose connections cause fires.
1. The slide shows a loose connection at a screw terminal. This loose connection only has two ohms (Ω) of resistance.
 2. 288 watts (W) of heat being dissipated at the screw head raises the temperature at the screw head.
 3. As the temperature increases, oxidation at the connection increases, furthering resistance.
 4. As the resistance continues to increase, the heat being generated at the screw head rises.

5. This cycle continues until the temperature stabilizes, when all of the heat generated on the screw can be radiated or conducted away as quickly as it is created, or the connection fails.

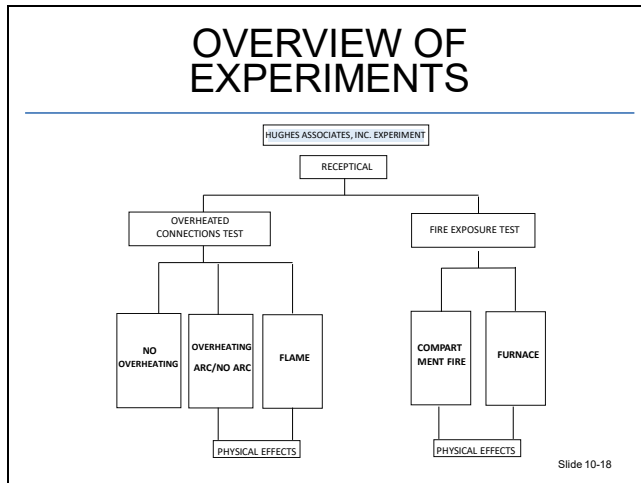


6. These thermal images show the increased heat at connections with high resistance.
7. The image on this slide illustrates an increased resistance at the connections.
8. Studies have shown that the temperature can stabilize when the screw head is red-hot. The screw head can reach temperatures well over 1,000 °C.
9. The resultant long-term heating breaks down the plastic receptacle body. As the plastic body breaks down into carbon, a current-limited fault path can occur. This results in excessive heating that can ignite nearby combustible materials.
10. An HRC may not trip the breaker.

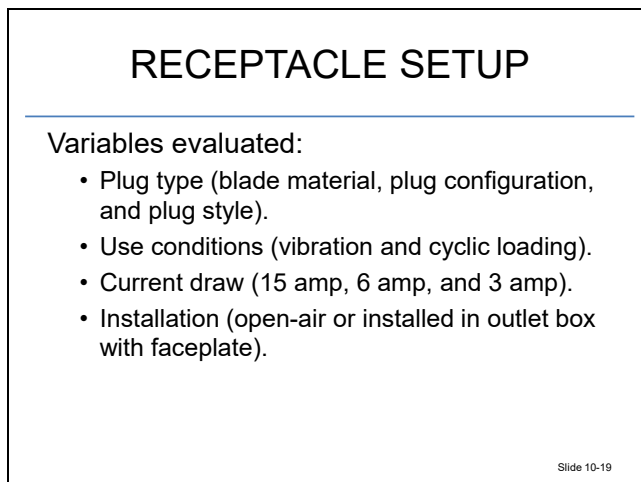
IV. INVESTIGATION OF RECEPTACLE FIRES



- A. Matthew Benfer and Dr. Daniel T. Gottuk of Hughes Associates Inc. produced the following information in the form of a presentation for the National Fire Academy (NFA) in August 2013. The following are excerpts. Findings were later published and can be found online in the Fire Safety Science-Proceedings of the Eleventh International Symposium, pp. 1010-1023.
- B. Objectives of the experiment:
1. Evaluate the impact of a wide range of variables on the formation of overheating connections.
 2. Compare the damage to receptacles exposed to fire to the damage to receptacles having had overheating connections.
 3. Characterize the similarities and differences between arc damage and melting in receptacle components and wiring.



- C. Overview of experiments conducted.



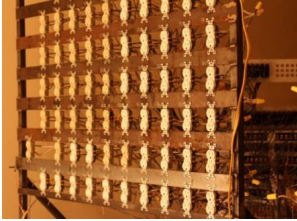
D. Receptacle testing setup.

Variables evaluated:

1. Wiring method (back wired and side wired).
2. Screw terminal torque (one-fourth turn loose, 1, 3, 5, 7, and 15 in/lb).
3. Number of back-wire removals and insertions (0, 1, and 2 cycles).
4. Receptacle body materials (polyvinyl chloride (PVC), polypropylene and phenolics).
5. Plug connection retention force (0.6 to 2.5 kg, 0.1 kg, and 0.01 kg).

RECEPTACLE TESTING:
SETUP

- Each rack with up to 78 receptacles.
- Wired using the “feed-through” method.
- Dedicated load banks.
- Seven test racks; 528 receptacle trials.
- Some receptacles with temperature and voltage measurements.



Slide 10-20

6. Each rack with up to 78 receptacles.
7. Wired using a “feed-through” method.
8. Dedicated load banks.
9. Seven test racks; 528 receptacle trials.
10. Some receptacles with temperature and voltage measurements.

OVERHEATING: PHYSICAL PROPERTIES

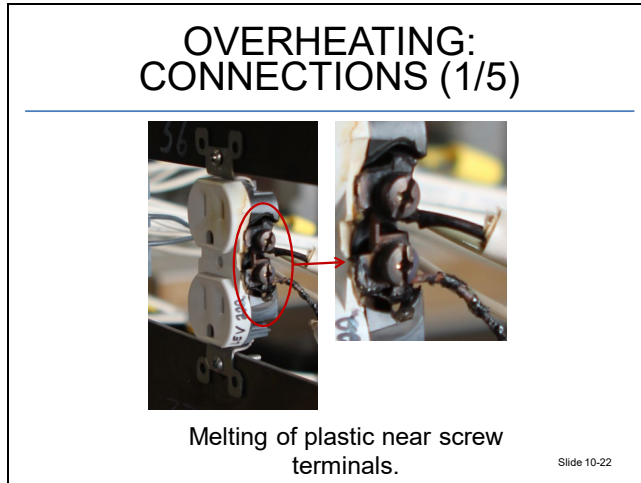
- **Plastics:**
 - Discoloration of plastic.
 - Melting of plastic.
 - Charring of plastic.
- **Metals:**
 - Oxidation.
 - Corrosion (from acid gases).
 - Dezincification of brass.
- **Connections with visible glowing:**
 - Welded conductor.
 - Severed conductor.
 - Enlarged screw head.

Slide 10-21

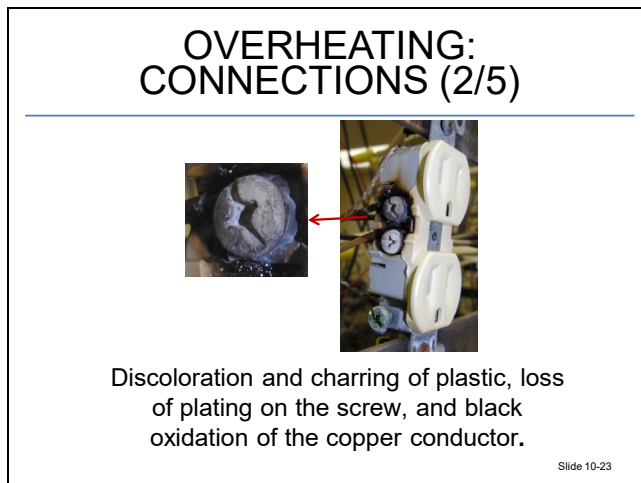
E. Physical properties of overheating of receptacle connections.

1. In the context of this project, overheating was determined by visual indicators of plastics, metals and glowing metals. Each material has a different visual characteristic when elevated to certain temperatures. For example:
 - a. Plastics:
 - Discoloration of plastic.
 - Melting of plastic.
 - Charring of plastic.
 - b. Metals:
 - Oxidation.
 - Corrosion (from acid gases).
 - Dezincification of brass.
 - c. Connections with visible glowing:
 - Welded conductor.
 - Severed conductor.
 - Enlarged screw head.

2. Although some receptacles were instrumented with thermocouples to measure the temperature of the terminals, elevated temperatures that do not produce any damage to a receptacle were not considered important. However, rises in temperature were analyzed to examine the driving factors behind overheating.

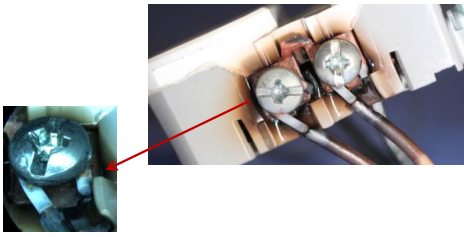


3. The photo on the slide shows the melting of plastic near screw terminals.



4. The photo on the slide shows discoloration and charring of plastic, loss of plating on the screw, and black oxidation of the copper conductor.

OVERHEATING: CONNECTIONS (3/5)



Discoloration and charring of plastic, corrosion of the copper conductor, and dezincification of brass contacts. (Dezincification and corrosion are caused by hydrogen chloride released by heating PVC materials.) Slide 10-24

5. The photo on the slide shows discoloration and charring of plastic, corrosion of the copper conductor, and dezincification of brass contacts. (Dezincification and corrosion are caused by hydrogen chloride released by heating PVC materials.)
6. Notice how the screw is originally brass colored, and now it is a copper color. This change in color occurred because the topmost layer of zinc has been leached out by the corrosive gases. Additionally, the insulation is changing color because of heat transfer back into the conductor.

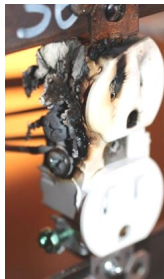
OVERHEATING: CONNECTIONS (4/5)

Polypropylene



Melting, running, and dripping.

PVC



Softening, deforming, and charring.

Phenolic

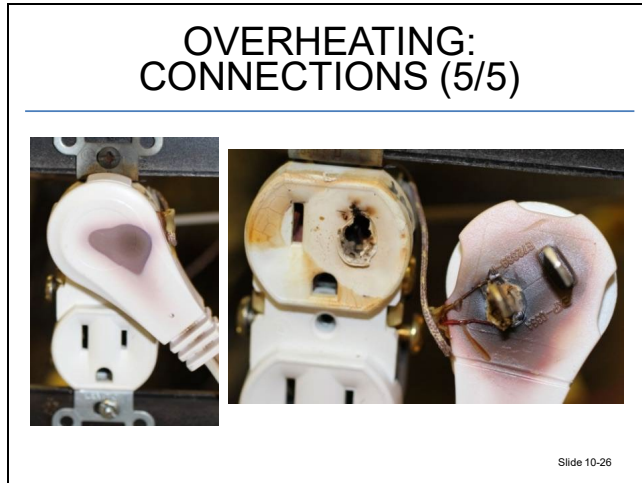


Cracking and localized crumbling.

Slide 10-25

7. The photo on the slide illustrates that all damage is localized around the overheating terminals. Notice the differences in appearance.
8. Various plastics exhibit different characteristics.
 - a. Polypropylene (thermoplastic) will melt, run and drip.
 - b. PVC (thermoplastic) will discolor, soften, sag and char.

- c. Phenolic (thermoset plastic) will discolor, crack, and crumble as it degrades.



9. The photo on the slide shows an overheated plug connection.
10. Notice:
- a. Damage is localized around the loose terminal (hot), but spreading a bit.
 - b. There is some discoloration and charring of both the plug and receptacle.
 - c. There is damage to the back of the plug, which is typical of low-profile plugs.

EXPERIMENT RESULTS (1/2)

No overheating damage occurred in receptacles with:

- Terminal torques ≥ 3 in/lb (79 receptacles).
- Current load of 3 amps (78 receptacles).

One of 78 receptacles with a current load of 6 amps had overheating damage.

Slide 10-27

- F. Overall experiment results.

1. No overheating occurred in receptacles with:
 - a. Terminal torques ≥ 3 in/lb (79 receptacles). This means that even with finger-tight loose receptacles, no overheating will likely occur.
 - b. A current load of 3 amperes (amps) or less (78 receptacles).
2. One of 78 receptacles with a current load of 6 amps had overheating damage. Note: Overheating is not necessarily a failure.

EXPERIMENT RESULTS (2/2)

Three of 42 receptacles with back-wired, push-in connections overheated (one failure).

There was limited overheating for DIY replacement plugs (solid brass blades).

The majority (300+) of receptacles showed some visual signs of overheating.

Slide 10-28

3. Three of 42 receptacles with back-wired, push-in connections overheated (one failure).
4. There was limited overheating for do-it-yourself (DIY) replacement plugs (solid brass blades).
5. The majority (300+) of receptacles showed some visual signs of overheating.

RECEPTACLE FAILURES DEFINED

A "failure event" during testing is an overheating connection accompanied by any of the following:

- Open circuit.
- Flames.
- Circuit breaker activation.
- Neutral to ground short (affected test configuration).

Slide 10-29

G. A “failure event” during testing is an overheating connection accompanied by any of the following:

1. Open circuit.
2. Flames.
3. Circuit breaker activation.
4. Neutral to ground short (affected test configuration).

OVERHEATING FAILURE EVENTS (1 of 3)

Severed conductors.

- With arc.
- Without arc.
- Arc unknown.



Slide 10-30

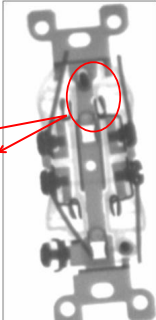
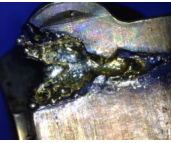
H. Overheating failure events.

1. Severed conductors.
 - a. These events occurred when a glowing connection was present.
 - b. The conductors severed at the glow.
 - c. Whether or not an arc occurred was determined from video footage.

OVERHEATING FAILURE EVENTS (2 of 3)

Shorted conductors:

- Hot to ground.
- Neutral to ground.
- Hot to neutral.



Slide 10-31

2. Shorted conductors.
 - a. Shorted hot to ground: Notch in ground strap shown by X-ray before it was disassembled.
 - b. Neutral to ground was an unintended flow of electricity through the ground. It prevented flow through downstream receptacles.
 - c. Shorter hot to ground and hot to neutral always tripped circuit breakers.
 - d. Only one hot to neutral arcing: This was in the wiring behind a receptacle in the open air.

OVERHEATING FAILURE EVENTS (3 of 3)

Flaming ignition:

- Series arcing at screw terminal.

Flaming ignition events will be discussed later in more detail.

In general, they were large enough to ignite a range of proximate materials.

Slide 10-32

3. Flaming ignition.
 - a. Flaming ignition events will be discussed later in more detail.
 - b. In general, they were large enough to ignite a range of proximate materials.

RECEPTACLE FAILURE RESULTS

Time: 5 to 511 days (average = 161 days).

Current levels and failures:

- 3 and 6 amps: None.
- 9 amps: One.
- 15 amps: 88.

Flaming: 17 events (19% of failures).

Only one back-wired, push-in receptacle failed.

Only receptacles with low-profile plugs failed.

Slide 10-33

- I. Receptacle failure results.
1. Time: 5 to 511 days (average = 161 days).
 2. Current levels and failures:
 - a. 3 and 6 amps: none.
 - b. 9 amps: one.
 - c. 15 amps: 88.
 3. Flaming: 17 events (19 percent of failures).
 4. Only one back-wired, push-in receptacle failed.
 5. Only receptacles with low-profile plugs failed.

FLAMING IGNITION (1 of 3)

For 10 polypropylene receptacles:

- Four with plugs inserted; six without.
- Four installed in outlet boxes; six not in boxes.

For 7 PVC receptacles:

- Two installed in an outlet box; five not in boxes.

Slide 10-34

- J. Flaming ignition of tested receptacles.
1. For 10 polypropylene receptacles:
 - a. Four with plugs inserted; six without.
 - b. Four installed in outlet boxes; six not in boxes.
 2. For seven PVC receptacles:
 - a. Two installed in an outlet box; five not in a box. This tells us that a box is not necessary for a fire to start.

FLAMING IGNITION (2 of 3)

- One back-wired, push-in connection.
- One with a plug connection.

Did not occur for receptacles constructed of phenolic plastics.

Duration (4 sec - 6 min); flames 8 - 46 cm (3 - 18 in.); ejected metallic material; flaming droplets.

Slide 10-35

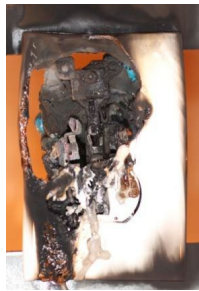
- One back-wired, push-in connection.
 - One with a plug connection.
- Did not occur for receptacles constructed of phenolic plastics.
 - Duration (four seconds to six minutes); flames eight to 46 centimeters (cm) (three to 18 inches); ejected metallic material; flaming droplets.

PVC FLAMING IGNITION VIDEO



Slide 10-36

FLAMING IGNITION (3 of 3)



Polypropylene receptacle –
faceplate melted and remained attached.



PVC receptacle –
flaming faceplate melted and fell to floor.

Slide 10-37

5. The photo on the slide shows two different receptacles after flaming ignition. The damage to receptacles, even after ignition, is still localized and does not progress from front to back.

MOVEMENT OF GLOW SPOT: WELDING OF CONDUCTOR



T = 0 hours



T = 2.7 hours



T = 5.5 hours

Slide 10-38

- K. The phenomenon of movement of glow spot and the welding of a conductor.
 1. The slide shows overheating connections sometimes developed into glowing connections.
 2. Localized glow spots formed and moved around the receptacle in a counter-clockwise fashion until they were not touching the screw head.
 3. The breaker was not tripped during the conditions shown on any of these images.

MOVEMENT OF GLOW SPOT: CONDUCTOR NECKING AND SEVERING

Measured
temperatures at glow
spot $\approx 1,100^{\circ}\text{C}/$
 $2,012^{\circ}\text{F}$.



Slide 10-39

4. At the point where the glow did not touch the screw head, the conductors began to neck, reducing the diameter of material (i.e., molten copper and copper oxides) carrying the current, and eventually severing.

EVIDENCE OF GLOWING CONNECTIONS



Welded conductor
with curved striations



Severed conductor
(welded with curved
striations)

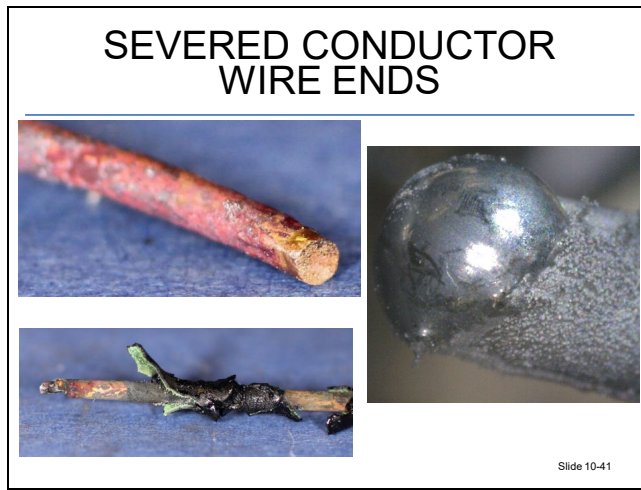


Enlarged screw
head

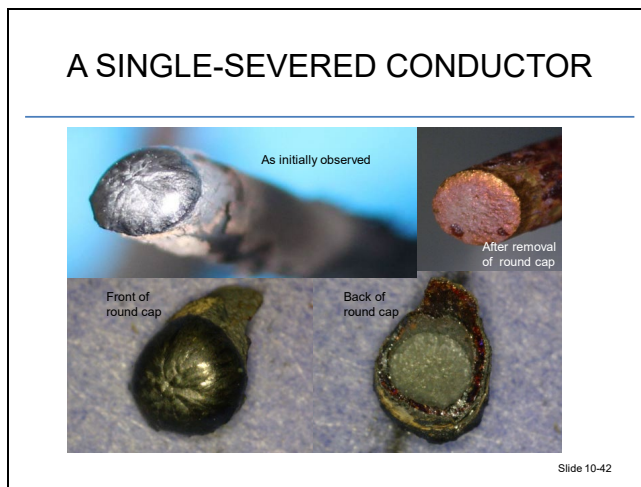
Slide 10-40

5. Glowing connections produced distinct evidence: welded conductors and enlarged screw heads.
- The first image on the slide shows conductor separation. Notice the welding process that creates a high temperature. The second image shows that there are unique artifacts at the end of the wire. The third image shows the enlarged screw head with corrosion. Notice that the screw is no longer shiny or smooth.
 - Welded conductors also had distinct curved striations as a result of the glow spot moving and resolidifying.

- c. Enlarged screw heads are characterized by their puffy, rough, and porous appearance and grey/black/reddish color. (These sometimes also had welded conductors and curved striations.)



6. Additional effect of glowing connections is the severed conductor wire as shown in the next series of slides.
7. Severing conductors at glow spots produced characteristic ends on the copper conductors: flat, round and irregular.
8. Irregular ends were less common than the round and flat ends.



9. Further examination of round ends found that the rounded part was actually a cap over a flat end. The cap is most likely copper oxides.
10. This conductor, shown on the slide, is from a flaming ignition event, but it is unknown if the arc occurred at parting.

DEVELOPMENT OF ENLARGED SCREW HEAD



T= 0 hours

T= 21.6 hours

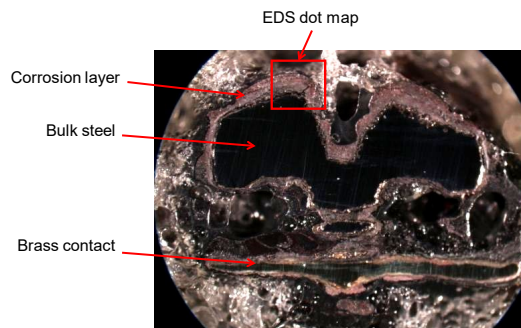
T = 29.2 hours

These pictures are of the same screw head and occurred in just over a day.

Slide 10-43

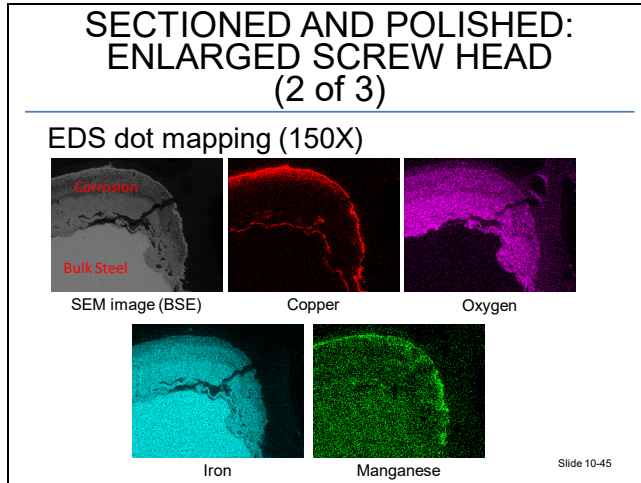
11. The slide shows enlargement of screw heads that was precipitated by heavy corrosion of the copper conductor and screw terminal at various time intervals.
12. Corrosion resulted from hydrogen chloride vapors liberated by the PVC as it was heated.
13. These photos show one instance of the development of an enlarged screw head occurring over a period of about one day.
14. Notice the crystals deposited on the copper conductor.

SECTIONED AND POLISHED: ENLARGED SCREW HEAD (1 of 3)

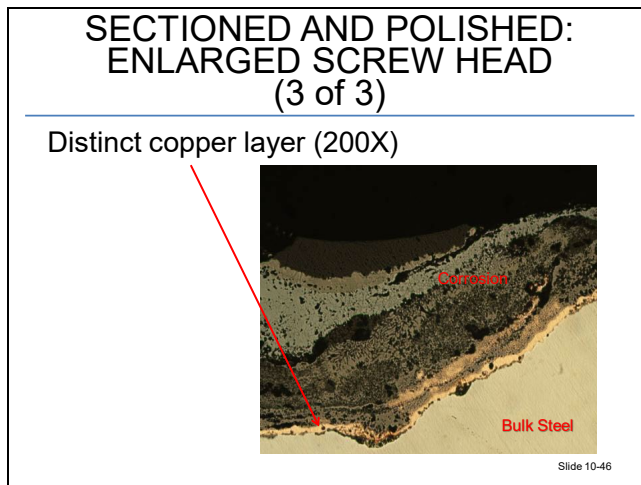


Slide 10-44

15. The slide shows an enlarged screw head that was progressively ground and polished until it reached approximately half-depth cross-section.
16. The red square shows the Energy Dispersive X-ray Spectroscopy (EDS) mapping area.



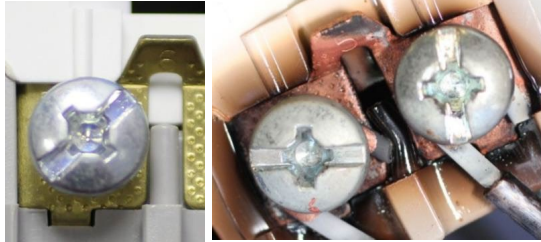
17. The slide illustrates mapping showing relative concentrations of elements in the corrosion layer atop the screw.
18. The corrosion layer is primarily iron and oxygen (rust), with some copper oxides at the surface.
19. There is a distinct copper layer between the corrosion and steel substrate.



20. The slide is a microscopic photo of the copper layer between the bulk steel of the screw and the corrosion layer.

DEZINCIFICATION

Selective leeching of zinc from brass due to corrosion.



Exemplar

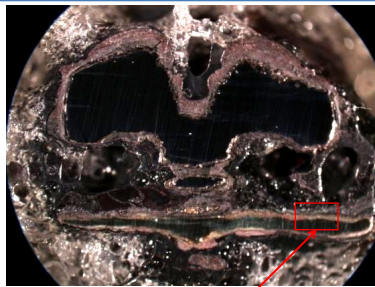
Dezincified

Only occurred with PVC receptacles. Did not occur during short-term heating with fire exposure.

Slide 10-47

21. The slide shows an illustration of dezincification.
22. Brass: typically 70 percent copper and 30 percent zinc. (EDS measurements are provided in the table.)
23. Dezincification is caused by a hydrogen chloride corrosion of brass. Only seen for PVC receptacles. Not seen in short-term heating from fire exposures.
24. Dezincification typically leaves the brass porous and mechanically weak.
25. Dezincified brass takes on more of a coppery color. Clearly, the dezincified area has a smaller ratio of zinc to copper.

SECTIONED AND POLISHED: ENLARGED SCREW HEAD



Dezincification

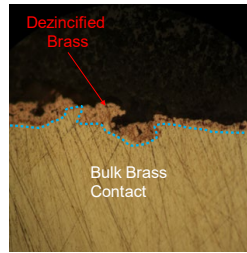
Slide 10-48

26. Notice the dezincification analysis area.

SECTIONED AND POLISHED: ENLARGED SCREW HEAD (cont'd.)

Dezincification:

- Selective leeching of zinc from brass due to corrosion.



Element	Bulk Brass	Dezincified Brass
Copper (Cu)	60%	66%
Zinc (Zn)	27%	17%
C, O, Cl, Fe	13%	17%

Slide 10-49

SUMMARY: DAMAGE FROM OVERHEATING CONNECTIONS

- Damage from overheating is localized.
- Damage is distinct between different materials—polypropylene vs. PVC vs. phenolics.
- Welding of the conductor (from glowing) can have distinct curved striations.

Slide 10-50

L. Summary: Damage from overheating connections.

1. Damage from overheating is localized.
2. Damage is distinct between different materials — polypropylene vs. PVC vs. phenolics.
3. Welding of the conductor (from glowing) can have distinct curved striations.

SUMMARY: DAMAGE FROM OVERHEATING CONNECTIONS (cont'd.)

- Distinct curved striations are not always seen when the enlarged screw head is present.
- Enlarged screw heads are a result of corrosion and overheating.
- Several unique severed conductor ends were observed.

Slide 10-51

4. Distinct curved striations are not always seen when the enlarged screw head is present.
5. Enlarged screw heads are a result of corrosion and overheating.
6. Several unique severed conductor ends were observed.

FIRE EXPOSURE TESTS (1 of 3)

Two sets of exposure tests:

- Compartment fire: room with upholstered furniture.
- Intermediate-scale furnace



Slide 10-52

M. Fire exposure tests.

1. Two sets of exposure tests.
 - a. Compartment fire (maximum temperature: 454 °C to 903 °C): room with upholstered furniture.
 - b. Intermediate-scale furnace (maximum temperature: 1,000 °C to 1,250 °C): premixed natural gas burners.

FIRE EXPOSURE TESTS (2 of 3)

Variables evaluated:

- Wiring method.
- Screw terminal torque.
- Receptacle materials.
- Outlet box material.
- Faceplate material.

Slide 10-53

2. Variables evaluated:

- a. Wiring method (side wired).
- b. Screw terminal torque (one-fourth turn loose; 1, 3, 7, and 12 in/lb).
- c. Receptacle materials (PVC, polypropylene and phenolics).
- d. Outlet box material (galvanized steel and PVC).
- e. Faceplate material (painted steel and nylon).

FIRE EXPOSURE TESTS (3 of 3)

Variables evaluated:

- Electrical state (nonenergized, energized, and energized with load).
- Plug type (blade material, plug configuration, and plug style).
- Receptacles with damage or evidence from overheating were used.

Slide 10-54

- f. Electrical state (nonenergized, energized and energized with load).
- g. Plug type (blade material, plug configuration, and plug style).
- h. Receptacles with damage or evidence from previous overheating were used.

COMPARTMENT FIRE TEST SETUP

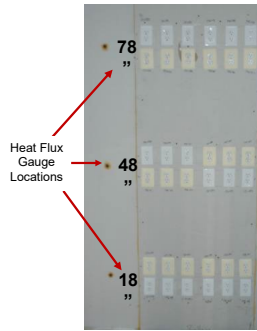
Eight tests; 36 receptacles per test.

Instrumentation:

- Heat flux gauges.
- Thermocouple tree.

Energized receptacles with individual 20-amp circuit breakers.

Individual loads for receptacles ~7 amps.



Slide 10-55

N. Compartment fire test setup.

1. Eight tests; 36 receptacles per test.
2. Instrumentation:
 - a. Heat flux gauges.
 - b. Thermocouple tree.
3. Energized receptacles with individual 20-amp circuit breakers.
4. Individual loads for receptacles ~7 amps.
5. Installed at three heights in the room to yield different thermal exposures.

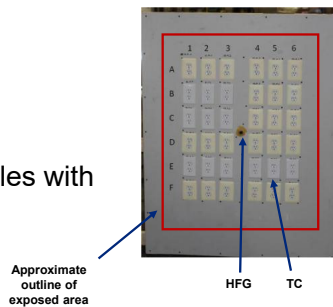
INTERMEDIATE SCALE FURNACE TEST SETUP

Five tests; 36 receptacles per test.

Instrumentation:

- Heat flux gauge.
- Thermocouples.

Energized receptacles with individual 20-amp circuit breakers.



Slide 10-56

O. Intermediate scale furnace test setup.

1. Five tests; 36 receptacles per test.
2. Instrumentation:
 - a. Heat flux gauge.
 - b. Thermocouples.
3. Energized receptacles with individual 20-amp circuit breakers.
4. Furnace temperatures are characterized at each location to better determine the temperature at the wall rather than the temperature in the furnace (which is not perfectly uniform).

FIRE EXPOSURE TESTING

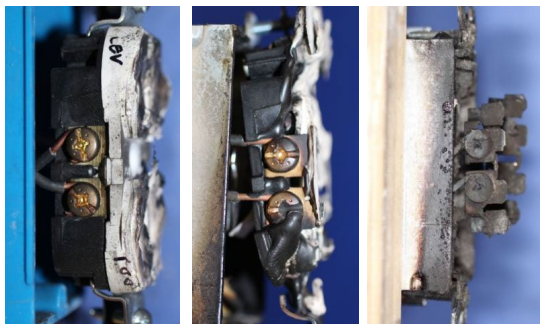
Fire damage to receptacles:

- Mostly uniform across exposed face.
- Progressed from front to back.
- Some evidence of overheated connections persists after fire exposure.

Slide 10-57

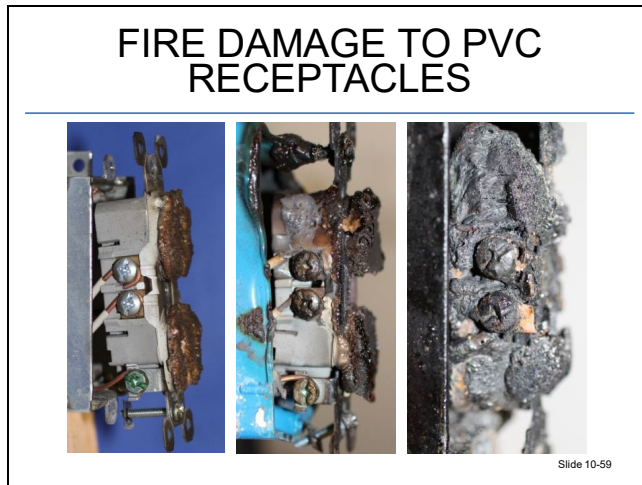
5. Fire exposure testing observations:
 - a. Mostly uniform across exposed face.
 - b. Progressed from front to back.
 - c. Some evidence of overheated connections persists after fire exposure.

FIRE DAMAGE TO POLYPROPYLENE RECEPTACLES



Slide 10-58

6. This photo shows fire damage to polypropylene receptacles that resulted in melting, dripping, and ultimately complete consumption.



7. This photo shows fire damage to PVC receptacles, which resulted in blistering, drooping, charring, and ultimately a rectangular piece of char remains.

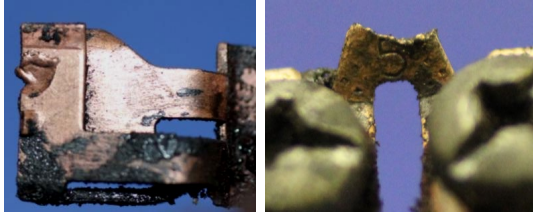


8. This photo shows fire damage to phenolic receptacles, which resulted in charring and discoloration, as well as cracking and separating of pieces (with the pieces eventually falling off).

CHARACTERISTICS OF ARCING IN RECEPTACLES

Defined edges, lettering, and shape outside of the damaged area.

- Applies to non-cylindrical conductors.



Slide 10-61

P. Characteristics of arcing in receptacles.

1. The conductive paths within a receptacle are not cylindrical, so we would not expect copper drawing lines or round/smooth beads, as are often seen in wiring.

OBSERVED LOCATIONS OF FIRE-INDUCED ARCING IN RECEPTACLES (1 of 5)

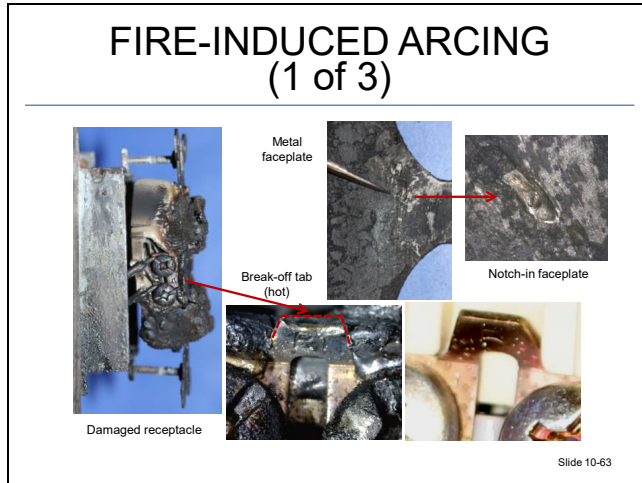
Hot-plug contacts and steel faceplate.



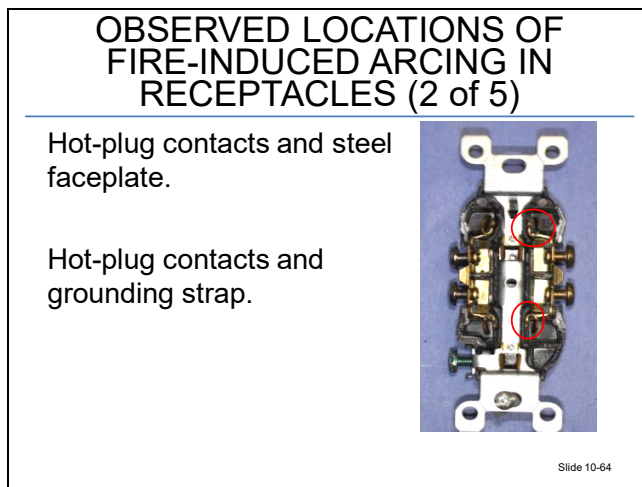
Slide 10-62

2. Common locations of arcing in receptacles were identified. These are usually different metals arcing.
3. It is very tough to get brass-to-copper arcing because of the receptacle configuration.
4. Brass-to-steel:
 - a. There is very little clearance between the receptacle contacts and faceplates.

- b. The brass contacts could be pushed forward, especially when the receptacle begins to sag or melt.

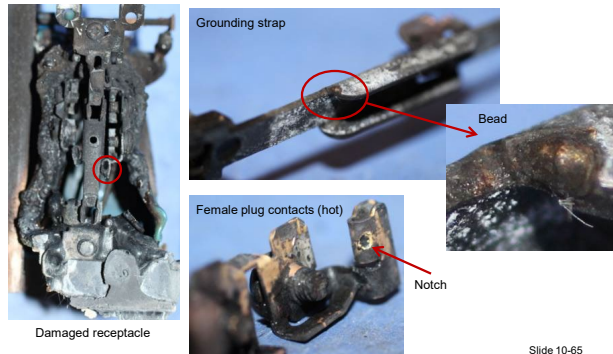


5. The photo shows fire-induced arcing.
6. Localized point of contact.
7. Corresponding damage on two conductors.
8. Edges and surfaces contiguous outside of the arc location.
9. The receptacle is still partially intact. (It is very unlikely the fire was hot enough to melt.)



10. Brass-to-steel: The amount of plastic between the brass contacts and the grounding strap is minimal.

FIRE-INDUCED ARCING (2 of 3)



11. The slide shows localized points of contact.
12. Corresponding damage is visible on two conductors.
13. Edges and surfaces are contiguous outside of the arc location.
14. Transfer of metal. (See the color of the arcing damage on the steel.)
15. The outlet box is still partially intact. (It is very unlikely that the fire was hot enough to cause melting if plastic from the box remains.)

OBSERVED LOCATIONS OF FIRE-INDUCED ARCING IN RECEPTACLES (3 of 5)

- Hot-plug contacts and steel faceplate.
- Hot-plug contacts and grounding strap.
- Screw terminal and steel outlet box.
- Hot conductor and steel outlet box.



16. Steel-to-steel and copper-to-steel:
 - a. As the receptacle melts, the brass contacts could dislodge, causing the screw to come into contact with the outlet box.
 - b. As wire insulation melts, the wires (bundled/coiled) in the back could come into contact with the box.

OBSERVED LOCATIONS OF FIRE-INDUCED ARCING IN RECEPTACLES (4 of 5)

- Hot-plug contacts and steel faceplate.
- Hot-plug contacts and grounding strap.
- Screw terminal and steel outlet box.



Slide 10-67

17. Copper-to-copper: As the wire insulation melts, two copper conductors could come into contact.

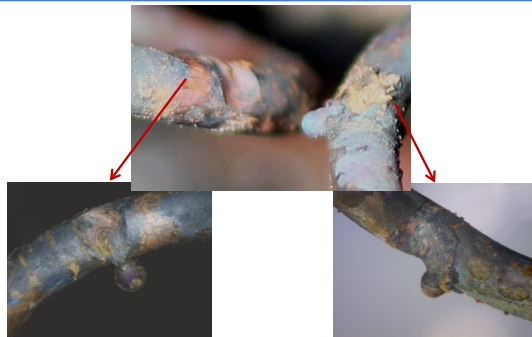
OBSERVED LOCATIONS OF FIRE-INDUCED ARCING IN RECEPTACLES (5 of 5)

- Hot conductor and steel outlet box.
- Hot conductor and neutral conductor.
- Hot conductor and ground conductor.



Slide 10-68

FIRE-INDUCED ARCING (3 of 3)



Slide 10-69

18. The slide shows localized damage.

- 19. Corresponding damage on two conductors.
- 20. Mass loss is consistent with arc damage.
- 21. Corresponding lines of demarcation.
- 22. Brass a couple of inches in front is not completely melted.

LOCATIONS OF FIRE-INDUCED ARCING IN RECEPTACLES

Location of arcing is a function of:

- Receptacle material.
- Surrounding materials (i.e., faceplates and outlet boxes).
- Construction of plug contacts.

Slide 10-70

- 23. Location of arcing is a function of:
 - a. Receptacle material.
 - b. Surrounding materials (i.e., faceplates and outlet boxes).
 - c. Construction of plug contacts.

ADDITIONAL OBSERVED CHARACTERISTICS OF MELTING

Thinning of brass components and holes.
Surface pitting.



Slide 10-71

- 24. The slide illustrates melting that was positively determined based on the fact the damage occurred with nonenergized receptacles.

25. Effects of gravity (dripping, running, etc.); smooth, round globules do not necessarily look like arc beads; and holes: fine, thin lattice sometimes.
26. Items in red are accepted indicators of arcing, which sometimes appear in melted copper wires. Opposite indicators also appear.



27. The slide shows, from left to right, non-melted to mostly melted; all receptacles were nonenergized.
28. Can see holes, extended areas of damage, and some pitting.



29. The slide shows a clear line of demarcation and copper drawing lines visible outside of the affected region, but this damage was thermally caused. Not all characteristics of either type of damage may be present. Sometimes conflicting characteristics will be present. This was a nonenergized outlet.
30. Notice the dimpled and irregular end.

FIRE DAMAGE: MELTING OF
COPPER WIRING IN OUTLET
BOXES (2 of 4)

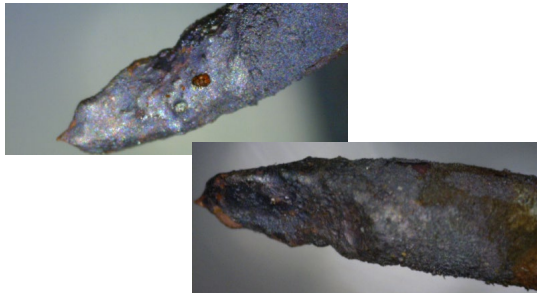


Wire from nonenergized receptacle.

Slide 10-74

31. The slide shows a pointed and jagged end, but a clear line of demarcation. Copper drawing lines are visible outside of the area. Again, this was a nonenergized outlet.

FIRE DAMAGE: MELTING OF
COPPER WIRING IN OUTLET
BOXES (3 of 4)



Wire from nonenergized receptacle.

Slide 10-75

32. The slide shows an irregular or tapered end (not smooth), with no clear line of demarcation.

FIRE DAMAGE: MELTING OF COPPER WIRING IN OUTLET BOXES (4 of 4)



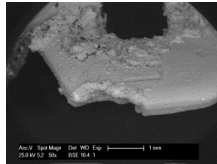
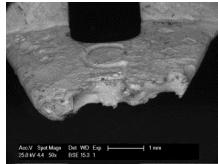
Wire from nonenergized receptacle.

Slide 10-76

33. The slide illustrates a round, somewhat clear line of demarcation, and a somewhat round and smooth shape.

DISTINGUISHING ARC FROM MELT USING SEM/EDS

- Brass conductors from PVC receptacles.
- Both installed in steel outlet boxes with steel faceplates.
- One from melting; the other arcing to steel faceplate. Which is which?

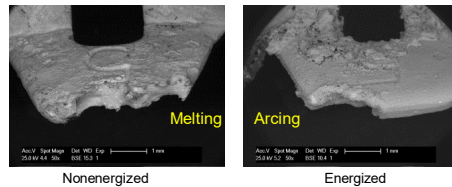


Slide 10-77

34. The damage is from arcing, because it has corresponding damage on the other conductor. Also, it was in a compartment fire with a maximum exposure temperature at that height of 546 °C, which is lower than the melting temperature of brass (900 °C to 940 °C).

DISTINGUISHING ARC DAMAGE FROM MELT DAMAGE (1 of 3)

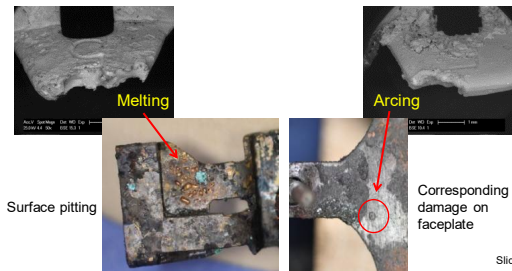
- Evaluate multiple characteristics.
- Evaluate in context with other evidence.



Slide 10-78

DISTINGUISHING ARC DAMAGE FROM MELT DAMAGE (2 of 3)

- Evaluate multiple characteristics.
- Evaluate in context with other evidence.

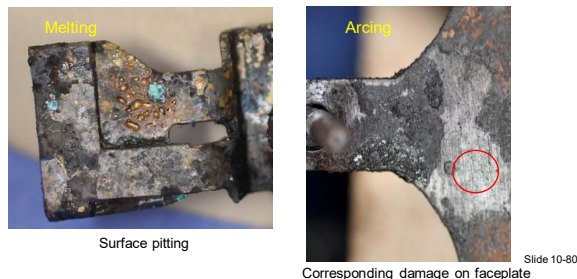


Slide 10-79

35. The damage is from arcing because it has corresponding damage on the other conductor. It was in a compartment fire with a maximum exposure temperature at that height of 546 °C, which is lower than the melting temperature of brass (900 °C to 940 °C).

DISTINGUISHING ARC DAMAGE FROM MELT DAMAGE (3 of 3)

- Evaluate multiple characteristics.
- Evaluate in context with other evidence.



Slide 10-80

PERSISTANT FIRE DAMAGE

- Metallic components: yes.
 - Welded conductors.
 - Curved striations.
 - Severed conductors.
 - Enlarged screw heads.
- Plastic components: possibly.
 - Dependent on exposure level.

Slide 10-81

Q. Persistent fire damage

1. Metallic components: yes.
 - a. Welded conductors.
 - b. Curved striations.
 - c. Severed conductors.
 - d. Enlarged screw heads.
2. Plastic components: possibly.

Dependent on exposure level.
3. Most of the metallic evidence persisted. The changes that were observed were slight color changes or loss of some detail.

FIRE EFFECTS ON OVERHEATED CONNECTIONS



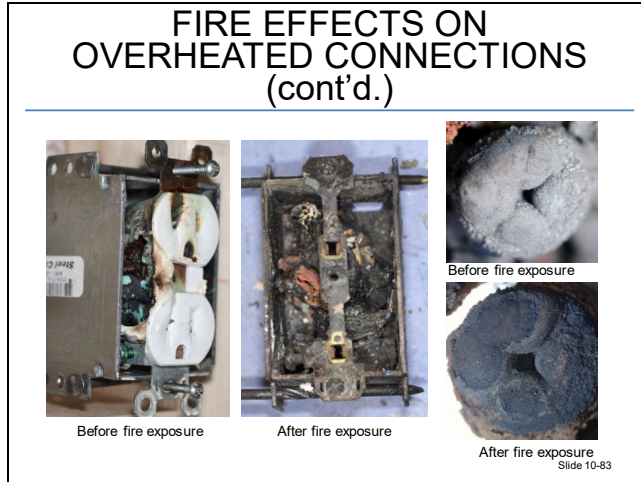
Before fire exposure



After fire exposure

Slide 10-82

4. The slide illustrates a welded conductor. An investigator can see copper color in the weld and striations.
5. The maximum exposure temperature is about 994 °C.



6. The slide shows color changes to the enlarged screw head. It appears that part of the corrosion layer might have been consumed, but would not affect the overall look or shape.
7. The maximum exposure temperature is about 1,058 °C.

V. CONCLUSIONS

CONCLUSIONS (1 of 4)

Overheating only developed for very loose connections (i.e., < 3 in/lb torque or ≤ 0.1 kg retention force).

Although about 80 percent of receptacles with very loose connections experienced overheating, only 30 percent led to a receptacle failure event (0.4 failures/year).

Approximately 4 percent of the receptacles with very loose connections led to flaming ignition (0.05 failures/year).

Slide 10-84

General conclusions.

- A. Overheating only developed for very loose connections (i.e., < 3 in/lb torque or ≤ 0.1 kg retention force).

- B. Although about 80 percent of receptacles with very loose connections experienced overheating, only 30 percent led to a receptacle failure event (0.4 failures/year).
- C. Approximately 4 percent of receptacles with very loose connections led to flaming ignition (0.05 failures/year).
- D. The failure rate is the number of failures (for very loose connections) divided by the total number of years tested for very loose connections.

CONCLUSIONS (2 of 4)

Unique characteristics of glowing connections include:

- Welding of the conductor with or without curved striations.
- Enlarged screw head from corrosion.
- Severed conductors at or near the screw terminal.

The majority of these characteristics persist after an intense fire exposure.

Slide 10-85

- E. Unique characteristics of glowing connections include:
1. Welding of the conductor with or without curved striations.
 2. Enlarged screw head from corrosion.
 3. Severed conductors at or near the screw terminal.
- F. The majority of these characteristics persist after an intense fire exposure.

CONCLUSIONS (3 of 4)

Thermal damage to receptacles:

- **From fire:** progresses from front to back.
- **From overheating:** localized around overheating terminal.

The majority of arcing evidence is identifiable using visual examination and low-powered microscopes.

Common arcing locations were identified.

Slide 10-86

- G. Thermal damage to receptacles:
1. From fire: progresses from front to back.
 2. From overheating: localized around overheating terminal.
- H. The majority of arcing evidence is identifiable using visual examination and low-powered microscopes.
- I. Common arcing locations were identified.

CONCLUSIONS (4 of 4)

Arcing vs. melting:

- Arcing and melting characteristics observed were similar to those in NFPA 921 (2024), Sections 6.6.2 through 6.6.6.
- Some characteristics that are unique to brass and steel receptacle components were also observed.
- Determination of arcing vs. melting should be based on multiple signatures and contextual information.

Slide 10-87

- J. Arcing vs. melting:
1. Arcing and melting characteristics observed were similar to those listed in National Fire Protection Association (NFPA) 921, *Guide for Fire and Explosion Investigations*, Sections 6.6.2 through 6.6.6 (2024).
 2. Some characteristics that are unique to brass and steel receptacle components were also observed.
 3. Determination of arcing vs. melting should be based on multiple signatures and contextual information.

VI. KEY POINTS

KEY POINTS (1 of 6)

- A total of 490 receptacles tested over 511 days.
 - Nearly all with connections < 3 in/lb showed signs of overheating.
- Glowing connections were limited to the loosest of connections.
 - Those connections with < 1 in/lb tightness.
 - Development of glowing was unpredictable.
 - Some would last for days.
 - Some would appear and disappear, and then restart days later.

Slide 10-88

- A. A total of 490 receptacles tested over 511 days.
 Nearly all with connections < 3 in/lb showed signs of overheating.
- B. Glowing connections were limited to the loosest of connections.
1. Those connections with < 1 in/lb tightness.
 2. Development of glowing was unpredictable.
 - a. Some would last for days.
 - b. Some would appear and disappear, and then restart days later.
 3. Some characteristics that are unique to brass and steel receptacle components were also observed.
 4. Determination of arcing vs. melting should be based on multiple signatures and contextual information.

KEY POINTS (2 of 6)

- Receptacle and plug failures occurred between 5 and 365 days, which is an average of 161 days.
- All receptacles with evidence of glowing connections before the fire still had evidence of that glowing connection after fire exposure.
- Timing of failure will depend on the amount and frequency of receptacle use.

Slide 10-89

- C. Receptacle and plug failures occurred between five and 365 days, which is an average of 161 days.
- D. All receptacles with evidence of glowing connections before the fire still had evidence of glowing connection after fire exposure.
- E. Timing of failure will depend on the amount and frequency of receptacle use.

KEY POINTS (3 of 6)

- About 19 percent of all failure events resulted in flaming combustion (flame heights up to 24 inches and lasting up to 6 minutes).
- A flaming event can occur with or without evidence of an overheated connection!

Slide 10-90

- F. About 19 percent of all failure events resulted in flaming combustion (flame heights up to 24 inches and lasting up to six minutes).
- G. A flaming event can occur with or without evidence of an overheated connection!

KEY POINTS (4 of 6)

- An overheated connection with flaming does not always trip the breaker (only occurred 3 out of 17 times during testing).
- During fire exposure testing, 201 of the 251 receptacles exposed tripped the breaker, and 178 of those 201 receptacles showing arcing damage.

Slide 10-91

- H. An overheated connection with flaming does not always trip the breaker (only occurred three out of 17 times during testing).
- I. During fire exposure testing, 201 of the 251 receptacles exposed tripped the breaker, and 178 of those 201 receptacles showed arcing damage.

KEY POINTS (5 of 6)

- All receptacles with extension cords in place tripped the breaker.
- Of the 133 receptacles with a steel faceplate cover, 76 of them had arcing damage on the faceplate.
 - When examining a receptacle for fire-induced arcing, all components must be examined, including the receptacle, outlet box, all wiring, and the faceplate (if conductive).

Slide 10-92

J. All receptacles with extension cords in place tripped the breaker.

K. Of the 133 receptacles with a steel faceplate cover, 76 of them had arcing damage on the faceplate.

When examining a receptacle for fire-induced arcing, all components must be examined, including the receptacle, outlet box, all wiring, and the faceplate (if conductive).

KEY POINTS (6 of 6)

- No fire-melted conductors had re-solidification waves present.
- If re-solidification waves are present, this is a strong indicator of arcing.
- Dezincification is a result of long-term corrosion, not short-term fire-induced melting.

Slide 10-93

DISCUSSION (1 of 5)



Slide 10-94

- L. This photo shows damage to the wire terminals of a breaker from an HRC.

DISCUSSION (2 of 5)



Slide 10-95

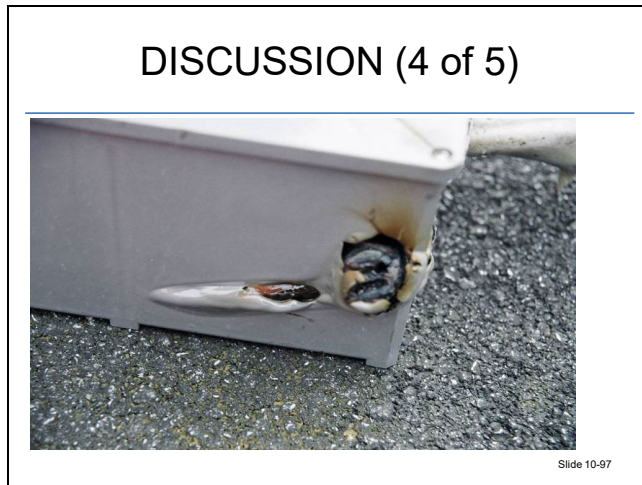
- M. This photo shows damage to the bus bar connection terminals of a breaker caused by an HRC.

DISCUSSION (3 of 5)

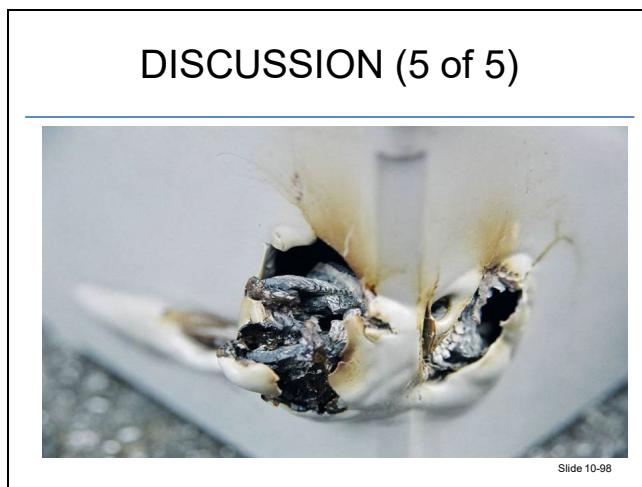


Slide 10-96

- N. This photo shows damage to the bus bar connection terminals of a breaker caused by an HRC.



- O. This slide illustrates an HRC at a split-bolt splice that caused the connection to overheat and melt through the side of this PVC enclosure.



- P. The photo on the slide shows an HRC at splice.

VII. CASE STUDY

CASE STUDY

Slide 10-99

VIII. SUMMARY



SUMMARY

- Explain best practices for establishing a good connection.
- Differentiate between arc damage and thermal impact to receptacle components.
- Compare and contrast the damage effects to receptacles caused by fire exposure.
- Differentiate the overheating characteristics for various materials, such as plastics and metals.

Slide 10-100

REFERENCE

Benfer, M., & Gottuk, D. T. (2014). Electrical receptacles — overheating, arcing, and melting. *Fire Safety Science*, 1010-1023. doi:10.3801/IAFSS.FSS.11-1010. Retrieved from https://www.iafss.org/publications/fss/11/1010/view/fss_11-1010.pdf

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UNIT 11: EVALUATE THE COMPONENTS

TERMINAL OBJECTIVE

The students will be able to:

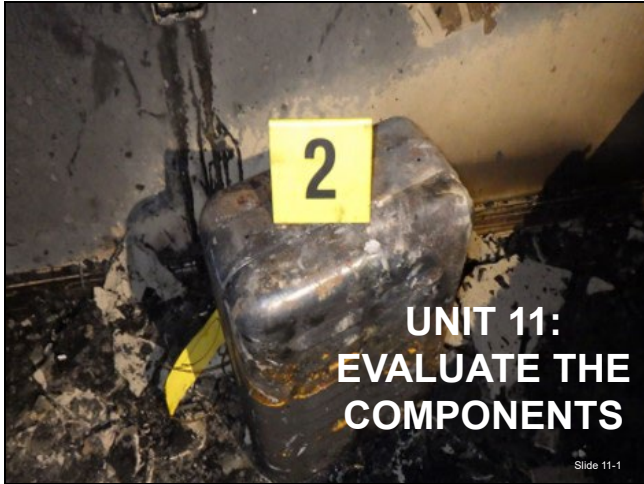
- 11.1 Evaluate the source, path, and load components to determine their potential involvement in a fire investigation.*

ENABLING OBJECTIVES

The students will be able to:

- 11.1 Examine the distribution system and panelboard.*
 - 11.2 Consider the types of heating sources, and estimate their damage potential.*
 - 11.3 Describe and demonstrate various heat/load sources.*
-

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TERMINAL OBJECTIVE

Evaluate the source, path, and load components to determine their potential involvement in a fire investigation.

Slide 11-2

ENABLING OBJECTIVES

- 11.1 Examine the distribution system and panelboard.
- 11.2 Consider the types of heating sources, and estimate their damage potential.
- 11.3 Describe and demonstrate various heat/load sources.

Slide 11-3

I. DETERMINE SOURCE CHARACTERISTICS

DETERMINE SOURCE CHARACTERISTICS

Utility transformer(s):

- Document their portion of the electrical service serving the structure.
- Document their physical location and appearance.
- Document when and how the utility power de-energized. (Test it to see if it is off.)
- Determine how many transformers service the structure.
- Determine if the transformers are pole- or pad-mounted.
- Determine if the transformer has been replaced since the fire.

Slide 11-4

A. Utility transformer considerations:

1. The utility company's portion of the electrical service serving the structure.
2. The physical location and appearance of the utility company's equipment.
3. If de-energized, determine and document when, how, and by whom the utility power was disconnected.
4. How many transformers service the structure.
5. Transformers are pole- or pad-mounted.
6. Transformer has/has not been replaced since the fire.

DETERMINE SOURCE CHARACTERISTICS
(cont'd.)

Utility transformer(s):

- Determine if the transformer served more than one structure.
- Determine if the utility-side transformer cutouts/fuses are open.
- Determine if anyone heard the fuses blow.
- Check the condition of the grounding electrode/connections.

Slide 11-5

7. Does the transformer serve more than one structure?

8. Utility-side transformer cutouts/fuses are/are not open.
9. Determine if anyone heard the fuses blow.
10. Check the condition of the grounding electrode/connections.

**DETERMINE PATH
CHARACTERISTICS (1 of 5)**

Service conductors.

- What type (drop or lateral)?
- What was the condition of the conductors (attached, broken, arced, impinged by fire)?
- What was the condition of the connections at transformer and meter base, if visible?
- Did you notice the presence of tree limbs, building members, etc.?

Slide 11-6

B. Service conductor considerations:

1. What type (drop or lateral)?
2. What was the condition of conductors (attached, broken, arced, impinged by fire)?
3. What was the condition of the connections at transformer and meter base, if visible?
4. Presence of tree limbs, building members, etc.?

**DETERMINE PATH
CHARACTERISTICS (2 of 5)**

Meter base.

- Is it present or absent?
- What was the condition of conductors and connections?
- Is there any arcing damage?

Slide 11-7

C. Meter base considerations:

1. Is the meter base present or absent?
2. What was the condition of conductors and connections?
3. Is arc damage present?

**DETERMINE PATH
CHARACTERISTICS (3 of 5)**

- Positions of circuit breakers (on, tripped, and off).
- Remember, some breakers trip to off.
- If present in the system, note any fuses that are blown.
- Document all fuse ratings and types.
- Copy any legends/breaker assignments.
- Find out which, if any, breakers were disturbed during or after the fire.
- Determine if any breakers tripped often.

Slide 11-8

D. Breaker considerations:

1. Document the panelboard.
2. Note the positions of circuit breakers (on, tripped, and off).
3. Note any fuses that are blown. Document all fuse ratings and types.
4. Copy any legends/breaker assignments.
5. Find out which, if any, breakers were turned off during or after the fire.
6. Determine if any breakers tripped often.

**DETERMINE PATH
CHARACTERISTICS (4 of 5)**

- Find out if recent work has been performed, electrical or otherwise.
- Determine if breakers were regularly used as switches.
- Document the manufacturer information.
- Remove cover and document panel enclosure interior.
- Look for burned, discolored, or melted insulation on wiring.

Slide 11-9

7. Find out if recent work has been performed, electrical or otherwise.
8. Determine if breakers were regularly used as switches.
9. Document the manufacturer information, both for the panel and the breakers.
10. Remove cover and document panel enclosure interior.
11. Look for burned, discolored or melted insulation on wiring.

**DETERMINE PATH
CHARACTERISTICS (5 of 5)**

- Verify that the panelboard's enclosure is properly grounded.
- Check main conductor connections.
- Look for modifications or poor workmanship.
- Do not move breaker handles.

Slide 11-10

12. Verify that the panelboard's enclosure is properly grounded.
13. Check main conductor connections.
14. Look for modifications or poor workmanship.
15. Do not move breaker handles.

II. PATH INSPECTION

DETERMINE PATH

Fire at the service panel or service panel impacted by fire?



Slide 11-11

Considerations:

- A. Is the picture indicative of an electrical fire? Do the burn patterns support the origin of the fire, or was the damage caused by the fire?
- B. The fire shown on this picture was impinging from the right of the “V” pattern on the panel, unrelated to the panel.

III. DETERMINE LOAD

DETERMINE LOAD (1 of 7)



Slide 11-12

- A. Load characteristics of service equipment:
 - 1. Conduct an examination of the breaker.
 - a. Determine if the breaker is overloaded.

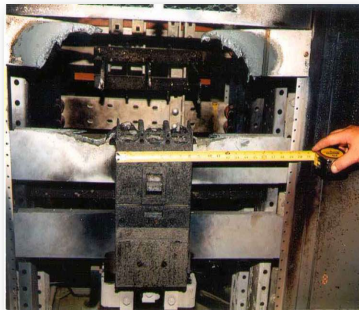
- b. Why is it important to identify the type of breaker?
- 2. Conduct an examination of the fuse.
 - a. Determine if the fuse is overloaded.
 - b. How do you determine the damaged connection point on a pullout fuse holder?

DETERMINE LOAD (2 of 7)



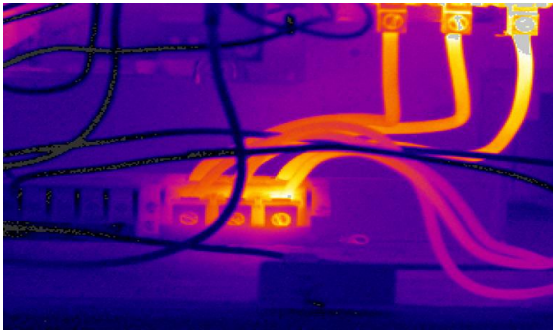
- c. The graphic on the slide depicts mass loss of material of one blade in comparison to identical blades in close proximity.
- d. Determine if there is an overheated connection and resultant failure.

DETERMINE LOAD (3 of 7)



- e. Note the localized mass loss of material where connection points once were.

DETERMINE LOAD (4 of 7)



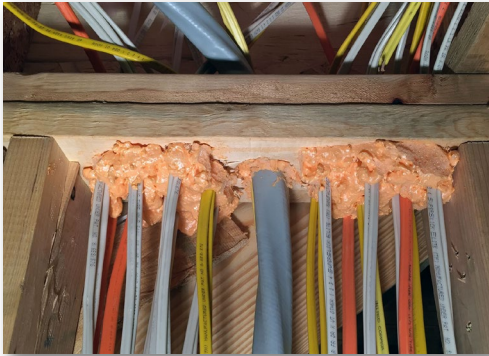
Slide 11-15

B. Load characteristics of conductors:

1. Overview.

- a. The thermal graphic on the slide shows increased heat at terminal connections and conductors.
- b. All current flow creates some amount of heat.

DETERMINE LOAD (5 of 7)



Slide 11-16

2. Conductor examination.

- a. Determine if cables are overheated.
- b. Multiple cables passing through an opening in a joist plate can be a point of overheating failure. Overheating is accelerated by the addition of foam insulation around the cables.

DETERMINE LOAD (6 of 7)



Slide 11-17

- c. The attic fire shown on the slides began where multiple cables passed through an undersized hole in a wall's top plate, without any foam insulation; arc damage (not pictured) was found on several of the conductors.
- d. Fire patterns and witness statements were consistent with the origin being at the wires where they passed through the joist.

DETERMINE LOAD (7 of 7)



Slide 11-18

- 3. The National Electrical Code® (NEC) specifies that when more than two cables pass through wood framing, and the opening is sealed against air movement, the maximum ampacity of those circuits must be reduced, or conductor size must be increased to limit the potential amount of heat that is generated and trapped in that area.
- 4. Note: Fire patterns indicate origin in the area where cables were passing through the joist. Inspection of the cables found arcing damage, and arcing damage was not from fire attack because there were no other potential ignition sources in the entire burned area.

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ACTIVITY 11.1

Identifying Poor Electrical Workmanship

Purpose

Consider the types of heating sources and their damage potential by identifying examples of poor workmanship, and discuss how poor workmanship can contribute to an electrical fire.

Directions

1. Working in your table group, conduct a general internet search for poor electrical workmanship.
2. Identify an example of poor electrical workmanship and notate:
 - a. What classifies the selected example as poor electrical workmanship?
 - b. What are the potential hazards or risks associated with this type of workmanship?
 - c. Is there a way to fix the issue?
3. After 10 minutes, be prepared to share your findings with the class.

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ACTIVITY 11.2

Black Box Activity

Purpose

Demonstrate various heat/load sources by creating three different electrical circuits. Students will use a multimeter to measure volts (V), amps, and calculate watts (W) using Joule's law.

Materials

- One Black Box Experiment Case (Pelican case).
- One multimeter with two test leads.
- Jumper wires.

Safety Precautions

The black boxes operate at a low voltage (12 V). Do not attempt to remove the component board from the case.

Directions

1. Working in groups of two, get one case, and take it back to your table.
2. Open your case and locate the multimeter.
3. On your multimeter, locate the On/Off switch.
4. Test your multimeter to make sure your meter turns on.
5. Determine which voltage mode to use (alternating current (AC)).
6. Turn the selector dial fully counterclockwise to "V," so that you are in V mode.
7. If you turn the dial one notch clockwise, you are in Ohm's or Continuity mode.
8. Notice how many lead ports you have on your meter, and notice the color codes.
9. Connect the black lead to the appropriate port (Common).
10. Attach the other lead to the V port.

11. Stay in Ohm's mode. (If we are in Ohm's mode, we are measuring resistance or continuity.)
12. If you touch the leads together, what happens to the reading?
13. Determine how to turn the beeping on or off.
14. What can you test in Continuity mode?
 - a. If a fuse is blown. (Beeping = good/blown = no sound).
 - b. Circuit breaker. (If the breaker is on, there will be a beeping sound.)
 - c. Can you test a fuse if it is still in the fuse holder?

15. Plug the box into the power strip on the table. (Move the jumper wires out of the way.)
16. Turn your box on.
17. In the top-left corner, notice the transformer (AC power supply/center tap transformer). Notice what the diagram looks like (transformer configuration for 120/240 Three-Wire residential electrical system), but notice it is only 12 V.
18. Measure AC voltage.
19. Determine how to measure AC voltage off a transformer.
20. If you cannot measure voltages to the ground, explain why.

21. Notice the location of the return path on the transformer (L1 to L2 or L1 to L3).
 - a. L1 to L3 is 14 V.
 - b. L1 or L3 to L2 is 7 V. (Should be half of what your first reading was because that circuit only uses half of the secondary winding.)

22. Create a light circuit.
- Remember that for any circuit, you need to have a source, a path and a load.
 - Jumper from L2 to S5.
 - The other side of the switch needs to get to load: jumper from S6 to V5.
 - Final connection is a jumper from V6 to L3.
 - Calculate the wattage of the light bulb. (You need two measurements — V and amps — to use Joule's law.)
 - $P = I \times E$.
 - Take the multimeter and put one lead on V6 and the other lead on V5. The reading should be approximately 7 V.
 - How to measure amperage:
 - Put leads in their correct ports. Start on the highest range first and work down if necessary, because if we measure more than the maximum current for the mode or port, it will burn out the internal safety fuse.
 - Turn the dial clockwise to the 10A position.
 - The two leads now become the equivalent of a jumper wire. Place the meter anywhere into the circuit (by replacing a jumper wire with the leads), and the meter will measure the amps we are drawing.
 - What is the amperage reading? It should be approximately 0.15 amps. The correct answer for the wattage of the bulb using Joule's law ($E \times I$) is 1.05, so it is roughly a 1 W bulb.
23. To prep for the doorbell circuit, strip all of your jumper wires.
24. What does the doorbell circuit show? A diode that is a check valve that only allows current to flow in one direction.
25. The buzzer only operates on direct current (DC).
- Jumper L2 to Z2.
 - Jumper Z1 to P4.
 - Jumper P3 to D2.

- d. Jumper D1 to L3.
 - e. Change your multimeter back to Voltage mode and move the leads to the correct ports. (This is very important.)
 - f. Take the leads and measure across your buzzer (Z1 to Z2), depress the button so the buzzer buzzes, and measure the voltage.
 - g. Reading is approximately 3.5 (only measuring half of the 7 V source).
26. To prep for a motor speed control:
- a. Check how many people have a box that has “BAD” on the potentiometer (in the bottom-right corner of the panel).
 - b. Those boxes will not work correctly, so we will have to work around the issue.
27. Create a motor circuit.
- a. This is a DC motor.
 - b. Jumper L3 to D1.
 - c. Jumper D2 to R6.
 - d. Jumper R5 to M2 of the motor.
 - e. Jumper from M1 to L2 to complete the circuit.
 - f. Rotate the knob of the potentiometer to turn the motor on and vary speed.
 - g. If your potentiometer says “BAD,” how can you bypass the variable speed control? Take the jumper from R6 to R5. Note that we still have a circuit, but do not have the ability to control the speed.
 - h. Take all jumper wires off, turn off the multimeter, and clean up the work area.

IV. SUMMARY



SUMMARY

- Examine a distribution system and panelboard.
- Discern between the types of heating sources, and estimate their damage potential.
- Describe and demonstrate various heat/load sources.

Slide 11-24

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UNIT 12: ARC MAPPING

TERMINAL OBJECTIVE

The students will be able to:

- 12.1 Apply arc mapping to the reconstruction of a fire scene to determine the area of origin.*

ENABLING OBJECTIVES

The students will be able to:

- 12.1 Use appropriate terminology to document arc mapping.*
- 12.2 Given an electrical artifact, determine if the cause of the damage was electrical, mechanical or thermal.*
- 12.3 Systematically employ the methodology of arc mapping.*
-

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UNIT 12: ARC MAPPING

Slide 12-1

TERMINAL OBJECTIVE

Apply arc mapping to the reconstruction of a fire scene to determine the area of origin.

Slide 12-2

ENABLING OBJECTIVES

- 12.1 Use appropriate terminology to document arc mapping.
- 12.2 Given an electrical artifact, determine if the cause of the damage was electrical, mechanical or thermal.
- 12.3 Systematically employ the methodology of arc mapping.

Slide 12-3

I. ARC FAULT MAPPING

THREE REQUIREMENTS TO ESTABLISH ORIGIN

Per NFPA 921, Section 18.1.2:

- Witness statements.
- Fire patterns.
- Fire dynamics.

This is not CAUSE determination.

Slide 12-4

A. National Fire Protection Association (NFPA) requirements.

1. Per NFPA 921, *Guide for Fire and Explosion Investigations* (2024), Section 18.1.2, “determination of the origin of a fire involves the coordination of information derived from one or more of the following:”
 - a. Witness statements.
 - b. Fire patterns.
 - c. Fire dynamics.
2. NFPA 921 states that one of the three sources of data for fire origin determination, not cause determination, is fire patterns. One of the methods of fire patterns analysis is arc mapping. (See Section 6.6.8, 2024 edition.) However, investigators must remember that arc mapping is just “another tool in the toolbox”; it does not tell us the cause of the fire. Arc mapping merely tells us whether the damage is interpreted correctly — that a conductor was energized at the time the fire attacked it.

ARC FAULT MAPPING (1 of 5)

NFPA 921(2024) - Section 6.6.8 arc surveys or arc mapping:

- Investigative tool for large-scale and small-scale incidents.
- Identification and documentation of electrical arc damage found in circuit wiring, conduits, load centers, cords, appliances, etc.
- Location of arc damage may provide evidence by identifying circuits that were energized at the time they were compromised by the fire.

Slide 12-5

3. NFPA 921, Section 6.6.8, arc surveys or arc mapping:
 - a. Investigative tool for large-scale and small-scale incidents.
 - b. Identification and documentation of electrical arc damage found in circuit wiring, conduits, load centers, cords, appliances, etc.
 - c. Location of arc damage may provide evidence by identifying circuits that were energized at the time they were compromised by the fire.

ARC FAULT MAPPING (2 of 5)

- Arc mapping requires careful examination of the electrical system to identify arcing that may have occurred.
- Once the arc is identified, plotting or mapping those points can, under certain circumstances, establish an area of origin or show the fire's progression through the structure.
- It will also help identify an area that might need additional examination.

Slide 12-6

B. General.

1. Arc mapping requires careful examination of the electrical system to identify arcing that may have occurred.
2. Once the arc is identified, plotting or mapping those points can, under certain circumstances, establish an area of origin or show the fire's progression through the structure.
3. It will also help identify an area that might need additional examination.
4. For arc mapping to be accurate and effective, you must understand the electrical system at the scene: where power comes from, where it goes to, and what portions of a circuit can be expected to be "live" under given circumstances. When electrical arc damage is located and mapped on a scene diagram, the resulting data or patterns can help to establish an area of origin, potentially documenting the fire's progression through a structure, and identify areas that might need additional examination or evaluation of the results.

ARC FAULT MAPPING (3 of 5)

- The theory behind arc mapping is that when the fire, including hot gases, impinges on an energized electrical circuit, it will compromise the insulation and cause an electrical fault at the first point that the fire comes in contact with the circuit.
- The following factors could affect the location where arcs are discovered and when they were produced:
 - Physical protection-concealed areas.
 - Walls, ceilings, insulation, etc.

Slide 12-7

5. The theory behind arc mapping is that when the fire, including hot gases, impinges on an energized electrical circuit, it will compromise the insulation and cause an electrical fault at the first point that the fire comes in contact with on the circuit.
6. The following factors could affect the location where arcs are discovered and when they were produced:
 - a. Physical protection-concealed areas.
 - b. Walls, ceilings, insulation, etc.
7. The underlying principle behind arc mapping is that once a conductor is compromised during a fire, the resulting fault — whether from arcing through char or direct conductor short circuiting — might sever the circuit or trip over-current protection devices (OCPDs). This de-energizes the circuit, either downstream of the severing fault or at the circuit breaker, and prevents further electrical arcing damage from occurring on that circuit. Factors that will influence arcing locations and the timeline in which they occurred might include physical protection (or lack thereof) of the conductors, such as enclosed walls and ceilings, insulation, and their physical location in relation to the fire or heat sources.

ARC FAULT MAPPING (4 of 5)

Differentiating between thermal and electrical damage is often the challenge.

- Additional forensic examination either at the scene, by an electrical engineer, or in a laboratory setting might be needed.

Slide 12-8

8. Differentiating between thermal and electrical damage is often the challenge. Additional forensic examination either at the scene, by an electrical engineer, or in a laboratory setting might be needed.
9. It can be a challenge to identify the damage to a conductor and determine whether that damage is from electrical activity, from thermal impact, or from mechanical causes — or possibly all three. A conductor can be severed electrically, and then the evidence of that damage can be obscured or obliterated by later thermal impact and torn from its location during a collapse. Some signs of electrical damage may only be determined through an electrical engineer's examination or in a laboratory setting.
10. No two arc faults leave exactly the same damage pattern. Some types of damage may be obvious to the unassisted eye, some might need closer inspection, and some may not be able to be determined at all. Depending on the size of the scene and the extent of the damage, the arc mapping process can be extremely time- and labor-intensive. The simple caveat is that if you do not even attempt it, you will never know.

ARC FAULT MAPPING (5 of 5)

- Some arc damage is very obvious while other damage is not. Investigating this can become a very labor-intensive undertaking, depending on the involved structure.
- What does the damage actually look like and what do they mean to the big picture?

Slide 12-9

11. Some arc damage is very obvious while other damage is not. Investigating this can become a very labor-intensive undertaking, depending on the involved structure.
12. What does the damage actually look like, and what does it mean to the big picture?

METHODOLOGY TO ARC MAP
(1 of 5)

- Identify the area to be arc mapped.
- Sketch or diagram the area.
- Identify all conductors within the area:
 - Identify the loads on circuits if possible.
 - Determine the direction of flow from the panel or source.
 - Document the size and type of the conductor.

Slide 12-10

C. Methodology to arc map.

1. Arc mapping is its own mini-investigation. Aspects of the electrical system must be determined before the investigation results and mapping can be properly interpreted.
2. Identify the area to be arc mapped.
3. Sketch or diagram the area.
4. Identify all conductors within the area.
 - a. Identify the loads on circuits if possible.
 - b. Determine the direction of flow from the panel or source.
 - c. Document the size and type of conductor.

METHODOLOGY TO ARC MAP (2 of 5)

- Record the OCPD type and handle position.
- Determine if the OCPD is a fuse, breaker, AFCI, or GFCI.
- Begin the process of examining each conductor.
- Examine and feel for abnormalities, such as beads and notches. If necessary, remove the conductor from the conduit. (This is not spoliation if done properly.)

Slide 12-11

- d. Record the OCPD type and handle position.
- e. Was the OCPD a fuse, breaker, Arc Fault Circuit Interrupter (AFCI), or a Ground Fault Circuit Interrupter (GFCI).
- f. Begin the process of examining each conductor.
- g. Examine and feel for abnormalities, such as beads or notches. If necessary, remove the conductor from the conduit. (This is not spoliation if done properly.)

METHODOLOGY TO ARC MAP (3 of 5)

Determine if the damage found on the conductor is from:

- Arcing.
- Environmental heating (thermal melting).
- Mechanical Damage (collapse, overhaul, etc.).
- Eutectic melting (alloying of metals).
 - This causes a lower melting temperature.

Slide 12-12

5. Determine if the damage found on the conductor is from:
 - a. Arcing.
 - b. Environmental heating (thermal melting).
 - c. Mechanical damage (collapse, overhaul, etc.).
 - d. Eutectic melting (alloying of metals).
 - This causes a lower melting temperature.

METHODOLOGY TO ARC MAP (4 of 5)

Locate the arc site on the sketch and document its physical characteristics.

- Faulted to another within the same conductor.
- Faulted to another conductor or ground source (i.e., conduit or building material).
- Completely severed or partially severed.

Slide 12-13

6. Once damage has been found on a conductor:
 - a. Determine the cause of damage: electrical activity, thermal melting, mechanical damage or eutectic melting.
 - b. Physically mark the location of all electrical arcs found (by using flagging tape, clothespins, etc.).
 - c. Record locations on the scene diagram.

METHODOLOGY TO ARC MAP (5 of 5)

- Flag the damage location on the conductor and document with photos.
- Preserve the item as evidence if necessary.

Slide 12-14

- d. Photograph the damage.
 - e. Preserve the damaged conductor as evidence if necessary. Place witness marks on each end of the wire, document in place, and remove enough conductor on each side of the damage that comparisons to other exposed areas can be made.

II. BALLS AND BEADS

BALLS AND BEADS

Discrete balls of molten copper at the ends of wire. The rest of the wire shows no melting.



Slide 12-15

- A. Slide illustrates a type of damage called “arcing through char.” Arcing through char occurs as fire attacks an energized conductor. As the insulation begins to burn and char, it forms carbon, which is a semiconductor. The presence of carbon between the energized conductor and grounded or grounding conductors creates a current limited fault path.

The resultant arc is of sufficient magnitude to melt and sever the copper conductor. This type of melting is often the result of an external attack by fire, not fire causation.

BALLS AND BEADS (cont'd.)

Indicate:

1. Arc damage
2. Damage location
3. Proximity to load center
4. Origin

Slide 12-16

- B. What do balls and beads indicate?

1. When arcing occurs in an energized conductor, the temperature of the conductor is almost instantaneously raised to the melting temperature of the conductor, which then causes the material to become molten and to be ejected from the area of the arc due to expanding hot gases. Once the electrical current that created the heat stops flowing — either because an OCPD was activated, the conductor was severed, or the portions of conductors in contact with each other were vaporized away — the temperature of the conductor begins to cool immediately.
2. This localized damage and remaining adjacent undamaged areas are what help to differentiate electrical damage from thermal damage.
3. The arc faulting of a conductor at a location farthest from the distribution panel is closer to the area of origin than an arc fault occurring closer to the panel (taking construction and fuel loads into consideration).
4. Arc fault location mapping can be useful in pinpointing the area of origin.

CHARACTERISTICS OF DAMAGE	
NFPA 921 Section 6.6.6 Electrical Arcing (Electrical Activity)	NFPA 921 6.6.2 Melting by Fire (Thermally Impacted)
• Round, smooth shape of artifact. • Localized contact point. • Identifiable corresponding area of damage on opposite conductor or grounded enclosure. • Small beads and divots over a small area. • Localized, round depressions.	• Blistering and distortion on surface of conductor. • Manufacturer striations and die tool marks become obliterated. • Pulled, spiked, and jagged appearance. • Irregular shape of bead. • No demarcation line and larger area of damage. • Low internal porosity.
Slide 12-17	

C. Characteristics of damage.

1. NFPA 921 highlights the differences between damage characteristics in electrical arcing and thermal damage from melting by fire. Note: It is possible for electrical arcing to occur first, and then for those characteristics to be obliterated by thermal exposure later.
2. NFPA 921, Section 6.6.6:
 - a. Round, smooth shape of artifact.
 - b. Localized contact point.
 - c. Identifiable corresponding area of damage on opposite conductor or grounded enclosure.
 - d. Small beads and divots over a small area.

- e. Conductor may be severed with distinguishable balls and beads.
- f. Bead may weld two conductors together.

CHARACTERISTICS OF DAMAGE (cont'd.)

NFPA 921 Section 6.6.6 Electrical Arcing (Electrical Activity) - Sharp demarcation between damaged and undamaged area. - Locally enlarged grain size. (SEM, metallurgist). - Resolidification waves. - High internal porosity view in cross section. - Copper drawing line visible outside of damaged area.	NFPA 921 6.6.2 Melting by Fire (Thermally Impacted) - Gradual necking of the conductor- (Assuming this is not mechanical break). - Visible effects of gravity on the artifact. - Eutectic Melting (alloying).
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Slide 12-18

- 3. NFPA 921, Section 6.6.2:
 - a. Visible effects of gravity on the artifact conductor.
 - b. Extended area of damage without a sharp demarcation from undamaged material.
 - c. Gradual necking of the conductor, assuming this is not due to a mechanical break.
 - d. Low internal porosity when viewed in a cross-section.
- 4. NFPA 921 defines a bead as “a rounded globule of re-solidified metal at the end of the remains of an electrical conductor that was caused by arcing and is characterized by a sharp line of demarcation between the melted and unmelted conductor surfaces” (NFPA 921, 2024, Section 3.3.20).

CHARACTERISTICS OF ARC BEADS (1 of 7)

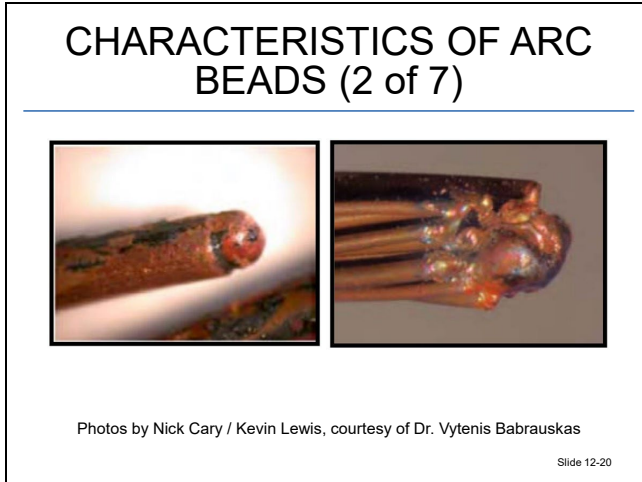



Photos by Kevin Lewis / E.C. Buc, courtesy of Dr. Vytenis Babrauskas

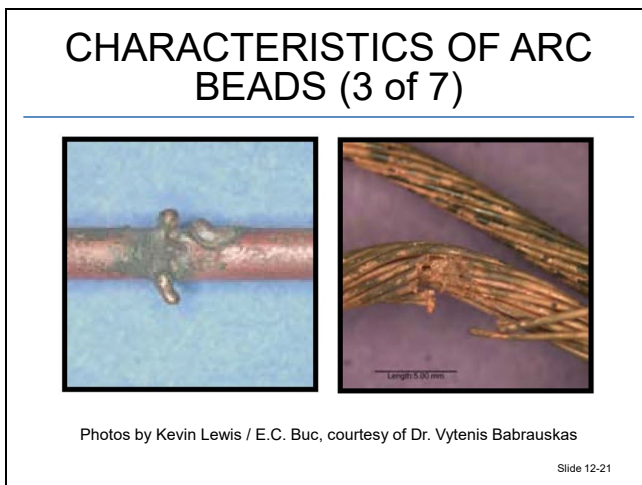
Slide 12-19

D. Characteristics of arc beads.

1. The slide displays a photo of a sharp line of demarcation between damaged and undamaged areas.



2. The slide displays a photo of conductors with a round and smooth bead.



3. The slide displays a photo of localized point of contact. Note that only a few conductors show electrical activity.

CHARACTERISTICS OF ARC BEADS (4 of 7)

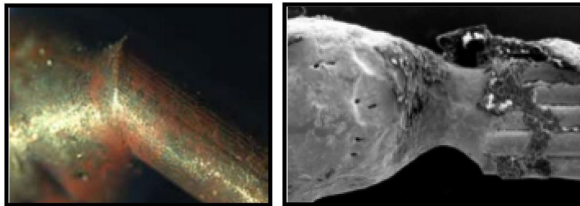


Photo by Kevin Lewis, courtesy of Dr. Vytenis Babrauskas

Slide 12-22

4. The slide displays a photo of an identifiable corresponding area of damage on an opposing conductor, which is common to find on a circuit.

CHARACTERISTICS OF ARC BEADS (5 of 7)



Photos by Kevin Lewis, courtesy of Dr. Vytenis Babrauskas

Slide 12-23

5. The slide displays a photo of copper drawing lines visible outside of the damaged area. Note the manufacturer's striations, and that the bead and the remainder of the conductor are still intact.

CHARACTERISTICS OF ARC BEADS (6 of 7)



Photos by David Reiter / Kevin Lewis, courtesy of Dr. Vytenis Babrauskas

Slide 12-24

6. The slide displays a photo of localized round depressions.

CHARACTERISTICS OF ARC BEADS (7 of 7)

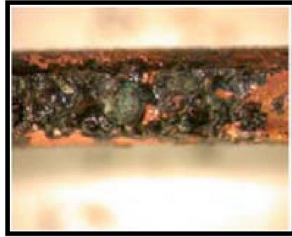


Photo by Nick Carey, courtesy of Dr. Vytenis Babrauskas

Slide 12-25

7. The slide displays a photo of small beads and divots over a small area.

CHARACTERISTICS OF MELT GLOBULES (1 of 5)

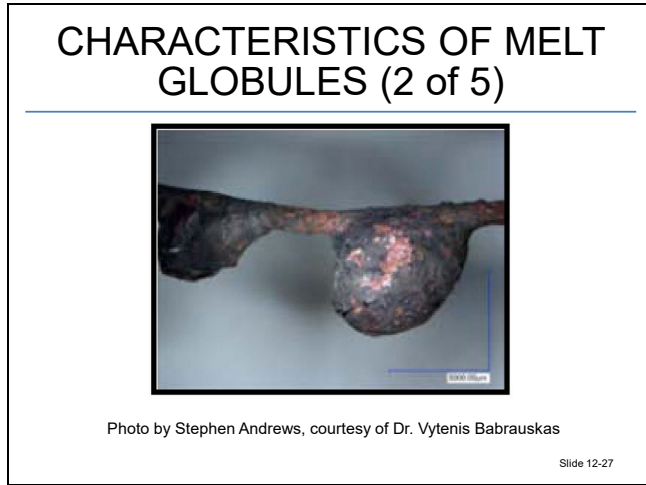


Photos by Yasuki Hagimoto / E.C. Buc, courtesy of Dr. Vytenis Babrauskas

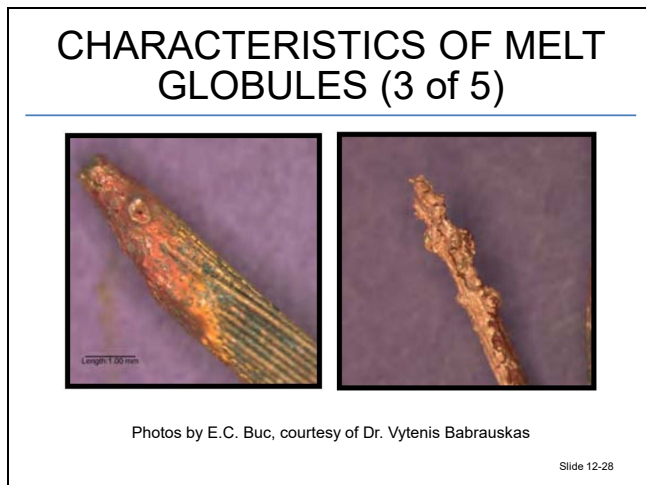
Slide 12-26

E. Characteristics of melt globules.

1. The slide displays a photo of an extended area of damage without a sharp line of demarcation between that area and undamaged material. Note the pulling or running effect and that there is no distinctive demarcation.



2. The slide displays a photo of visible effects of gravity in the artifact. Note multiple globules.



3. The slide displays a photo of blisters on the surface. Notice the material melts, runs and drips, and then resolidifies.

CHARACTERISTICS OF MELT GLOBULES (4 of 5)



Photo by Jeremy Neagle – Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)

Slide 12-29

4. The slide displays a photo of gradual necking of the conductor.

CHARACTERISTICS OF MELT GLOBULES (5 of 5)

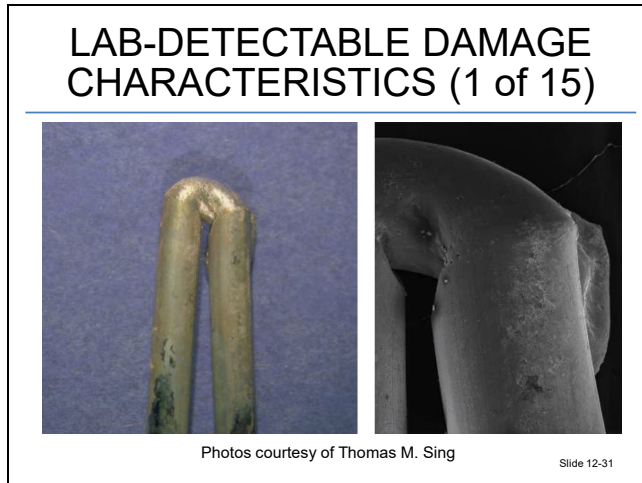


Photo by Michael Keller - ATF

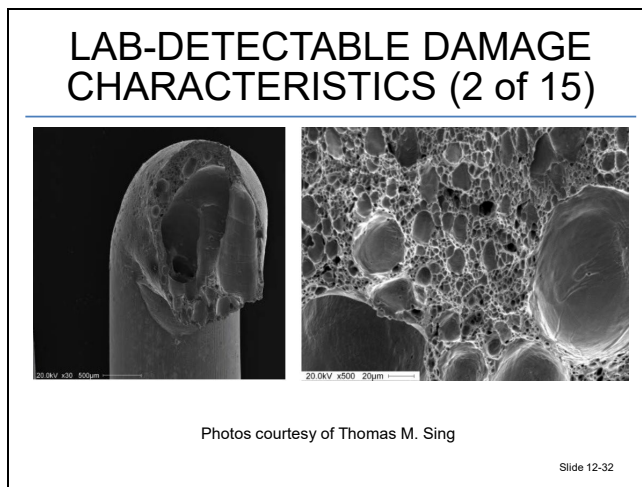
Slide 12-30

5. The slide displays a photo of nonlocalized loss of integrity of individual strands on a stranded conductor.

III. LAB-DETECTABLE DAMAGE CHARACTERISTICS

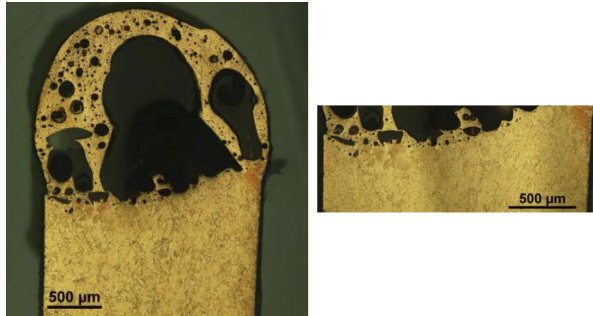


- A. Microscopy may be required to discern damage.
- B. The conductors shown on the slide were fused together from arcing through char. The right image shows the same conductors through a scanning electron microscope (SEM) and shows the copper drawing lines and a sharp line of demarcation.



- C. The conductors from the previous slide were broken apart, and the joint was visualized using an SEM. The images on the slide show the high porosity associated with rapid cooling from an arcing event.

LAB-DETECTABLE DAMAGE CHARACTERISTICS (3 of 15)

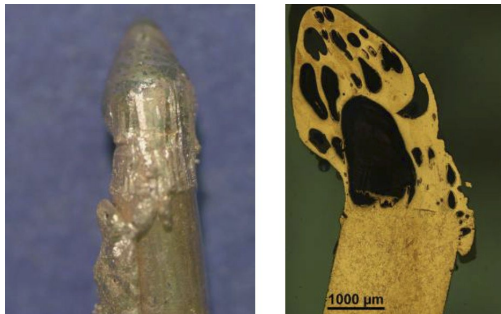


Photos courtesy of Thomas M. Sing

Slide 12-33

- D. On the slide, high magnification of a cross-section of the same conductor shown in the previous slide shows the high internal porosity and sharp line of demarcation between damaged and undamaged areas.

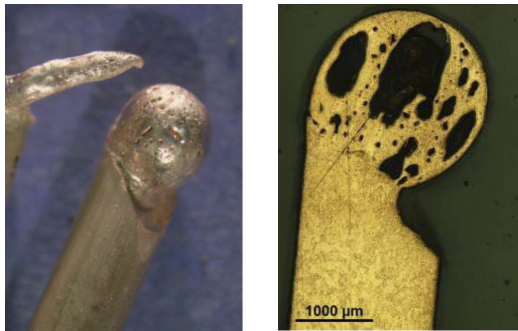
LAB-DETECTABLE DAMAGE CHARACTERISTICS (4 of 15)



Photos courtesy of Thomas M. Sing

Slide 12-34

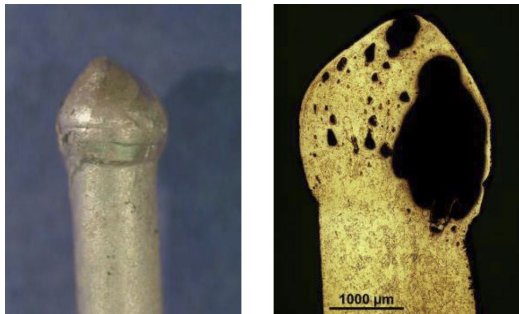
- E. The damage on the conductor shown on the slide is the result of an electrical arc. Note the internal porosity and sharp line of demarcation between damaged and undamaged areas of the conductor.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (5 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-35

- F. The damage on the conductor shown on the slide is the result of an electrical arc. Again, notice the internal porosity and sharp line of demarcation between damaged and undamaged areas of the conductor.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (6 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-36

- G. The damage on the conductor shown on the slide is the result of an electrical arc. Internal porosity and the sharp line of demarcation between damaged and undamaged areas of the conductor are present.

LAB-DETECTABLE DAMAGE CHARACTERISTICS (7 of 15)



Photos courtesy of Thomas M. Sing

Slide 12-37

- H. The damage on the conductor shown on the slide is the result of an electrical arc. Notice the internal porosity and sharp line of demarcation between damaged and undamaged areas of the conductor.

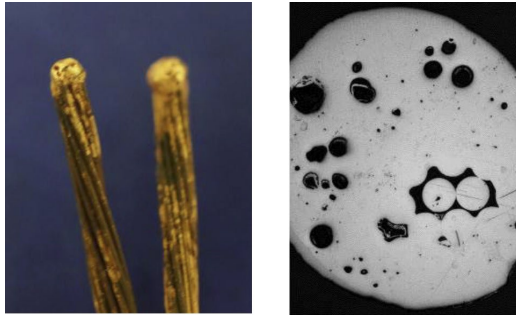
LAB-DETECTABLE DAMAGE CHARACTERISTICS (8 of 15)



Photos courtesy of Thomas M. Sing

Slide 12-38

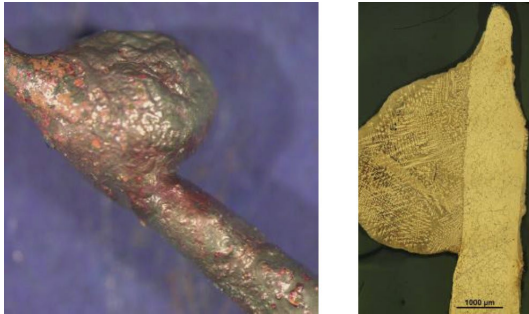
- I. The damage on the conductor shown on the slide is the result of an electrical arc. This is a stranded conductor; the right image is a cross-section of the conductor viewed from the end of the conductor looking down. Note the high porosity in the quickly resolidified material.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (9 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-39

- J. The damage on the conductor shown on the slide is the result of an electrical arc. This is a stranded conductor; the right image is a cross-section of the conductor viewed from the end of the conductor looking down. Note the areas of porosity, and notice that two of the individual strands can be readily identified.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (10 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-40

- K. The damage on the conductor shown on the slide is the result of thermal melting. Note the lack of porosity and the nonlocalized area of damage.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (11 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-41

- L. The damage on the conductor shown on the slide is the result of thermal melting. The lack of porosity and the absence of a clear line of demarcation are indicative of thermal melting.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (12 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-42

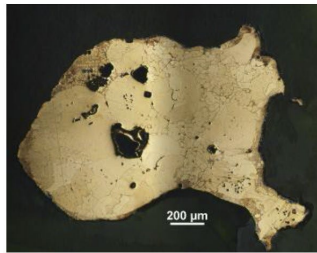
- M. The damage on the conductor shown on the slide is the result of thermal melting. The lack of porosity and the absence of a clear line of demarcation point to thermal melting.

**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (13 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-43

- N. The damage on the conductor shown on the slide is the result of thermal melting. Note the lack of extensive porosity, and the absence of a sharp line of demarcation between areas of damage, as well as the absence of damage.

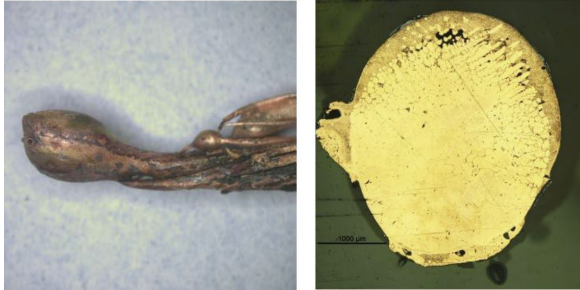
**LAB-DETECTABLE DAMAGE
CHARACTERISTICS (14 of 15)**

Photos courtesy of Thomas M. Sing

Slide 12-44

- O. The damage on the conductor shown on the slide is the result of thermal melting. Notice the lack of extensive porosity and the nonlocalized area of damage.

LAB-DETECTABLE DAMAGE CHARACTERISTICS (15 of 15)



Photos courtesy of Thomas M. Sing

Slide 12-45

- P. The damage on the conductor shown on the slide is the result of thermal melting. A lack of porosity in the globule is indicative of thermal melting.

IV. BLOWOUTS

BLOWOUTS



Slide 12-46

- A. General.

1. “Blowouts” or “snake arcs” in panelboards, such as those shown here, are caused by the enclosure being heated from fire attack. This heat is conducted to the insulation of the conductors inside, which then melts away and allows the conductor and the grounded enclosure to make contact, creating a short circuit. The damage is often extensive because the larger incoming feed conductors are protected by high-amperage breakers — if they are protected at all. Referring back to service entrances, remember that the feed conductors from the utility company side usually do not have over-current protection and will continue arcing and melting away until they can no longer physically contact each other. In larger structures, this type of evidence can be used as an electrical arc fault point, indicating that electricity was present at this panel at the time it was attacked by fire. If a panelboard has conductors inside that are melted and compromised — and in contact with the enclosure (or other conductors of different potential) — but without any type of arcing damage evident, it can be assumed that those conductors were not energized at the time of the fire attack.

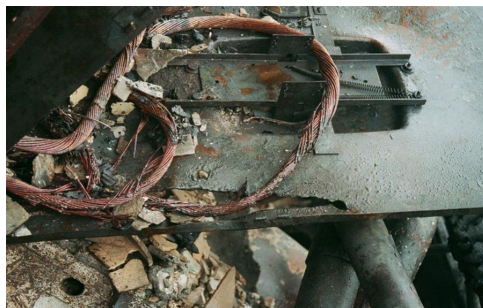
BLOWOUTS (cont'd.)



Slide 12-47

2. The slide displays another example of a fire attack on an enclosure with energized conductors.

BLOWOUT: ARC DAMAGE



Slide 12-48

3. The slide displays a photo showing arc damage to an enclosure with corresponding arc damage on an adjacent conductor.

ARC FAULT DAMAGE-FLAME IMPINGEMENT

Remember that between the transformer and the service panel there is no over-current protection.

Grounded

Notice how the supply conductors are routed against the metal enclosure.

As the fire attacks the panel, the metal begins to heat up. The insulation between the metal enclosure and the supply conductors melt. This allows the conductor to arc to the enclosure. Because there is no overcurrent device, the arcing can occur in multiple locations and for long periods. The result is long, snaky arc burn holes in the enclosure adjacent to the conductors. The conductors exhibit arcing and melting. This type of damage is commonly mistaken for fire causation, but is almost always the result of an external attack by fire.

Slide 12-49

4. The diagram on the slide shows how the routing of service conductors within a panelboard enclosure is conducive to melting from fire attack and resultant arcing.

BLOWOUT IN CONDUIT (1 of 8)

Slide 12-50

5. Blowouts in conduits, such as the one shown here on the slide, occur for the same reason as blowouts at service panels: The insulation of a conductor pressed against the wall of the conduit is raised to melting temperature from fire attack, causing the two to come in direct contact and short circuit. With low-voltage systems, the blowout of material seen here is the result of preheating (and softening) of the conduit before the arc activity occurs. Without the preheating of flame impingement, it is difficult to have material blowout like this at lower voltages.
6. At higher voltages, such as a 480-volt (V) system, it is possible to see this type of damage from mechanically caused conductor arcing. Example: long-term chafing from vibration.

7. This type of damage will most often be found at elbows and transition points where the conductors are pressed or pulled tightly against the conduit material.
8. This type of damage indicates that the conductor was energized at the time of the fire attack. It does not indicate the fire cause.

BLOWOUT IN CONDUIT (2 of 8)



Slide 12-51

9. The slide displays an example of conduit blowout from a fire attack.

BLOWOUT IN CONDUIT (3 of 8)



Slide 12-52

10. The slide displays an example of conduit blowout from a fire attack.

BLOWOUT IN CONDUIT (4 of 8)



Slide 12-53

11. The slide displays an example of conduit blowout from a fire attack.

BLOWOUT IN CONDUIT (5 of 8)



Slide 12-54

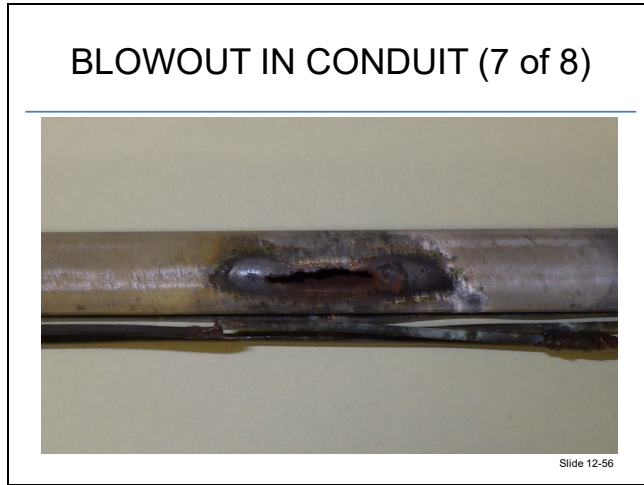
12. The slide displays a photo that shows the conductor insulation failure and the resulting conduit blowout.

BLOWOUT IN CONDUIT (6 of 8)

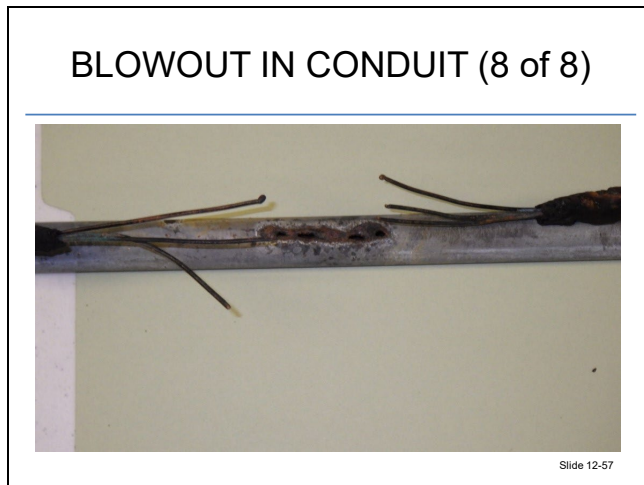


Slide 12-55

13. This example of conduit blowout on the slide was created during a lab at the burn cells. It is caused by preheating of the conduit before conductor failure, because the 120 V circuit within the conduit, which was protected by a 20-ampere (amp) breaker, does not have the energy potential to create this type of damage.

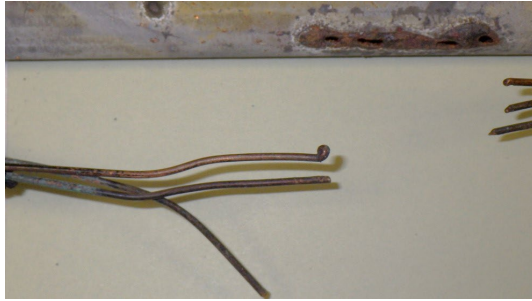


14. The slide displays a closeup photo of conduit blowout from the previous slide.



15. The slide provides another example of conduit blowout. Note the corresponding damage to the conductors, indexed to their location and removed from the conduit for inspection.

BLOWOUT IN CONDUIT (cont'd.)



Slide 12-58

16. Conductors: The slide displays a photo of a closeup of the conductors from the previous slide.

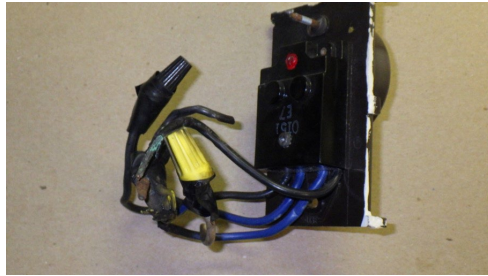
BLOWOUT IN CONDUIT (cont'd.)



Slide 12-59

17. Severed conductors: The slide displays a photo of a closeup of a severed conductor from the previous slide. Note the sharp line of demarcation between the ball of molten copper and the undamaged conductor immediately adjacent to it.

THERMOSTAT



Slide 12-60

- B. Thermostat: The slide displays a photo of a thermostat removed from service. Note the discoloration and corrosion of conductor material, as well as the melting of the plastic wire nut caused by a high-resistance connection (HRC).

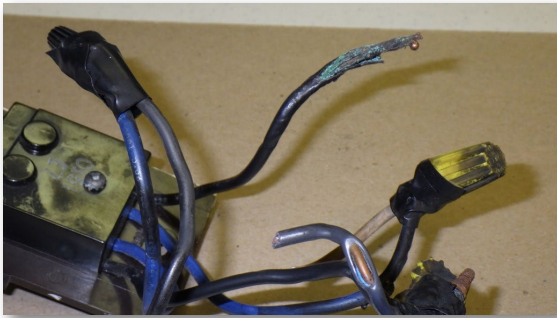
SHORT CIRCUIT



Slide 12-61

- C. Short circuit: The slide displays a closeup view from the previous slide. The bead of molten copper resulted from a short circuit.

ARC DAMAGE ON WIRE



Slide 12-62

D. Arc damage on wire.

1. The slide displays another photo of the arc damage in the conductor.

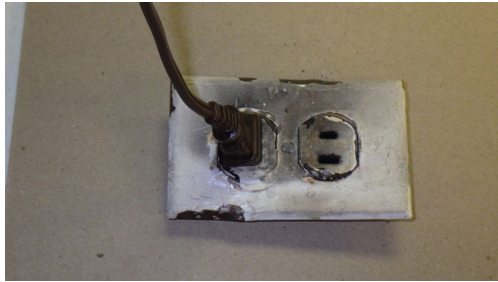
ARC DAMAGE ON WIRE (cont'd.)



Slide 12-63

2. The slide shows a closeup of arc damage. Note the relatively undamaged areas of a stranded conductor that is adjacent to a ball of melted material. This indicates the instantaneous heating and cooling associated with electrical arcing.

ARC DAMAGE CASE STUDY (1 of 3)



Slide 12-64

E. Arc damage case study.

1. The outlet, cord and faceplate shown on the slide were removed from a room in which a mattress fire occurred. The power cord could not be removed from the receptacle, and there were no visible external signs of damage or electrical activity.

ARC DAMAGE CASE STUDY (2 of 3)



Slide 12-65

2. When the receptacle was removed from the junction box, it was found that the lower half of the mounting/ground yoke had separated, and visible melting of the brass contacts within the receptacle had occurred as shown.

ARC DAMAGE CASE STUDY (3 of 3)



Slide 12-66

3. The slide illustrates the localized melting of the brass contacts within the receptacle from an HRC, which leads to the hypothesis that a fault occurred, which caused molten material to eject and ignite the adjacent mattress.

ARC DAMAGE CASE STUDY (cont'd.)



Slide 12-67

4. Terminal screw: The slide illustrates the damage caused when a terminal screw was not properly tightened.

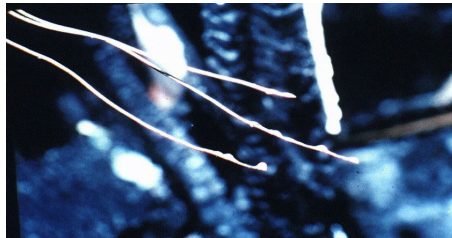
ARC DAMAGE



Slide 12-68

- F. Arc damage on large conductors: The slide shows the typical electrical arc damage found on large conductors. They are comprised of strands of smaller wire, so the damage becomes more visible.

HEAT-DAMAGED WIRE



Slide 12-69

- G. Heat-damaged wire.
1. De-energized melting: The wire was exposed to temperatures in excess of 1,980 °F and has a tapered appearance. Balls and globules appeared in several locations, and the wire became brittle and easily fractured.
 2. Gravity affects the direction and size of physical changes in copper wire. It will often have a pulled, stretched or jagged appearance, and small blisters may also form on the skin of the conductor. The heating/cooling is of longer duration; therefore, the lines of demarcation will not be as defined as they would be with electrical arc damage.

V. KNOWLEDGE CHECK

KNOWLEDGE CHECK (1 of 23)

Form an opinion based on the damage noted.

Electrical Activity

Thermal Melting

Mechanical

Unknown

Slide 12-70

- A. Determine, based on the arc, whether the fire was electrical, thermal, mechanical or of an unknown cause.

KNOWLEDGE CHECK (2 of 23)



Slide 12-71

KNOWLEDGE CHECK (4 of 23)



Slide 12-73

KNOWLEDGE CHECK (6 of 23)



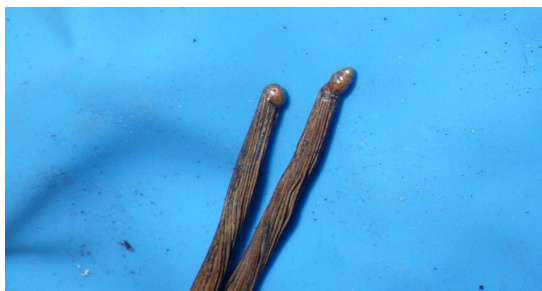
Slide 12-75

KNOWLEDGE CHECK (8 of 23)



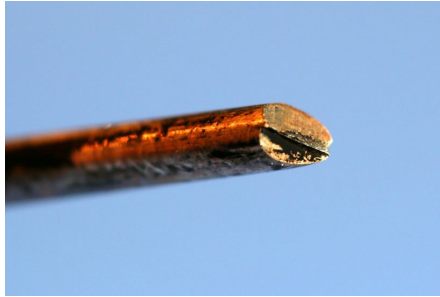
Slide 12-77

KNOWLEDGE CHECK (10 of 23)



Slide 12-79

KNOWLEDGE CHECK (12 of 23)



Slide 12-81

KNOWLEDGE CHECK (14 of 23)



Slide 12-83

KNOWLEDGE CHECK (16 of 23)



Slide 12-85

KNOWLEDGE CHECK (18 of 23)



Slide 12-87

KNOWLEDGE CHECK (20 of 23)



Slide 12-89

KNOWLEDGE CHECK (22 of 23)



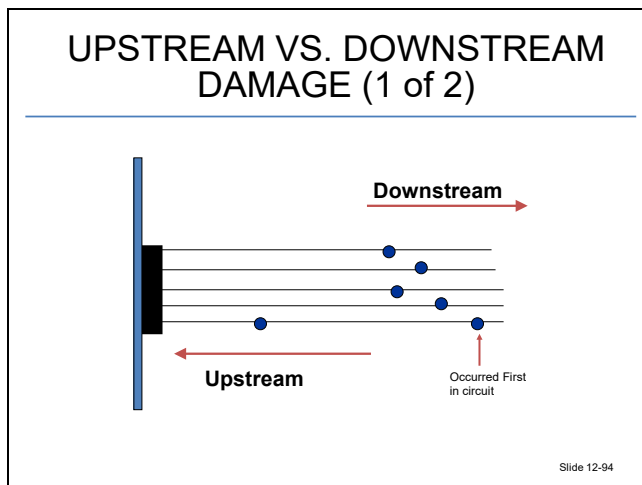
Slide 12-91



B. Do not be deceived.

Sometimes, like the bunny rabbits pictured on the slide, the conductor damage will look the same from the exterior. Mark them for further analysis!

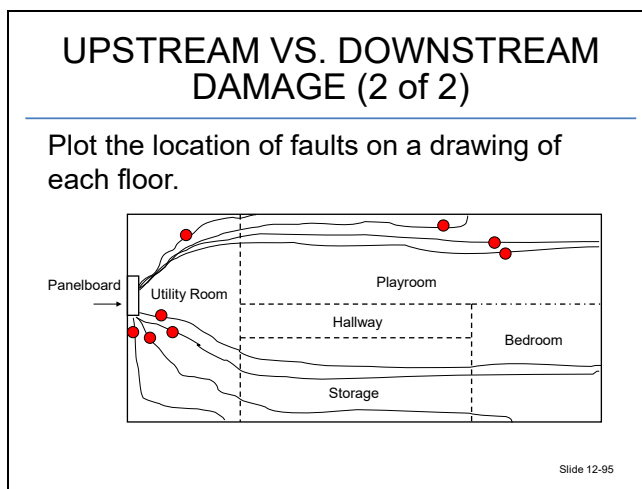
VI. UPSTREAM VERSUS DOWNSTREAM



A. NFPA 921, Section 6.6.8.

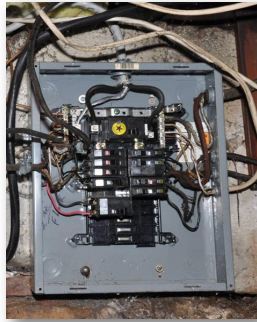
1. NFPA 921 describes “upstream” as the conductors between a specific location and the source of power (such as the panelboard), and “downstream” as the remaining conductors heading away from the source of power.
2. If the lower conductor was found to have two locations of arc damage, the sequence must be determined. If one arc is a conductor-severing event, then it can be reasonably determined that any arc damage downstream of that break occurred first.

3. A cluster of arc damage may be used as an indicator of fire origin. If a cluster of arc damage occurs in one area, and an outlier is located, the outlier of arc damage does not negate the value of the cluster.
4. If breakers are tripped, the number of tripped breakers or blown fuses indicates the minimum number of faults. For example, if six breakers are tripped, there are at least six faults, but there could be many more faults. However, do not assume there are no faults if no breakers are tripped. For example, fire department personnel may turn them off, unaware of the importance in an investigation.
5. Locate all faults and tag with tape.



6. In this example, the fire could not have started in the utility room. Taking into account concealment of wires, the arc faults found in the playroom indicate that the fire attacked the energized conductors there first. Had the fire started in the utility room, those same conductors would have been de-energized there by fire attack with arc damage present, and no downstream arcing would have been found in the playroom.

TRIPPED CIRCUIT BREAKERS

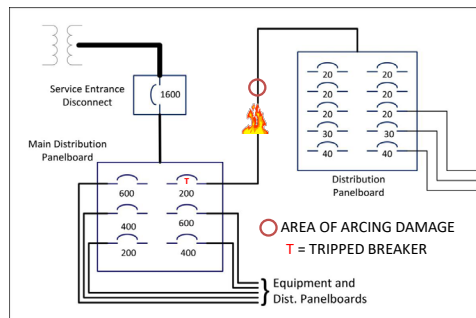


Slide 12-96

B. Tripped circuit breakers.

1. Tripped circuit breakers in an undamaged panelboard may provide a basis for tracing circuits.
2. Identify thermal trip patterns that may be misleading.
3. Determine which circuits may be compromised by inspecting the position of breakers in the panel.
4. Determine if any breakers were turned off prior to the fire by conducting interviews. (Remember that Cutler Hammer (CH) breakers can trip to the off position.)

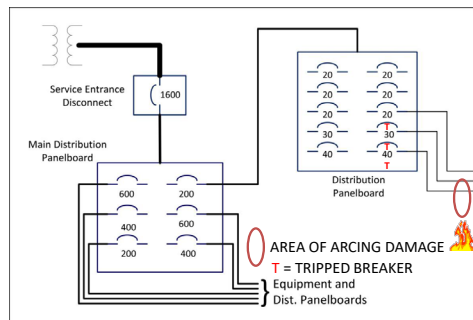
PANEL/SUBPANEL



Slide 12-97

5. In this example, a fire that compromises the feeder conductors to the subpanel first would be expected to trip the 200-amp breaker in the main distribution panel.

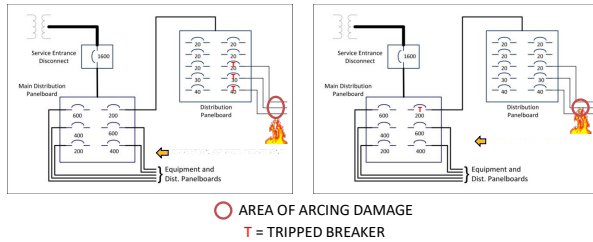
PANEL/SUBPANEL (cont'd.)



Slide 12-98

6. In this example, a progressing fire that compromises the branch circuit conductors downstream from the subpanel **first** would be expected to trip the individual breakers of each of those circuits.

CASCADING BREAKERS



Slide 12-99

7. When simultaneous damage occurs to multiple circuits of a subpanel, it is referred to as cascading breakers. The damage results in high current flow that can trip a larger breaker in a feeder panel upstream.

VII. CASE STUDIES

CASE STUDIES

Slide 12-100

CASE STUDY 1

- Basement fire.
- September 2013.
- Kingston, PA.
- Accidental fire.
- Contained to basement.

Slide 12-101

- A. Case study 1.
1. Basement fire.
 2. September 2013.
 3. Kingston, Pennsylvania.
 4. Accidental fire.
 5. Contained to basement.

PANEL



Slide 12-102

6. The panel on the slide shows four circuits tripped, indicating possible existence of at least four arc sites.

CONDUCTORS



Slide 12-103

7. The slide provides an overview of fire damage. Note the conductors running perpendicular to joist cavities.

OVERVIEW OF DAMAGED AREA



Slide 12-104

8. The slide provides an overview of a damaged area. The wall in the background is painted cardboard.

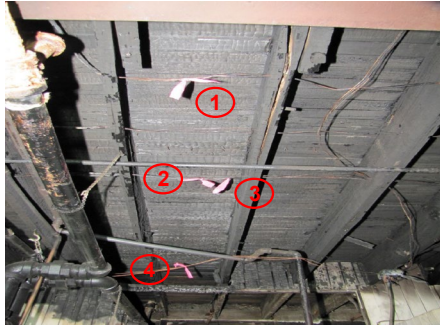
SUSPECTED AREA OF ORIGIN



Slide 12-105

9. The slide provides an overview of the suspected area of origin, pre-arc mapping survey.

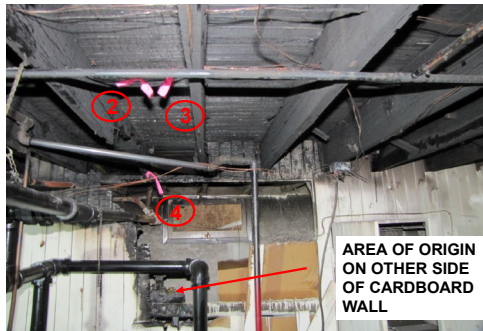
ARC SITES



Slide 12-106

10. On the slide, arc sites are identified with surveyor's tape. Arc damage in four different circuits was located and identified in the single joist bay above the suspected area of origin.

ARC LOCATIONS



Slide 12-107

11. The slide shows arc locations in relation to the suspected area of origin.

CAUSE



Slide 12-108

12. As shown on the slide, cause was determined to be an unprotected 100 watt (W) lightbulb that was on and in direct contact with the cardboard wall.

CASE STUDY 2

- Double-fatality house fire.
- December 2015.
- Emmitsburg, MD.
- Accidental fire.
- Originated in living room.
- Two fatalities.

Slide 12-109

B. Case study 2.

1. Double-fatality house fire.
2. December 2015.
3. Emmitsburg, Maryland.
4. Accidental fire.
5. Originated in living room.
6. Two fatalities.

OVERVIEW OF POSSIBLE ORIGIN



Slide 12-110

7. The slide provides an overview of room of origin. Note the location of the Christmas tree in front of the window.

FIRE PATTERN



Slide 12-111

8. Fire patterns and witness statements placed the origin in the area of the rocking chair on the left side of photo.
9. A witness stated he was sitting in the rocking chair when the decorative lights on the Christmas tree went out.
10. The witness got out of the chair and went to investigate the breaker panel in the kitchen hallway.

TRIPPED BREAKER



Slide 12-112

11. After the witness found the tripped breaker shown, he re-energized the breaker. He then heard a humming noise at the breaker panel, and the breaker subsequently tripped again.
12. The witness returned to the living room and observed fire in the area behind the rocking chair.

REMNANTS OF A TWO-CONDUCTOR CORD



Slide 12-113

13. The slide shows the remnants of a two-conductor, 16-American Wire Gauge (AWG) extension cord found entangled in the rocking mechanism of the chair.

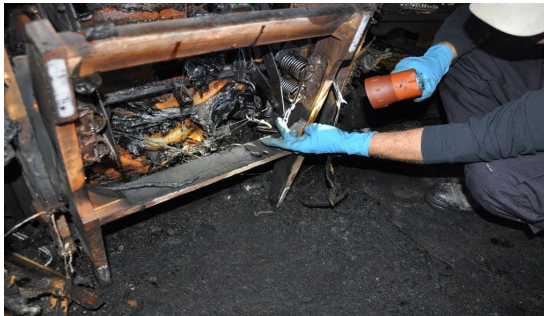
BURN PATTERN



Slide 12-114

14. In the image on the slide, note the burn pattern on the bottom of the chair consistent with burning in the area that should have been protected if the fire originated outside of the chair base.

EXTENSION CORD ENTANGLEMENT



Slide 12-115

15. The slide shows entanglement of an extension cord in the rocking mechanism of the chair.

ARC-SEVERED WIRE



Slide 12-116

16. The slide shows an arc-severed wire end removed from the rocking mechanism of the chair.

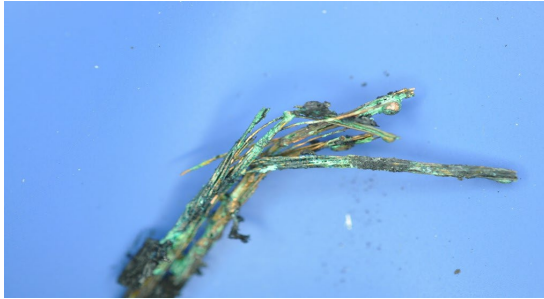
ELECTRICAL ARC LOCATION



Slide 12-117

17. The slide illustrates the examination of conductors of an extension cord, which were found to have multiple electrical arc locations with corresponding beads.

CONDUCTOR



Slide 12-118

18. The slide displays a closeup photo of a conductor showing arc beads.

CONDUCTOR (cont'd.)



Slide 12-119

19. The slide displays another closeup photo of a conductor showing arc beads.

CASE STUDY 3

- Convenience store fire.
- April 2004.
- Bloomsburg, PA.
- Incendiary fire.

Slide 12-120

- C. Case study 3.
1. Convenience store fire.
 2. April 2004.
 3. Bloomsburg, Pennsylvania.
 4. Incendiary fire.

UNIMART FIRE, BLOOMSBURG, COLUMBIA COUNTY, PA



5. The fire occurred in a 24-hour convenience store. One employee was on duty at the time of the fire.
6. The photo on the slide shows an overview of damage from the store's exterior. Note the heating, ventilating, and air conditioning (HVAC) units on the roof.

CONDUIT BLOWOUT



7. The fire chief believed the cause of the fire was electrical, based on a conduit blowout in the area of origin shown. The conduit fed the HVAC unit on the roof.

SERVICE EQUIPMENT



Slide 12-123

8. The slide displays a photo of service equipment.

CONDUIT BLOWOUT



Slide 12-124

9. The slide shows an overview of the ceiling area above the area of origin. The conduit blowout that was suspected to be the cause is circled.
10. Conduit blowout is almost always the result of a fire attack, not electrical failure.

LIGHT FIXTURE



Slide 12-125

11. The slide shows a fluorescent light fixture rehung in its original position as part of scene reconstruction. The fixture was directly over the area of origin and source of fuels.
12. Note the heavy damage and oxidation of the fixture housing on the near end, in comparison to the damage on the far end.

COMBUSTIBLE RACK STORAGE



Slide 12-126

13. The slide shows the combustible rack storage beneath the lighting fixture. The damage to the rack shelves is consistent with fire on the near end of bench.
14. Subsequently, an employee admitted to setting the fire. This employee had a history of setting and discovering fires.

CASE STUDY 4

- Caesar's Paradise Stream Resort fire.
- April 2003.
- Mount Pocono, PA.
- Undetermined cause.

Slide 12-127

D. Case study 4.

1. Caesar's Paradise Stream Resort fire.
2. April 2003.
3. Mount Pocono, Pennsylvania.
4. Undetermined cause.
5. Fire occurred at the occupied resort at approximately 7 a.m. There were no witness statements because all customers left the scene. The guest registry proved useless.

FIRE DAMAGE



Slide 12-128

6. The slide displays an aerial photo of fire damage. Note the direction of north for orientation of upcoming photos.
7. The red circle on the slide shows the three-phase service entrance that entered the building at the north end in a laundry room, going into a 1,200-amp distribution panel that then fed subpanels for groups of guest rooms.

SUSPECTED AREA OF ORIGIN



Slide 12-129

8. The slide displays an aerial photo of the suspected area of origin.

UNDAMAGED SECTION OF BUILDING



Slide 12-130

9. As shown, the remainder of the building was undamaged and provided exemplars of equipment and electrical service associated with each individual guest room.

FIRE BREAK CREATION



Slide 12-131

10. As seen on the slide, heavy equipment was used to create a fire break between damaged and undamaged areas.

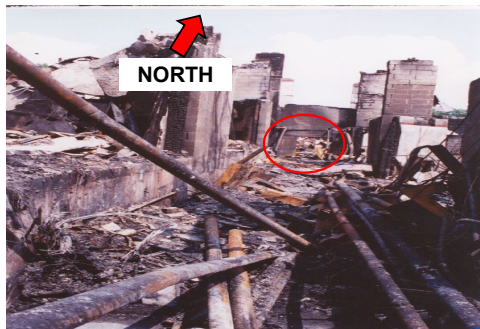
UNDAMAGED SERVICE CORRIDOR



Slide 12-132

11. The slide displays a photo of an undamaged service corridor that ran down the middle of the structure, with individual equipment that served each guest room.
12. Each guest room had its own pool pump, water heater and real wood fireplace. A 150-amp service panel served every two rooms to support the equipment and related circuits.
13. Each of these electrical sources in the burned area had to be located, and attempts had to be made to rule them out as causes of the fire.

DISTRIBUTION PANEL



Slide 12-133

14. The slide shows the view facing north. Photo depicts the interior of the service corridor. Note the main distribution panel at the far-north end and the large conduits that ran overhead to subpanels.

MAIN DISTRIBUTION PANEL



Slide 12-134

15. The slide displays a closeup photo of the suspected area of origin. The red circle shows the location of the main distribution panel.
16. Fire patterns in the remaining wall studs showed a pattern consistent with an area of origin in proximity to the white circle, which is where ashes from the fireplaces were discarded into metal containers.

MAIN DISTRIBUTION PANEL (cont'd.)



Slide 12-135

17. The slide displays an overview photo of the main distribution panel location.

CLOSEUP OF DISTRIBUTION PANEL



Slide 12-136

18. The slide displays a closeup photo of the distribution panel. Heavy fire damage to breakers rules out any relevance of their handle position and operational status.

BLOWOUT



Slide 12-137

19. On the slide, note the “snaking” or blowout from the fire attack on the panel and the subsequent failure of conductor insulation. The absence of any OCPD is what allowed damage this significant to occur.

CONDUIT BLOWOUT



Slide 12-138

20. As shown in the image, the areas of conduit blowout due to fire attack were located, marked and mapped. No remaining conductors were found in the conduit. They were aluminum and completely melted away due to the fire's intensity and high heat level.

ADDITIONAL CONDUIT BLOWOUT (1 of 4)



Slide 12-139

21. The slide displays a photo of additional conduit blowouts that were located.

ADDITIONAL CONDUIT BLOWOUT (2 of 4)



Slide 12-140

22. The slide shows another photo of additional conduit blowouts that were located.

ADDITIONAL CONDUIT BLOWOUT (3 of 4)



Slide 12-141

23. The slide displays another photo of additional conduit blowouts that were located.

ADDITIONAL CONDUIT BLOWOUT (4 of 4)



Slide 12-142

24. The slide displays a conduit blowout shown in relation to the suspected area of origin. No other conduit blowout or arcing damage was located downstream of this damage area.



25. Inspection of the panels damaged by the fire — located downstream of the arcing damage and conduit blowout in the feeder conduit — showed no arcing within the panels or arcing damage in the branch circuits fed by them, as illustrated on the slide.
26. If these panels had been energized and exposed to fire attack first, evidence of arcing damage would be expected within the panel from conductor insulation failure caused by the fire, or in the branch circuits wiring in the service corridor.



27. The slide displays an overview of the suspected area of origin and fire patterns in the stud walls.

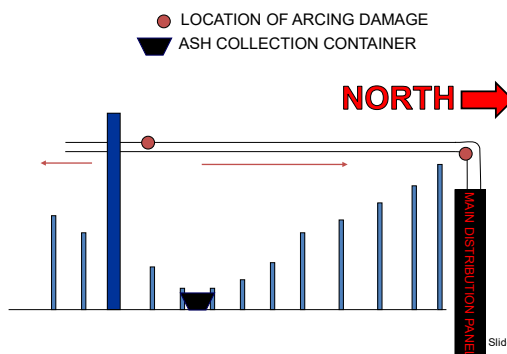
V-PATTERN



Slide 12-145

28. On the slide, note the “V” pattern formed by the heights of remaining wall studs.

LOCATION OF ARCING DAMAGE



Slide 12-146

29. The slide displays a diagram of wall stud lengths and the location of arc damage. The location of arc damage and the lack of arc damage downstream from these locations — in conjunction with other factors, such as fire patterns and consideration of fire dynamics — strongly support the conclusion that the area of origin was in the area of the ash collection containers.

VIII. LIMITATIONS OF ARC FAULT MAPPING

LIMITATIONS OF ARC FAULT MAPPING

- Failure to identify the key components of the distribution system.
- Failure to identify arc damage on conductors.
- Complete destruction of the branch circuit conductors.
- Inability to trace circuits back to the source.

Slide 12-147

A. Limitations.

1. Failure to identify the key components of the distribution system.
2. Failure to identify arc damage on conductors.
3. Complete destruction of the branch circuit conductors.
4. Inability to trace circuits back to the source.

LIMITATIONS OF ARC FAULT MAPPING (cont'd.)

- Melting of conductors from fire exposure.
- Post-fire re-energizing of the electrical system (generators, UPS systems, breakers being turned back on).
- Failure to expend adequate effort and/or resources.

Slide 12-148

5. Melting of conductors from fire exposure.
6. Post-fire re-energizing of the electrical system (generators, uninterruptible power supply (UPS) systems, breakers being turned back on).
7. Failure to expend adequate effort and/or resources.

KEYS TO SUCCESS

Know how electricity is distributed through any given structure.

Use the interview process to identify which circuits should have been energized and which were known to be energized.

Slide 12-149

B. Keys to success.

1. Know how electricity is distributed through any given structure.
2. Use the interview process to identify which circuits should have been energized and which were known to be energized.

KEYS TO SUCCESS (cont'd.)

Begin an evaluation at the primary distribution system and follow it to the end, regardless of the fire damage.

Collect all data using investigative tools, and evaluate the results before making a final conclusion.

Slide 12-150

3. Begin an evaluation at the primary distribution system and follow it to the end, regardless of the fire damage.
4. Collect all data using investigative tools, and evaluate the results before making a final conclusion.

IX. LAB ACTIVITY DEMONSTRATIONS

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ACTIVITY 12.1

Ohm's Wall

Purpose

Develop a hypothesis using arc mapping to determine which fire started first. To apply knowledge of the characteristics of thermal, electrical and mechanical damage to conductors, examine the conductors found in Ohm's wall, and determine if any damage found was caused by thermal, electrical or mechanical impact.

Materials

- Ohm's wall.
- Multiple colors of surveyor's tape.
- Gloves.
- Tools.

Safety

Students are required to wear eye protection during the Ohm's wall examination. We also recommend using latex/nitrile gloves during the exercise to prevent contamination of skin from burned or charred debris. Some conductors or conduit may have sharp edges, so use caution when examining or removing conductors in these situations. The students must report any injury immediately to the instructor.

Directions

1. Each group will examine half of the conductors. One group will examine the circuits controlled by breakers on the panel's left side, and the other group will examine the circuits controlled by breakers on the panel's right side.
2. Your group will attempt to locate any damage to the assigned conductors, and if found, make a determination as to whether that damage is thermal, electrical or mechanical in nature. If your group determines that the damage is electrical, flag it with a piece of surveyor's tape.
3. At the conclusion of the examination of the assigned conductors, your group will make a hypothesis as to which of the fires was started first based upon your examination of the conductors and the categorization of any damage found.

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ACTIVITY 12.2

Artifact Identification

Purpose

Make a determination as to the cause of the damage to each of the conductors using the provided numbered artifacts.

Materials

- Artifacts 1 through 21.
- Handheld or headgear-style magnifying glasses.
- Pro-scope digital microscope.

Directions

1. Using the handheld or headgear-style magnifying glasses, or the digital microscope, work together to determine if the damage found on each conductor is thermal, electrical or mechanical in nature.
2. Record your determination for each artifact, and when complete, your answers will be checked against the answer key.

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X. SUMMARY



SUMMARY

- Use appropriate terminology to describe arc damage.
- Given an electrical artifact, determine if the cause of the damage was electrical, mechanical, or thermal.
- Systematically employ the methodology of arc mapping.

Slide 12-153

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UNIT 13: APPLIANCE FAILURES

TERMINAL OBJECTIVE

The students will be able to:

- 13.1 *Evaluate artifacts to determine if an appliance failed, if it caused a fire, or if the appliance was damaged as a result of the fire.*

ENABLING OBJECTIVES

The students will be able to:

- 13.1 *Examine and evaluate the circuitry and operation of safety devices in household appliances.*
- 13.2 *Determine the circumstances that cause appliances to fail.*
- 13.3 *Explain existing safeguards to prevent a small household appliance from exceeding normal temperatures.*
-

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TERMINAL OBJECTIVE

Evaluate artifacts to determine if an appliance failed, if it caused a fire, or if the appliance was damaged as a result of the fire.

Slide 13-2

ENABLING OBJECTIVES

- 13.1 Examine and evaluate the circuitry and operation of safety devices in household appliances.
- 13.2 Determine the circumstances that cause appliances to fail.
- 13.3 Explain existing safeguards to prevent a small household appliance from exceeding normal temperatures.

Slide 13-3

I. OVERVIEW: ISSUES WITH APPLIANCES AND FIXTURES

APPLIANCE OVERVIEW

Electrical activity outside the appliance on the power cord typically supports the hypothesis that fire attack was the cause of the appliance failure, not that the failure was the cause.

Complete and proper electrical evaluation and analysis are typically required to make these determinations.

Slide 13-4

- A. General considerations: Arc damage inside of an appliance likely indicates fire cause. Fire damage outside of an appliance likely indicates fire attack.
1. Electrical activity outside the appliance on the power cord typically supports the hypothesis that fire attack was the cause of the appliance failure, not that the appliance failure was the cause.
 2. Complete and proper electrical evaluation and analysis are typically required to make these determinations.

ELECTRICAL APPLIANCES

- | | |
|-------------------------------|--------------------------|
| - Fluorescent light fixtures. | - Clothes dryers. |
| - Relocatable power taps. | - Microwaves. |
| - Refrigerators. | - Coffee makers. |
| - Dehumidifiers. | - Radiant space heaters. |
| - Dishwashers. | - Electronic devices. |

Slide 13-5

- B. Electrical appliances.
1. Fluorescent light fixtures.
 2. Relocatable power taps (RPTs).

3. Refrigerators.
4. Dehumidifiers.
5. Dishwashers.
6. Clothes dryers.
7. Microwaves.
8. Coffee makers.
9. Radiant space heaters.
10. Electronic devices.
11. Note: The appliances/devices mentioned above can sometimes be the ignition source of the fire.
12. Any appliance or device powered by electricity can be the source of a fire.

ELECTRICAL APPLIANCES
(cont'd.)

Electrical components can fail, mechanical damage can cause insulation to wear away from conductors, and many appliances generate heat, which can be a source of ignition.

Any electrical device can be a source of ignition.

Slide 13-6

13. Electrical components can fail, mechanical damage can cause insulation to wear away from conductors, and many appliances generate heat, which can be a source of ignition.
14. Any electrical device can be a source of ignition.

KEY POINTS

Investigators possess no legal right to disassemble appliances.

Investigators may consult a forensic engineer to examine items and ascertain the mode of failure.

Slide 13-7

C. Key points to remember:

1. Investigators possess no legal right to disassemble appliances.
2. Investigators may consult a forensic engineer to examine items and ascertain the mode of failure.

II. FLUORESCENT LIGHT INVESTIGATIONS

FLUORESCENT LIGHT INVESTIGATIONS

Two main fire-producing failure modes:

- Arc penetrations through the ballast and fixture.
- Arcing/overheating at lamp holders.

Slide 13-8

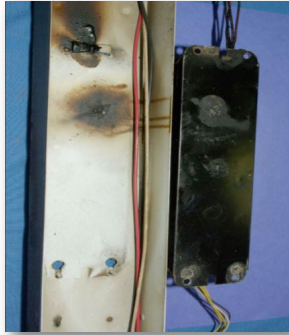
A. Two main fire-producing failure modes:

1. Arc penetrations through the ballast and fixture.
2. Arcing/overheating at lamp holders.

BALLAST WITH ARC PENETRATION

Typical arc penetration through the back of a fluorescent ballast.

Note the hot gases exiting the hole in both the ballast and fixture.



Slide 13-9

B. Arc penetrations through the ballast and fixture.

1. This is a typical arc penetration through the back of a fluorescent ballast. Note the hot gases exiting the opening in both the ballast and fixture.
2. Magnetic ballast failure can:
 - a. Occur in thermally protected ballasts.
 - b. Burn a hole through the fixture housing, usually the top.
 - Ignite combustible materials above fixture.
 - Occur through side of the ballast case.

ARCING/OVERHEATING AT LAMP HOLDERS

- Typically result of poor connection to lamps.
- Improper seating of the lamps.
- Improper spacing of lamp holders.
- Improper installation of lamp holders.



Slide 13-10

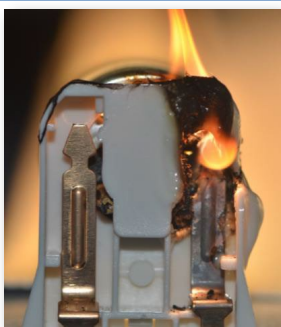
C. Arcing/overheating at lamp holders.

1. In any mechanical interface, the installation and removal of lamps can cause the contacts to spread over time, loosening and degrading the electrical connection. Improper installation can cause a loose connection and cause the socket to fail and potentially burn, as shown in the picture.

2. Overheating is typically the result of:
 - a. Poor connection to lamps.
 - b. Improper seating of the lamps.
 - c. Improper spacing of lampholders.
 - d. Improper installation of lampholders.

ARCING/OVERHEATING AT LAMP HOLDERS (cont'd.)

- More common with higher-current lamps.
- Generally occurs with instant-start circuits.
- Ballast is designed to maintain an arc, and it will.



Slide 13-11

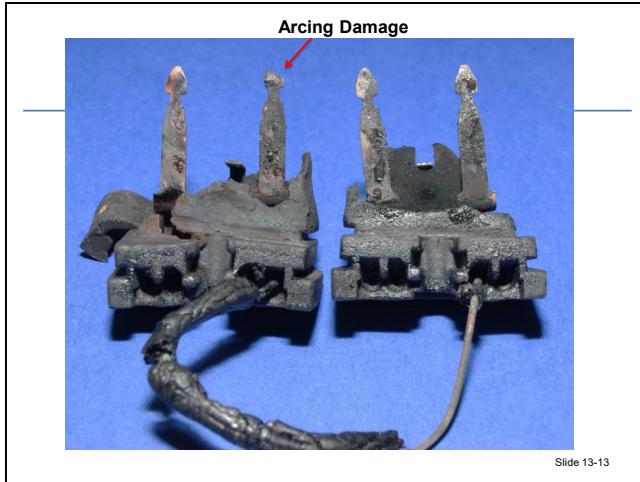
3. Overheating is more common with:
 - a. Higher-current/wattage lamps.
 - b. Instant-start circuits.



Slide 13-12

D. Example of wall-mounted fixture.

1. The item shown on the slide was a wall-mounted fixture with a lens. The occupant saw the lens/fixture on fire. The fire was blamed on the ballast. A private fire investigator sifted debris and found lampholder contacts were missing on the left side of the fixture. The contact of the lampholder showed arcing damage. Notice how the fixture is more badly damaged on the left side. That pattern is clearly seen on the ballast label. Also, notice that the wire insulation on the right end of the fixture is intact. The cause is still accidental, but liability shifted from manufacturer to consumer due to improper bulb installation.



2. The physical contacts of the lamp socket show arc damage and could allow an investigator to identify the socket as a potential point of failure.

III. RELOCATABLE POWER TAP

RELOCATABLE POWER TAP (RPT)

- Provide multiple power outlets external to a wall receptacle.
- Varying types and styles.
- Number of outlets.
- Power buses or individual outlets.
- Switched/fused/surge protection.



Slide 13-14

A. RPTs:

1. Provide multiple power outlets external to a wall receptacle.

2. Also referred to as surge protectors or power strips.
3. Come in varying types and styles: vary in quality and current-carrying capability.
4. Have a number of outlets.
5. Can be power bus strips or individual standard receptacles.
6. Provide switched/fused/surge protection.

B. RPTs can be the source of failure for multiple reasons:

1. **Overloading:** By providing additional receptacles, an end-user is able to plug numerous devices into the RPT. As a result, the potential exists to overload and overheat the RPT.
2. **Switching failures:** The switches on most RPTs are not designed to connect and disconnect high-current loads. Over time, using the RPT switch to power on and power off heavier-duty appliances can cause the switch to fail prematurely.
3. **Mechanical failure:** Over time, the contacts of the individual receptacles can start to spread. This creates a loose connection, which always increases heat that can become a source of ignition.
4. **Metal-oxide varistor (MOV):** Some power taps come with surge suppression capabilities to protect sensitive electronics. An MOV is designed to dissipate the surge energy. The MOV is not designed to handle repetitive or higher-energy surges. As a result, a failure of the MOV will cause heat, smoke and the potential for flame. The damage in the bottom picture of Slide 13-14 is likely the result of an MOV failure.



- C. RPT failure: The photo here shows a failure caused for one (or both) of two reasons: either a high-current appliance or a device plugged into the strip, overloading it at that particular outlet, and/or a failure due to a loose connection.

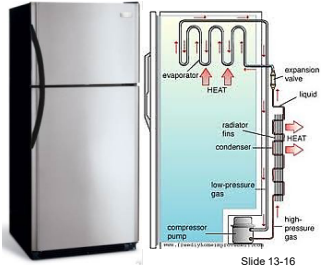
IV. REFRIGERATORS

REFRIGERATORS

Use refrigerant gas, compression, and expansion to remove heat from the unit.

Main components:

- Evaporator coil.
- Condenser coil.
- Cooling fan.
- Compressor.



Slide 13-16

- A. How it works.

1. Refrigerators use refrigerant gases, compression, and expansion of gases to remove heat from the unit. Any failure of this closed system can cause a fire; some refrigerant gases are combustible.
2. Condenser coil leaks.
3. Cooling fan.
4. Compressor.

REFRIGERATOR FAILURES

- Electrical shorts.
- Motor/control failures.
- Defrost control failures.
- Cord damage/abuse.



Slide 13-17

B. Types of refrigerator failures.

1. Electrical shorts.
2. Motor failures.
3. Defrost failures: Self-defrosting models contain a heating element which warms up the heat exchange coils to melt accumulated ice and frost. The defrost heater has the potential to overheat, the timer can fail in the ON position, and the combination of water and electricity presents a hazard.
4. Cord damage/abuse: Installation and removal of the refrigerator can cause the power cord to become smashed, frayed, or scraped, creating another point of failure.

V. DISHWASHERS

DISHWASHER ELECTRICAL FAILURES

- Failed door switch.
- Failed wiring harness.
- Failed heating element.
- Failed wax-motor actuator.
- High-resistance connection.

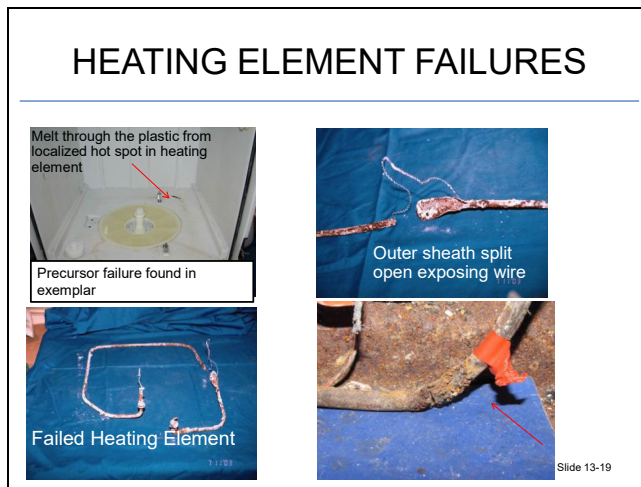


Slide 13-18

A. Typical sources of failure.

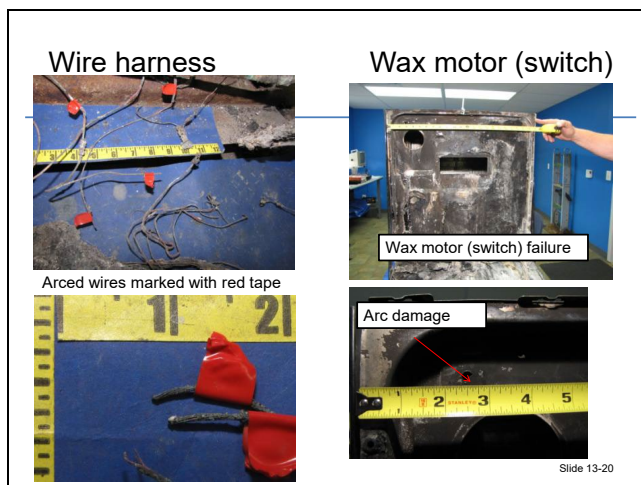
1. An appliance failure can occur at any point where current is interrupted, such as a switch. In an environment like a dishwasher, moisture can be an aggravating factor in the failure of components. Water presents a unique challenge in that it rarely remains around as a clue. While water is generally a poor conductor, detergent and rinse additives tend to make water more conductive. As a result, this water can become a path for unintended current flow, causing arcing and other issues. Look for electrical arcing located on the door switch components (connected wires or metal brackets).
2. A wiring harness can come in contact with metal edges, and due to wear from vibration and normal use, it can become a point of failure. This usually occurs at points of movement, such as the harness between the door and the main dishwasher enclosure.

3. Heating elements, motor vibration and the introduction of water are all factors that contribute to creating points of failure which can overheat or fail mechanically.
4. Failed wax motor or actuator: Actuators operate on the principle that as heated wax expands, the expanding wax moves some type of activation lever. Actuators are often used to release the detergent door during a wash cycle, or to release rinse agents. Because they contain sources of heat and electrical connections, they are subject to failure.
5. High-resistance connections (HRCs).

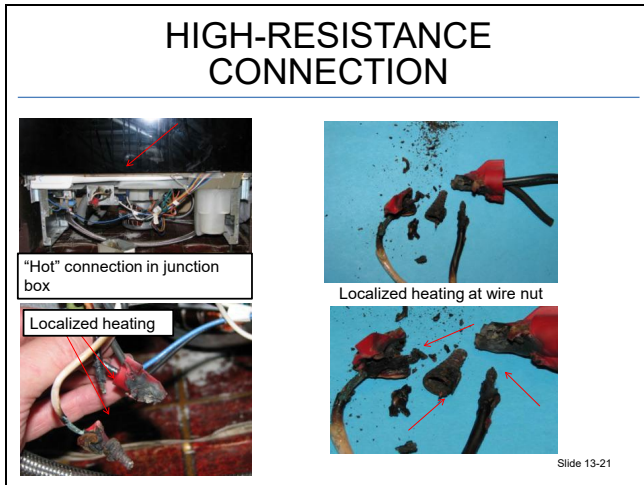


B. Heating element failures.

1. Look for a heating element where the metal sheath has split open or shows localized bulging and cracking.
2. In the first photo on the slide, the heating element had already been removed.



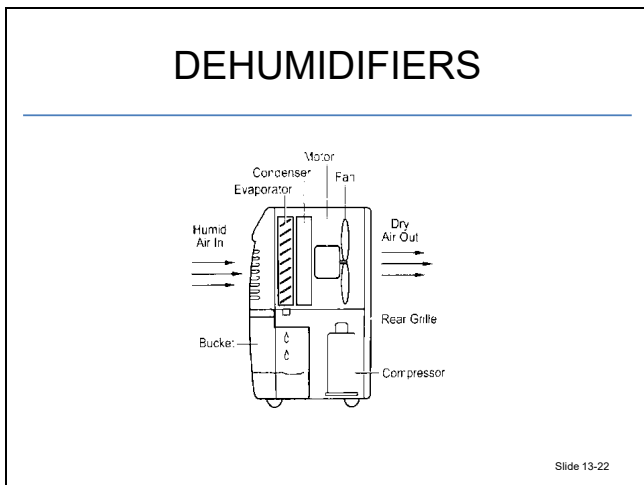
- C. Wire harness: Look for electrical arcing on wiring to the door harness and near the base where the wires in the harness make the turn under the dishwasher.
- D. Wax motor: Look for localized damage near the door vent and electrical arcing on the wax motor components, the connected wires, and the door.



E. HRC.

1. Look for signs of a "hot" connection, including localized heating, discoloration and electrical arcing. This may occur at the point where power wires connect to the dishwasher, but can occur in other locations, like heating element terminals.
2. The failure depicted in the photos could be the result of improper installation, vibration, the presence of water, or some combination of those issues.

VI. DEHUMIDIFIERS



A. How a dehumidifier works.

1. Warm, moist air is pulled through a grille on one side of the dehumidifier with a fan.
2. The warm air passes over the cold evaporator, through which a coolant circulates.
3. As the air cools, the moisture it contains turns back into liquid water (condenses) onto the evaporator coil and drips downward off the evaporator coil.
4. Now free of moisture, the air passes over another condenser, through which the warm refrigerant gas circulates, and the air warms back up to its original temperature. The warm, dry air blows back into the room through another grille.

B. Typical sources of failure.

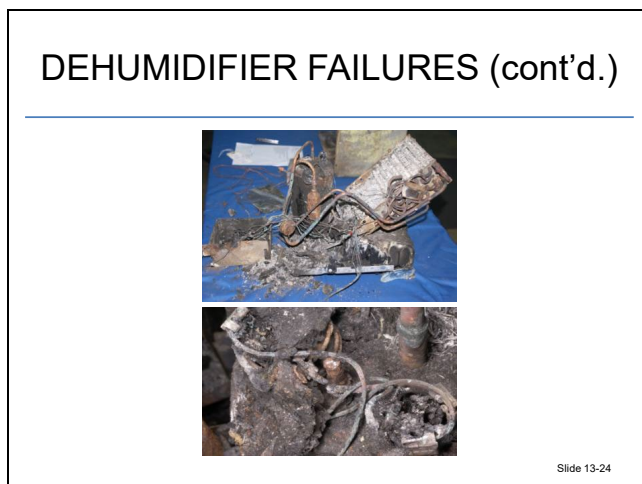
1. Compressor/compressor overload: overheating, welded contacts, switch failure.
2. Circulation fan: shorted windings, HRC.
3. Bucket switch: overheating, HRC.
4. Power switch/humidistat: overheating, HRC.
5. Main printed circuit board (PCB): component failure, HRC.
6. Power cord failure at the grommet: HRC.

DEHUMIDIFIER FAILURES



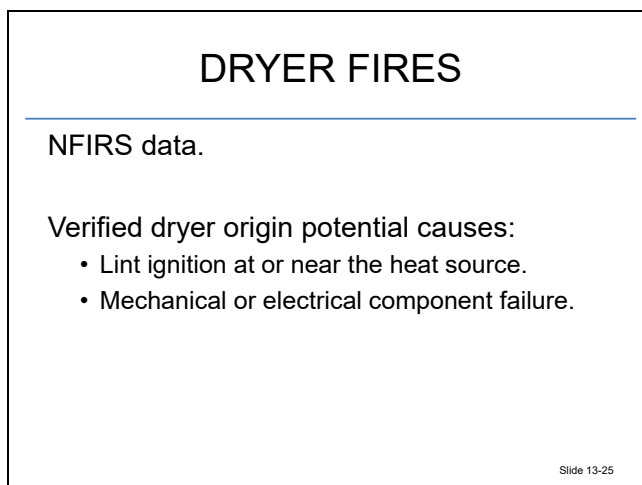
Slide 13-23

- C. Dehumidifier failure examples: Precursor failure on the power wire around the mounting post. Exemplar dehumidifier with the recall failure mitigated.



- D. Dehumidifier failure examples:
1. Top picture: remains of a dehumidifier with the enclosure removed.
 2. Bottom picture: failure of the input power wire to the mounting post.

VII. CLOTHES DRYERS



- A. How they work.
1. By the nature of the appliance, clothes dryers generate a great amount of heat in the course of normal operation. In the case mentioned on the slide with an electric dryer, a coiled heating element provides the source of heat to dry the clothes.

2. Alternatively, gas (natural or propane) dryers provide heat through a burner and flame.
3. In addition to the heat source, clothes dryers accumulate fire fuel in their operation: lint. Without proper cleaning and maintenance, this fuel can accumulate in close proximity to the heat source of electric coils or burners.

B. Typical sources of failure.

1. Lint ignition at or near the heat source.
2. Mechanical or electrical component failure.

COMMON CAUSES

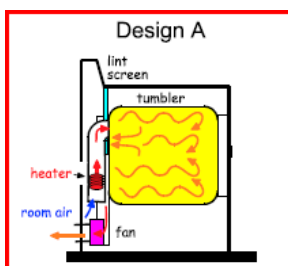
- Contamination of the load by flammable liquids or materials prone to spontaneous combustion.
- Overheated electrical connection.
- Foreign object contacting the heating element.
- Failure of the single rear drum bearing/pivot, resulting in the drum arcing against the heating element.

Slide 13-26

3. Contamination of the load by flammable liquids or materials prone to spontaneous combustion. However, with spontaneous combustion, this does not occur while the dryer is properly operating and the load is tumbling during the drying cycle. True spontaneous combustion incidents occur only when the load of hot textiles stops tumbling and piles at the bottom of the drum.
4. Overheated electrical connection.
5. Foreign object contacting the heating element.
6. Failure of the single rear drum bearing/pivot, resulting in the drum arcing against the heating element during rotation, causing sparks that ignite built-up lint or clothing.

DRYER DESIGN A

- Features:
 - Two-piece drum.
 - Rear bulkhead with heat and exhaust ducts.
 - Top-mounted lint screen.
- Brand:
 - Whirlpool (original).



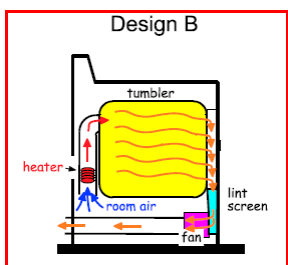
Slide 13-27

7. Dryer design A:

- a. The graphics on the slides show how lint screens and air intake/exhaust paths are different from model to model, and the investigator needs to be cognizant of the differences.
- b. The graphic shows the following features:
 - Two-piece drum.
 - Rear bulkhead with heat and exhaust ducts.
 - Top-mounted lint screen.
 - Brand: Whirlpool® (original).

DRYER DESIGN B

- Features:
 - Two-piece drum.
 - Rear bulkhead with heat duct.
 - Front-mounted lint screen.
- Brand:
 - Maytag, Whirlpool (new), LG, Samsung, Electrolux (new).



Slide 13-28

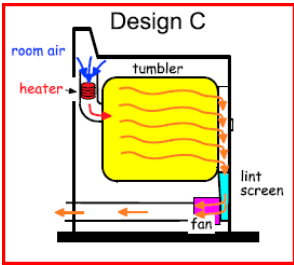
8. Dryer design B: The graphic shows the following features:

- a. Two-piece drum.

- b. Rear bulkhead with heat duct.
- c. Front-mounted lint screen.
- d. Brand: Maytag[®], Whirlpool[®] (newer), LG[®], Samsung[®], Electrolux[®] (newer).

DRYER DESIGN C

- Features:
 - Two-piece drum.
 - Rear bulkhead with heater compartment.
 - Front-mounted lint screen.
- Brand:
 - Amana.
 - DISCONTINUED.



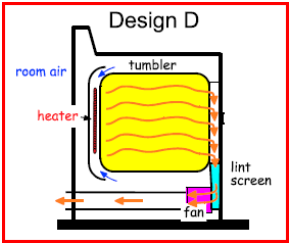
Slide 13-29

9. Dryer design C: The graphic shows the following features:

- a. Two-piece drum.
- b. Rear bulkhead with heater compartment.
- c. Front-mounted lint screen.
- d. Brand: discontinued Amana[®].

DRYER DESIGN D

- Features:
 - One-piece drum.
 - Heater pan located behind drum.
 - Front-mounted lint screen.
- Brand:
 - Electrolux (original), General Electric.



Slide 13-30

10. Dryer design D: The graphic shows the following features:

- a. One-piece drum.

- b. Heater pan located behind drum.
- c. Front-mounted lint screen.
- d. Brand: Electrolux® (original), General Electric™ (GE).



11. The slide illustrates origin determination patterns.



12. The slide shows a continuation of the previous illustration of origin determination patterns.

GROWTH PATTERNS: INTERNAL FUELS



Slide 13-33

13. The slide is a photo representation of growth patterns when internal fuels are involved.

TIMELINE

A timeline is helpful in understanding the history of the dryer, the events leading up to the fire, and potential cause scenarios.

It is important to obtain key timeline information:

- Home: date built, date purchased.
- Dryer: dryer purchase date, venting install/change dates, and maintenance/service history for life of dryer and venting.
- Fire: timeline of loads on day of, time last load was dried, length of time dryer was running (or resting if cycle finished) until discovery.

Slide 13-34

C. Timeline.

1. A timeline is helpful in understanding the history of the dryer, the events leading to the fire, and potential cause scenarios.
2. It is important to obtain key timeline information:
 - a. Home: date built, date purchased.
 - b. Dryer: dryer purchase date, venting install/change dates, and maintenance/service history for life of dryer and venting.
 - c. Fire: timeline of loads on day of, time last load was dried, length of time that dryer was running (or time resting, if cycle finished) until discovery of the fire, possible contaminants on clothing in dryer.

HEAT SOURCE: ELECTRIC ELEMENT



Slide 13-35

- D. Heat source: electric element: The slide shows an example of a coiled heating element.

HEAT SOURCE: GAS BURNER



Slide 13-36

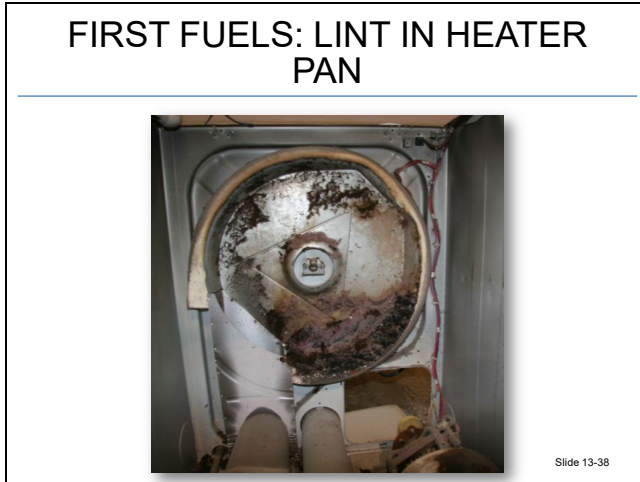
- E. Heat source: gas burner: The slide shows an example of a dryer with a gas burner as a heat source.

FIRST FUELS: CABINET LINT



Slide 13-37

- F. First fuels: cabinet lint: The slide shows an example of a dryer with excessive lint buildup. This was a brand-new dryer after 15 wash-dry cycles of 10 brand new-towels. Poor design of the dryer allowed the accumulation of lint inside the dryer housing, which was out of sight of the consumer.



- G. First fuels: lint in heat pan.
1. The slide shows how lint in a heat pan can burn.
 2. Because the heater pan is not airtight, lint may also accumulate in the heater pan. This puts the lint in even closer proximity to the heat source. As you can see in the picture of the heater pan, the lint that has accumulated in the pan has burned at some point, leaving behind charred residue. In sufficient quantity, the lint could provide fuel enough to start and sustain a fire in the heater pan.



- H. First fuels: lint encroachment.

1. The slide illustrates lint encroachment.
2. As with the heater pan, lint has accumulated and burned near the gas burner of this dryer. A significant enough accumulation could sustain burning to the extent that other materials in the dryer, such as plastic pieces and wiring harnesses, could burn as well.

VIII. MICROWAVES



- A. How they work.
 1. The slide shows various types and styles of microwave ovens.
 2. Microwave ovens operate on the principle that high-frequency microwaves cause the atoms in food material to vibrate rapidly, thereby heating the food. To create those microwaves, the microwave oven uses a high-voltage transformer. As a result, there are both low- and high-voltage internal components that can fail and become a source of heat.
 3. Not all microwaves are the same; they have different features and configurations.
 4. Over-the-range microwaves typically contain temperature controls that turn on a blower.
 5. Certain models contain thermal cutoffs for the magnetron, fan and flame sensor.

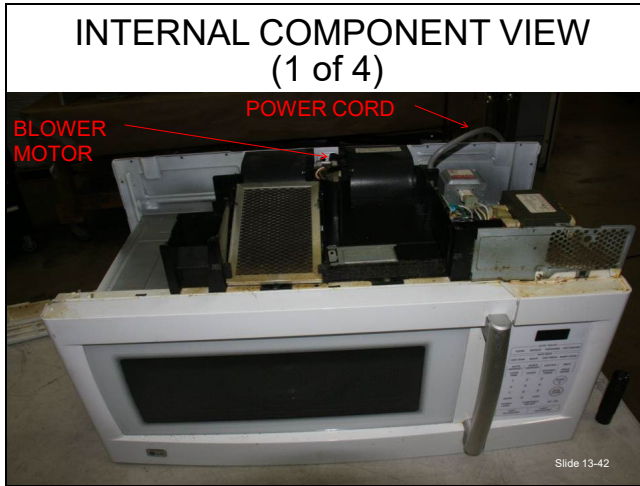
FAULT ANALYSIS

- | | |
|-----------------------------|--------------------------|
| - High-voltage transformer. | - High resistance. |
| - High-voltage capacitor. | - Ground faults. |
| - High-voltage diode. | - Printed circuit board. |
| - Magnetron. | - Door switch. |
| - Blower motor. | - Monitor switch. |

Slide 13-41

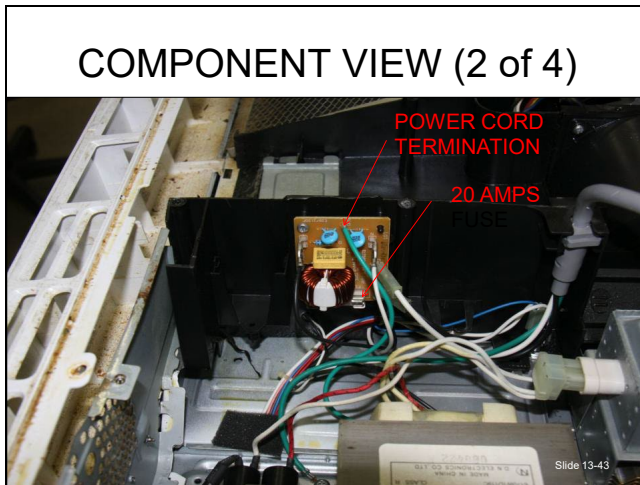
B. Typical sources of failure. Fault analysis:

1. High-voltage transformer.
2. High-voltage capacitor.
3. High-voltage diode: Any of the high-voltage components can suffer failure. With the high voltage levels, this can allow arc tracking and/or arcing, which is not detectable or interrupted by any type of over-current protection device (OCPD).
4. Magnetron failure (the oven component that creates the microwaves — a short of the high-voltage portion of the system — does not usually disable the microwave) often manifests as a loud short-circuit/humming sound when the microwave operates.
5. Blower motor failures (failure to remove internal heat causes component failure).
6. HRCs (caused by moisture contamination/humidity from cooking foods or boiling water).
7. Ground faults (unintended circuit paths).
8. PCB component failures.
9. Door switch failures from high resistance: Door switches are typically wired in series with the incoming power in a way that if one of the multiple redundant door (safety) switches fails — which could allow the door to open during operation if the other fails — a short circuit is intentionally created, causing the internal fuse to blow, and disabling operation of the microwave. If opening the door is the consumer's primary way of ending the cooking process (as opposed to pressing the "STOP" button first), this subjects the door switches to parting arcs and accelerated electrical wear, possibly creating HRCs.



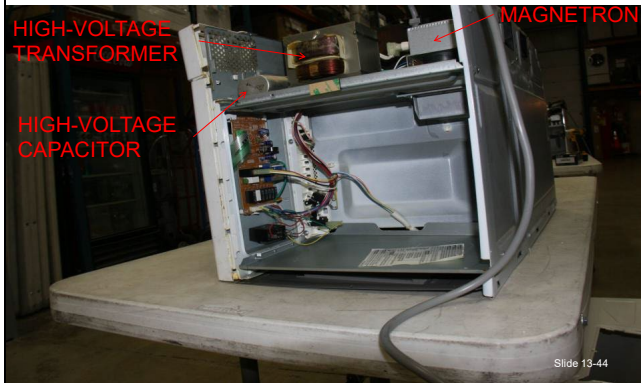
C. Internal components of the microwave.

1. The slide shows the internal components of one style of microwave.
2. The layout can vary from model to model. Note that the sample microwave in the picture is probably 10 years old, but it is not that uncommon to find an old microwave in a house.



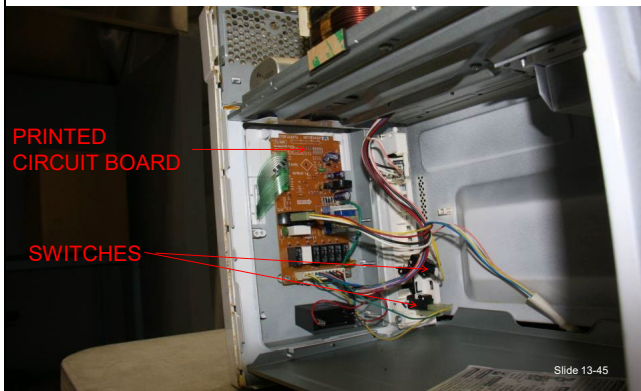
3. These photos show the multiple internal electronic components of a microwave. It is not necessary to discuss the individual function of each, but rather to show that there are multiple points of failure possible within the microwave cabinet.
4. The photo on the slide shows an overhead view of typical microwave components. High-voltage components that power the magnetron are often located high in the microwave cabinet.

COMPONENT VIEW (3 of 4)

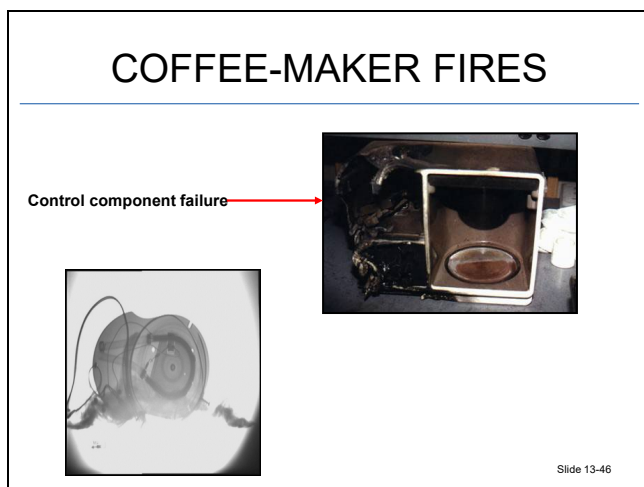


5. The high-voltage portion of a microwave is designed so that it can sustain arcs that occur from high-voltage system component failure. The increased temperature from internal arcing may ignite combustible materials commonly found on top of the microwave housing, such as a wooden cabinet, if the microwave is installed beneath one.

COMPONENT VIEW (4 of 4)

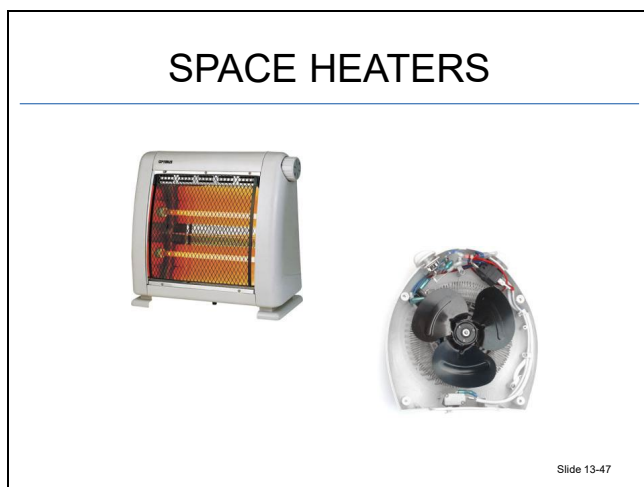


6. There are also low-voltage components that are subject to failure and possible ignition. The largest source of fuel in most microwaves is the plastic control panel and adjacent plastic components.

IX. COFFEE MAKERS OVERVIEW

- A. Coffee-maker fires are less common today than they were in the past. Current designs employ redundant thermal cutouts (TCOs) to prevent failure.
- B. Failure modes: heater energized with no water or continuously energized.
- C. Look for severe melting damage: Heating elements themselves show severe melting damage.
- D. Removed or tampered with TCOs: Open condition of TCO after a fire may be irrelevant, because the heat from an external fire can cause an energized or unenergized TCO to open.
- E. Burning to enclosure clearly emanating from interior.
- F. Tampering that may not be visible.
- G. Destructive examination and X-ray analysis can detect signs of component failure or tampering that may not otherwise be visible.

X. SPACE HEATERS



A. Overview.

1. The slide shows an example of a space heater.
2. Radiant electric heaters commonly produce a heat flux around 10 kilowatts (kW)/square meter (m^2) at the face of the grille, and the value drops rapidly with distance.
3. Unless overt electrical failure occurs, it can be assumed that there is no source of pilot ignition.
4. The question of interest then becomes what materials might autoignite at a heat flux of 10 kW/m^2 or lower. Fabric and paper goods generally require substantially higher heat fluxes for autoignition, but cardboard can be ignited at fluxes below 10 kW/m^2 .
5. Of course, pushing any combustibles up to the face of a radiant heater is a misuse of the heater. In that same vein, more abusive misuses are possible: stuffing material inside the grille or blocking the entire face of the heater. In the latter case, however, a properly designed TCO should operate.

FORCED-AIR SPACE HEATER



Slide 13-48

- B. Forced-air space heater: The slide shows a picture of the switches on a space heater. Examine the switches of a forced-air space heater.

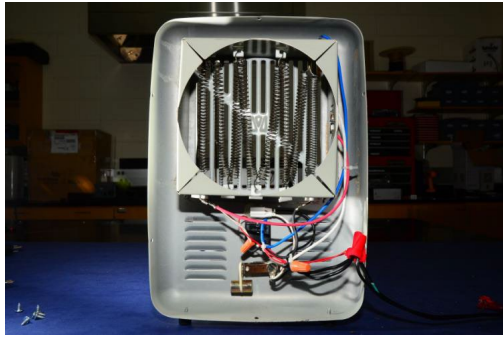
CONTROLS



Slide 13-49

- C. Controls: The slide is another illustration of the controls on a space heater. This shows a close-up of space heater controls/indicators. A space heater must be connected to a source of power, and heat level/temperature controls must be in a position to allow the generation of heat before they can be ruled as a competent ignition source. Examination of intact exemplar units can help the investigator to examine the burned remains of a heater to determine if it was in the ON position.

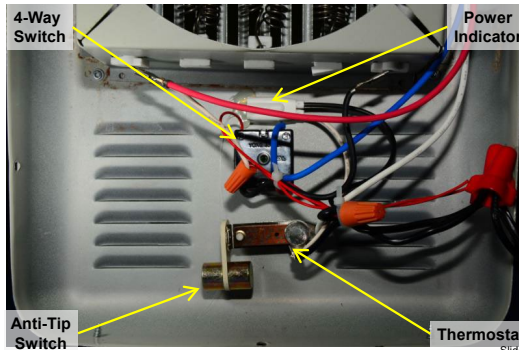
RADIANT COILS



Slide 13-50

- D. Radiant coils: The slide shows a picture of radiant coils of a typical modern electric space heater.

CONTROLS



Slide 13-51

- E. Controls: The slide shows a close-up and identification of control components of a typical modern electric space heater.

ANTI-TIP SWITCH



Slide 13-52

- F. Anti-tip switch: The slide shows an example of an anti-tip switch. Anti-tip switches are designed to turn off power to heater if the unit is in a position other than normal operating position (blower vent/direction horizontal).

XI. LITHIUM-ION BATTERIES OVERVIEW

LITHIUM-ION BATTERY ISSUES

- Lithium-ion batteries can be a source of intense heat and flame upon failure.
- Internal shorts, problems with charging circuits, and the breach of the battery pack are all things that can cause a lithium-ion battery to fail by venting fire or exploding.
- Examples include hoverboards and cell phones.

Slide 13-53

Lithium-ion batteries can be a source of intense heat and flame upon failure. Internal shorts, problems with charging circuits, and physical breach or shock damage to the battery cells are all things that can cause a lithium-ion battery to begin a chemical reaction that generates a large amount of heat, causing failure and subsequent venting of fire, sometimes explosively. Since most lithium-ion batteries are contained within the device they power, if the investigator suspects a particular device as the point of origin, then some basic research should be able to show how the device in question was powered. Additionally, there are many recent recalls for lithium-ion battery failures — hoverboards, cell phones, etc. — so an investigator could match the device against recall lists to help make that determination. If the investigator suspects a particular device as having been the cause of a fire, they can ask the user if that device was noticed as being unusually hot before the fire, or if any noises like hissing and popping were heard.

ACTIVITY 13.1

Appliance Modification

Purpose

Use knowledge of safety features commonly found in household heat-generating appliances, and bypass that safety feature or those safety features to induce fire.

Materials

- One appliance per table group.
- One tool kit (specialized appliance disassembly tools).
- Various materials to bypass safety features (students decide).

Safety

Disassembling some appliances may require force to open the outer housing or other assemblies that were never intended to be opened after original manufacture. Use caution to avoid pinch or laceration injuries when disassembling or reassembling your appliance.

DO NOT AT ANY TIME ATTEMPT TO ENERGIZE AN APPLIANCE IN THE CLASSROOM ONCE IT HAS BEEN DISASSEMBLED, MODIFIED OR NOT!

Any injury must be immediately reported to an instructor!

Directions

1. As a group, disassemble the provided appliance, and using your knowledge of Source-Path-Load, analyze the internal circuitry and locate any safety components in the appliance that prevent overheating.
2. Formulate a method to bypass any safety features and/or operational controls so that when re-energized, the appliance becomes a competent ignition source without further intervention once connected to the power source.
3. Reassemble your appliance to “like-new” appearance so that tampering is as undetectable as possible.
4. Be prepared to explain to the other groups what safety or operational controls you located and how they were modified or bypassed in your appliance.

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XII. SUMMARY



SUMMARY

- Examine and evaluate the circuitry and operation of safety devices in household appliances.
- Determine the circumstances that cause appliances to fail.
- Explain existing safeguards to prevent a small household appliance from exceeding normal temperatures.

Slide 13-55

XIII. EXAM IN BLACKBOARD

XIV. EVALUATION

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ACRONYMS

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ACRONYMS

AC	alternating current
AFCI	Arc Fault Circuit Interrupter
ATF	Bureau of Alcohol, Tobacco, Firearms and Explosives
AWG	American Wire Gauge
BUD	buried underground distribution
CFI	Certified Fire Investigator
CFL	compact fluorescent light
CH	Cutler Hammer
CT	current transformer
DC	direct current
DIY	do-it-yourself
EB	Edison Base
ECT	Evidence Collection Technician
EDS	Energy Dispersive X-ray Spectroscopy
EGC	Equipment Grounding Conductor
EMF	Electromotive Force
EMS	emergency medical services
FI: E	“Fire Investigation: Essentials”
FI: ES	“Fire Investigation: Electrical Systems”
FI: FECD	“Fire Investigation: Forensic Evidence Collection and Documentation”
FIT	Fire Investigation Technician
FPE	Federal Pacific Electric

GE	General Electric™
GFCI	Ground Fault Circuit Interrupter
gpm	gallons per minute
GTE	General Telephone and Electric
HRC	high-resistance connection
HVAC	heating, ventilating, and air conditioning
IAAI	International Association of Arson Investigators
IC	insulation contact
IG	Instructor Guide
IT	Information Technology
LCD	liquid-crystal display
LED	light-emitting diode
MC	metallic sheathed cable
MOV	metal-oxide varistor
NEC	National Electrical Code®
NETC	National Emergency Training Center
NFA	National Fire Academy
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NMC	non-metallic sheathed cable
OCPD	over-current protection device
PCB	printed circuit board
PPE	personal protective equipment
psi	pounds per square inch

PVC	polyvinyl chloride
ROCB	remotely operated circuit breaker
RPM	revolutions per minute
RPT	relocatable power tab
SAW	Student Activity Worksheet
SCADA	supervisory control and data acquisition
SCC	short-circuit current
SEM	scanning electron microscope
TCO	thermal cutout
UPS	uninterruptible power supply
USFA	U.S. Fire Administration
VAC	Volts Alternating Current

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