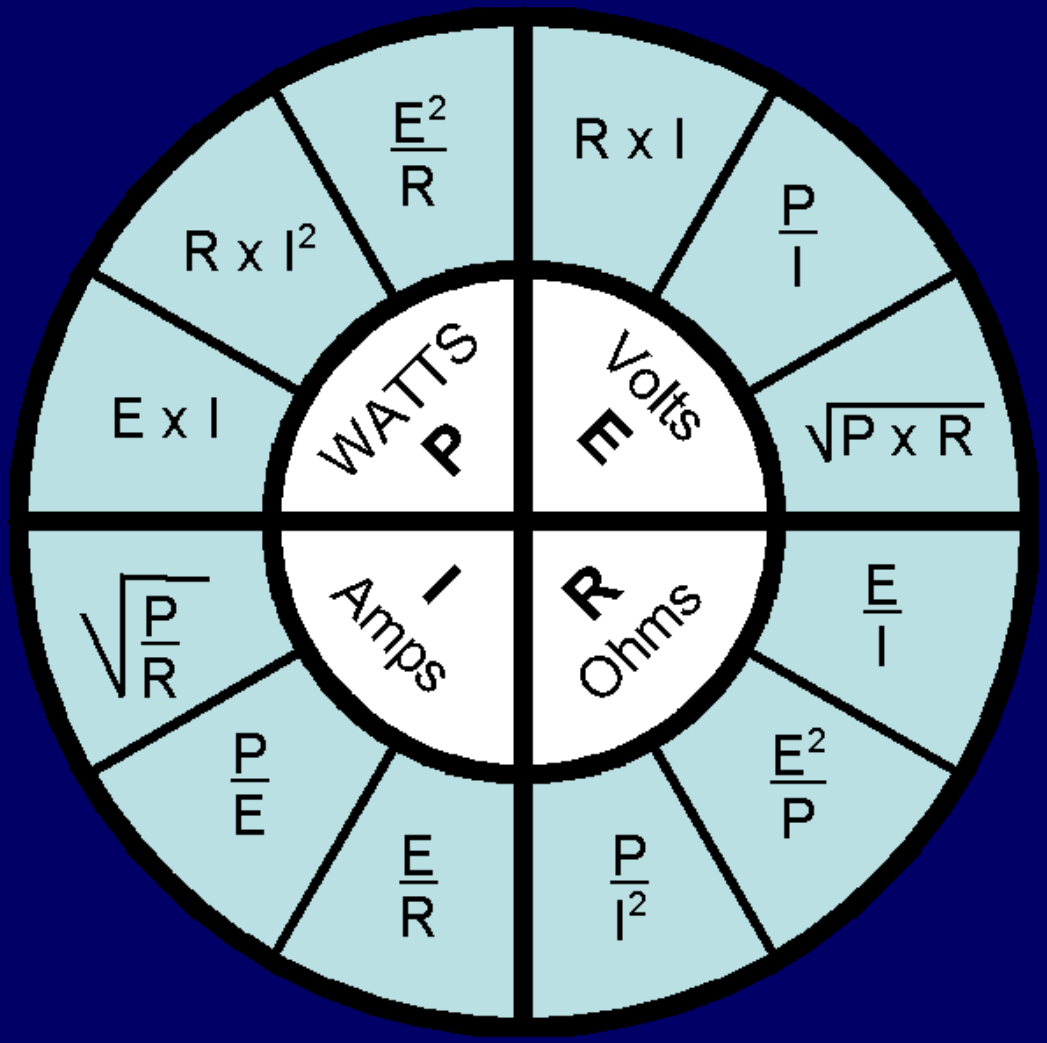
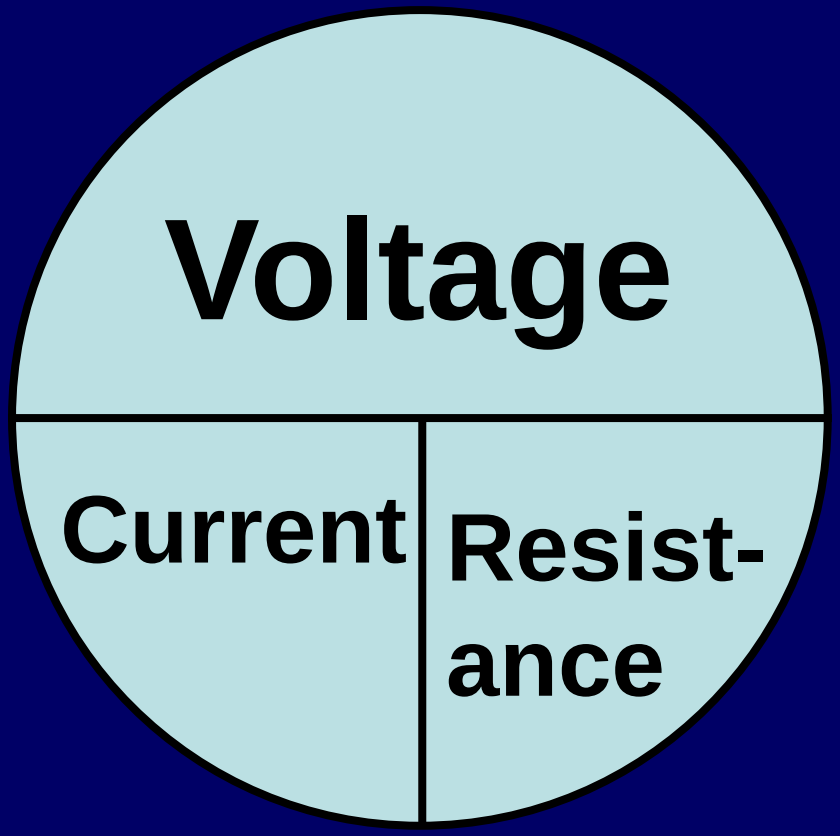
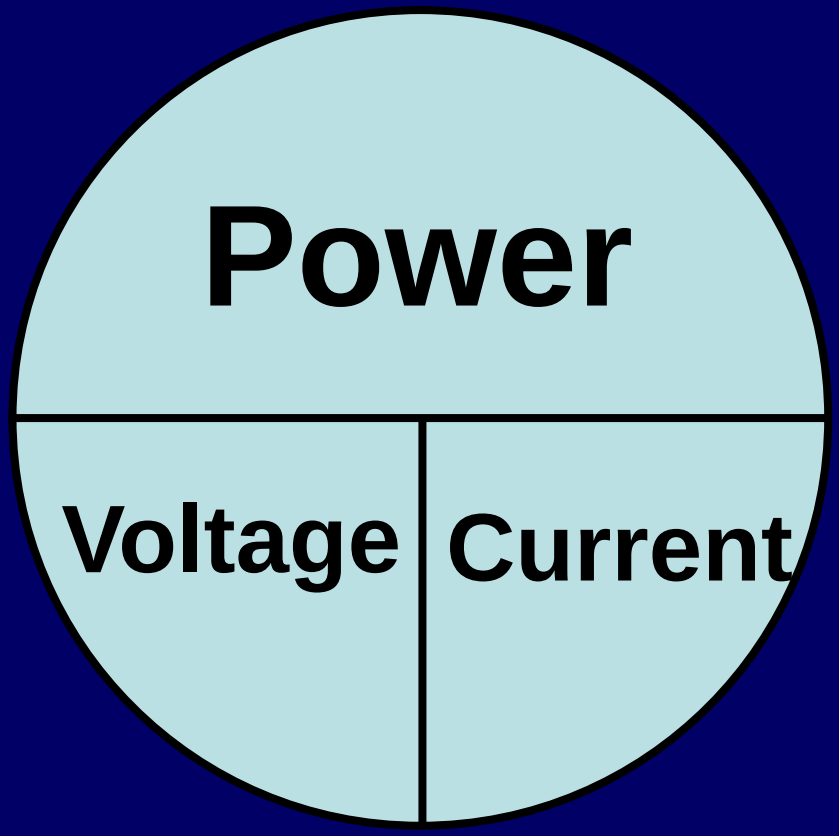
Ohm's Law / Joule's Law Calculator



Ohm's Law / Joule's Law Cheat Sheet

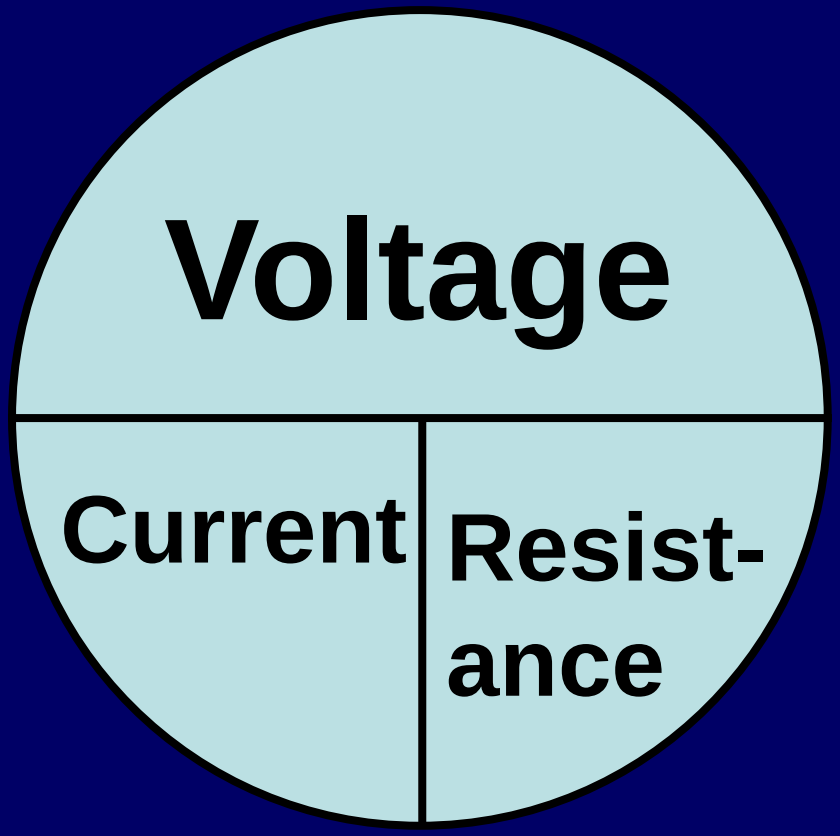


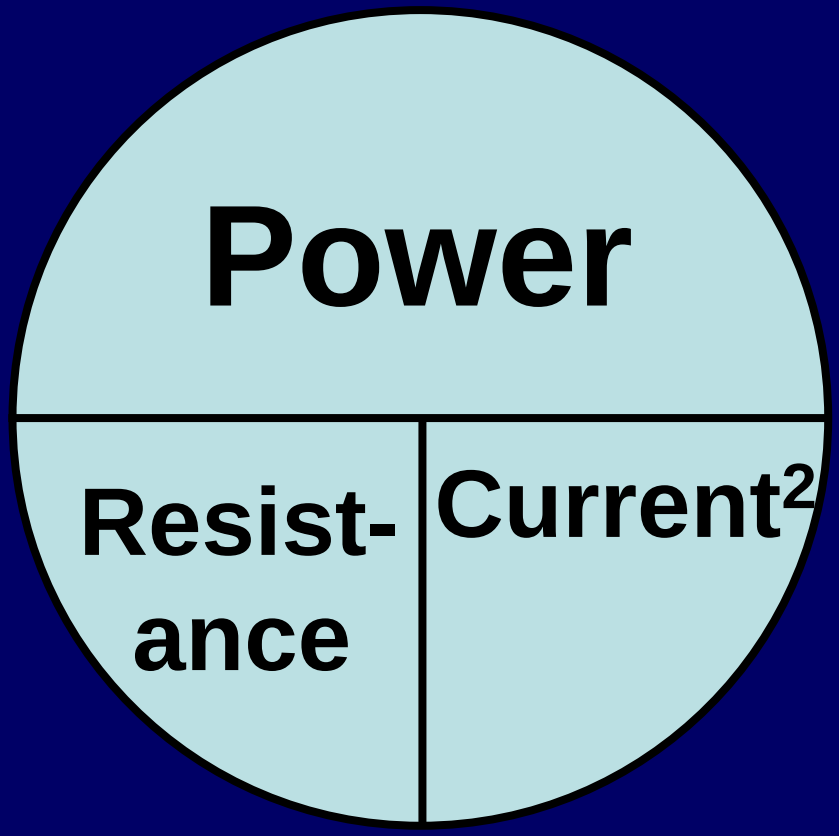


Power = Current^2 x Resistance

1 HP = 746 Watts

Ohm's Law / Joule's Law Cheat Sheet

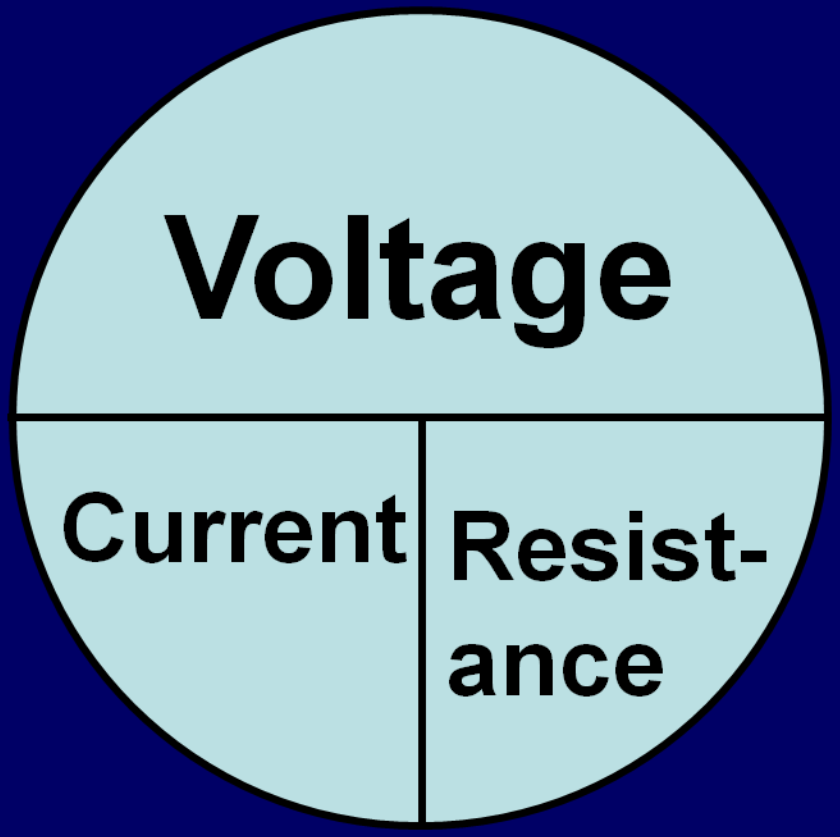




1 HP = 746 Watts

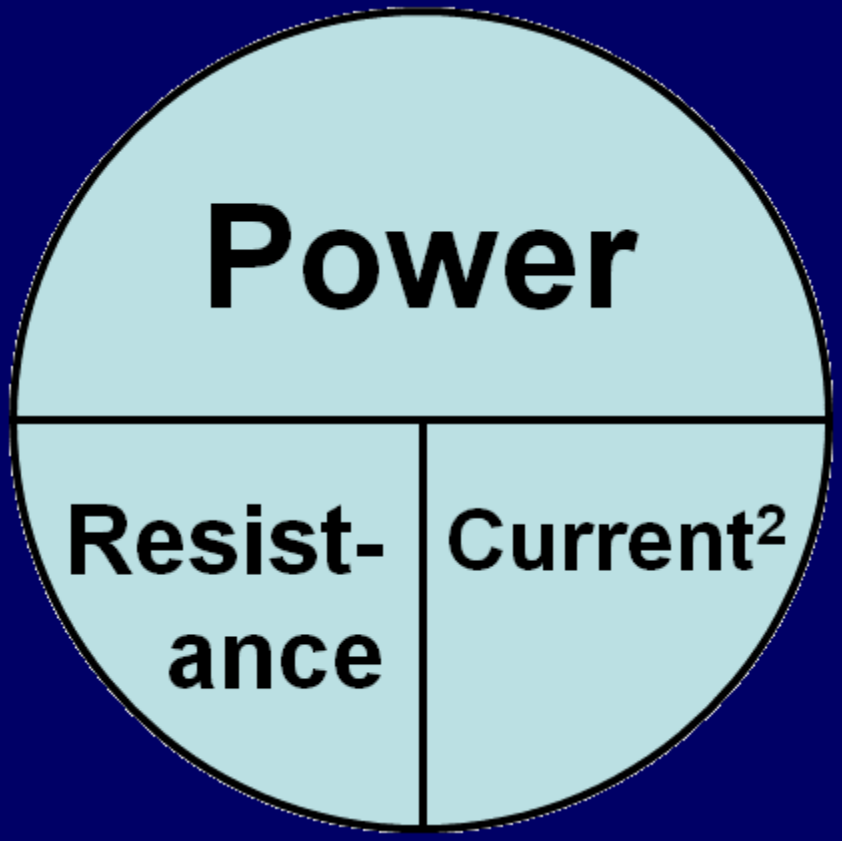
Ohm's Law

- **Under constant voltage, what does the current do as the resistance approaches:**
  - 0?
  - Something very big?



Joules Law

- **What does the power do as the resistance / current approaches:**
  - 0?
  - Something very big?



Joule's Law / Ohm's Law Combined Summary

- As resistance goes down the current goes up.
- As the resistance approaches ZERO the current goes through the roof!!
- As the current goes through the roof the heat goes to the moon!!
- Ultimately there is enough current to trip a circuit breaker (or open a fuse) and melt metal.

Arc Mapping

- **NFPA 921-2017 9.11.7.5.1:**

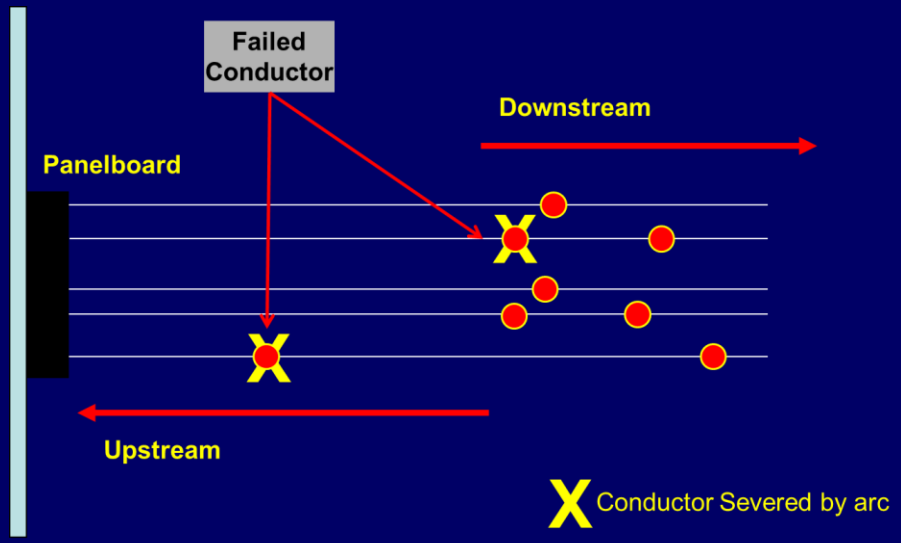
  Full-scale, single-compartment testing has indicated that arcs may be more prevalent in the area of origin. However, there does not seem to be a direct correlation between the origin and arcing on conductors at the closest geometric point. Research continues on this issue.

Arc Mapping

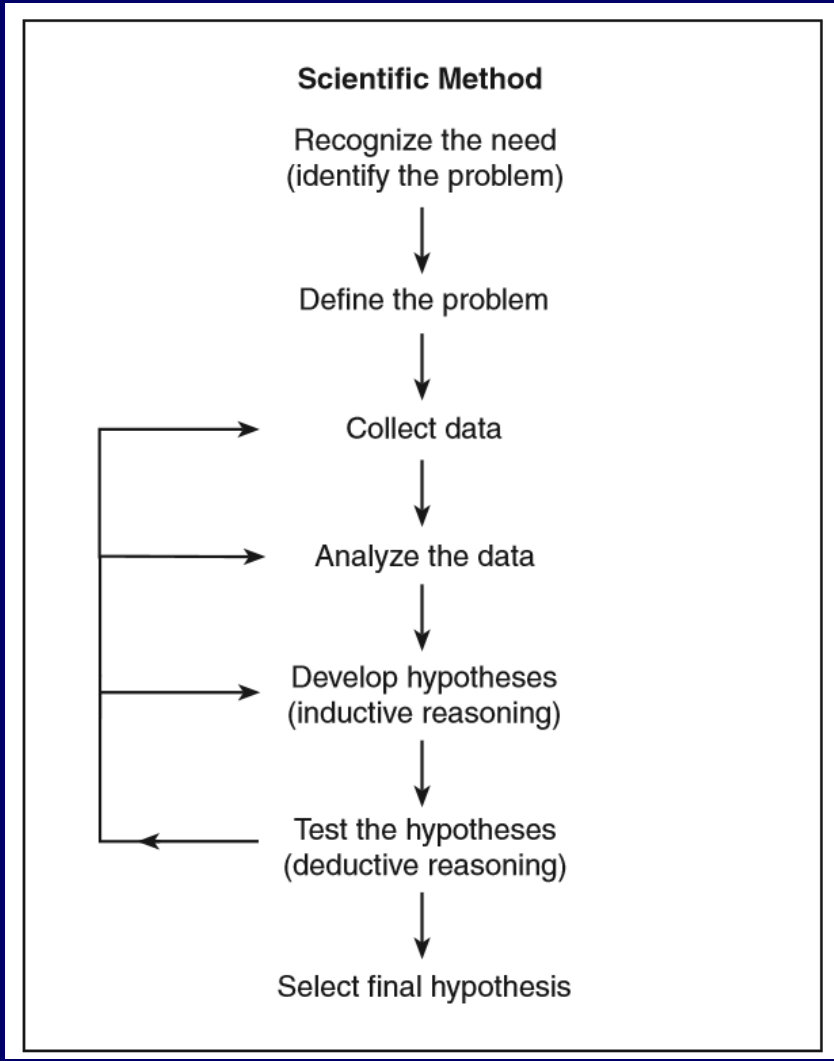
- **NFPA 921 (2017)**
  - 9.11.7.2 An electrical engineer is not required to perform arc mapping. Arc mapping is fundamentally pattern recognition, which fire investigators routinely perform in other areas of fire investigation.

End-State Analysis
Where was the origin?

- 9.11.7.5.2 When multiple arcs are found on a single circuit and there is a sever arc closer to the supply then other arcs, then the downstream arcs necessarily occurred no later than the sever arc.



The Scientific Method



- **1.3.2 As every fire and explosion incident is in some way unique and different from any other, this document is not designed to encompass all the necessary components of a complete investigation or analysis of any one case. The scientific method, however, should be applied in every instance.**

- **3.3.160 Scientific Method. The systematic pursuit of knowledge involving the recognition and definition of a problem; the collection of data through observation and experimentation; analysis of the data; the formulation, evaluation and testing of hypotheses; and, where possible, the selection of a final hypothesis.**

More on the Scientific Method

- 4.3.3 Collect Data. Facts about the fire incident are now collected by observation, experiment, or other direct data gathering means. The data collected is called empirical data because it is based on observation or experience and is capable of being verified or known to be true.

- 4.3.4* Analyze the Data. The scientific method requires that all data collected be analyzed. This is an essential step that must take place before the formation of the final hypothesis. The identification, gathering, and cataloging of data does not equate to data analysis. Analysis of the data is based on the knowledge, training, experience, and expertise of the individual doing the analysis. If the investigator lacks expertise to properly attribute meaning to a piece of data, then assistance should be sought. Understanding the meaning of the data will enable the investigator to form hypotheses based on the evidence, rather than on speculation.

- 4.3.6.1* Any hypothesis that is incapable of being tested either physically or analytically, is an invalid hypothesis. A hypothesis developed based on the absence of data is an example of a hypothesis that is incapable of being tested. The inability to refute a hypothesis does not mean that the hypothesis is true.

NFPA 921 - 2017

- 19.1.1 The determination of the cause of a fire requires the identification of those factors that were necessary for the fire to have occurred. Those factors include the presence of a competent ignition source, the type and form of the first fuel ignited, and the circumstances, such as failures or human actions, that allowed the factors to come together and start the fire.

NFPA 921 - 2017

- 9.9.1.2 The presence of sufficient energy for ignition does not assure ignition. Distribution of energy and heat loss factors need to be considered.

NFPA 921 - 2017

- 9.9.1.2 The presence of sufficient energy for ignition does not assure ignition. Distribution of energy and heat loss factors need to be considered.

- 9.9.1.3 In considering the possibility of electrical ignition, the temperature and duration of the heating must be great enough to ignite the initial fuels. The type and geometry of the fuel must be evaluated to be sure that the heat was sufficient to generate combustible vapors and for the heat source still to be hot enough to ignite those vapors. If the suspect electrical component is not a competent ignition source, other causes should be investigated.

NFPA 921 - *2008*

- 18.2.6 In a determination of an accidental cause, the same precautions regarding elimination of other potential ignition sources should be carefully considered. For example, the determination that an appliance is the ignition source in a fire is not simply related to its being at the origin. Prior to an appliance being identified as the ignition source, the method or mode of failure should be established. It is equally important that the material first ignited and the ignition sequence also be identified, especially to establish a fire cause in the absence of the physical evidence of an ignition source.

Old words that are still applicable.

Methodology Summary

- **Start Outside**
  - Document the primary distribution transformer.
  - Get information about the service from the utility provider.
  - Determine when the scene was de-energized.
  - Examine and document the service entrance.

- **Conduct Interviews**
  - Obtain information about facility status, wiring, maintenance, etc from interviews.
  - Obtain information about what was / should have been energized.

- **Move inside**
  - Trace the system throughout the facility starting at the service entrance.
  - Emphasis is placed on feeders and branch circuits that are tripped or open.
  - Identify all instances of arc melting.
  - Obtain information from the alarm system

- **Conclusions are only drawn when they are overlayed on the other information obtained from the scene.**

Electrical System Documentation

- **The utility (gas, electric) entrances and controls both inside and outside a structure should be photographed. Photos should include gas and electric meters, gas regulators, and their location relative to the structure. The electric utility pole(s) near the structure that is equipped with the transformer serving the structure, and the electrical services coming into the structure, as well as the fuse or circuit breaker panels, should also be photographed. If there are gas appliances in the fire area of origin, the position of all controls on the gas appliances should be photographed. When photographing electrical circuit breaker panels, the position of all circuit breaker handles and the panel's schedule indicating what electrical equipment is supplied by each breaker, when available, should be photographed. Likewise, all electrical cords and convenience outlets pertinent to the fire's location should be photographed.**
  - NFPA 921-2017 16.2.6.7

Electrical System Documentation

- **The electrical system should be documented. The means used to distribute electricity should be determined, and damage to the systems should be documented. The documentation process should begin with the incoming electrical service. The main panel amperage and voltage input should be noted. The type, rating, position (on/tripped/off), and condition of the circuit protection devices may be relevant to the investigation and should be documented.**
  - NFPA 921-2017 18.3.3.6

Electrical System Documentation

- **Note the location of electrical receptacles and switches within the room or area of origin. Electrical items plugged into the receptacles should be identified and documented. The investigative process may involve the tracing of circuits throughout a structure. The purpose for tracing these circuits is to identify the switches, receptacles, and fixtures on a particular circuit, as well as which overcurrent device protects that circuit, and its position and condition. Electrical appliances and loads should be noted. A more detailed documentation of electrical systems and devices may be necessary where they are believed to be the fire cause or a contributing factor, or when arc mapping is used. Use caution when interpreting damage to electrical wiring and equipment because it may be difficult to distinguish cause from effect. For a more detailed explanation of electrical systems, see Chapter 8.**
  - NFPA 921-2017 18.3.3.7

Before You go Inside… Basic Interview Questions

- **DO NOT forget that witness interviews are also part of the electrical investigation**
- **The following are questions for the owner / maintenance manager / electrician / employees:**
  - How is the facility wired?
  - Are there any drawings?
  - Who did the maintenance for the facility?
  - Where are the distribution panelboards?
  - What was on?
  - What was off?
  - How are different pieces of equipment turned on or off?
  - Is machinery turned off at the panelboard or at the equipment?
  - What was acting “funny”?
  - What kind of problems have happened in the past?
  - What has recently been changed in the facility?
- **The main goal is to understand what should have been energized at the time of the fire.**

Basic Interview Questions

- **The following are questions for the first in firefighters:**
  - What lights did you see on?
  - At what point did you see the lights go out?
  - Did you hear something that sounded like a shotgun?
  - Did you hear anything shorting out?
  - Did you hear any motors running?
  - Did you hear any alarm horns?

What Does the Transformer Tell You?

- **The only overcurrent protection for the transformers is normally on the "high" side (HV side) and is generally the means of disconnecting the facility from the local grid.**
  - Normally this is a time delay fuse.
- **Data Point: when was the scene de-energized?**

Where Does This Information Come From?

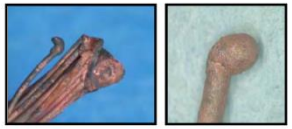
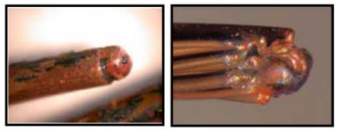
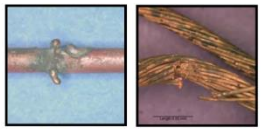
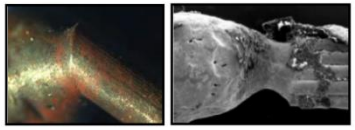
- **Utility Provider**
  - Ask for a Line Supervisor.
    - Determine when they were on scene and what the fuse status was.
    - How did they isolate the scene?
    - Did the FD record the event?
      - Sometimes the incident commander will report that the scene is de-energized.

Panelboard Examination

- **Panelboards:**
  - Note the positions of circuit breakers (on, tripped, off) [Note what fuses are open]
  - Copy any legend
  - Find out which, if any, circuit breakers were disturbed during or after the fire
  - Determine if any circuit breakers tripped fuses routinely opened
  - Find out if recent work has been performed
  - Determine if circuit breakers were regularly used as switches
  - Remove cover and document interior
  - Look for burned or melted insulation on wiring
  - Verify panelboard is properly grounded
  - Check main connections
  - Look for modifications or poor workmanship
  - Check condition of any bus attachments – look for any pitting on bus
  - Check condition of connections to the circuit breakers
  - Examine entire enclosure for evidence of arc melting
  - DO NOT ATTEMPT TO MOVE CIRCUIT BREAKER HANDLES UNLESS YOU KNOW WHAT YOU ARE DOING!

Excerpt from *ATF Technical Bulletin (NFPA 921-2017 9.11.1)*

Table 1
Characteristics of Arc Beads

	Sharp Line of Demarcation between damaged and undamaged area (Photos by Kevin Lewis / E. C. BUC)
	Round Smooth Shape (Photos by Nick Cary / Kevin Lewis)
	Localized Point of Contact (Photos by Kevin Lewis / E.C. Buc)
	Identifiable Corresponding Area of Damage on Opposing Conductor (Photo by Kevin Lewis)
	Copper Drawing Lines Visible Outside the Damaged Area (Photos by Kevin Lewis)
	Localized Round Depressions (Photos by David Reiter / Kevin Lewis)
	Small Beads and Divots Over a Small Area (Photo by Nick Carey)

Photos and descriptions courtesy of Dr. Vytenis Babrauskas.

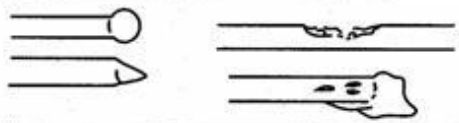
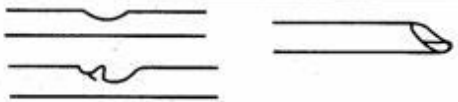
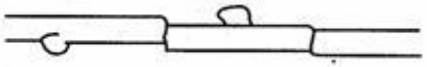
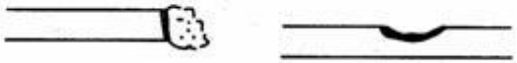
Excerpt from *ATF Technical Bulletin (NFPA 921-2017 – 9.11.2)*

Table 2
Characteristics of Melt Globules

 	Extended Area of Damage Without a Sharp Line of Demarcation from Undamaged Material (Photos by Yasuki Hagimoto / E. C. Buc)
	Visible Effects of Gravity in the Artifact (Photo by Stephen Andrews)
 	Blisters on the Surface (Photos by E. C. Buc)
	Gradual Necking of the Conductor (Photo by Jeremy Neagle)
	Non-Localized Loss of Integrity of Individual Strands on a Stranded Conductor (Photo by Michael Keller) (NOTE: This characteristic was not included in Dr. Babrauskas' proposal but is included here since it is part of the ATF training curriculum.)

Excerpt from Users Manual for NFPA 921

FIGURE 6.10.1 Guide for interpreting damage to electrical wires.

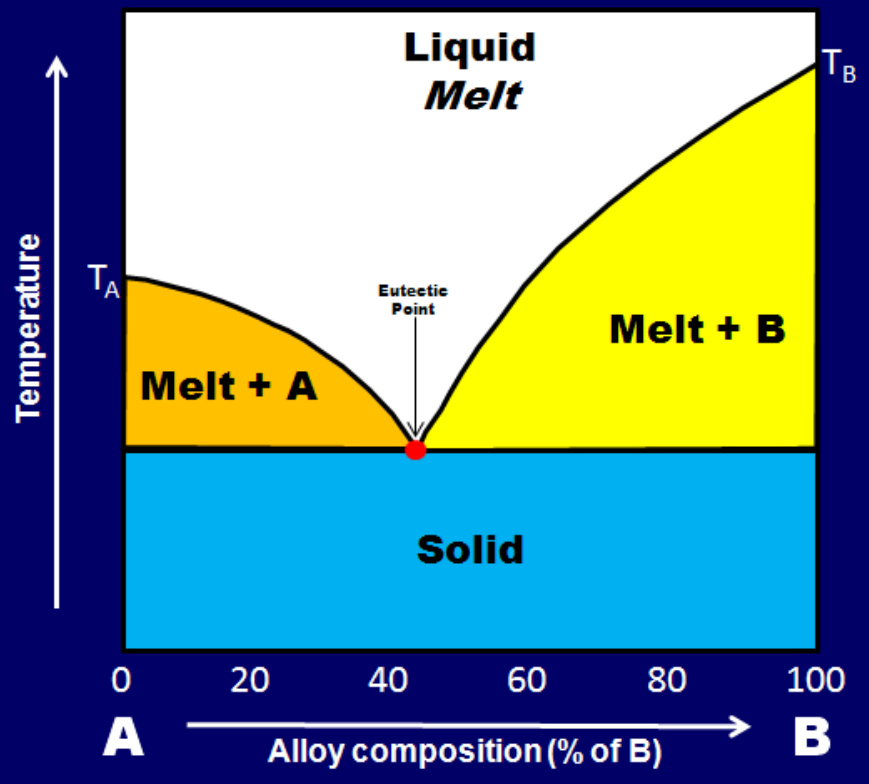
Mode of damage	Effects	Result of	Cause of fire?
Arcing through char		Direct fire heating	No, always a result of fire
Parting arcing		Heating at about 400°F (205°C) but no direct fire	Usually not
Overcurrent		Short circuit or failure in a device plus failure of overcurrent protection	Yes, but also may be a result of fire
Fire		Cable exposed to existing fire	N/A
Heating connection		Connection not tight	Yes
Mechanical		Scraping or gouging by something	No
Alloying		Melted aluminum on the wire	No

Key Points to Document
(as much as possible)

- **Arced wiring**
  - The damaged portion of the wire should be photographed and location marked on drawings.
  - The branch circuit and device load should be noted. The size of OCP should be recorded.
  - Recover enough of the wire to include the fault and also portions of undamaged insulation at each end.
  - Record the supply and load ends. Preserve and package to protect from mechanical damage, fracturing of the wire, etc.

- **Panelboards and Over Current Protection Devices**
  - Circuit breakers become very brittle when heated. Extreme care should be taken in the recovery of panelboards to prevent mechanical damage from preventing further analysis.
  - All conductors should be cut outside to panelboard. The branch circuits should be identified and conductors marked accordingly.
  - Since the potential for damage is very high, this type of equipment may be best suited for examination in the field.

Definitions



Eutectic Phase Diagram

- **Alloying / Eutectic Melting**
  - Alloying refers to the mixing of, generally, two or more metals in which one or more of the metals is in a liquefied state, resulting in an alloy. Metals such as copper and iron (steel) can be affected by alloying with lower melting point metals such as aluminum, zinc, and lead.
    - NFPA 921-2017 6.2.8.6

Approximate Melting Points of Metals Found in Electrical Systems

- **Solder ~ 350°F**
  - Connections in alarm panelboards and alarm equipment
- **Zinc ~ 700°F**
  - connectors and coatings

< 1,000°F

- **Aluminum Wire ~ 1,200°F**
- **Yellow Brass ~ 1,700°F**
  - receptacle and switch components
- **Copper Wire ~ 2,000°F**
- **Carbon Steel ~ 2,600°F**
  - conduit, boxes, and enclosures

Approximate Melting Points of Metals

- **Solder ~ 350°F ~ 180°C**
  - Connections in alarm panelboards and alarm equipment
- **Zinc ~ 800°F ~ 430°C**
  - connectors and coatings

< 1,000°F

- **Aluminum Wire ~ 1,200°F ~ 650°C**
- **Yellow Brass ~ 1,700°F ~ 930°C**
  - receptacle and switch components
- **Copper Wire ~ 2,000°F ~ 1,100°C**

Nichrome Wire ~ 2,550°F ~ 1,400°C

- **Carbon Steel ~ 2,600°F ~ 1430°C**
  - conduit, boxes, and enclosures

Ignition Handbook

- Portable heaters come in two basic varieties, radiant and convection. Heaters with a visible glowing element are classed as radiant, the others as convection .

- Unless the heater sustains a failure, the peak temperatures at convection heaters will be below the ignition temperature of household solid combustibles . Thus, these fires (which were only about 1/5 as numerous as from radiant heaters) primarily involved malfunctions of heaters, typically of wiring or controls .

Ignition Handbook

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Ignition Handbook

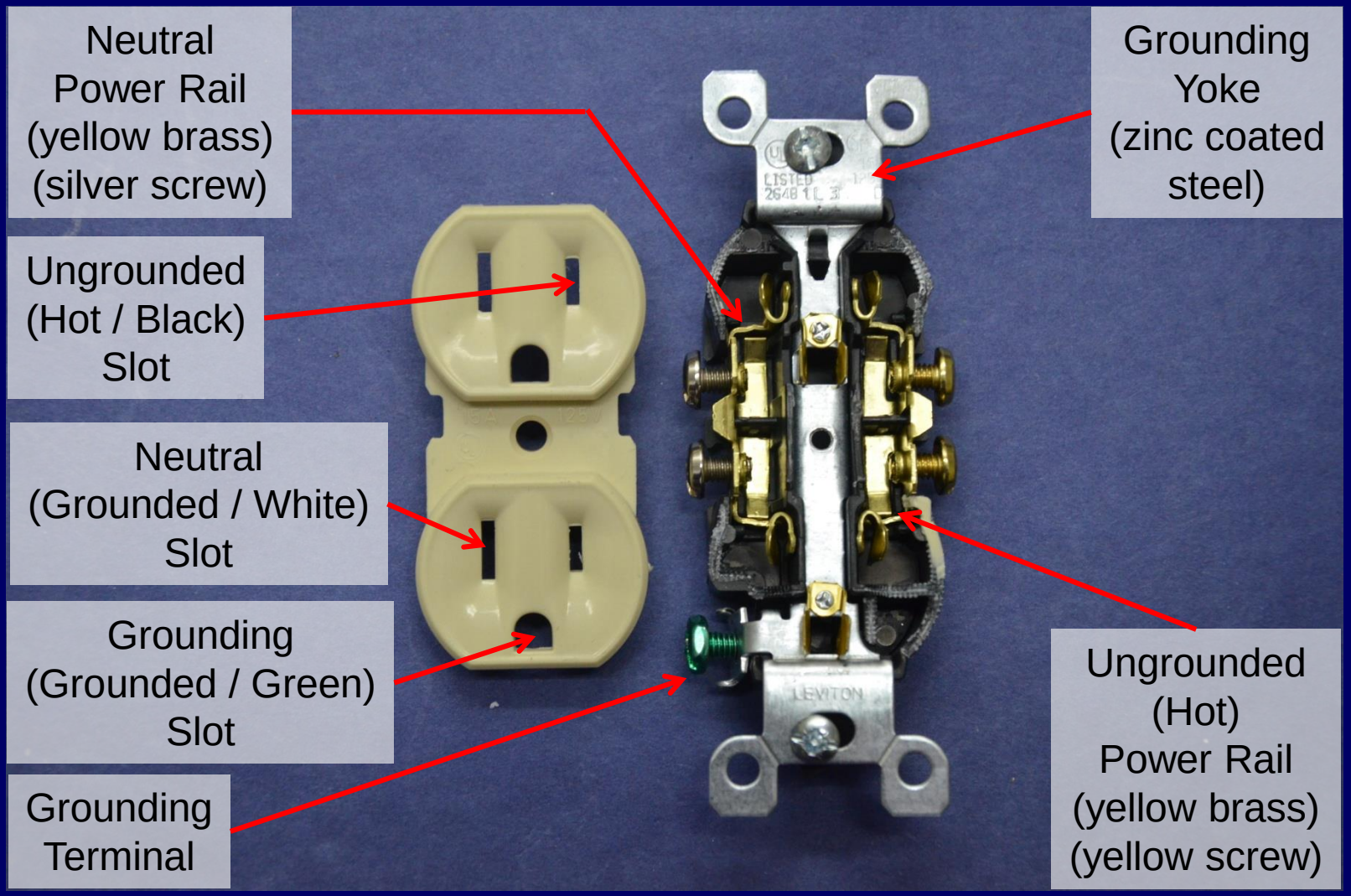
- Radiant electric heaters commonly produce a heat flux around 10 kW/m2 at the face of the grille and the value drops rapidly with distance .

- Unless overt electrical failure occurs, it can be assumed that there is no source of pilot ignition .

- The question of interest then becomes what materials might auto- ignite at a heat flux of 10 kW/m^2 or lower. Fabric and paper goods generally require substantially higher heat fluxes for auto-ignition. But cardboard can be ignited at fluxes below 10 kW/m^2 .

- Of course, pushing any combustibles up to the face of a radiant heater is a misuse of the heater and, 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 design thermal cutout should operate.

15 Amp Receptacle



20 Amp Receptacle