BURGLAR & FIRE ALARM ASSOCIATION OF MICHIGAN

ESTABLISHED 1981

APPRENTICESHIP PROGRAM

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Period 1
Related Training Instruction (RTI)
Module 2 – Basic Electricity / Electronics

Reading material associated with this module:

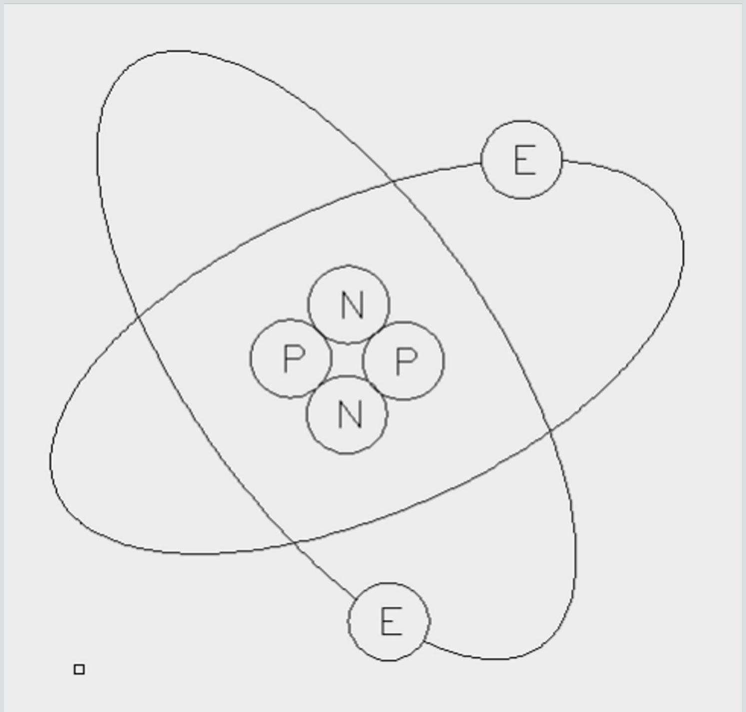
Ugly's Electrical References, 2023 Edition
On-Line Resources Referencing Basic Electrical Theory.

Physics of Electricity

Atoms:

- All matter is made up of atoms.
- Atoms consist of three types of particles:
  - Protons, which carry a positive charge
  - Neutrons, which carry no charge
  - Electrons, which carry a negative charge
- Atoms are composed of a nucleus at the central core, which contains protons and neutrons.
- The core is surrounded by orbiting electrons
- The electrical force of an atom is what binds it together
- The total number of protons in a single atom determines its atomic number and identifies the element.

Illustration of an Atom



Electrical Charge

- The charge inherent in protons and electrons is fundamental to the study of electricity.
- In an intact atom the number of negatively charged electrons is equal to the number of positively charged protons. This equal balance of charges results in a net charge of zero making the atom electrically neutral. Intact atoms are generally stable as the balanced forces hold it together.
- Any object that is electrically charged exerts a force on other charges. This is an attractive force if the charges are different (+ to -) and a repellant force if the charges are like (+ to + or – to -). See next slide for an illustration of this principal.
- Electrons can be transferred or shared between atoms, and this movement of charged particles constitutes an electric current.
- Materials like metals (copper, aluminum) have loosely bound electrons that can easily move, making them good conductors of electricity. Other materials (plastics, ceramics) hold their electrons more tightly, acting as insulators.

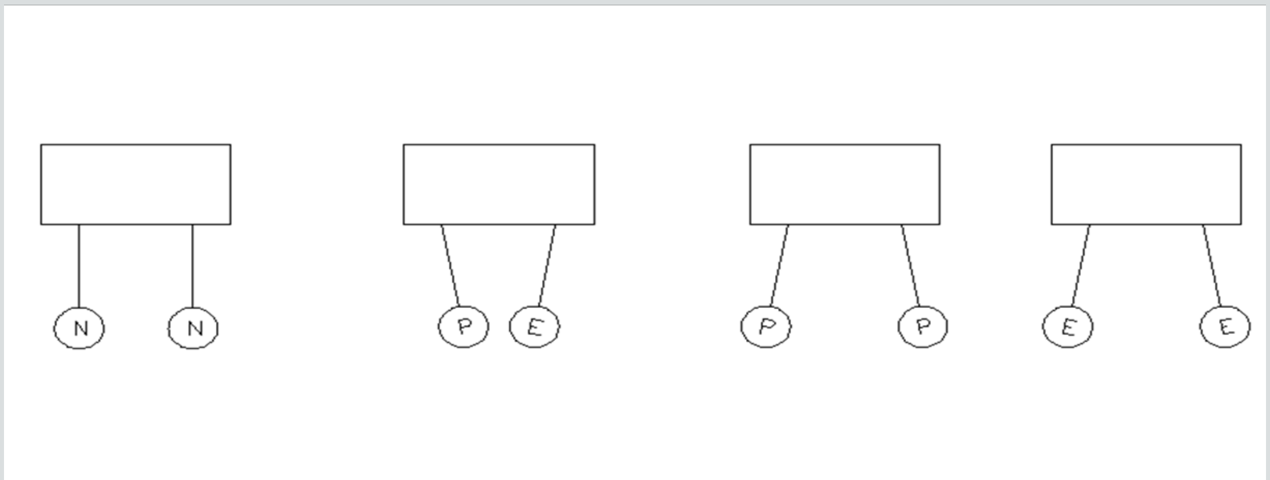
Electrical Charge

Neutral Charge

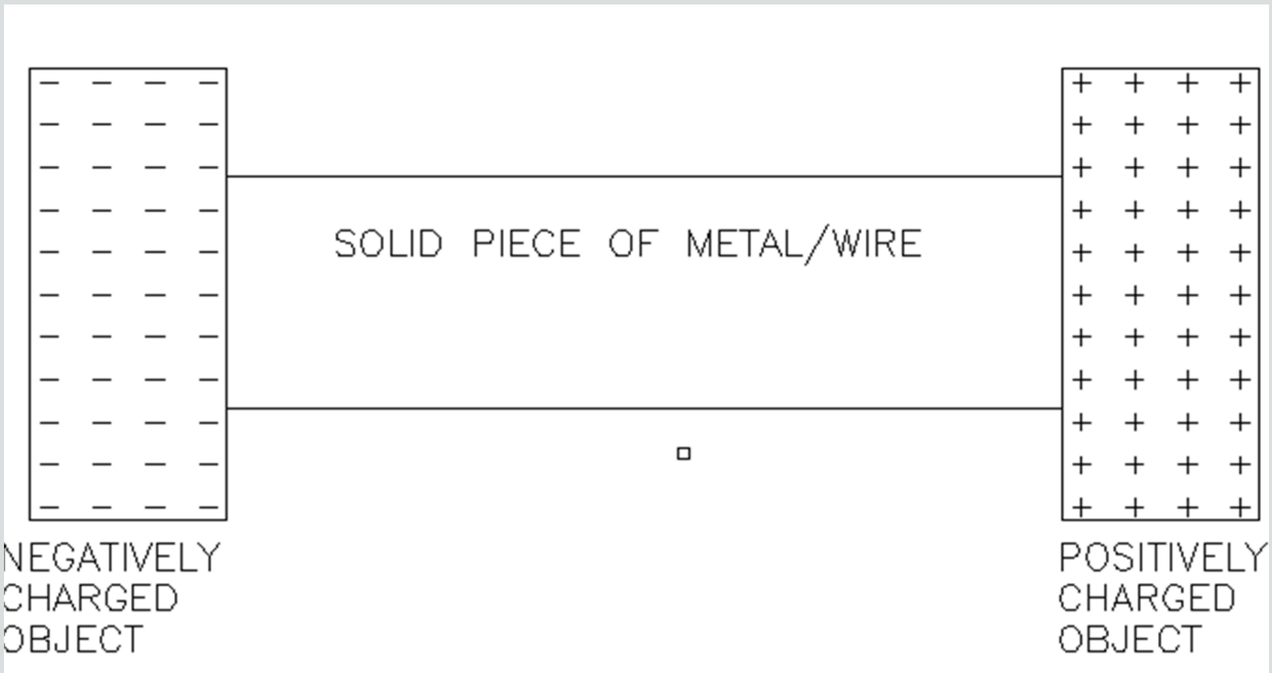
Unlike Charge

Positive Like Charge

Negative Like Charge



Current Theory



Current Theory

- In the previous illustration, electrons from atoms on the left side are strongly repelled by the negatively charged object.
- The electrons on the right side are strongly attracted to the positively charged object.
- In metals (copper, aluminum) electrons can move relatively freely between atoms. When these electrons move in a specific direction, it creates an electrical current.
- While electrons flow from negative to positive, current is normally described as flowing from positive to negative, a convention stemming from early understanding of electricity.
- It is necessary to have a method to describe the amount of current that is flowing.
- 1 coulomb of electrons is equal to 6.24 to 10^{18} electrons. In order to make this less cumbersome in practical use, we use 1 ampere as equivalent to 1 coulomb of electrons passing a specific point in one second.
- The letter I is used to symbolize current in formulas, but the letter A is used to abbreviate its units (ampere).

Current Example

- We measure 12.48 x 10^{18} electrons passing a point in a wire in an elapsed time of 10 seconds.
  - What is the quantity of electrons that have moved in coulombs?

$$\frac{12.48\times10^{18}}{6.24\times10^{18}}=2\text{C (coulombs)}$$

  - What is the value of current flowing in the wire in amperes?

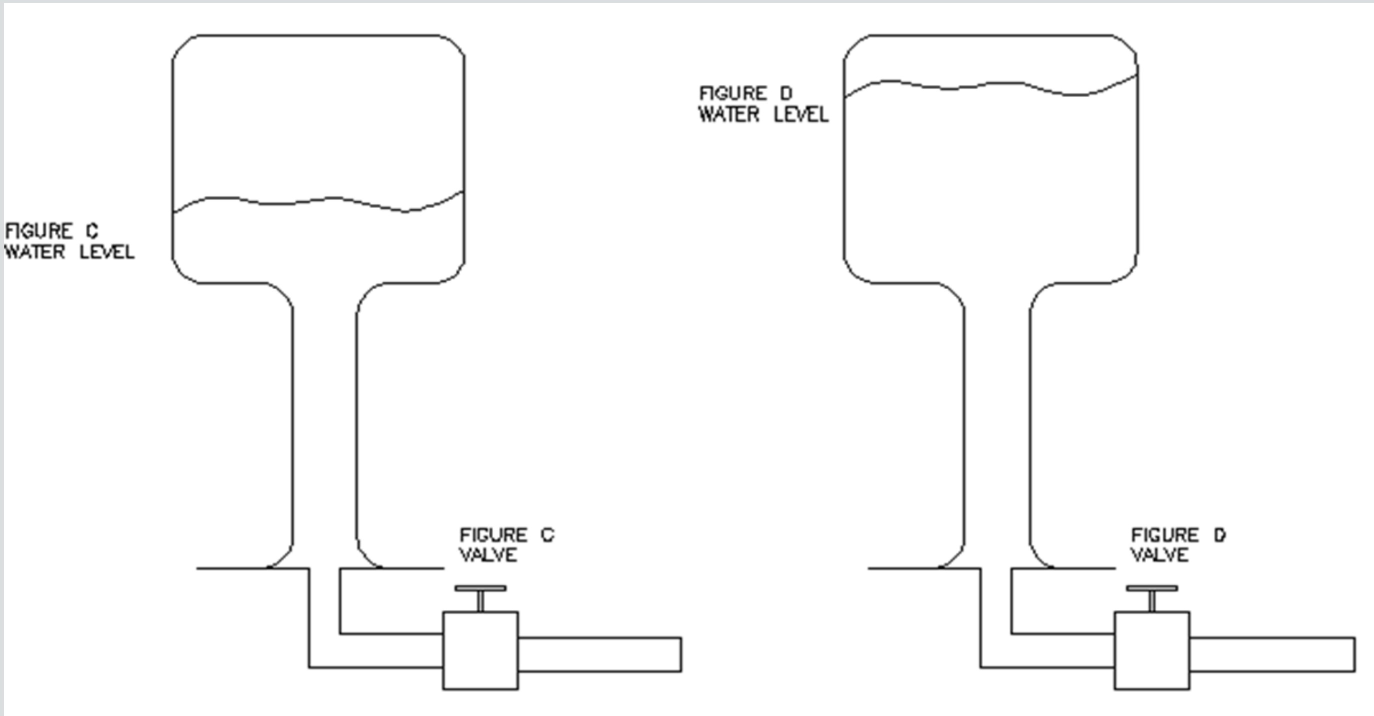
$$I=\frac{Q}{t}=\frac{2C}{10seconds}=0.2A\ (200mA)$$

  - Note the change from amperes (amps) to milliamps. When working with low voltage systems, you will frequently find yourself dealing with small amounts of current. An amp is equivalent to 1000 milliamps.

Voltage Theory

- Voltage is a difference between two points, indicating how much potential energy a charged particle would have at one point compared to another.
- Voltage provides the driving force for electrons to move through a circuit. A higher voltage means a stronger push, potentially leading to a higher current.
- Batteries and generators are common sources of voltage, creating the potential difference that drives current.
- Voltage affects how components in a circuit behave. Too high a voltage can damage components, while too low a voltage may prevent them from working.

Water Tank Analogy



Water Tank Analogy

- We can equate voltage theory to the water tank drawing shown in the previous slide.
- As you will note, the water level in tank D is much higher than in tank C.
- The force pushing down to drive the water through the supply pipe is dependent upon the height of the water above the pipe. The height difference between the water level in the two tanks and the outlet pipes is analogous to voltage.
- The higher the water level, the more pressure and potential for water flow.
- Similarly, a higher voltage providing more pressure on a circuit will drive more current through the wire or device.

Voltage vs. Current Theory

- The basic unit of measurement for voltage is the volt, symbolized by the letter V. The letter E is also used to indicate voltage in formulas.
- Voltage is an electromotive force (electron moving force). The amount of force is directly related to the number of volts. The higher the voltage, the stronger the force.
- Voltage is strictly a force; by itself it is not motion.
- Current provides the motion; the motion of electrons (charge).
- It is possible to have voltage without current (ex., an unconnected battery), just as it is possible to have mechanical force without motion.
- In the previous water tank example, the height of water creates a force (voltage), but if the outlet valve is closed there is no motion (current).
- Voltage is the cause, current is the effect.

Voltage Sources

There are various sources to provide voltage:

- Batteries: A battery stores chemical energy and converts it to electrical energy.
- Generator: A generator converts mechanical energy into electrical energy using electromagnetic induction. This process involves a rotor (rotating element) spinning within a magnetic field (the stator).
- Solar Cells (photovoltaic cells – PV): These cells convert sunlight into electricity through the photovoltaic effect. When sunlight (photons) strikes the cell it can knock electrons loose from the atoms within a semiconductor, usually silicon. These freed electrons, carrying a negative charge, create an electrical imbalance, resulting in a voltage potential.
- Rectified Power Supplies: These power supplies provide DC (direct current) power from AC (alternating current) wall outlets by allowing one voltage direction to appear, while blocking the other voltage direction.

Resistance Theory

- Electrical resistance is a measurement of how much an electrical circuit opposes the flow of current.
- If a device allows very little current to flow when a voltage is applied, then the device is considered to have a high resistance.
- If the device allows a high current to flow, then the device is considered to have a low resistance.
- The basic unit of resistance is the ohm, symbolized by the Greek letter omega (Ω).
- In formulas resistance is represented by the letter R.
- The statement indicating a resistance equal to 10 ohms is: $R = 10\Omega$
- The standard symbol for a resistor in an electrical circuit diagram is a zigzag line. See below:

Resistance Theory

Resistance in Series and Parallel:

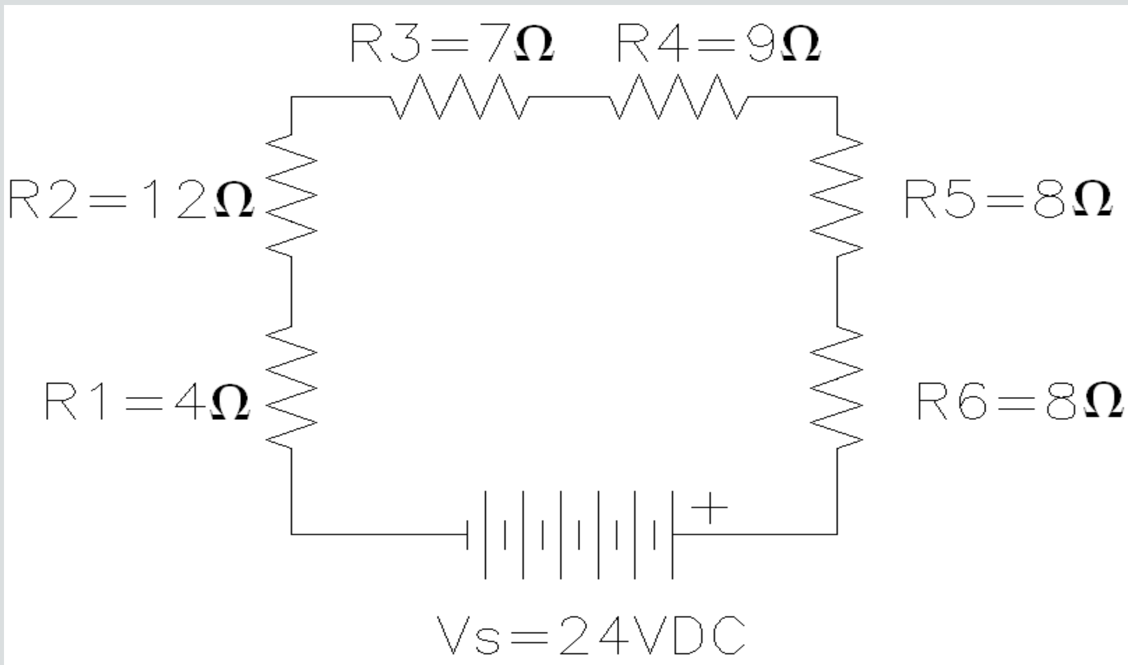
- A series circuit is a circuit that has only one path through which electrons can flow.
- A parallel circuit is a circuit that has more than one path through which electrons can flow.
- Resistances connected in series or parallel have specific properties that are important to understand.
- Series resistance:
  - The total resistance of a series circuit is the sum of the individual resistance values:

    $R_T = R_1 + R_2 + R_3....$
  - The total current flow in a series circuit remains constant throughout the circuit:

    $I_T = I_1 = I_2 = I_3$
  - The total source voltage in a series circuit is the sum of the individual voltage drops across the individual resistances:

    $V_S = V_{R1} + V_{R2} + V_{R3}....$

Resistance Theory – Series Circuit Example



Resistance Theory

Resistance in Series and Parallel:

- Parallel resistance:
  - The total resistance of a parallel circuit is the reciprocal of the sum of the reciprocals of the individual resistance values:

    $$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \cdots$$

  - The source voltage in a parallel circuit remains constant throughout the circuit:

    $V_S = V_1 + V_2 + V_3 \ldots.$

  - The total current flow in a parallel circuit is the sum of the individual current flows through the individual resistances:

    $I_T = I_{R1} + I_{R2} + I_{R3} \ldots.$

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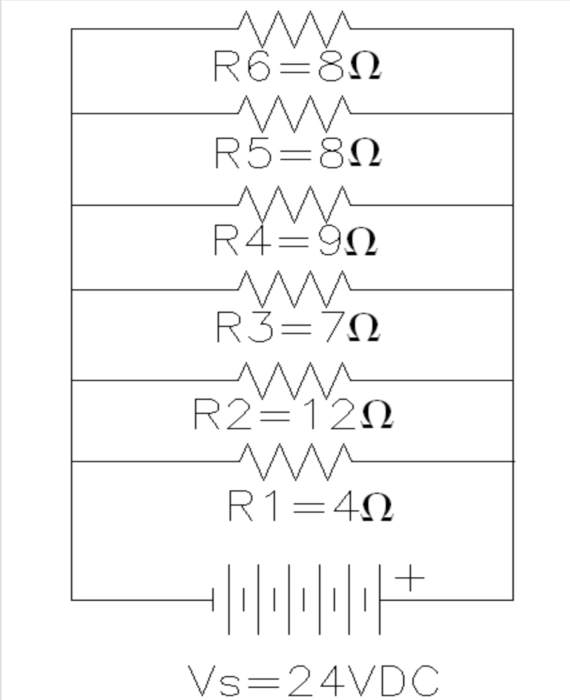
Resistance Theory – Parallel Circuit Example



Resistor Values

- When working with fire alarm circuits, you will frequently find it necessary to determine the value of various resistors used as end-of-line devices on indicating device circuits, notification appliance circuits, and for device supervision.
  - Referring to the chart on the following slide:
    - Color coding is used to identify small resistors, where a printed value on the body would be unreadable. Resistors may have from 3 to 6 colored bands, indicating the digits (1 to 3 bands), a multiplier (1 band), the tolerance of the resistor value (1 band), and the temperature coefficient (1 band – rarely used).
    - Determining the resistor value from the bands is as follows:
      - 3 bands – 1st digit, 2nd digit, multiplier
      - 4 bands – 1st digit, 2nd digit, multiplier, tolerance
      - 5 bands – 1st digit, 2nd digit, 3rd digit, multiplier, tolerance
      - 6 bands – 1st digit, 2nd digit, 3rd digit, multiplier, tolerance, temperature coefficient

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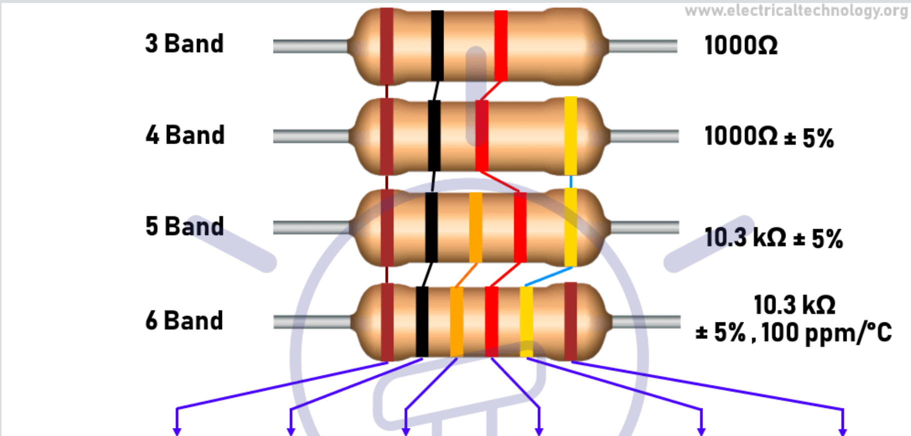

COLOR	1st DIGIT	2nd DIGIT	3rd DIGIT	MULTIPLIER	TOLERANCE	TEMP .Co
BLACK	0	0	0	1Ω		
BROWN	1	1	1	10Ω	± 1% (F)	100
RED	2	2	2	100Ω	± 2% (G)	50
ORANGE	3	3	3	1kΩ	± 3%	15
YELLOW	4	4	4	10kΩ	± 4%	25
GREEN	5	5	5	100kΩ	± 0.5% (D)	
BLUE	6	6	6	1MΩ	± 0.25% (C)	10
VIOLET	7	7	7	10MΩ	± 0.10% (B)	5
GREY	8	8	8	100MΩ	± 0.05% (A)	
WHITE	9	9	9	1GΩ		
GOLD				0.1Ω	± 5% (J)	
SILVER				0.01Ω	± 10% (K)	

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Resistor Values

- Example:
  - A resistor has the following 4 bands:

    Brown, Black, Yellow, Silver

    This would indicate a 10,000Ω (*10KΩ) resistor with a 10% tolerance

    Brown = 1

    Black = 0

    Yellow = x1000

    Silver = 10%

    ** The abbreviation K = 1000*

Resistor Values

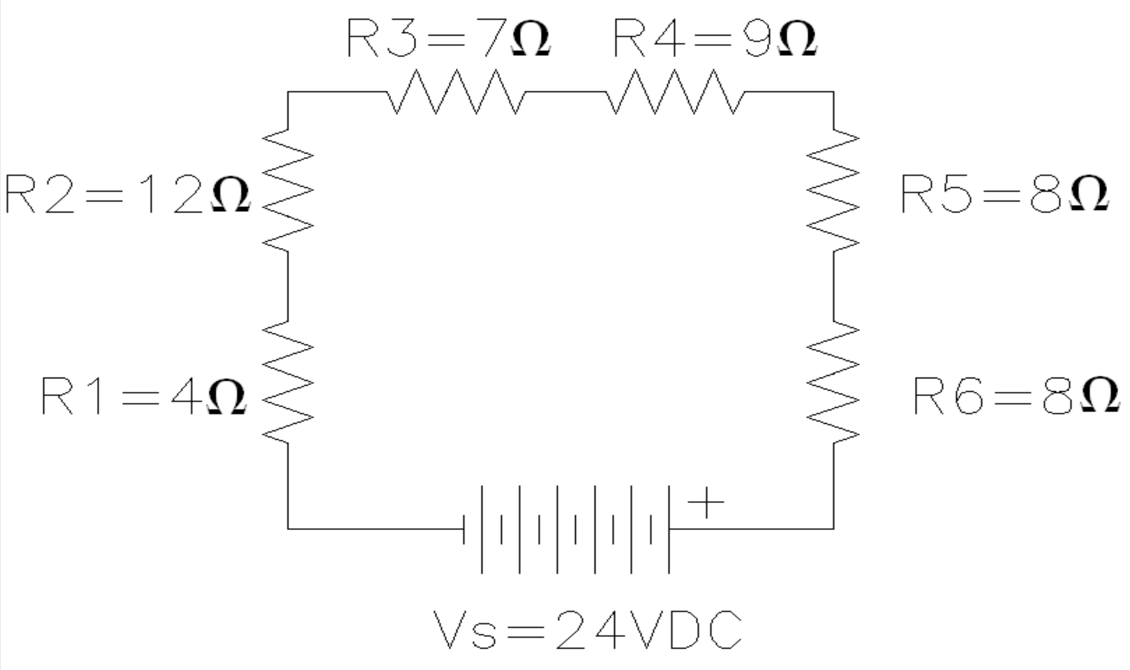
- Recent advances in printing technology have enabled manufacturers to print the value on small resistors, but you will find color coding quite frequently in the field. Trying to remember the values, or not having access to a chart, has led to the use of various mnemonics, such as:

Big	Black	0
Boys	Brown	1
Race	Red	2
Our	Orange	3
Young	Yellow	4
Girls	Green	5
But	Blue	6
Violet	Violet	7
Generally	Grey	8
Wins	White	9

Introduction to Ohm's Law

- Ohm's Law defines the relationship between voltage, current, and resistance in electrical circuits.
- In its most basic form, the formula states that the voltage of a circuit is equal to the current flow in the circuit times the resistance of the circuit.
- A voltage of 1V, connected across a resistance of 1Ω will allow a current of 1A to flow.
- Referring to our previous series circuit slide (see following), we can determine the values associated with voltage, current, and resistance in this circuit.
- Basic algebra provides us the relationships of voltage, current, and resistance within Ohm's law.
  - $E = I \times R$
  - $I = E/R$
  - $R = E/I$

Ohm's Law – Series Circuit Example



Introduction to Ohm's Law

- The total resistance of the series circuit in the previous slide is shown below:

$$R_T = R_1 + R_2 + R_3 \cdots$$
$$R_T = 4\Omega + 12\Omega + 7\Omega + 9\Omega + 8\Omega + 8\Omega$$
$$R_T = 48\Omega$$

- The total current flow within the circuit given the source voltage of 24VDC and the calculated resistance of 48Ω is shown below:

$$I = E/R$$
$$I = 24VDC/48\Omega$$
$$I = 0.5A$$

- As a reminder, the current flow in a series circuit remains constant, so the current flow through each resistance will be .5A.

Introduction to Ohm's Law

- The sum of the total voltage drops across the resistances in a series circuit is equal to the source voltage. To prove this statement, we will again utilize Ohm's Law.

$E_{R1} = .5A \times 4\Omega = 2V$ $E_{R2} = .5A \times 12\Omega = 6V$ $E_{R3} = .5A \times 7\Omega = 3.5V$

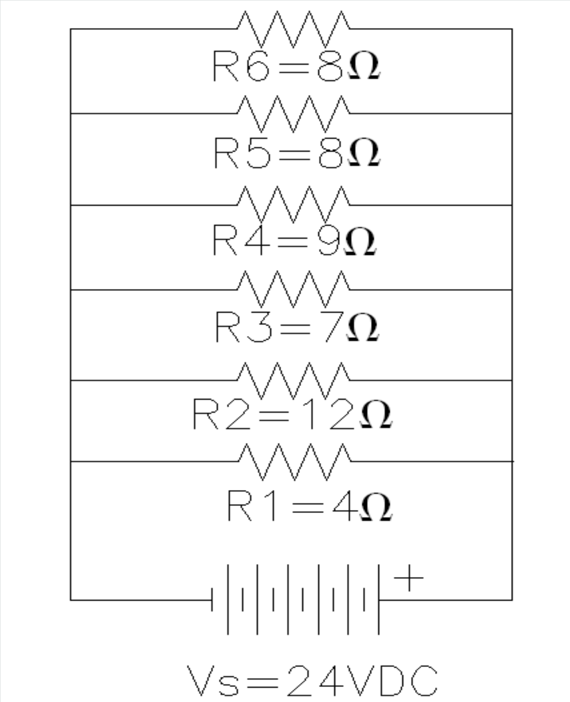
$E_{R4} = .5A \times 9\Omega = 4.5V$ $E_{R5} = .5A \times 8\Omega = 4V$ $E_{R6} = .5A \times 8\Omega = 4V$

- The total voltage drop for the above circuit is 24V, which matches the source voltage from the illustration.

$$E_T = 2V + 6V + 3.5V + 4.5V + 4V + 4V$$

$$E_T = 24V$$

Ohm's Law – Parallel Circuit Example



Introduction to Ohm's Law

- The total resistance of the parallel circuit in the previous slide is shown below:

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \cdots$$

$$\frac{1}{RT} = \frac{1}{4\Omega} + \frac{1}{12\Omega} + \frac{1}{7\Omega} + \frac{1}{9\Omega} + \frac{1}{8\Omega} + \frac{1}{8\Omega}$$

$$\frac{1}{RT} = .25 + .083 + .143 + .111 + .125 + .125$$

$$\frac{1}{RT} = .837$$

$$RT = \frac{1}{.837} = 1.2\Omega$$

- Note that the total resistance of the circuit is smaller than the smallest individual resistance in the circuit. This will always be true in parallel circuits.

Introduction to Ohm's Law

- The source voltage in the illustration is 24VDC, while the calculated total resistance is 1.2Ω. This information will allow us to calculate total current flowing in the circuit.

$$I = E/R$$

$$I = 24VDC/1.2\Omega$$

$$I = 20A$$

- As a reminder, the voltage in a parallel circuit remains constant, so the voltage at each resistance will be 24VDC. Looking at the illustration, this is clear as the source is directly connected across each resistance.
- The sum of the current flow through the individual resistances in a parallel circuit is equal to the total current flow. To prove this statement, we will again utilize Ohm's Law.

$I_{R1} = 24V/4\Omega = 6A$ $\quad I_{R2} = 24V/12\Omega = 2A$ $\quad I_{R3} = 24V/7\Omega = 3.4A$

$I_{R4} = 24V/9\Omega = 2.6A$ $\quad I_{R5} = 24V/8\Omega = 3A$ $\quad I_{R6} = 24V/8\Omega = 3A$

$$I_T = 6A + 2A + 3.4A + 2.6A + 3A + 3A = 20A$$

Introduction to Ohm's Law

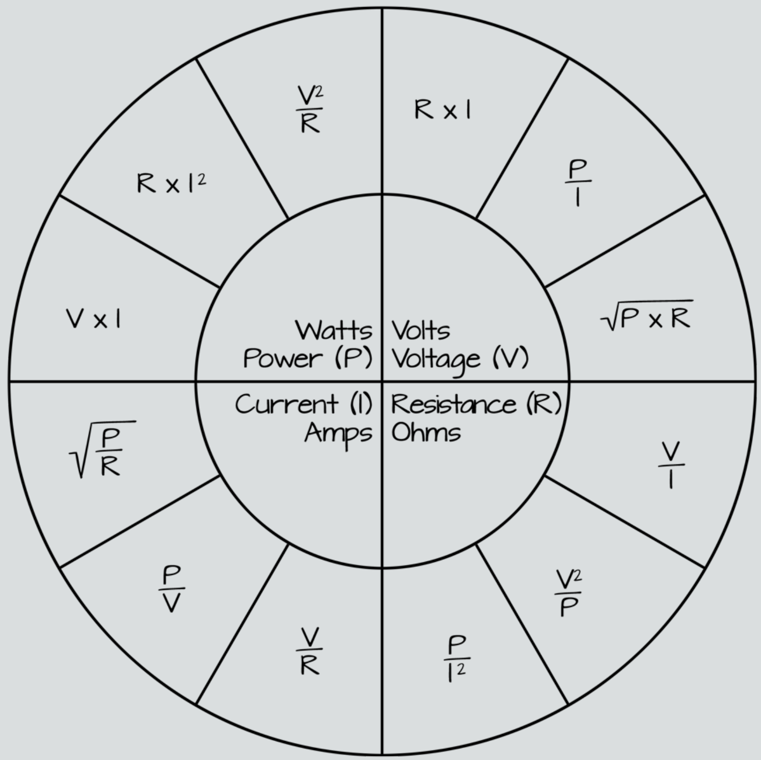
- An additional principal related to Ohm's Law is the concept of power. Electrical power is the rate at which electrical energy is transferred or used. It is essentially the speed at which electrical work is done and is expressed in watts. A higher power (watts) means energy is being used or transferred faster.
- Power is related to Ohm's Law as shown in the following formulas:

$$P = E \times I$$

$$P = I^2/R$$

$$P = E^2/R$$

Introduction to Ohm's Law



Basic Voltage Drop Calculations

<u>The resistance of any material depends upon three factors:</u>

- Length: The longer the material, the higher the resistance.
- Cross-sectional area: The larger the cross-sectional area, the lower the resistance.
- Resistivity: The greater the resistivity of the material, the higher the resistance.
- These factors give us the following formula:

$R = {}^{r \times l}/_{A}$ Where R is the resistance, r is the resistivity, and A is the cross-sectional area

- Understanding of this relationship provides the basis for notification appliance circuit voltage drop calculations.
- Wire, although it is a conductor, also has resistance. To ensure that the voltage drop across this wire is not excessive to the point of impairing the device's ability to operate, we perform voltage drop calculations. These are primarily performed on notification appliance circuits, but can also apply to various other circuits as well.

Basic Voltage Drop Calculations

- Based on information provided by Table 8 of NFPA 70 (National Electrical Code – NEC), we can obtain the cross-sectional area of various types and sizes (American Wire Gauge - AWG) of wire.
- Below are cross-sectional areas for common AWG wire used on fire alarm systems.
  - 18AWG 1620cm *
  - 16AWG 2580cm
  - 14AWG 4110cm
  - 12AWG 6530cm

  *cm = circular-mils, which is a unit of measure to express cross-sectional area. This is defined as the area of a circle with a diameter of one mil (0.0001 inch). Ex., a wire with a diameter of 10 mils has an area of 10^2 which equals 100 circular mils. MCM (thousand circular-mils) is also used for large cables.

Basic Voltage Drop Calculations

Example Problem:

- We have a 200’ length of 18AWG, 2 conductor cable and we intend to connect to a single explosion-proof horn/strobe that has a minimum operating voltage of 16VDC and a current draw of 1.7A. We are using a copper cable which has a resistivity (r) at 75°C of 13.09Ω-cm/ft. Based on the information provided will this device operate properly when activated?
- Our first step is to determine the resistance of the wire. We also need to consider there are two conductors in our cable, so the total wire distance for our calculation is 400’.
- From our previous slides, the formula for calculating the total resistance of the cable is:

$$R = {}^{r \times l}/_{A}$$

$$R = \frac{13.09\Omega \times 400'}{1620cm} = 3.23\Omega$$

Basic Voltage Drop Calculations

Example Problem (continued):

- Fire alarm devices must operate between 85% and 110% of the rated nameplate voltage.
- A fire alarm panel typically operates at a nominal 24VDC on battery power.
- We must design for the worst-case scenario where the fire alarm panel is operating at 85% of it's rated nameplate voltage.
- Our starting voltage for this circuit at the control panel will be $24VDC \times .85 = 20.4VDC$
- Since we know our current draw for the horn/strobe is 1.7A and the wire resistance is 3.23Ω, we can calculate the voltage that is lost (dropped) along the length of the cable using Ohm's Law.

$$E = I \times R$$

$$E = 1.7A \times 3.23\Omega = 5.49V$$

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Basic Voltage Drop Calculations

Example Problem (continued):

- Based on our reduced starting voltage of 20.4VDC and our voltage loss due to cable resistance of 5.49VDC, the remaining voltage at the horn/strobe will be 14.91VDC.
- The minimum operating voltage of the horn/strobe was 16VDC. This device would not operate if the control panel was operating at 85% of its rated nameplate voltage as required by code.
- To ensure proper operation of the horn/strobe, larger conductors would be required.

END OF PERIOD 1 - MODULE 2