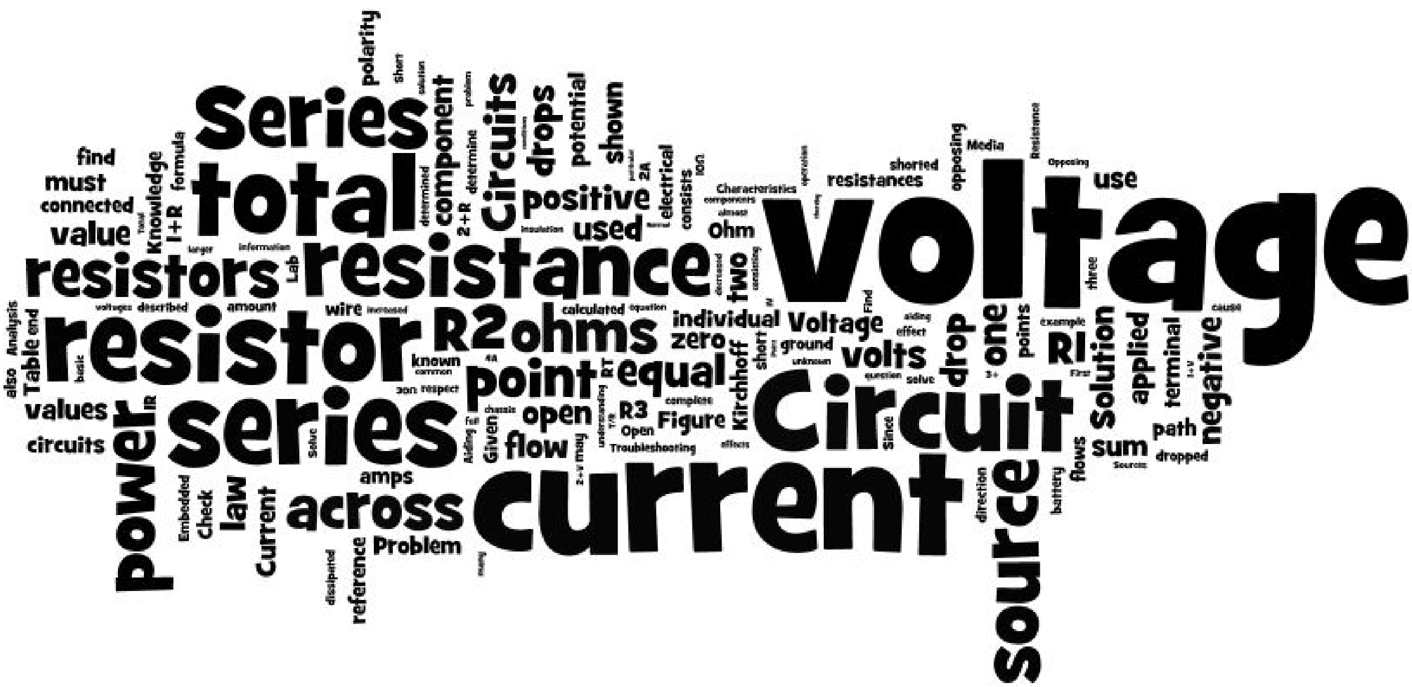
4 Series Circuits



Contents

4 Series Circuits 1
Characteristics of Series Circuits 5
Current in a Series Circuit 5
Resistance in a Series Circuit 6
Voltage in a Series Circuit 8
Power in a Series Circuit 11
Summary of the Characteristics of Series Circuits 13
Rules for Series DC Circuits 14
Knowledge Check 14
Series Circuit Analysis 15
Embedded Media 19
Knowledge Check 19
Kirchhoff's Voltage Law 21
Polarity of Voltage 22
Series Aiding and Opposing Sources 23
Reference Points 26
Embedded Media 29
Knowledge Check 30
Troubleshooting 31
Circuit Faults 31
Open Circuit 31
Short Circuit 32
Component Failure Analysis 34
Embedded Media 38
Knowledge Check- need more 38
Series Circuits Lab 1: A Simple Series Circuit 39

Components & Equipment Needed 39

Circuit Diagram 39

How to wire a breadboard in Series 39

Procedure 40

Table for Series Circuits Lab 1 41

Observations and Conclusions 41

Series Circuits Lab 2: Series Aiding Voltage 42

Components & Equipment Needed 42

Circuit Diagram 42

Procedure 42

Table for Series Circuits Lab 1 43

Observations and Conclusions 43

Series Circuits Lab 3: Series Opposing Voltage 44

Components & Equipment Needed 44

Circuit Diagram 44

Procedure 44

Table for Series Circuits Lab 3 45

Observations and Conclusions 45

Series Circuits Lab 4: Critical Thinking 46

The Problem 46

Index of Important Terms 47

Answers to Knowledge Checks 48

Characteristics of Series Circuits 48

Series Circuit Analysis 48

Series Aiding and Opposing Voltages 50

Troubleshooting 50

Additional Resources 52
Physics Resources 52
Video Resources 52
References 53
Attributions 54
Table of Figures 55
Table of Tables 55
Table of Circuits 55
Table of Equations 56

Characteristics of Series Circuits

When two unequal charges are connected by a conductor, a complete pathway for current exists. An electric circuit is a complete conducting pathway. It consists not only of the conductor, but also includes the path through the voltage source. Inside the voltage source, current flows from the positive terminal, through the source, and emerges at the negative terminal.

A **series circuit** is defined as a circuit that contains only one path for current flow. To compare the basic circuit that has been discussed and a more complex series circuit, Figure 1 shows two circuits. The basic circuit has only one lamp and the series circuit has three lamps connected in series.

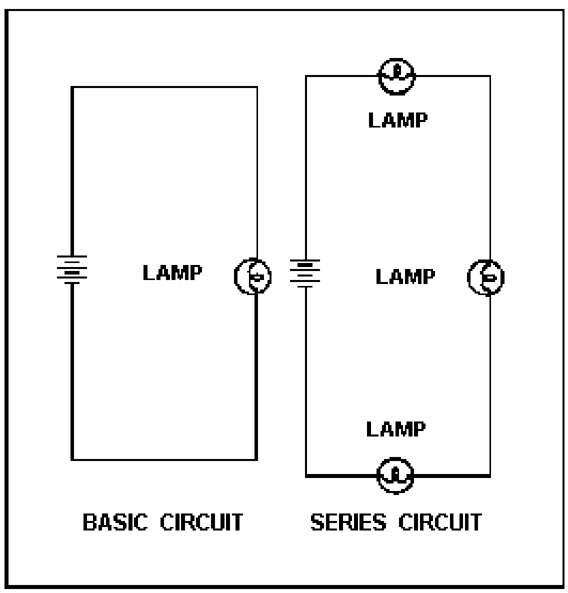
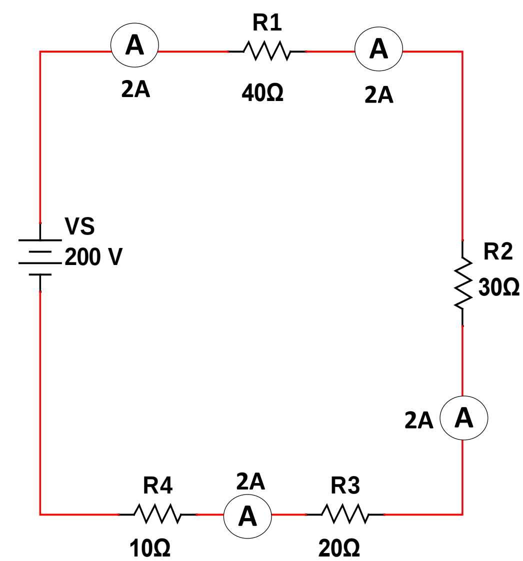


Figure 1: Comparison of basic and series circuits.

Current in a Series Circuit

Since there is only one path for current in a series circuit, the same current must flow through each component of the circuit. To determine the current in a series circuit, only the current through one of the components need be known.

The fact that the same current flows through each component of a series circuit can be verified by inserting meters into the circuit at various points, as shown in Circuit 1. If this were done, each meter would be found to indicate the same value of current.



Circuit 1: Current in a series circuit.

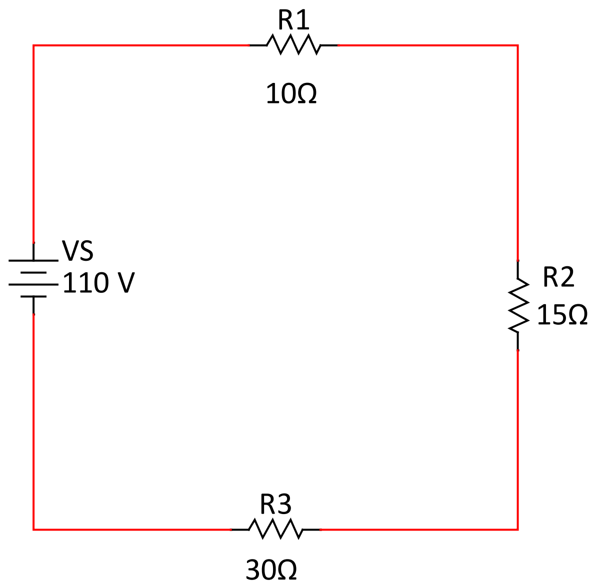
Resistance in a Series Circuit

Referring back to Figure 1, the current in a series circuit must flow through each lamp to complete the electrical path in the circuit. Each additional lamp offers added resistance. In a series circuit, the total circuit resistance (R_T) is equal to the sum of the individual resistances.

$$R_T = R_1 + R_2 + R_3 + \cdots R_n$$

Equation 1: Total Resistance in a Series Circuit

Problem: In Circuit 2, a series circuit consisting of three resistors: one of 10 Ω, one of 15 Ω, and one of 30 Ω, is shown. A voltage source provides 110 V. What is the total resistance?



Circuit 2: Solving for total resistance in a series circuit.

Given:

$R_1 = 10\Omega$

$R_2 = 15\Omega$

$R_3 = 30\Omega$

Solution:

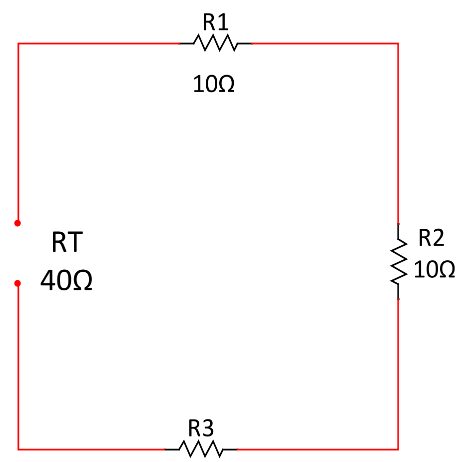
$R_T = R_1 + R_2 + R_3$

$R_T = 10\Omega + 15\Omega + 30\Omega$

$R_T = 55\Omega$

In some circuit applications, the total resistance is known and the value of one of the circuit resistors has to be determined. The equation $R_T = R_1 + R_2 + R_3$ can be transposed to solve for the value of the unknown resistance.

Problem: In Circuit 3 the total resistance of a circuit containing three resistors is 40 Ω. Two of the circuit resistors are 10 Ω each. Calculate the value of the third resistor (R3).



Circuit 3: Calculating the value of an unknown resistance in a series

Given: $R_T = 40\Omega$

$R_1 = 10\Omega$

$R_2 = 10\Omega$

Solution: $R_T = R_1 + R_2 + R_3$

To find R_3, subtract ($R_1 + R_2$) from both sides of the formula:

$$R_T - (R_1 + R_2) \quad = R_1 + R_2 + R_3 - (R_1 + R_2)$$

Reduce: $R_T - R_1 - R_2 = R_3$

Substitute in the values and solve: $40\Omega - 10\Omega - 10\Omega = 20\Omega$

Voltage in a Series Circuit

The voltage dropped across the resistor in a circuit consisting of a single resistor and a voltage source is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit that consists of more than one resistor is also equal to the applied voltage, but consists of the sum of the individual resistor voltage drops. In any series circuit, the sum of the resistor voltage drops must equal the source voltage. This statement can be proven by an examination of the circuit shown in Circuit 4. In this circuit a source potential (VT) of 20 volts is dropped across a series circuit consisting of two 5-ohm resistors. The total resistance of the circuit (RT) is equal to the sum of the two individual resistances, or 10 ohms. Using Ohm's law the circuit current may be calculated as follows:

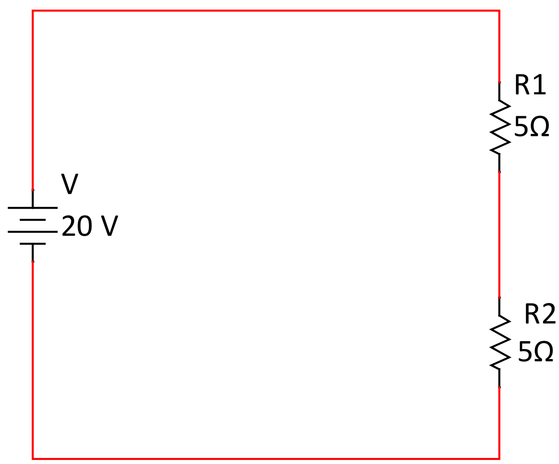
Given: $V_T = 20V$

$\mathrm{R_T} = 10\Omega$

Solution: $I_T = \frac{V_T}{R_T}$

$I_T = \frac{20\,V}{10\Omega}$

$I_T = 2\,A$



Circuit 4: Calculating individual voltage drops in a series circuit.

Since the value of the resistors is known to be 5 ohms each, and the current through the resistors is known to be 2 amperes, the voltage drops across the resistors can be calculated. The voltage (V_1) across R_1 is therefore:

Given: $I_1 = 2\,A$

$\mathrm{R_1} = 5\,\Omega$

Solution:

$$V_1 = I_1 \times R_1$$

$$V_1 = 2A \times 5\Omega$$

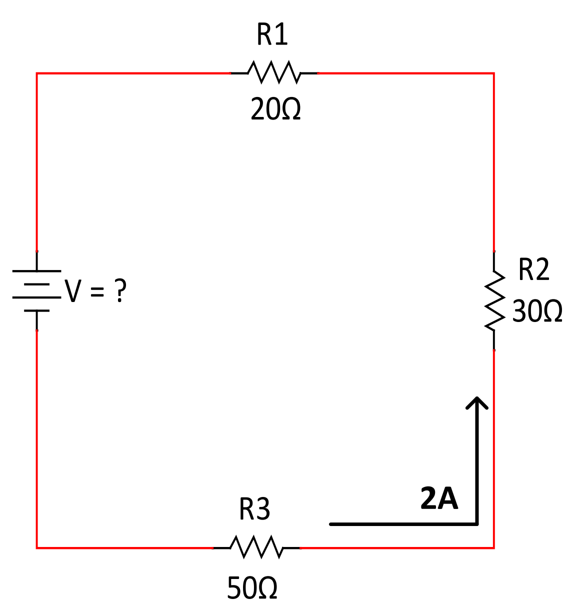
$$V_1 = 10\ V$$

By inspecting the circuit, you can see that R2 is the same ohmic value as R1 and carries the same current. The voltage drop across R2 is therefore also equal to 10 volts. Adding these two 10-volts drops together gives a total drop of 20 volts, exactly equal to the applied voltage. For a series circuit then:

$$V_T = V_1 + V_2 + V_3 + \cdots V_n$$

Equation 2: Total Voltage in a Series Circuit

Problem: A series circuit consists of three resistors having values of 20 ohms, 30 ohms, and 50 ohms, respectively. Find the applied voltage if the current through the 30 ohm resistor is 2 amps. (The abbreviation amp is commonly used for ampere.) To solve the problem, a circuit diagram is first drawn and labeled (Circuit 5).



Circuit 5: Solving for applied voltage in a series circuit.

Given: $R_1 = 20\ \Omega$

$R_2 = 30\ \Omega$

$R_3 = 50\ \Omega$

$I = 2A$

Solution: $V_T = V_1 + V_2 + V_3$

$V_1 = R_1 \times I_1$ (I_1 = the current through R_1)

$V_2 = R_2 \times I_2$

$V_3 = R_3 \times I_3$

Substituting:

$$V_T = (R_1 \times I_1) + (R_2 \times I_2) + (R_3 \times I_3)$$

$$V_T = (20\Omega \times 2A) + (30\Omega \times 2A) + (50\Omega \times 2A)$$

$$V_T = 40V + 60V + 100\ V$$

$$V_T = 200\ V$$

NOTE: When you use Ohm's law the quantities for the equation MUST be taken from the SAME part of the circuit. In the above example the voltage across R2 was computed using the current through R2 and the resistance of R2.

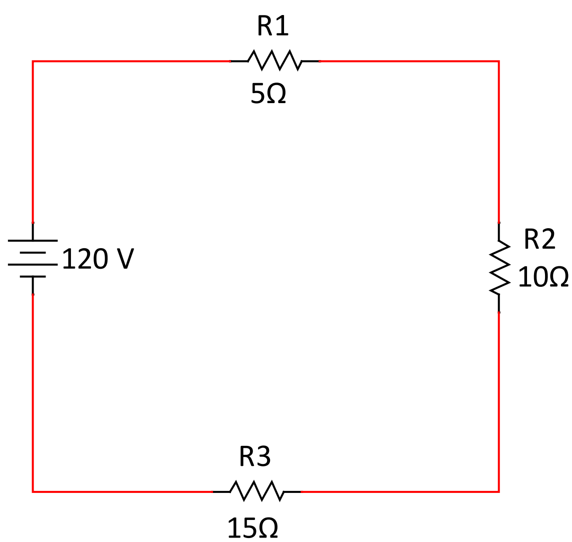
The value of the voltage dropped by a resistor is determined by the applied voltage and is in proportion to the circuit resistances. The voltage drops that occur in a series circuit are in direct proportion to the resistances. This is the result of having the same current flow through each resistor—the larger the ohmic value of the resistor, the larger the voltage drop across it.

Power in a Series Circuit

Each of the resistors in a series circuit consumes power which is dissipated in the form of heat. Since this power must come from the source, the total power must be equal to the power consumed by the circuit resistances. In a series circuit the total power is additive, or is equal to the sum of the power dissipated by the individual resistors. Total power (P_T) is equal to:

$$P_T = P_1 + P_2 + P_3 + \cdots P_n$$

Equation 3: Total power in a series circuit.



Circuit 6: Total power in a series circuit.

Problem: A series circuit consists of three resistors having values of 5 ohms, 10 ohms, and 15 ohms. Find the total power when 120 volts is applied to the circuit. (Circuit 6)

Given:

$R_1 = 5\ \Omega$

$R_2 = 10\ \Omega$

$R_3 = 15\ \Omega$

$V = 120\ V$

Solution: First, solve for total resistance (R_T):

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 5\Omega + 10\Omega + 15\Omega$$

$$R_T = 30\Omega$$

Next, use RT and the applied voltage to solve for current, I:

$$I = \frac{V_T}{R_T}$$

$$I = \frac{120\,V}{30\Omega}$$

$$I = 4A$$

Finally, use the power formula $P = I^2 \times R_n$ to calcuate power dissipation for each resistor:

$$P_1 = (4A)^2 \times 5\ \Omega = 80\ W$$

$$P_2 = (4A)^2 \times 10\ \Omega = 160\ W$$

$$P_3 = (4A)^2 \times 15\ \Omega = 240\ W$$

Calculate the total power dissipated by this circuit:

$$P_T = 80\ W + 160\ W + 240\ W = 480\ W$$

To check the answer, the total power delivered by the source can be calculated:

$$P_{Source} = I_{source} \times V_{source}$$

$$480\ W = 4\ A \times 120\ V$$

The total power is equal to the sum of the power used by the individual resistors.

Summary of the Characteristics of Series Circuits

The important factors governing the operation of a series circuit are listed below. These factors have been set up as a group of rules so that they may be easily studied. These rules must be completely understood before the study of more advanced circuit theory is undertaken.

Rules for Series DC Circuits

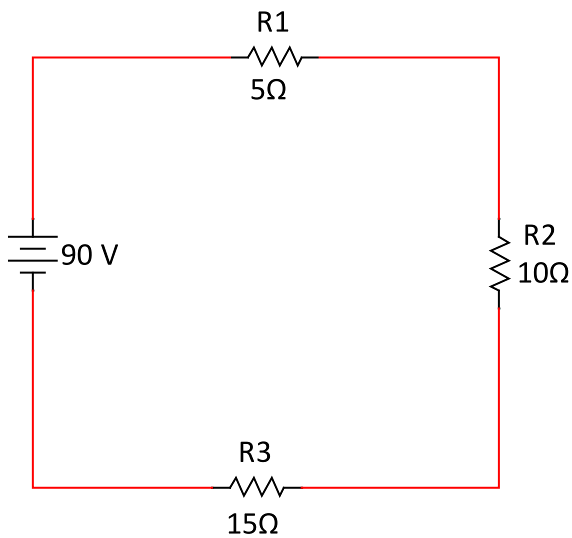
$I_T = I_1 = I_2 = I_3 = \cdots I_n$	The same current flows through each part of a series circuit.
$R_T = R_1 + R_2 + R_3 + \cdots R_n$	The total resistance of a series circuit is equal to the sum of the individual resistances.
$V_T = V_1 + V_2 + V_3 + \cdots V_n$	The total voltage across a series circuit is equal to the sum of the individual voltage drops.
$P_T = P_1 + P_2 + P_3 + \cdots P_n$	The total power in a series circuit is equal to the sum of the individual powers used by each circuit component.

Knowledge Check

1. A series circuit consisting of three resistors has a current of 3 amps. If R_1 = 20 ohms, R_2= 60 ohms, and R_3 = 80 ohms, what is the (a) total resistance and (b) source voltage of the circuit?
2. What is the voltage dropped by each resistor of the circuit described in question 1?
3. If the current was increased to 4 amps, what would be the voltage drop across each resistor in the circuit described in question 1?
4. What would have to be done to the circuit described in question 1 to increase the current to 4 amps?

Series Circuit Analysis

To establish a procedure for solving series circuits, the following sample problems will be solved.



Circuit 7: Solving for unknown values in a series circuit.

Problem: Three resistors of 5 ohms, 10 ohms, and 15 ohms are connected in series with a power source of 90 volts as shown in Circuit 7. Find the total resistance, circuit current, voltage drop of each resistor, power of each resistor, and total power of the circuit.

In solving the circuit, the total resistance will be found first. Next, the circuit current will be calculated. Once the current is known, the voltage drops and power dissipations can be calculated.

Given:

$R_1 = 5\ \Omega$

$R_2 = 10\ \Omega$

$R_3 = 15\ \Omega$

$V = 90\ V$

Solution: Solve for total resistance (RT):

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 5\ \Omega + 10\ \Omega + 15\ \Omega = 30\ \Omega$$

Solve for current, I:

$$I = \frac{V_T}{R_T}$$

$$I = \frac{90\ V}{30\ \Omega} = 3\ A$$

Solve for each voltage drop:

$$V_n = IR_n$$

$$V_1 = (3\ A\ )(5\ \Omega) = 15\ V$$

$$V_2 = (3\ A\ )(10\ \Omega) = 30\ V$$

$$V_3 = (3\ A\ )(15\ \Omega) = 45\ V$$

Solve for power dissipated at each resistor:

$$P_n = IV_n$$

$$P_1 = (3\ A\ )(15\ V) = 45\ W$$

$$P_2 = (3\ A\ )(30\ \mathrm{V}) = 90\ W$$

$$P_3 = (3\ A\ )(45\ \mathrm{V}) = 135\ W$$

Solve for total power dissipated by the circuit:

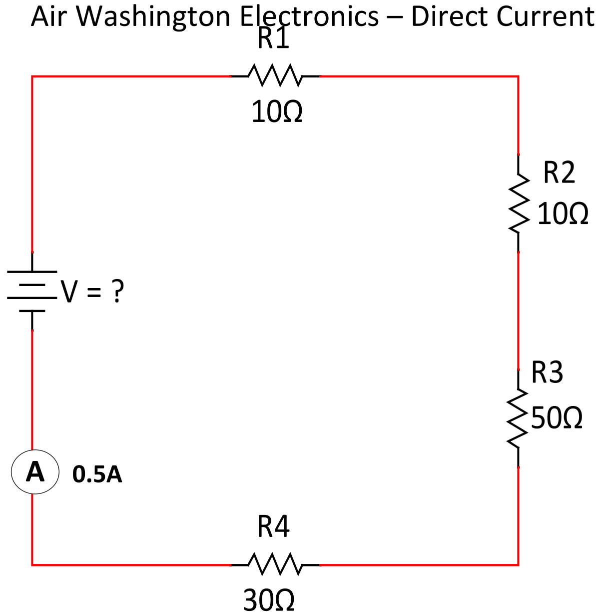
$$P_T = IV_T$$

$$P_T = (3\ A)(90\ V) = 270\ W$$

OR

$$P_T = P_1 + P_2 + P_3$$

$$P_T = 45\ W + 90\ W + 135\ W = 270\ W$$



Circuit 8: Computing series circuit values.

Problem: Four resistors, R1 = 10 ohms, R2 = 10 ohms, R3 = 50 ohms, and R4 = 30 ohms, are connected in series with a power source as shown in Circuit 8. The current through the circuit is 1/2 ampere.

a) What is the battery voltage?

b) What is the voltage across each resistor?

c) What is the power expended in each resistor?

d) What is the total power?

Given:

$R_1 = 10\ \Omega$

$R_2 = 10\ \Omega$

$R_3 = 50\ \Omega$

$R_4 = 30\ \Omega$

$I = 0.5\ A$

Solution (a): $V_T = IR_T$

$R_T = R_1 + R_2 + R_3 + R_4$

$R_T = 10\ \Omega + 10\ \Omega + 50\ \Omega + 30\ \Omega = 100\ \Omega$

$V_T = (0.5A)(100\ \Omega) = 50\ V$

Solution (b): $V_n = IR_n$

$$V_1 = (0.5\ A) \times 10\ \Omega = \ 5\ V$$
$$V_2 = (0.5\ A) \times 10\ \Omega = \ 5\ V$$
$$V_3 = (0.5\ A) \times 50\ \Omega = 25\ V$$
$$V_4 = (0.5\ A) \times 30\ \Omega = 15\ V$$

Solution (c): $P_n = IV_n$

$$P_1 = (0.5\ A) \times 5\ V = \ \ 2.5\ W$$
$$P_2 = (0.5\ A) \times 5\ V = \ \ 2.5\ W$$
$$P_3 = (0.5\ A) \times 25\ V = 12.5\ W$$
$$P_4 = (0.5\ A) \times 15\ V = \ \ 7.5\ W$$

Solution (d): $P_T = IV_T$

$$P_T = (0.5\ A)(50\ V) = 25\ W$$

OR

$$P_T = P_1 + P_2 + P_3$$
$$P_T = 2.5\ W + 2.5\ W + 12.5\ W + 7.5\ W = 25\ W$$

OR

$$P_T = \frac{(V_T)^2}{R_T}$$
$$P_T = \frac{(50V)^2}{100\ \Omega} = 25\ W$$

An important fact to keep in mind when applying Ohm's law to a series circuit is to consider whether the values used are component values or total values. When the information available enables the use of Ohm's law to find total resistance, total voltage, and total current, total values must be inserted into the formula. For example:

To find total resistance: $R_T = \frac{V_T}{I_T}$

To find total voltage: $V_T = (I_T)(R_T)$

To find total current: $I_T = \frac{V_T}{R_T}$

NOTE: I_T is equal to I in a series circuit. However, the distinction between I_T and I in the formula should be noted. The reason for this is that future circuits may have several currents, and it will be necessary to differentiate between I_T and other currents.

To compute any quantity (V, I, R, or P) associated with a single given resistor; the values used in the formula must be obtained from that particular resistor. For example, to find the value of an unknown resistance, the voltage across and the current through that particular resistor must be used.

To find the value of a resistor: $R = V_R/I_R$

To find the voltage drop across a resistor: $V_R = (I_R)(R)$

To find current through a resistor: $I_R = \frac{V_R}{R}$

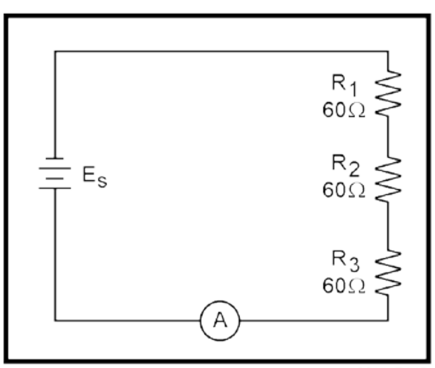
Embedded Media

Front Range Community College (Ken Floyd)

- Series Circuit Example: http://www.youtube.com/watch?v=4uipDPiSVR8

Knowledge Check

1. A series circuit consists of two resistors in series. R_1 = 25 ohms and R_2 = 30 ohms. The circuit current is 6 amps. What is the (a) source voltage, (b) voltage dropped by each resistor, (c) total power, and (d) power used by each resistor?



Questions 2 – 8 refer to the circuit above.

2. What is the total circuit resistance (R)?
    a. 20Ω
    b. 60Ω
    c. 180Ω
    d. 240Ω
3. If the circuit current is 3 amps, what is the source voltage (E_s)?
    a. 60 V
    b. 180 V
    c. 540 V
    d. 720 V
4. What is the total voltage dropped by each resistor in question 3-18?
    a. 20 V
    b. 60 V
    c. 180 V
    d. 540 V
5. If the current decreases to 2 amps, what is the total voltage drop across each resistor?
    a. 120 V
    b. 230 V
    c. 310 V
    d. 400 V
6. What would have to be done to the circuit to cause the current to decrease to 2 amps?
    a. The source voltage would have to be increased
    b. The source voltage would have to be decreased
    c. The resistance of R_1 would have to be decreased
    d. One of the resistors would have to be removed from the circuit
7. If the circuit current is 2 amps, what is the total power used by each resistor?
    a. 240 W
    b. 460 W
    c. 620 W
    d. 800 W
8. What is the total power used in the circuit if E_s = 360 V?
    a. 720 W
    b. 1380 W
    c. 1860 W
    d. 2400 W

Kirchhoff's Voltage Law

In 1847, G. R. Kirchhoff extended the use of Ohm's law by developing a simple concept concerning the voltages contained in a series circuit loop. Kirchhoff's voltage law states: The algebraic sum of the voltage drops in a series circuit equals the applied voltage. To state Kirchhoff's law another way, the sum of the voltage drops in a series circuit will be equal to the applied voltage. We will expand upon Kirchhoff's voltage law in a later module. Kirchhoff's voltage law can be written as an equation, as shown below:

$$V_T = V_a + V_b + V_c + \cdots V_n$$

Equation 4: Kirchhoff's Voltage Law

Through the use of Kirchhoff's voltage law, circuit problems can be solved which would be difficult, and is often impossible, with knowledge of Ohm's law alone. When Kirchhoff's law is properly applied, an equation can be set up for a closed loop and the unknown circuit values can be calculated.

Problem: Three resistors are connected across a 50-volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15 volts?

Solution: For a simple problem such as this, the voltages are substituted into the formula:

$$V_T = V_1 + V_2 + V_3$$

The formula is rearranged so the unknown value is on the left, and solved:

$$V_3 = V_T - V_1 - V_2$$

$$V_3 = 50V - 25V - 15V$$

$$V_3 = 10V$$

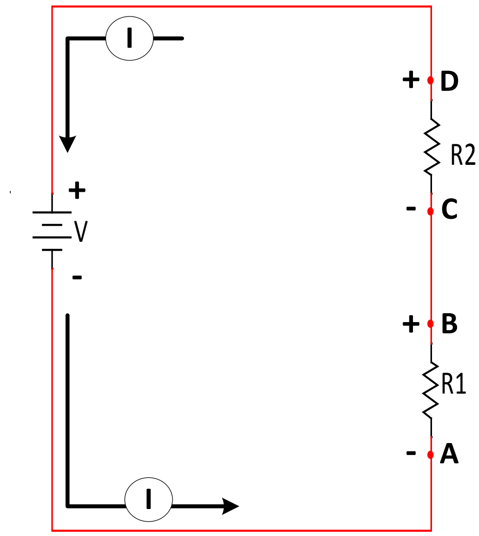
Polarity of Voltage

In earlier modules, an electrical charge was described as always having either a negative or positive polarity. Difference of potential, or voltage, can exist only between two points if they have different charges. The difference in charge is the polarity of a voltage drop through a resistor, also known as an IR (current x resistance) voltage drop, and is related to the direction of current (I) flowing through the resistor (R).

A dc voltage source has a polarity that is fixed. Current flows from one terminal of the voltage source through the circuit to the other terminal of the voltage source. The polarity of IR voltage drops through resistors is in relationship to the polarity of the voltage source. As shown in the circuit below, the polarities of the resistors are indicated. Closer examination will show that the end of R1 closest to the negative terminal of the voltage source is negative. In contrast, the end of R2 closest to the positive terminal of the voltage source is positive. This is because these are electrically common points.

The polarity of a voltage drop through a resistor, also known as an IR drop, is related to the direction of current (I) flowing through the resistor (R). In review, for electron flow, the electrons move from the negative side of the voltage source through the circuit towards the positive side of the voltage source. For conventional flow, the positive charges are moving the opposite. It should be understood however that these are human-created descriptions and that the polarity of the IR voltage drop will be the same regardless of which description is preferred.

In the circuit shown in Circuit 9, the current is shown flowing in a counterclockwise direction. Notice that the end of resistor R_1, into which the current flows, is marked negative (-). The end of R1 at which the current leaves is marked positive (+). These polarity markings are used to show that the end of R_1 into which the current flows is at a higher negative potential than the end of the resistor at which the current leaves. Point A is more negative than point B.



Circuit 9: Voltage polarities.

Point C, which is at the same potential as point B, is labeled negative. This is to indicate that point C is more negative than point D. To say a point is positive (or negative) without stating what the polarity is based upon has no meaning.

Series Aiding and Opposing Sources

In many practical applications a circuit may contain more than one source of voltage or emf. Sources of emf that cause current to flow in the same direction are considered to be **series aiding** and the voltages are added. Sources of emf that would tend to force current in opposite directions are said to be **series opposing,** and the effective source voltage is the difference between the opposing voltages. When two opposing sources are inserted into a circuit current flow would be in a direction determined by the larger source. Examples of series aiding and opposing sources are shown in Figure 2:

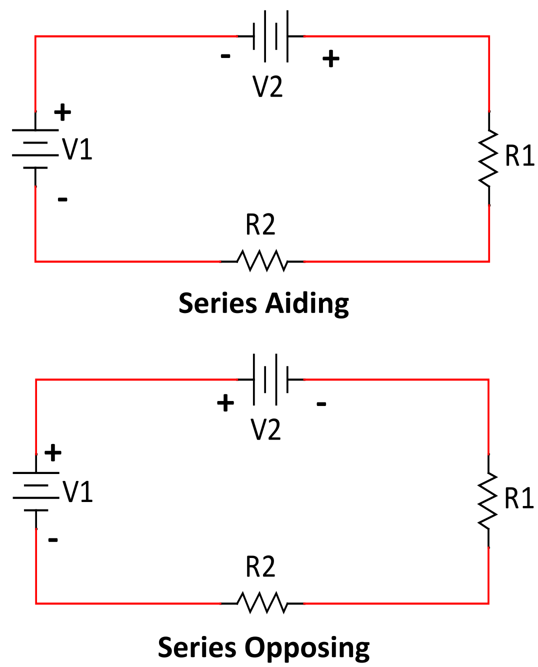
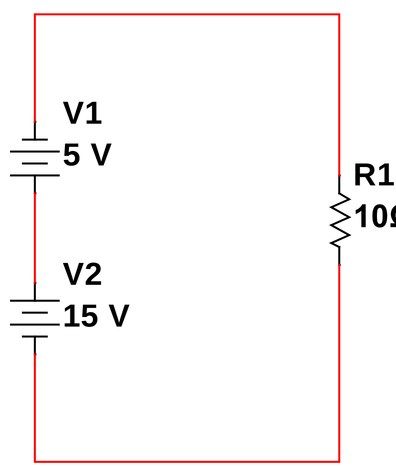


Figure 2: Aiding and opposing sources.

Recall that the shorter line on the dc voltage source indicates the negative terminal while the longer line indicates the positive terminal.

Problem: Find the amount of current in the circuit shown in Circuit 10.



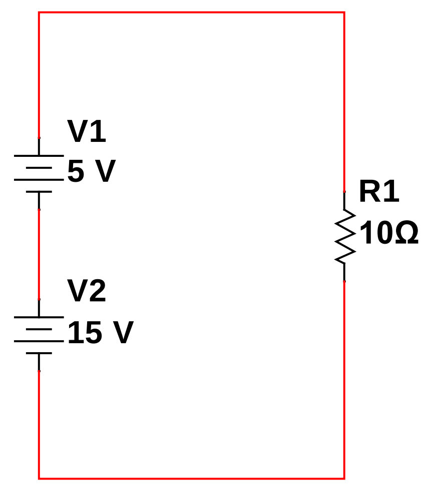
Circuit 10: Series-Opposing Voltage Supplies

Solution: First, determine if the power supplies are series aiding or opposing. In this circuit, the positive sides of the two batteries are connected, thereby making them in opposition to one another. Subtract the smaller from the larger then use Ohm's law to calculate current.

$$V_T = 15V - 5V = 10\ V$$

$$I = \frac{10V}{10\Omega} = 1A$$

Problem: Find the amount of current in Circuit 11.



Circuit 11: Series-Aiding Voltage Supplies

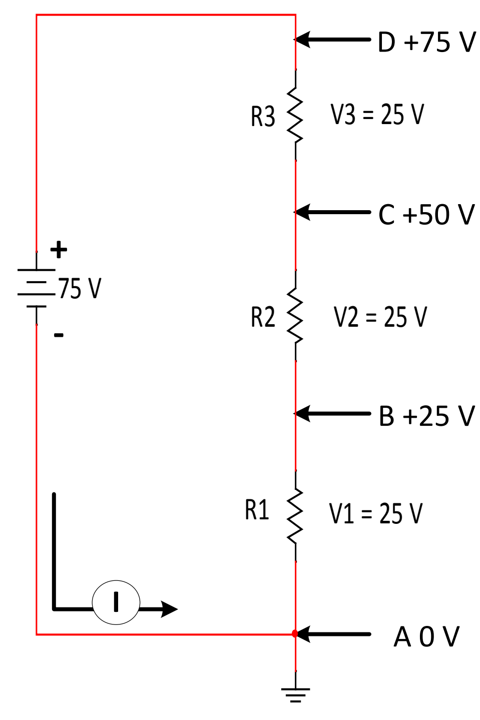
Solution: First, determine if the power supplies are series aiding or opposing. In this circuit, the positive terminal of one battery is attached to the negative terminal of the other, thereby making them additive. Add the two together then use Ohm's law to calculate current.

$$V_T = 15V + 5V = 20\ V$$

$$I = \frac{20V}{10\Omega} = 2A$$

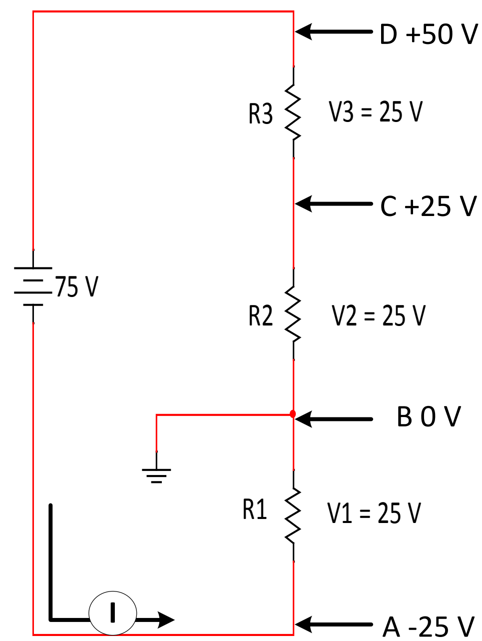
Reference Points

A **reference point** is an arbitrarily chosen point to which all other points in the circuit are compared. In series circuits, any point can be chosen as a reference and the electrical potential at all other points can be determined in reference to that point. In Circuit 12, point A shall be considered the reference point. Each series resistor in the illustrated circuit is of equal value. The applied voltage is equally distributed across each resistor. The potential at point B is 25 volts more positive than at point A. Points C and D are 50 volts and 75 volts more positive than point A respectively.



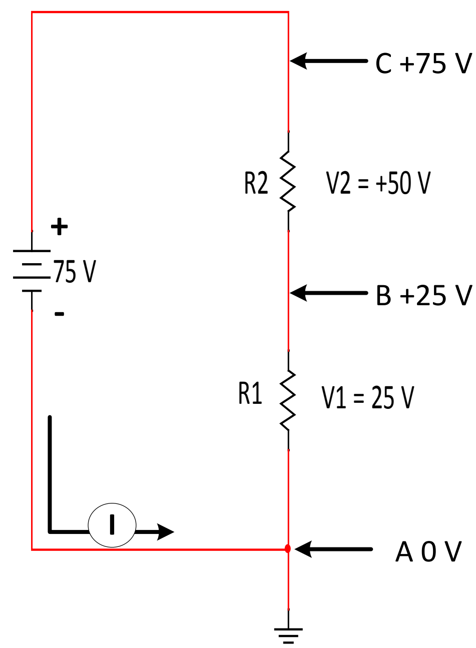
Circuit 12: Reference points in a series circuit.

When point B is used as the reference, as in Circuit 13, point D would be positive 50 volts in respect to the new reference point. The former reference point, A, is 25 volts negative in respect to point B.



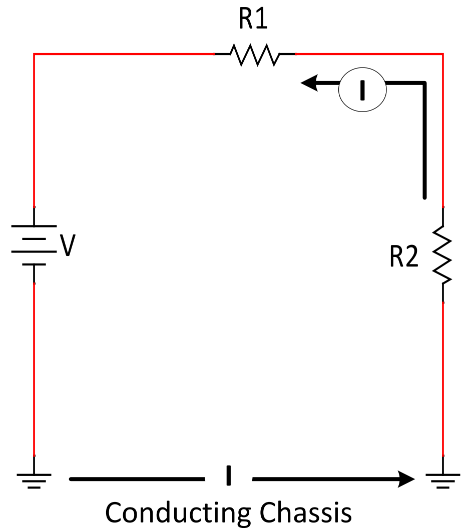
Circuit 13: Determining potentials with respect to a reference point.

As in the previous circuit illustration, the reference point of a circuit is always considered to be at zero potential. Since the earth (ground) is said to be at a zero potential, the term **ground** is used to denote a common electrical point of zero potential. In Circuit 14, point A is the zero reference, or ground, and the symbol for ground is shown connected to point A. Point C is 75 volts positive in respect to ground.



Circuit 14: Reference Points in a Series Circuit

In most electrical equipment, the metal chassis is the common ground for the many electrical circuits. When each electrical circuit is completed, common points of a circuit at zero potential are connected directly to the metal chassis, thereby eliminating a large amount of connecting wire. The electrons pass through the metal chassis (a conductor) to reach other points of the circuit. An example of a chassis grounded circuit is illustrated in Circuit 15.



Circuit 15: Ground used as a conductor.

Most voltage measurements used to check proper circuit operation in electrical equipment are taken in respect to ground. One meter lead is attached to a grounded point and the other meter lead is moved to various test points.

Embedded Media

Instructional Engineering Videos

- Single Loop Circuits: http://www.engineeringvideos.org/circuit-analysis/single-loop-circuits

Knowledge Check

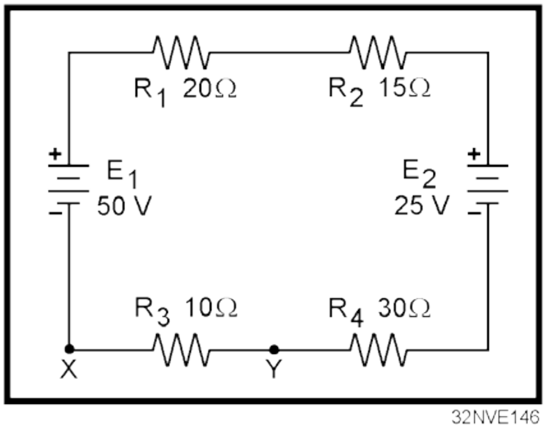


Figure 3D.—multiple source circuit.

For Questions 1 and 2, refer to figure above.

1. What is the effective source voltage?

    a. 15 V
    b. 25 V
    c. 50 V
    d. 75 V

2. What is the total amount and direction of current through R 3?

    a. 1.0 A from Y to X
    b. 1.0 A from X to Y
    c. 0.33 A from Y to X
    d. 0.33 A from X to Y

Troubleshooting

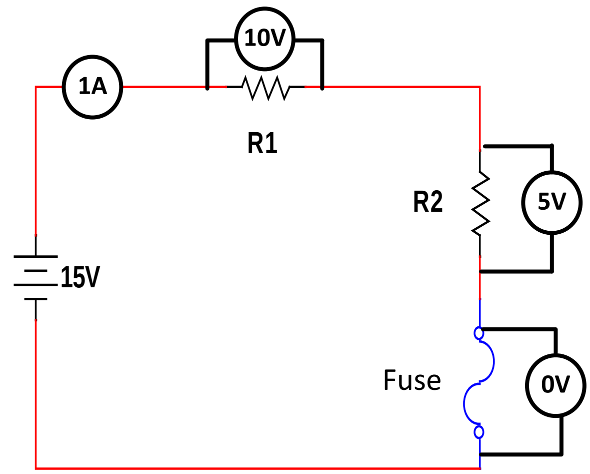
Circuit Faults

Open Circuit

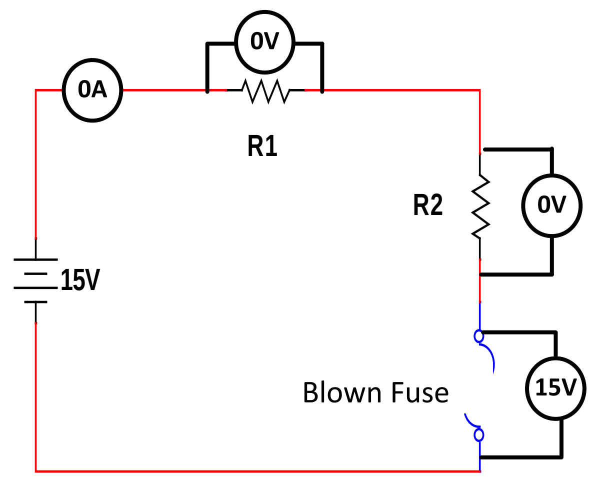
A circuit is said to be an **open circuit** when a break exists in a complete conducting pathway. Although an open occurs when a switch is used to deenergize a circuit, an open may also develop accidentally. To restore a circuit to proper operation, the open must be located, its cause determined, and repairs made.

Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned out resistors, can usually be discovered by this method. Others, such as a break in wire covered by insulation or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of the effect an open has on circuit conditions enables a technician to make use of test equipment to locate the open component.

In Circuit 16, the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens (Circuit 17). Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals and the voltage felt across the open is equal to the applied voltage (V_A). An open circuit has infinite resistance. **Infinity** represents a quantity so large it cannot be measured. The symbol for infinity is ∞. In an open circuit, $R_T = \infty$.



Circuit 16: Normal Circuit (Normal Current)



Circuit 17: Open Circuit (Due to Excessive Current)

Short Circuit

A **short circuit** is an accidental path of low resistance which passes an abnormally high amount of current. A short circuit exists whenever the resistance of a circuit or the resistance of a part of a circuit drops in value to almost zero ohms. A short often occurs as a result of improper wiring or broken insulation.

In Figure 3, a short is caused by improper wiring. Note the effect on current flow. Since the resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor. Electrons flow through the short (a path of almost zero resistance) and the remainder of the circuit by passing through the 10-ohm resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 ohms to 10 ohms. Due to the excessive current flow the 10-ohm resistor becomes heated. As it attempts to dissipate this heat, the resistor will probably be destroyed. Figure 4 shows a pictorial wiring diagram, rather than a schematic diagram, to indicate how broken insulation might cause a short circuit.

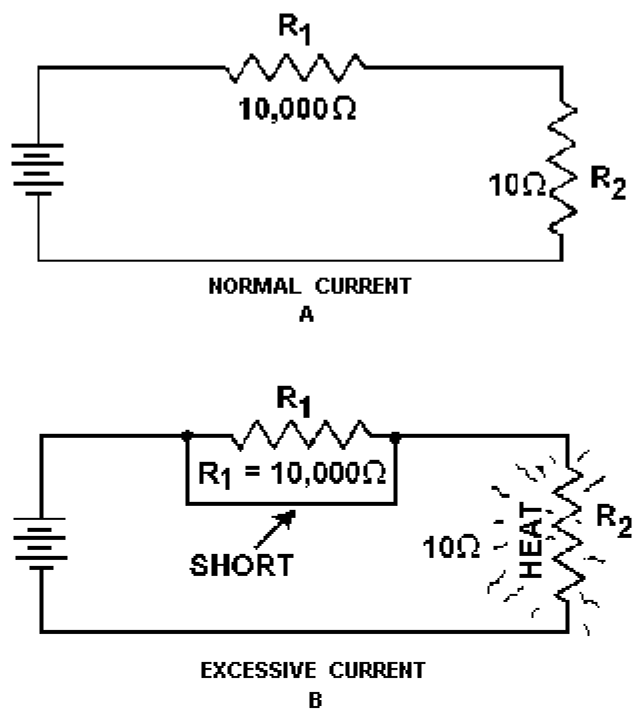


Figure 3: (A) Normal Current and (B) Excessive Current

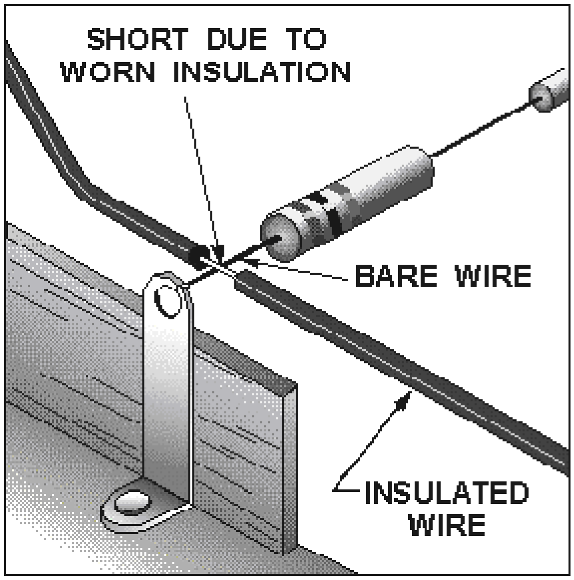


Figure 4: Short due to broken insulation

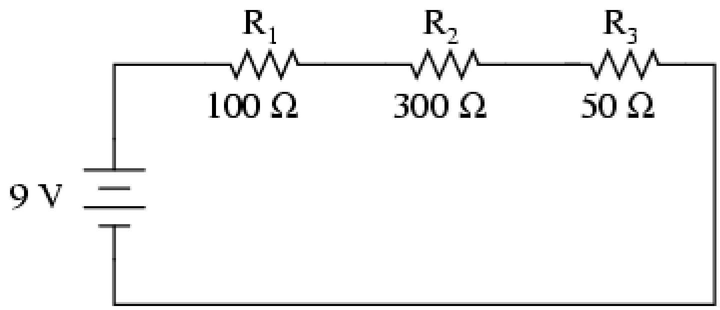
Component Failure Analysis

The job of a technician frequently entails "troubleshooting" (locating and correcting a problem) in malfunctioning circuits. Good troubleshooting is a demanding and rewarding effort, requiring:

- A thorough understanding of the basic concepts.
- The ability to formulate hypotheses (proposed explanations of an effect).
- The ability to judge the value of different hypotheses based on their probability (how likely one particular cause may be over another).
- A sense of creativity in applying a solution to rectify the problem.

While it is possible to distill these skills into a scientific methodology, most practiced troubleshooters would agree that troubleshooting involves a touch of art, and that it can take years of experience to fully develop this art.

An essential skill to have is a ready and intuitive understanding of how component faults affect circuits in different configurations. Throughout this course, we will explore some of the effects of component faults in both series and parallel circuits. First, let's start with a simple series circuit:



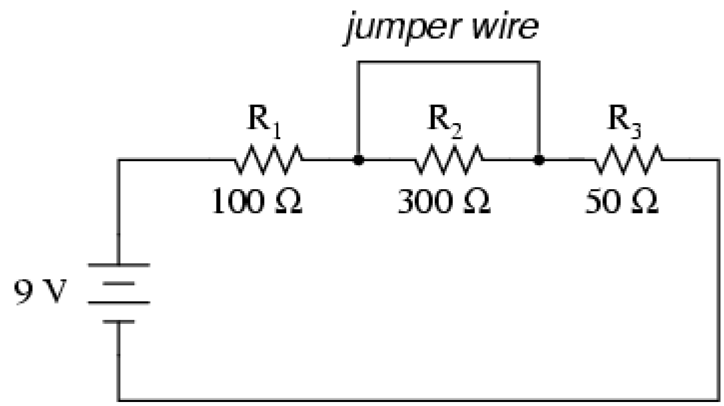
Circuit 18: Simple Series Circuit.

With all components in this circuit functioning at their proper values, we can mathematically determine all currents and voltage drops using a table of values based on Ohm's law.

	R1	**R2**	**R3**	**Total**	
Voltage	2	6	1	9	V
Current	0.020	0.020	0.020	.020	A
Resistance	300	50	450		Ω

Table 1: Analysis of Circuit 18

Now let us suppose that R_2 fails shorted. As described earlier, **shorted** means that the resistor now acts like a straight piece of wire, with little or no resistance. The circuit will behave as though a "jumper" wire were connected across R_2. What causes the shorted condition of R_2 is no matter to us in this example; we only care about its effect upon the circuit:



Circuit 19: Shorted simple series circuit.

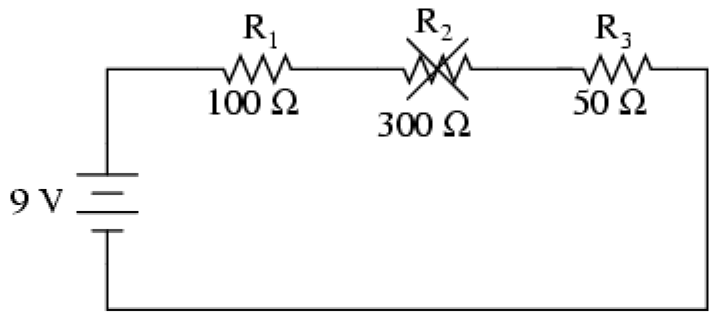
With R_2 shorted, either by a jumper wire or by an internal resistor failure, the total circuit resistance will *decrease*. Since the voltage output by the battery is a constant (at least in our ideal simulation here), a decrease in total circuit resistance means that total circuit current *must increase*:

	R1	R2	R3	Total	
Voltage	6	0	3	9	V
Current	0.060	0.060	0.060	.060	A
Resistance	100	0	50	150	Ω

Table 2: Resistor R2 Shorted.

As the circuit current increases from 20 milliamps (mA) to 60 mA, the voltage drops across R_1 and R_3 (which haven't changed resistances) increase as well, so that the two resistors are dropping the whole 9 volts. R_2, being bypassed by the very low resistance of the jumper wire, is effectively eliminated from the circuit, the resistance from one lead to the other having been reduced to zero. Thus, the voltage drop across R_2, even with the increased total current, is zero volts.

On the other hand, if R_2 were to fail "**open**" -- resistance increasing to nearly infinite levels -- it would also create wide-reaching effects in the rest of the circuit:



Circuit 20: Open Simple Series Circuit

With R_2 at infinite resistance and total resistance being the sum of all individual resistances in a series circuit, the total current decreases to zero. With zero circuit current, there is no electron flow to produce voltage drops across R_1 or R_3. R_2, on the other hand, will manifest the full supply voltage across its terminals.

	R1	R2	R3	Total	
Voltage	0	9	0	9	V
Current	0	0	0	0	A
Resistance	100	∞	50	∞	Ω

Table 3: Resistor R2 Open

Eventually, you will be able to troubleshoot a circuit without the use of calculations, that is, by analyzing the effects of component failure in a circuit without knowing exactly how many volts the battery produces or how many ohms of resistance is in each resistor. This deeper intuitive understanding of electric circuit operation will come with good knowledge of theory and experience.

Basic Troubleshooting Guidelines

- To determine what would happen in a circuit if a component fails, re-draw that circuit with the equivalent resistance of the failed component in place, and re-calculate all values.
- The ability to intuitively determine what will happen to a circuit with any given component fault is a *crucial* skill for any electronics troubleshooter to develop. The best

way to learn is to experiment with circuit calculations and real-life circuits, paying close attention to what changes with a fault, what remains the same, and *why*!

- A *shorted* component is one whose resistance has dramatically decreased.
- An *open* component is one whose resistance has dramatically increased. For the record, resistors tend to fail open more often than fail shorted, and they almost never fail unless physically or electrically overstressed (physically abused or overheated).

Embedded Media

Internet Archive - FEDFLIX

- Series Resistive Circuits – Troubleshooting
    - https://archive.org/details/gov.ntis.ava13995vnb1
        - Dept. of the Air Force, 1952. The basic theory remains the same even though the technology seems dated.

Knowledge Check- need more

1. What is the term for a circuit in which there is NO complete path for current?

    a) Open
    b) Short
    c) Closed
    d) Grounded

2. A circuit in which the resistance is almost zero ohms is referred to by which of the following terms?

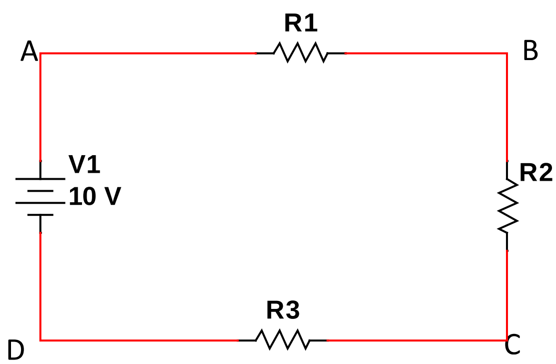
    A. Open
    B. Short
    C. Closed
    D. Broken

Series Circuits Lab 1: A Simple Series Circuit

Components & Equipment Needed

- Resistors, wire, and breadboard

Circuit Diagram



Specifications for Circuit

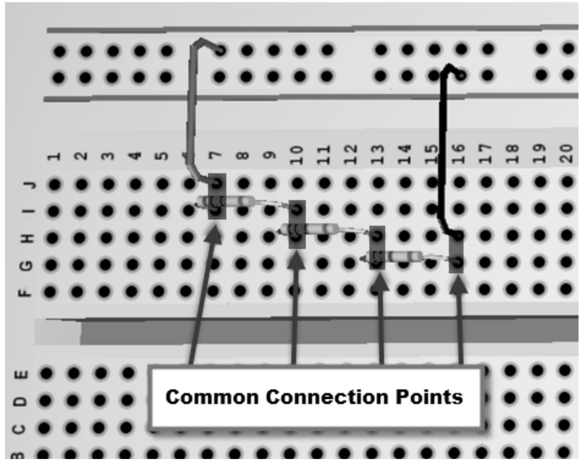
- VT = 10 V
- RT = 1.175 kΩ
- IT = 8.5 mA

Circuit 21: Series Circuits Lab 1

How to wire a breadboard in Series

Up to now, nearly all of the breadboard circuits created have been very simple series circuits. Now you are ready to begin using additional components. The theory is the same – there must be a continuous connection from positive through all components and then to ground.

In the image below, the flow of electrons can be followed from the red "power" bus (top line) to the blue "ground" bus (bottom line). Starting with the blue wire plugged into the red bus, notice how it connects to one end of the first resistor. The other end of that resistor shares a common connection with the next resistor, and that resistor shares a common connection with the third resistor. Finally, the black wire shares a connection with the third resistor and plugs in on the blue bus. A series circuit consists of wires and components that are connected in a continuous line from positive to ground.



Procedure

Step 1: **Build the circuit per specifications.**

- Build the circuit shown in the schematic using the values below in **both** Multisim and on a breadboard.
- For the total resistance, you may use **only** 3 standard (±5%) value resistors of differing values.
- The total resistance must equal 1.175 kΩ

Step 2: **Take measurements and record in Table 4.**

- Measure the following:
  - Voltage drops across each resistor.
  - Current at each point (A, B, C, and D)
  - Total current.

Table for Series Circuits Lab 1

(Record the value of resistor used.)	Measurements		
	Multisim	**Breadboard**	**% Difference**
V_{R1} (R_1=________)			
V_{R2} (R_2=________)			
V_{R3} (R_3=________)			
I_A			
I_B			
I_C			
I_D			
I_T			

Table 4: Table for Series Circuit Lab 1

Observations and Conclusions

In your lab report, include your results from Table 4 as well as any observations or conclusions you may have made during this exercise.

Answer the following questions in your lab report:

1. If a short existed across R3, how would that affect the total resistance, total voltage, and total current of the circuit? Explain your answer.

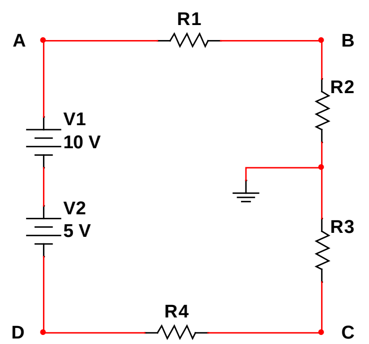
2. If the wire between R1 and R2 were to break, what would the voltage potential be between the two resistors? Explain your answer.

Series Circuits Lab 2: Series Aiding Voltage

Components & Equipment Needed

- Resistors, wire, and breadboard

Circuit Diagram



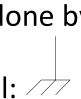
Circuit 22: Series Circuit Lab 2

Specifications for Circuit

- Reuse the resistors from Part 1 above.
- R4 should bring the total resistance to 1.505 kΩ
- V1 = 10V; V2 = 5V

Procedure

Step 1: **Build the circuit per specifications.**

- Build the circuit shown in the schematic using the values below in **both** Multisim and on a breadboard.
- Add a second power source to the circuit. Remember, the long line indicates positive and the short line indicates negative. Therefore, these power sources are connected so that the negative side of the 10V is attached to the positive side of the 5 V.
- Place a ground point between R2 and R3. On a bench power supply, this would be done by connecting it to chassis ground, usually indicated by this symbol: 
- Following the given specifications, add a single standard ±5% resistor to bring the total resistance to 1.505 kΩ.

Step 2: **Take measurements and record in Table 5**

- Measure the following:
    - Voltage drops across each resistor.
    - Total current and Total Voltage
    - Voltage between indicated point and ground

Table for Series Circuits Lab 1

	Measurements		
	Multisim	**Breadboard**	**% Difference**
V_{R1} (R_1=________)			
V_{R2} (R_2=________)			
V_{R3} (R_3=________)			
V_{R4} (R_4=________)			
V_T			
I_T			
$V_{A - GND}$			
$V_{B – GND}$			
$V_{C – GND}$			
$V_{D – GND}$			

Table 5: Table for Series Circuits Lab 2

Observations and Conclusions

In your lab report, include your results from Table 4 as well as any observations or conclusions you may have made during this exercise.

Answer the following question in your lab report:

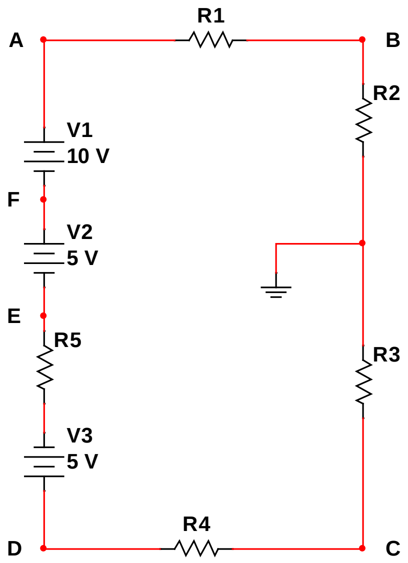
1. If the circuit opened at Point C, what would the voltage drop from D – GND be? Explain your answer.

Series Circuits Lab 3: Series Opposing Voltage

Components & Equipment Needed

- Resistors, wire, and breadboard

Circuit Diagram



Specifications for Circuit

- R1, R2, R3, and R4 the same as in Part 2
- R5 should bring the total resistance to 2.505 kΩ

Circuit 23: Series Circuit Lab 3

Procedure

Step 1: Build the circuit per specifications.

- Build the circuit shown in the schematic using the values below in **both** Multisim and on a breadboard.
- Add a third power source to the circuit.
- Following the given specifications, add a single standard ±5% resistor to bring the total resistance to 2.505 kΩ.

Step 2: Take measurements and record in Table 4.

- Measure the following:

- Voltage drops across each resistor.
- Total current and Total Voltage
- Voltage between indicated point and ground. **Note** that you cannot measure between Point F and Ground. This is an imaginary point and used for calculations only.

Table for Series Circuits Lab 3

	Measurements	
	Multisim	**Breadboard**
V_{R1} (R_1=_________)		
V_{R2} (R_2=_________)		
V_{R3} (R_3=_________)		
V_{R4} (R_4=_________)		
V_{R5} (R_5=_________)		
V_T		
I_T		
V_{A-GND}		
V_{B-GND}		
V_{C-GND}		
V_{D-GND}		
V_{E-GND}		

Table 6: Table for Series Circuit Lab 3

Observations and Conclusions

In your lab report, include your results from Table 6 as well as any observations or conclusions you may have made during this exercise.

Answer the following question in your lab report:

1. Calculate the voltage drop between point F and Ground.
2. Explain why some of the measurements are negative.
3. If R_5 were to open, calculate and explain the following:
    a. Voltage drop between B and C

b. I_T

Series Circuits Lab 4: Critical Thinking

The Problem

Some time ago, your supervisor asked you to design a circuit. She wanted to use a light bulb that the company already used in other products, but because this was a specialized circuit, it was important that it dissipated a very specific amount of heat, or power. She didn't have much information on the lamp, except that it has 10 Ω of resistance. The amount of power that needs to be dissipated is a *total* of 45 W. The only kind of power supplies that the company uses are 12 V or 24 V. In addition, it is necessary that the voltage supply chosen be within ± 3% of the needed voltage.

After working through it, you discovered that your company would not be able to make this circuit to meet the customer's specifications. However, your supervisor has asked that you revisit this problem and consider how this circuit can be redesigned. Now that you know more about series circuits, you realize that it would be a simple thing to change the circuit. All the specifications stated above must be followed, with the exception of the addition of a single standard value resistor with a tolerance of± 5%, due to very limited space.

Some points to keep in mind:

- R_{lamp} = 10 Ω
- P_{total} = 45 W
- Power Supply = 12 V or 24 V
- Restrictions = required voltage and power supply voltage must be within 3% of each other.
- Must be a series circuit

Support your answers with logic and reasoning. Keep your explanations brief and concise.

1. Which power supply would be acceptable to use in this case?

2. Is the resistance value a standard value? If not, is there a standard value resistor that is adequate (tolerance of± 5%) for the specifications?

Index of Important Terms

open circuit, 34

short circuit, 36

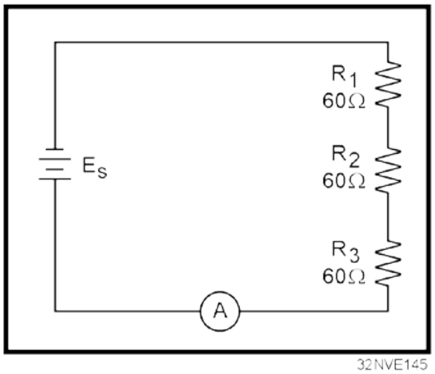
Answers to Knowledge Checks

Characteristics of Series Circuits

1. A series circuit consisting of three resistors has a current of 3 amps. If R_1 = 20 ohms, R_2= 60 ohms, and R_3 = 80 ohms, what is the (a) total resistance and (b) source voltage of the circuit?
   (a) 160 ohms
   (b) 480 ohms
2. What is the voltage dropped by each resistor of the circuit described in question 1?
   V_{R1} = 60 V
   V_{R2} = 180 V
   V_{R3} = 240 V
3. If the current was increased to 4 amps, what would be the voltage drop across each resistor in the circuit described in question 1?
   V_{R1} = 80 V
   V_{R2} = 240 V
   V_{R3} = 320 V
4. What would have to be done to the circuit described in question 1 to increase the current to 4 amps?
   The source voltage would have to be increased to 640 V.

Series Circuit Analysis

1. A series circuit consists of two resistors in series. R_1 = 25 ohms and R_2 = 30 ohms. The circuit current is 6 amps. What is the (a) source voltage, (b) voltage dropped by each resistor, (c) total power, and (d) power used by each resistor?
   a. 330 V
   b. V_{R1} = 150 V; V_{R2} = 180 V
   c. 1.98 kW
   d. P1 = 900 W; P2 = 1.08 kW



Questions 2 – 8 refer to the circuit above.

2. What is the total circuit resistance (R)?
   a. 20Ω
   b. 60Ω
   c. 180Ω
   d. 240Ω
3. If the circuit current is 3 amps, what is the source voltage (E_s)?
   a. 60 V
   b. 180 V
   c. 540 V
   d. 720 V
4. What is the total voltage dropped by each resistor in question 3-18?
   e. 20 V
   a. 60 V
   b. 180 V
   c. 540 V
5. If the current decreases to 2 amps, what is the total voltage drop across each resistor?
   a. 120 V
   b. 230 V
   c. 310 V
   d. 400 V
6. What would have to be done to the circuit to cause the current to decrease to 2 amps?
   a. The source voltage would have to be increased
   b. The source voltage would have to be decreased
   c. The resistance of R_1 would have to be decreased
   d. One of the resistors would have to be removed from the circuit
7. If the circuit current is 2 amps, what is the total power used by each resistor?
   e. 240 W
   a. 460 W
   b. 620 W
   c. 800 W
8. What is the total power used in the circuit if E_s = 360 V?
   a. 720 W
   b. 1380 W

c. 1860 W
d. 2400 W

Series Aiding and Opposing Voltages

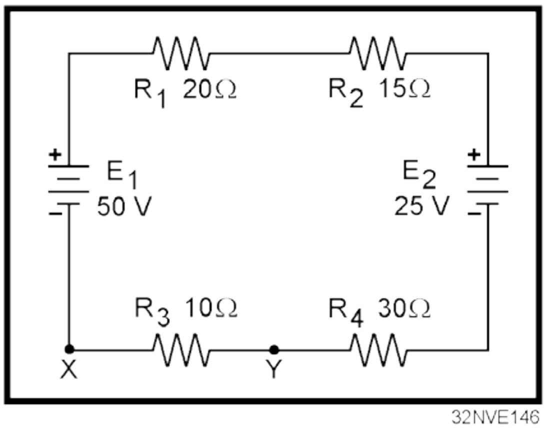


Figure 3D.—multiple source circuit.

For Questions 4 and 5, refer to figure above.

1. What is the effective source voltage?
    a. 15 V
    b. 25 V
    c. 50 V
    d. 75 V
2. What is the total amount and direction of current through R 3?
    a. 1.0 A from Y to X
    b. 1.0 A from X to Y
    c. 0.33 A from Y to X
    d. 0.33 A from X to Y

Troubleshooting

1. What is the term for a circuit in which there is NO complete path for current?
    a) Open
    b) Short
    c) Closed
    d) Grounded

2. A circuit in which the resistance is almost zero ohms is referred to by which of the following terms?
    a) Open
    b) Short
    c) Closed
    d) Broken

Additional Resources

Physics Resources

Georgia State University – HyperPhysics: http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

Video Resources

Collin's Lab

- Schematics: http://www.youtube.com/watch?v=9cps7Q_IrX0

Front Range Community College (Ken Floyd)

- **Circuit Essentials: http://www.youtube.com/watch?v=gYKbLdJSI-c**
- **Circuit Ground or Common: http://www.youtube.com/watch?v=vhZQbFeEfPM**
- **Circuit Symbols: http://www.youtube.com/watch?v=c68Q5xU6lQM**

Khan Academy

- Circuits (part 1): https://www.khanacademy.org/science/physics/electricity-and-magnetism/v/circuits--part-1

References

Kuphaldt, T. (n.d.). *Component Failure Analysis*. Retrieved February 14, 2014, from All About Circuits: http://www.allaboutcircuits.com/vol_1/chpt_5/7.html

United States Navy. (2003). Module 1 - Introduction to Matter, Energy, and Direct Current. In *Navy Electricity and Electronics Training Series (NEETS).* Pensacola, FL: Naval Education and Training Professional Development and Technology Center.

Attributions

Floyd, Ken. Front Range Community College. Via YouTube Creative Commons

http://www.youtube.com/yt/copyright/creative-commons.html

Series Circuit Example: http://www.youtube.com/watch?v=4uipDPiSVR8

Instructional Engineering Videos. Arizona State University. CC BY SA 3.0

http://creativecommons.org/licenses/by-sa/3.0/us/.

Series Circuit Example: http://www.youtube.com/watch?v=4uipDPiSVR8

Single Loop Circuits: http://www.engineeringvideos.org/circuit-analysis/single-loop-circuits

Internet Archive. Public.Resource.Org under Joint Venture NTIS-1832 with the National Technical Information Service. Public Domain

Series Resistive Circuits – Troubleshooting:

https://archive.org/details/gov.ntis.ava13995vnb1

Kuphaldt, T. All about Circuits. CC BY 1.0 http://creativecommons.org/licenses/by/1.0/

United States Navy. Navy Electricity and Electronics Training Series (NEETS). Public Domain per Distribution Statement A

http://www.dtic.mil/dtic/submit/guidance/distribstatement.html

Table of Figures

Source of figures indicated in parentheses. Some figures were modified by Olympic College.

Figure 1: Comparison of basic and series circuits. 5
Figure 2: Aiding and opposing sources. 24
Figure 3: (A) Normal Current and (B) Excessive Current 33
Figure 4: Short due to broken insulation 34

Table of Tables

Created by Olympic College

Table 1: Analysis of Circuit 20 35
Table 2: Resistor R2 Shorted. 36
Table 3: Resistor R2 Open 37
Table 4: Table for Series Circuit Lab 1 41
Table 5: Table for Series Circuits Lab 2 43
Table 6: Table for Series Circuit Lab 3 45

Table of Circuits

Unless otherwise noted, created using National Instruments Multisim v. 12.

Circuit 1: Current in a series circuit. 6
Circuit 2: Solving for total resistance in a series circuit. 7
Circuit 3: Calculating the value of an unknown resistance in a series circuit. 8
Circuit 4: Calculating individual voltage drops in a series circuit 9
Circuit 5: Solving for applied voltage in a series circuit. 10
Circuit 6: Total power in a series circuit 12
Circuit 7: Solving for unknown values in a series circuit. 15
Circuit 8: Computing series circuit values. 17
Circuit 9: Voltage polarities. 23

Circuit 10: Series-Opposing Voltage Supplies 24
Circuit 11: Series-Aiding Voltage Supplies 25
Circuit 12: Reference points in a series circuit........ 26
Circuit 13: Determining potentials with respect to a reference point. 27
Circuit 14: Reference Points in a Series Circuit 28
Circuit 15: Ground used as a conductor. 29
Circuit 16: Normal Circuit (Normal Current) 32
Circuit 17: Open Circuit (Due to Excessive Current) 32
Circuit 18: Simple Series Circuit (All About Circuits).. 35
Circuit 19: Shorted simple series circuit (All About Circuits).. 36
Circuit 20: Open Simple Series Circuit (All About Circuits). 37
Circuit 21: Series Circuits Lab 1 39
Circuit 22: Series Circuit Lab 2........ 42
Circuit 23: Series Circuit Lab 3........ 44

Table of Equations

Created by Olympic College

Equation 1: Total Resistance in a Series Circuit 6
Equation 2: Total Voltage in a Series Circuit 10
Equation 3: Total power in a series circuit........ 12
Equation 4: Kirchhoff's Voltage Law 21