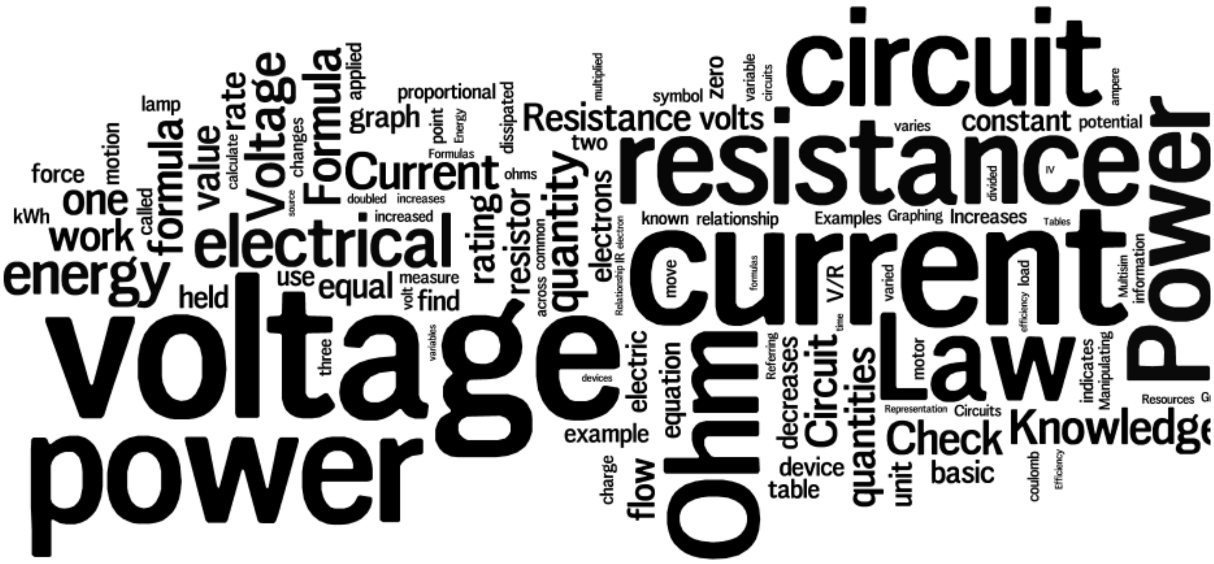
3 Ohm's Law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How Current, Voltage, and Resistance Relate

An electric circuit is formed when a conductive path is created to allow free electrons to continuously move. This continuous movement of free electrons through the conductors of a circuit is called a **current**, and it is often referred to in terms of "flow," just like the flow of a liquid through a hollow pipe.

The force motivating electrons to "flow" in a circuit is called **voltage**. Voltage is a specific measure of potential energy that is always relative between two points. When we speak of a certain amount of voltage being present in a circuit, we are referring to the measurement of how much **potential energy** exists to move electrons from one particular point in that circuit to another particular point. Without reference to <u>*two*</u> particular points, the term "voltage" has no meaning.

Free electrons tend to move through conductors with some degree of friction, or opposition to motion. This opposition to motion is more properly called **resistance**. The amount of current in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow. Just like voltage, resistance is a quantity relative between two points. For this reason, the quantities of voltage and resistance are often stated as being "between" or "across" two points in a circuit.

Symbols and Units

To be able to make meaningful statements about these quantities in circuits, we need to be able to describe their quantities in the same way that we might quantify mass, temperature, volume, length, or any other kind of physical quantity. For mass we might use the units of "kilogram" or "gram." For temperature we might use degrees Fahrenheit or degrees Celsius. Here are the standard units of measurement for electrical current, voltage, and resistance:

Quantity	Symbol	Unit of Measurement	Unit Abbreviation
Current	I	Ampere (Amp)	A
Voltage	V or E	Volt	V
Resistance	R	Ohm	Ω

Table 1: Symbols and Units

The "symbol" given for each quantity is the standard alphabetical letter used to represent that quantity in an algebraic equation. Standardized letters like these are common in the disciplines of physics and engineering, and are internationally recognized. The "unit abbreviation" for each quantity represents the alphabetical symbol used as a shorthand notation for its particular unit of measurement. The horseshoe shaped symbol is the capital Greek letter omega.

The mathematical symbol for each quantity is meaningful as well. The "R" for resistance and the "V" for voltage are both self-explanatory, whereas "I" for current might not be as clear. The "I" is thought to have been meant to represent "Intensity" (of electron flow). In addition, the other symbol for voltage, "E," stands for "electromotive force." The symbols "E" and "V" are generally interchangeable, however some texts reserve "E" to represent voltage across a source (such as a battery or generator) and "V" to represent voltage across anything else, such as a load or resistor. These units and symbols for electrical quantities will become very important to know as we explore the relationships between them in circuits.

Introduction to Ohm's Law

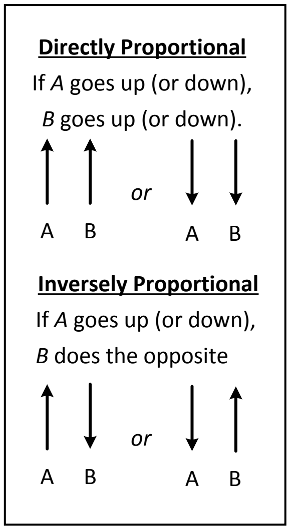


Figure 1: Proportionality

The first, and perhaps most important, relationship between current, voltage, and resistance is called **Ohm's Law**, discovered by Georg Simon Ohm and published in his 1827 paper, *The Galvanic Circuit Investigated Mathematically*. Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship is called Ohm's law and is stated as follows:

The current in a circuit is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the circuit resistance.

Ohm's Law may be expressed as an equation:

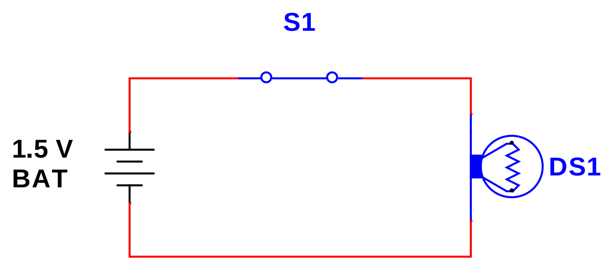
$$I = \frac{V}{R}$$

Where: I = current in amperes
V = voltage in volts
R = resistance in ohms

Equation 1: Ohm's Law

As stated in Ohm's Law, current is inversely proportional to resistance. This means, as the resistance in a circuit increases, the current decreases proportionately.

In the equation $I = \frac{V}{R}$, if any two quantities are known, the third one can be determined. Refer to Circuit 1, the schematic of the flashlight. If the battery (BAT) supplies a voltage of 1.5 volts and the lamp (DS1) has a resistance of 5 ohms, then the current in the circuit can be determined.



Circuit 1: Flashlight Circuit

Using this equation and substituting values:

$$I = \frac{V}{R} = \frac{1.5V}{5\Omega} = 0.3\ A$$

If the flashlight were a two-cell flashlight, we would have twice the voltage, or 3.0 volts, applied to the circuit. Using this voltage in the equation:

$$I = \frac{V}{R} = \frac{3V}{5\Omega} = 0.6\ A$$

You can see that the current has doubled as the voltage has doubled. This demonstrates that the current is directly proportional to the applied voltage.

If the value of resistance of the lamp is doubled, the equation will be:

$$I = \frac{V}{R} = \frac{3V}{10\Omega} = 0.3\ A$$

The current has been reduced to one half of the value of the previous equation, or 0.3 ampere. This demonstrates that the current is inversely proportional to the resistance. Doubling the value of the resistance of the load reduces circuit current value to one half of its former value.

Ohm's Law also makes intuitive sense if you apply it to the water-and-pipe analogy. If we have a water pump that exerts pressure (voltage) to push water around a "circuit" (current) through a restriction (resistance), we can model how the three variables interrelate. If the resistance to water flow remains constant and the pump pressure increases, the flow rate must also increase.

Pressure (Voltage) = increase
Flow Rate (Current) = increase
Resistance (Resistance = constant

$$\overset{\uparrow}{V} = \overset{\uparrow}{I}\ R$$

Figure 2: Relationship between V and I in Ohm's Law

If the pressure stays the same and the resistance increases (making it more difficult for the water to flow), then the flow rate must decrease:

Pressure (Voltage) = constant
Flow Rate (Current) = decrease
Resistance (Resistance = increase

$$V = \overset{\downarrow}{I}\ \overset{\uparrow}{R}$$

Figure 3: Relationship between Current and Resistance in Ohm's Law

If the flow rate were to stay the same while the resistance to flow decreased, the required pressure from the pump would necessarily decrease:

Pressure (Voltage) = decrease
Flow Rate (Current) = constant
Resistance (Resistance = decrease

$$\overset{\downarrow}{V} = \overset{\downarrow}{I}\ R$$

Figure 4: Relationship between Voltage and Current in Ohm's Law

Knowledge Check

1. If circuit voltage is held constant, circuit current will react in what manner as the resistance either (a) increases, or (b) decreases?

    A. (a) Current Increases (b) Current decreases
    B. (a) Current Increases (b) Current Increases
    C. (a) Current decreases (b) Current decreases
    D. (a) Current decreases (b) Current Increases

2. If circuit resistance is held constant, circuit current will react in what manner as the voltage either (a) increases, or (b) decreases?

    A. (a) Voltage Increases (b) Voltage decreases
    B. (a) Voltage Increases (b) Voltage Increases
    C. (a) Voltage decreases (b) Voltage decreases
    D. (a) Voltage decreases (b) Voltage Increases

Using and Manipulating Ohm's Law

By using Ohm's Law, you are able to find the resistance of a circuit, knowing only the voltage and the current in the circuit. In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's Law, if current (I) and voltage (V) are known, the only parameter not known, resistance (R), can be determined:

1. Basic formula:

$$I = \frac{V}{R}$$

2. Remove the divisor by multiplying both sides by R:

$$R \times I = \frac{V}{\cancel{R}} \times \frac{\cancel{R}}{1}$$

3. Result of step 2:

$$R \times I = V$$

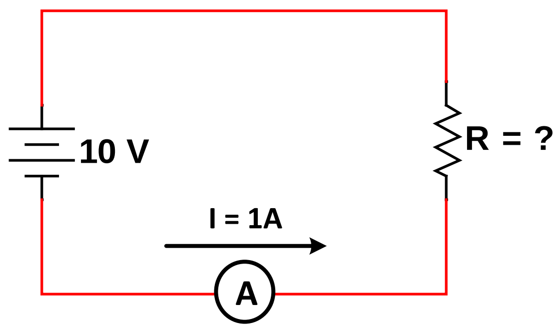
4. To get R alone (on one side of the equation) divide both sides by I:

$$\frac{R\cancel{I}}{\cancel{I}} = \frac{V}{I}$$

5. The basic formula, transposed for R, is:

$$R = \frac{V}{I}$$

Refer to Circuit 2 where V equals 10 volts and I equals 1 ampere. Solve for R, using the equation just explained.

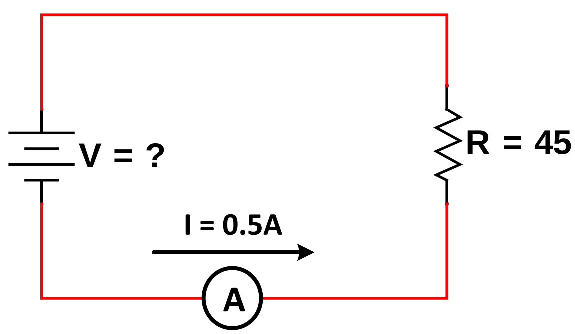


Circuit 2: Ohm's Law – Solve for R

Given: V = 10 volt and I = 1 ampere

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

Refer to Circuit 3 where I equals 0.5 A and R equals 45 Ω, solve for V.



Circuit 3: Ohm's Law – Solve for V

The basic formula can also be manipulated so that voltage can be derived from the known values.

1. Basic formula:

$$I = \frac{V}{R}$$

2. Remove the divisor by multiplying both sides by R:

$$R \times I = \frac{V}{\cancel{R}} \times \frac{\cancel{R}}{1}$$

3. Result of step 2 is the basic formula, transposed for V:

$$R \times I = V$$

Therefore, given V = 10 volt and I = 1 ampere, solve for V:

Solution: $R \times I = V = 45\Omega \times 0.5A = 22.5V$

The Ohm' s Law equation and its various forms may be obtained readily with the aid of the Ohm's Law Pyramid shown in Table 2. A pyramid containing V, I, and R is divided into three parts, with V above and with I and R below. To determine the unknown quantity, first cover that quantity with a finger. The position of the uncovered letters in the pyramid will indicate the mathematical operation to be performed. For example, to find I, cover I with your finger. The uncovered letters indicate that V is to be divided by R. To find the formula for R, cover R. The result indicates that V is to be divided by I. To find the formula for V, cover V with your finger. The result indicates that I is to be multiplied by R, or V = IR.

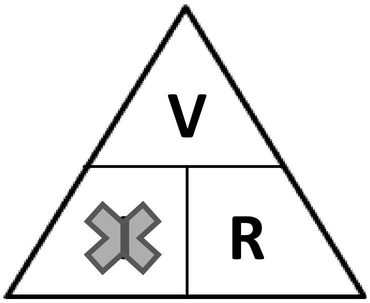
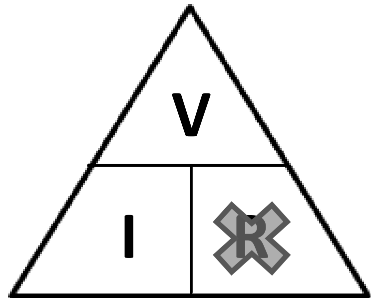
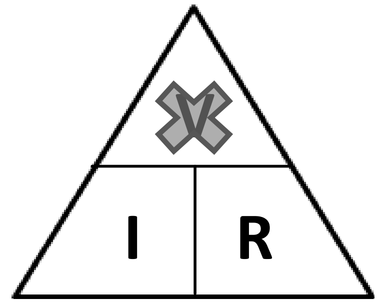
To find Current (I)	To find Resistance (R)	To find Voltage (V)
		
$I = \frac{V}{R}$	$R = \frac{V}{I}$	$V = IR$

Table 2: Ohm's Law Pyramid

You are cautioned not to rely wholly on the use of this diagram when you transpose the Ohm's Law formulas. The diagram should be used to supplement your knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems.

Embedded Videos

Front Range Community College (Ken Floyd)
- Ohm's Law http://www.youtube.com/watch?v=URWlkxWroow
- Ohm's Law Examples http://www.youtube.com/watch?v=OA1I6BmeMw

Instructional Engineering Videos
- Basic Ohm's Law http://www.engineeringvideos.org/circuit-analysis/ohm-s-law
- Ohm's Law Examples http://www.engineeringvideos.org/circuit-analysis/ohm-s-law-examples

Sukubasukuba
- Ohm's Law: http://www.youtube.com/watch?v=EiZOyXgxuAs

Washtenaw Community College (Allen Day)
- Ohm's Law Practice http://www.merlot.org/merlot/goToMaterial.htm;jsessionid=9B86A887C93BC488A9CB745752EAB399?url=https%3a%2f%2fwww.msu.edu%2f~dayallen%2fSTAIR_AMD.ppsx&materialid=526825&entrytype=1

Knowledge Check

1. According to Ohm's Law, what formula should be used to calculate circuit voltage if resistance and current value are known?

   A. $V = \frac{R}{I}$

   B. $V = \frac{I}{R}$

   C. $V = IR$

   D. $V = \frac{I}{IR}$

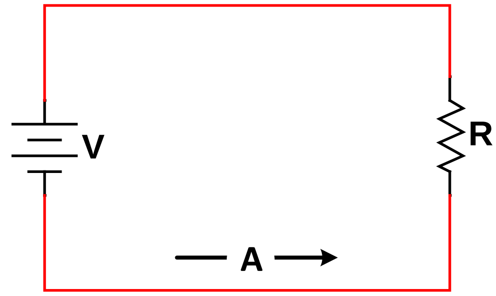
Graphical Analysis of Ohm's Law

One of the most valuable methods of analyzing a circuit is by constructing a graph. No other method provides a more convenient or more rapid way to observe the characteristics of an electrical device.

The first step in constructing a graph is to obtain a table of data. The information in the table can be obtained by taking measurements on the circuit under examination, or can be obtained theoretically through a series of Ohm's Law computations. The latter method is used here.

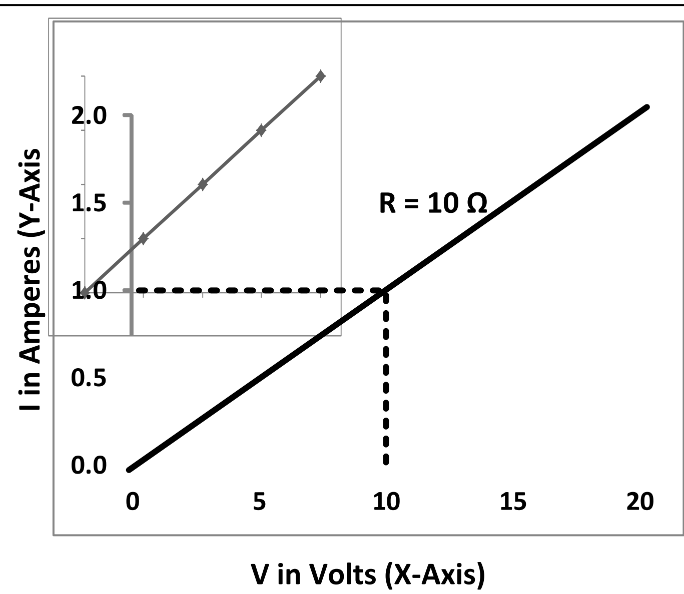
Since there are three variables (V, I, and R) to be analyzed, there are three distinct graphs that may be constructed. To construct any graph of electrical quantities, it is standard practice to vary one quantity in a specified way and note the changes which occur in a second quantity. The quantity which is intentionally varied is called the **independent variable** and is plotted on the horizontal axis. The horizontal axis is known as the **X-AXIS**. The second quantity, which varies as a result of changes in the first quantity, is called the **dependent variable** and is plotted on the vertical, or **Y-AXIS**. Any other quantities involved are held constant.

For example, in the circuit shown in Circuit 4, if the resistance was held constant at 10 ohms and the voltage was varied, the resulting changes in current could then be graphed. The resistance is the constant, the voltage is the independent variable, and the current is the dependent variable.



Circuit 4: Graphing Ohm's Law

Figure 5 shows the graph and a table of values. This table shows R held constant at 10 ohms as V is varied from 0 to 20 volts in 5-volt steps. Through the use of Ohm's Law, you can calculate the value of current for each value of voltage shown in the table. When the table is complete, the information it contains can be used to construct the graph shown below. For example, when the voltage applied to the 10-ohm resistor is 10 volts, the current is 1 ampere. These values of current and voltage determine a point on the graph. When all five points have been plotted, a smooth curve is drawn through the points.



R = 10 Ω	
V (volts)	I (amps)
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

Figure 5: Graphing Relationship between I and V in Ohm's Law

Through the use of this curve, the value of current through the resistor can be quickly determined for any value of voltage between 0 and 20 volts.

Since the curve is a straight line, it shows that equal changes of voltage across the resistor produce equal changes in current through the resistor. This fact illustrates an important characteristic of the basic law—the current varies directly with the applied voltage when the resistance is held constant.

When the voltage across a load is held constant, the current depends solely upon the resistance of the load. For example, Figure 6 shows a graph with the voltage held constant at 12 volts. The independent variable is the resistance which is varied from 2 ohms to 12 ohms. The current is the dependent variable. Values for current can be calculated as:

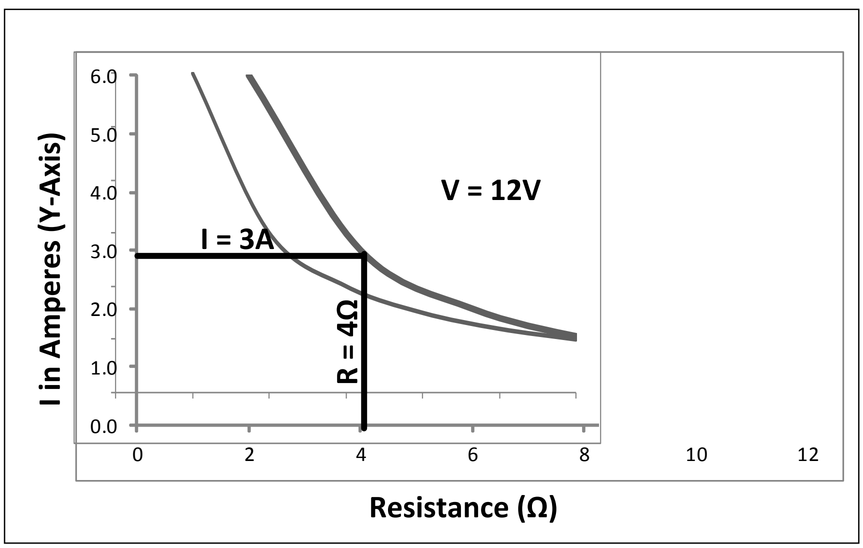


Figure 6: Graphing relationship between Current and Resistance in Ohm's Law

Problem: If V = 12V and R varies in 2Ω steps from 2Ω to 12Ω, find I, in amps (A).

Solution: Using Ohm's Law, $I = \frac{V}{R}$

$$I = \frac{12V}{2\Omega} = 6A$$

$$I = \frac{12V}{4\Omega} = 3A$$

$$I = \frac{12V}{6\Omega} = 2A$$

$$I = \frac{12V}{8\Omega} = 1.5A$$

$$I = \frac{12V}{10\Omega} = 1.2A$$

$$I = \frac{12V}{12\Omega} = 1A$$

This process can be continued for any value of resistance. You can see that as the resistance is halved, the current is doubled; when the resistance is doubled, the current is halved.

This illustrates another important characteristic of Ohm's Law—current varies inversely with resistance when the applied voltage is held constant.

Knowledge Check

1. Using the graph in Figure 5, what is the approximate value of current when the voltage is 12.5V?
2. Using the graph in Figure 6, what is the approximate value of current when the resistance is 3Ω?

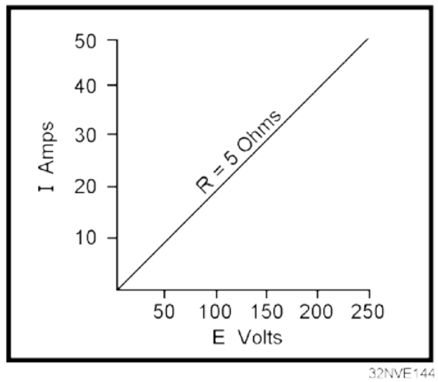


Figure 7: Graphical Analysis Knowledge Check

Referring to

3. Figure 7, if the current is 15 A, what is the value of the voltage?

   A. 50 V
   B. 75 V
   C. 100 V
   D. 150 V

Referring to

4. Figure 7, if the voltage is 200 V, what is the value of the current?

   A. 10 A
   B. 20 A
   C. 30 A
   D. 40 A

Power in Electric Circuits

In addition to voltage and current, there is another measure of free electron activity in a circuit: *power*. First, we need to understand just what power is before we analyze it in any circuits. Power is a measure of how much work can be performed in a given amount of time. **Work** is generally defined in terms of the lifting of a weight against the pull of gravity. The heavier the weight and/or the higher it is lifted, the more work has been done. **Power** is a measure of how rapidly a standard amount of work is done.

Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. When a mechanical force is used to lift or move a weight, work is done. However, force exerted without causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

Previously, it was shown that voltage is an electrical force, and that voltage forces current to flow in a closed circuit. However, when voltage exists but current does not flow because the circuit is open, no work is done. There is however, potential. This is similar to a spring under tension that produces no motion. When voltage causes electrons to move, work is done. The instantaneous **rate** at which this work is done is called the electric power rate, and is measured in **watts**.

Voltage is the measure of potential energy per unit charge available to move electrons from one point to another. Before we can precisely define what a "volt" is, we must understand how to measure this quantity we call "potential energy." The general metric unit for energy of any kind is the **joule** and is equal to the amount of work performed by a force of one Newton exerted through a motion of one meter in the same direction. This is slightly less than 3/4 pound of force exerted over a distance of 1 foot. Put in common terms, it takes about 1 joule of energy to lift a

3/4 pound weight 1 foot off the ground. Defined in these scientific terms, 1 volt is equal to 1 joule of electric potential energy per (divided by) 1 coulomb of charge. Thus, a 9 volt battery releases 9 joules of energy for every coulomb of electrons moved through a circuit.

One foundational unit of electrical measurement, often taught in the beginnings of electronics courses but used infrequently afterwards, is the unit of the **coulomb**, which is a measure of electric charge proportional to the number of electrons in an imbalanced state. One coulomb of charge is equal to 6.25×10^{18} or 6,250,000,000,000,000,000 electrons. The symbol for electric charge quantity is the capital letter "Q," with the unit of coulombs abbreviated by the capital letter "C." The unit for electron flow, the amp, is equal to one coulomb of electrons passing by a given point in a circuit in one second of time. Cast in these terms, current is the *rate of electric charge motion* through a conductor. $1A = \frac{1C}{1s}$, or 1 amp of current is equal to the rate of one coulomb per second passing by a given point.

Knowledge Check

1. Which of the following terms applies to the rate at which an electrical force causes motion?

    A. Power
    B. Energy
    C. Inertia
    D. All of the above

Introduction to the Power Formula

As stated, the basic unit of power is the watt (W). Power in watts is equal to the voltage across a circuit multiplied by current through the circuit. This represents the rate at any given instant at which work is being done. The symbol P indicates electrical power. Thus, the basic power formula is P = I x V, where V is voltage and I is current in the circuit. The amount of power changes when either voltage or current, or both voltage and current, are caused to change.

It must be understood that neither voltage nor current by themselves constitute power. Rather, power is the combination of both voltage and current in a circuit. Remember that voltage is the specific work (or potential energy) per unit charge, while current is the rate at which electric charges move through a conductor. Voltage (specific work) is comparable to the work done in lifting a weight against the pull of gravity. Current (rate) is analogous to the speed at which that weight is lifted. Together as a product (multiplication), voltage (work) and current (rate) constitute power.

In an open circuit, where voltage is present between the terminals of the source and there is zero current, there is zero power dissipated, no matter how great that voltage may be. Since $P=IV$ and $I=0$ and anything multiplied by zero is zero, the power dissipated in any open circuit must be zero. Likewise, if we were to have a short circuit constructed of a loop of superconducting wire (absolutely zero resistance), we could have a condition of current in the loop with zero voltage, and likewise no power would be dissipated. Since $P=IV$ and $V=0$ and anything multiplied by zero is zero, the power dissipated in a superconducting loop must be zero.

In practice, the only factors that can be changed are voltage and resistance. In explaining the different forms that formulas may take, current is sometimes presented as a quantity that is changed. Remember, if current changes, it is because either voltage or resistance has been changed.

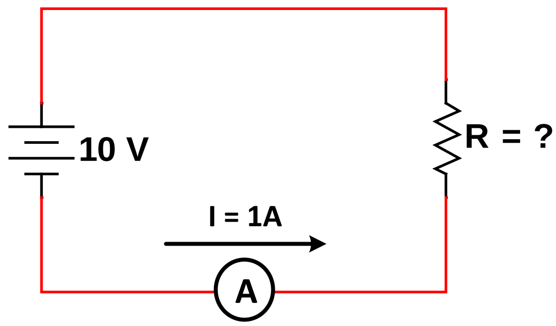
Knowledge Check

1. Which of the following circuit quantities can be varied ONLY by varying one of the other circuit quantities?

    A. Voltage
    B. Current
    C. Resistance
    D. Each of the above

Using and Manipulating the Power Formula

A Simple Problem



Circuit 5: Power Formula

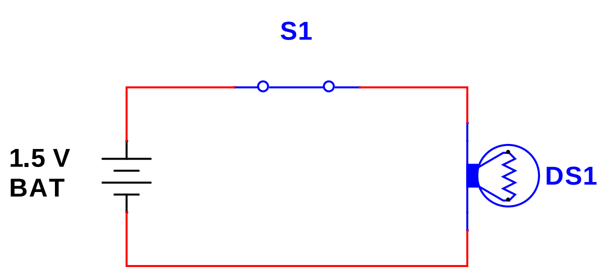
Problem: If V = 10V and I = 1A, solve for power (P), in Watts (W).

Solution: Using the power formula, $P = I * V$

$$100W = 10A * 10$$

Manipulating the Formulas

Recall the flashlight circuit from the Ohm's Law section. In this circuit, values for voltage and resistance were given. To calculate the power dissipated by this circuit, you will need to derive power based on the information given to you and Ohm's Law.



Circuit 6: Solving for power based on V and R

Problem: Referring to the schematic above, if the voltage is 1.5V and the resistance of the lamp is 5 Ω, calculate the power dissipated in this circuit.

Solution #1: You can use Ohm's Law to calculate the current:

$$I = \frac{V}{R} = \frac{1.5V}{5\Omega} = 0.3A$$

Then plug this amount into the Power Formula:

$$P = IV = 0.3A * 1.5V = 0.45W$$

Solution #2: Derive a power formula given voltage and resistance.

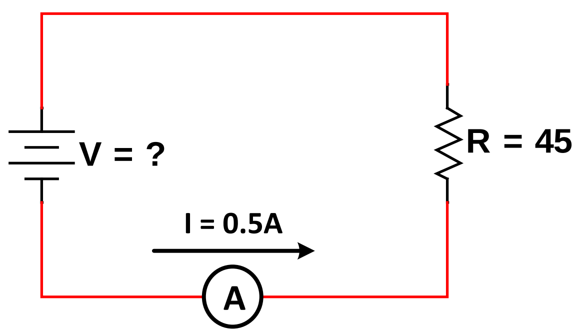
Since: $I = \frac{V}{R}$

By substitution, you get: $P = \frac{V}{R} * V$

Or: $P = \frac{(V*V)}{R}$

Therefore: $P = \frac{V^2}{R}$

Solving the problem is now: $P = \frac{1.5V^2}{5\Omega} = \frac{2.25V}{5\Omega} = 0.45W$



Circuit 7: Solving for power based on I and R

Problem: Referring to the schematic above, if the current is 0.5 A and the resistance of the load is 45 Ω, calculate the power dissipated in this circuit.

Solution: Derive a power formula given current and resistance.

Since: $V = IR$

By substitution, you get: $P = I * (IR)$

Or: $P = I * I * R$

Therefore: $P = I^2R$

Solving the problem is now: $P = 0.5A^2 * 45\Omega = 11.25W$

Up to this point, four of the most important electrical quantities have been discussed. These are voltage (V), current (I), resistance (R), and power (P). You must understand the relationships which exist among these quantities because they are used throughout your study of electricity. In the preceding paragraphs, P was expressed in terms of alternate pairs of the other three basic quantities V, I, and R. In practice, you should be able to express any one of these quantities in terms of any two of the others.

Embedded Videos

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- Power Formula (1 of 2): http://www.youtube.com/watch?v=jRs8ZQdhNZ0
- Power Formula (2 of 2): http://www.youtube.com/watch?v=6fqWLPOtmVI
- Power Formula Examples: http://www.youtube.com/watch?v=V2bKE_v70R8
- Power Formula Examples 2: http://www.youtube.com/watch?v=ZLwmGPvpHiU
- Power Formula 2 More Examples: **http://www.youtube.com/watch?v=RIB0XFD3WN0**

Instructional Engineering Videos

- Introduction to Power in Circuits: http://www.engineeringvideos.org/circuit-analysis/introduction-to-power-in-circuits

Knowledge Check

2. Which of the following is a correct formula for determining power in an electrical circuit?

    A. $P=VI$
    B. $P=I^2R$
    C. $P = E^2/R$
    D. All of the above

3. What is the current in a circuit with 15 ohms of resistance that uses 135 watts of power?

    A. 10 A
    B. 15 A
    C. 3 A
    D. 9 A

4. What is the total power used by a 15-ohm resistor with 4 amps of current?

    A. 60 W
    B. 240 W
    C. 360 W
    D. 900 W

Graphical Representation of Power

The Basic Power Formula

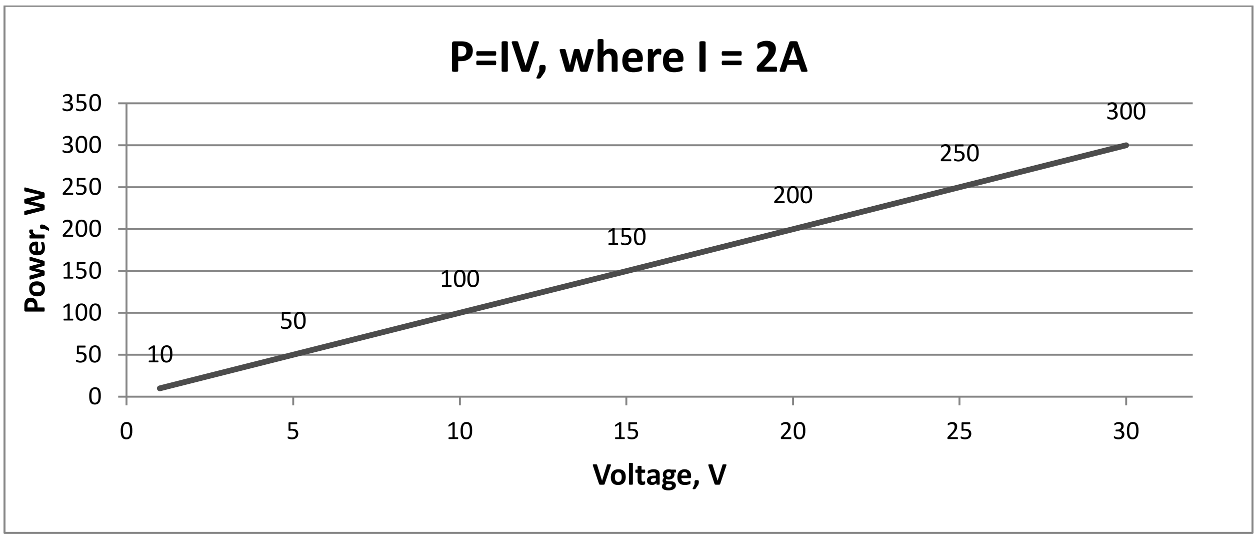


Figure 8: Graphing the Power Formula I

In the graph shown in Figure 8, current is held steady at 10 A as voltage is increased from 1 to 30 V in 5V increments. In electric circuits, power is a function of both voltage and current. This graph shows the linear relationship between Power, Current, and Voltage. While this linear relationship bears striking resemblance to the proportional Ohm's Law formula, it should be understood that in this case, power (P) is exactly equal to current (I) multiplied by voltage (V), rather than being proportional to IV.

The Power Formula based on Voltage and Resistance

Figure 9 shows a basic circuit using a source of power that can be varied from 0 to 8 volts and a graph that indicates the relationship between voltage and power.

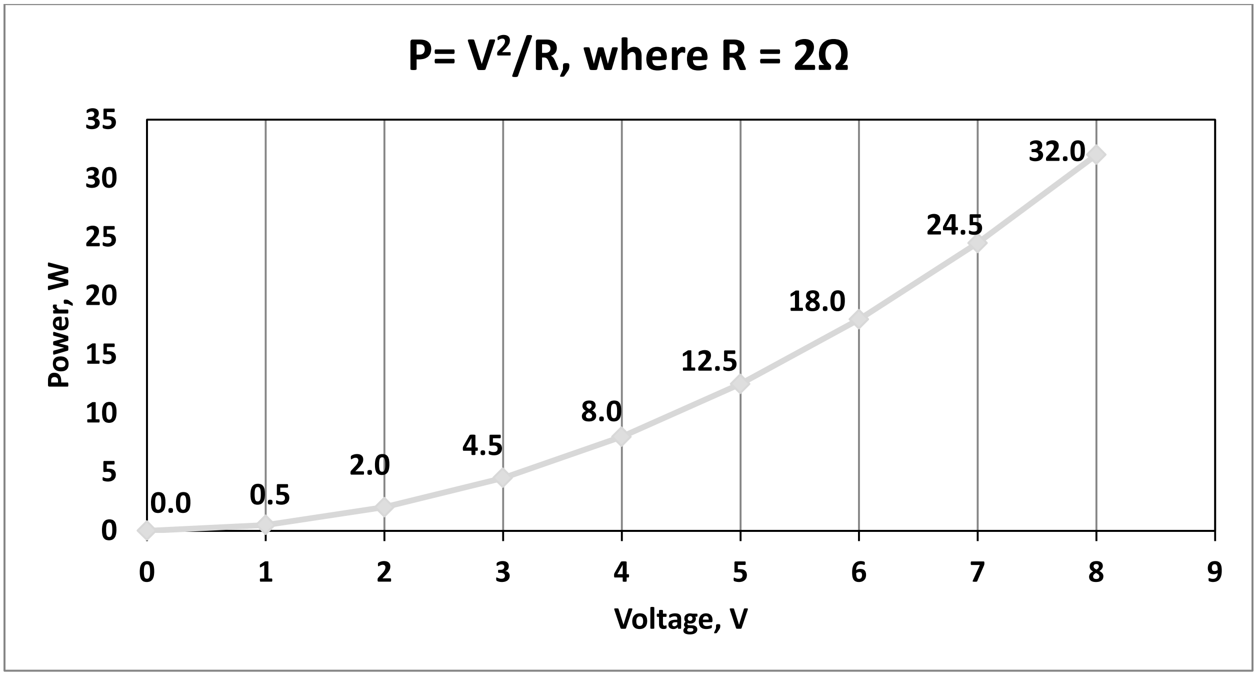


Figure 9: Graphing the Power Formula II

The resistance of this circuit is held steady at 2Ω. Voltage (V) is increased in steps of 1 volt, from 0 volts to 8 volts. You should notice that when the voltage was increased to 2 volts, the power increased from 0.5 W to 2 W or four times. When the voltage increased to 3 volts, the power increased to 4.5 W or nine times. **This shows that if the resistance in a circuit is held constant, the power varies directly with the square of the voltage.**

The Power Formula based on Current and Resistance

Referring to Figure 10, note that **power also varies as the square of current just as it does with voltage**. Thus, another formula for power, with current and resistance as its factors, is $P = I^2R$.

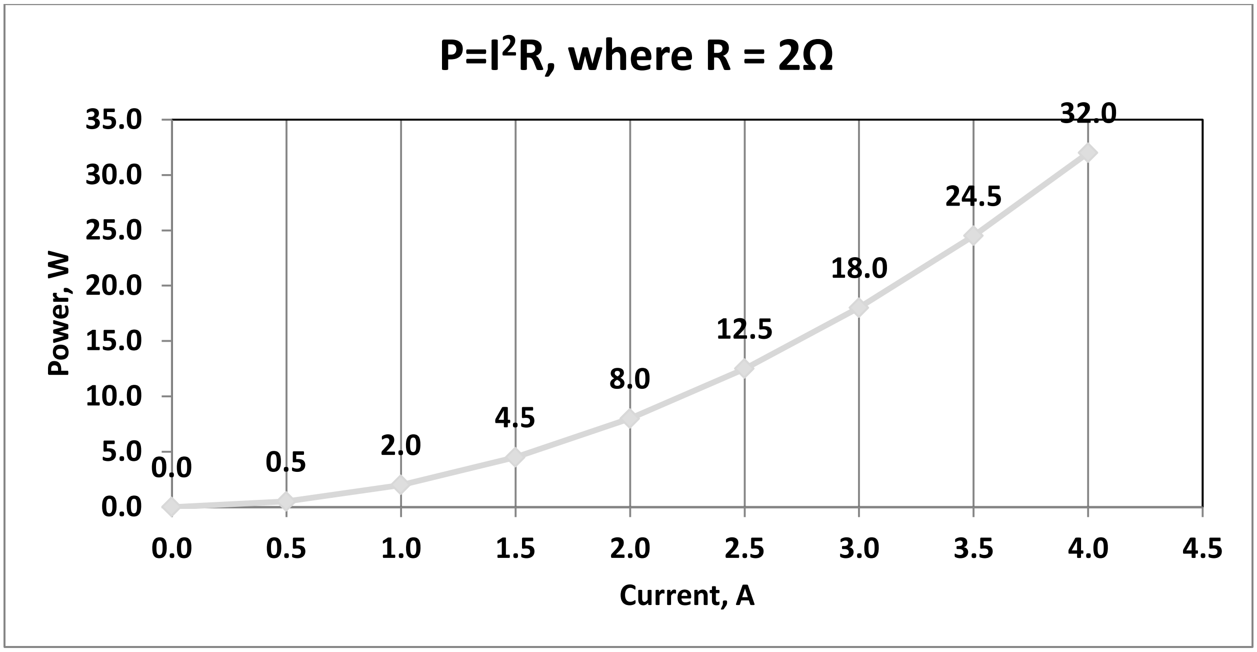


Figure 10: Graphing the Power Formula III

Visual Representation of Power Formulas

Figure 11 shows a summary of the 12 basic formulas you should know. The four quantities V, I, R, and P are at the center of the figure. Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

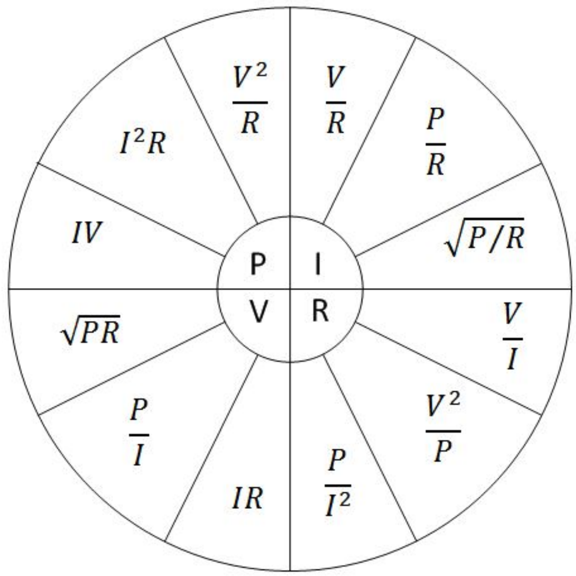


Figure 11: The Power Wheel

For example, the formula wheel in Figure 11 could be used to find the formula to solve the following problem.

Problem: A circuit has a voltage source that delivers 6 volts and the circuit uses 3 watts of power. What is the resistance of the load?

Solution: Since R is the quantity you have been asked to find, look in the section of the wheel that has R in the center. Review the three possible formulas that "equal" resistance to find the one that fits the problem. Because the problem gives voltage and power, select the formula that contains those variables. The problem can now be solved:

$$R = \frac{V^2}{P} = \frac{6V^2}{3W} = \frac{36V}{3W} = 12\Omega$$

Power Conversion and Efficiency

The term power consumption is common in the electrical field. It is applied to the use of power in the same sense that gasoline consumption is applied to the use of fuel in an automobile. Another common term is power conversion. Power is used by electrical devices and is converted from one form of energy to another. An electrical motor converts electrical energy to mechanical energy. An electric light bulb converts electrical energy into light energy and an electric range converts electrical energy into heat energy. Power used by electrical devices is measured in energy. This practical unit of electrical energy is equal to 1 watt of power used continuously for 1 hour. The term kilowatt hour (kWh) is used more extensively on a daily basis and is equal to 1,000 watt-hours.

The **efficiency** of an electrical device is the ratio of power converted to useful energy divided by the power consumed by the device. This number will always be less than one (1.00) because of the losses in any electrical device. If a device has efficiency rating of .95, it effectively transforms 95 watts into useful energy for every 100 watts of input power. The other 5 watts are lost to heat, or other losses which cannot be used.

$$\boxed{Efficiency = \frac{Power\ Converted}{Power\ Used}}$$

Equation 2: Efficiency Formula

Calculating the amount of power converted by an electrical device is a simple matter. You need to know the length of time the device is operated and the input power or horsepower rating. **Horsepower** unit of work is often found as a rating on electrical motors. One horsepower (hp) is equal to 746 W.

Problem: A 3/4-hp motor operates 8 hours a day. How much power is converted by the motor per month? How many kWh does this represent?

Given: t = 8 hrs. x 30 days (t = time)

P = 3/4 hp

Solution: Convert horsepower to watts:

$$P = \frac{3}{4} hp * 746W = 559\ W$$

Convert watts to watt-hours:

$$P = 559W * 8 * 30 = 134{,}160 = 134.16\ kWh$$

Problem: If the motor actually uses 137 kWh per month, what is the efficiency of the motor?

Given: Power converted = 134.16 KWh per month

Power used = 137 kWh per month

Solution:

$$Efficiency = \frac{Power\ Converted}{Power\ Used} = \frac{134.16\ kWh}{137\ kWh} = 0.979$$

Embedded Videos

Front Range Community College (Ken Floyd)

- Energy http://www.youtube.com/watch?v=kIYJ-mu-smw
- Energy Calculation Examples http://www.youtube.com/watch?v=9S2hNfrb8f4
- Energy Cost http://www.youtube.com/watch?v=pafgkSXWz9A
- Energy Cost Calculation Examples http://www.youtube.com/watch?v=tH46Blrzp7M

Knowledge Check

1. How much power is converted by a 1-horsepower motor in 12 hours?
2. What is the efficiency of the motor if it actually uses 9.5 kWh in 12 hours?

Power Ratings

Electrical components are often given a **power rating**. The power rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion. An example of such a rating is noted when comparing a 150-watt lamp to a 100-watt lamp. The higher wattage rating of the 150-watt lamp indicates it is capable of converting more electrical energy into light energy than the lamp of the lower rating. Other common examples of devices with power ratings are soldering irons and small electric motors.

In some electrical devices the wattage rating indicates the maximum power the device is designed to use rather than the normal operating power. A 150-watt lamp, for example, uses 150 watts when operated at the specified voltage printed on the bulb. In contrast, a device such as a resistor is not normally given a voltage or a current rating. A resistor is given a power rating in watts and can be operated at any combination of voltage and current as long as the power rating is not exceeded. In most circuits, the actual power used by a resistor is considerably less than the power rating of the resistor because a 50% safety factor is used. For example, if a resistor normally used 2 watts of power, a resistor with a power rating of 3 watts would be used.

Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor the higher the wattage rating. This is true because a larger surface area of material radiates a greater amount of heat more easily.

When resistors with wattage ratings greater than 5 watts are needed, wirewound resistors are used. Wirewound resistors are made in values between 5 and 200 watts. Special types of wirewound resistors are used for power in excess of 200 watts.

As with other electrical quantities, prefixes may be attached to the word watt when expressing very large or very small amounts of power. Some of the more common of these are the kilowatt (1,000 watts), the megawatt (1,000,000 watts), and the milliwatt (1/1,000 of a watt).

Knowledge Check

1. What is the total power used by a 15-ohm resistor with 4 amps of current?
    A. 60 W
    B. 240 W
    C. 360 W
    D. 900 W
2. What type of resistor should be used in question above?
    A. Carbon
    B. Wirewound
    C. Precision
    D. Composition

Ohm's Law Lab 1: Linear Resistance

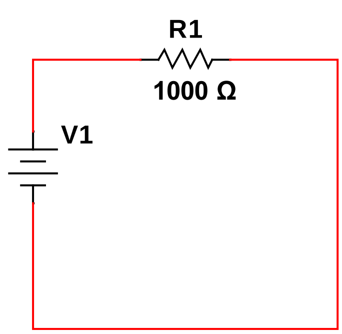
Georg Ohm, in 1827, formulated that the current through a conductor between two points is directly proportional to the potential difference across the two points. Resistance is the constant of this proportionality, meaning that resistance is held constant in the formula. Potential difference, as you know, is another way of referring to voltage. Electromotive Force (emf) is another. Oftentimes, you will see formulas written with an "E" instead of a "V."

This lab will prove Ohm's Law by showing that there is a linear relationship between current and voltage when the resistance is held steady.

Components & Equipment Needed

- Bread Board
- Wire (22 AWG)
- 1k Ω ohm Resistor, 0.25 W
- Variable DC Power Supply
- DMM

Circuit Diagram



Circuit 8: Ohm's Law Lab 1

Procedure

Step 1: **Take starting measurements.**

Before connecting the circuit, complete the following steps, measure and record the resistance of R1. Measured Resistance: _________

Step 2: **Calculated Values**

Using the nominal resistance and the applied voltage, calculate the current and record in the table below. Remember that "nominal resistance" refers to the resistance value that the resistor should have.

Step 3: **Build the circuit**

Connect the circuit as shown in the schematic.

Step 4: **Take measurements**

Measure and record current for each voltage setting and calculate the error difference between the calculated and measured currents.

Step 5: **Graph Relationship**

Using the values recorded in the table to draw a graph of the relationship between Applied Voltage and Measured Current. (V = x axis, I = y axis)

Tables for Ohm's Law Lab 1: Linear Resistance

Applied Voltage, V	Calculated Current, I	Measured Current, I	% Difference
2.0			
4.0			
6.0			
8.0			
10.0			
12.0			

Table 3: Ohm's Law Lab 1: Linear Resistance

Observations and Conclusions

In your lab report, include your results from Table 3 as well as any observations or conclusions you may have made during this exercise.

Some questions to answer in your discussion:

- Do your observations support what you have learned about the relationship between current and voltage?

Ohm's Law Lab 2: Non-Linear Resistance

While it does still adhere to Ohm's Law, the relationship between voltage, current, and resistance sometimes doesn't act the way we expect. Other factors, such as temperature, can have an effect on how this relationship is played out. For example, an incandescent bulb has a tungsten filament that increases in temperature when voltage is applied. As a result, the resistance of the filament is affected and therefore, current is affected. With the constant of proportionality, resistance, no longer constant, the final result is a relationship that is not linear in nature.

If Ohm's Law is changed so that it reads, "for a conductor in a given state, the electromotive force is proportional to the current produced," it introduces the idea that if the state, such as temperature, of the conductor is changed, the proportions will change. This happens with respect to time, but as the mathematical concepts are beyond the scope of this course, it is easy enough to show in the lab.

Contemporaries of Georg Ohm, such as Joseph Fourier, studied the processes of heat conduction and discovered that temperature changed the conductivity of a material. The constant resistance was no longer constant as its conductivity changed as temperatures changed. This is evident when using an analog multimeter, such as a Simpson 260, to measure the resistance of the 7382 bulb used in previous experiments. It is not possible to get an accurate resistance reading on the 7382 bulb due to its low wattage (about 1.12 W) and low resistance (less than 20 Ω) because the Simpson meter uses a small current when measuring resistance and this current is sufficient to heat the filament, which changes it conductivity, and thus increases the resistance.

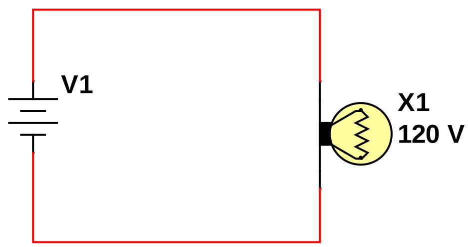
Please note that when using Multisim to simulate this type of circuit, the relationship remains linear. The simulation is not affected by the heating of the tungsten filament and therefore, the resistance remains stable as voltage increases.

In this lab, you will use a regular C-7 (or similar) style bulb (120 V, 5W) to demonstrate the effect of heat on resistance and ultimately on the relationship between voltage and current.

Components & Equipment Needed

- Bread Board
- Wire (22 AWG)
- C-7 Bulb (120 V, 5 W) These are the small bulbs used for night lights and decorating
- Variable DC Power Supply
- DMM

Circuit Diagram



Circuit 9: Ohm's Law Lab 2

Procedure

Step 1: **Take starting measurements.**

Before connecting any part of the circuit, measure the resistance of the light bulb and record below. This is to ensure that you get the "cold" resistance.
Measured "Cold" Resistance of Light bulb: __________

Step 2: **Calculated values**

Using the measured resistance and the applied voltage values, calculate the current and record in the table below.

Step 3: **Build the circuit**

Connect the circuit as shown in the schematic.

Step 4: **Take measurements**

Measure and record current for each voltage setting and calculate the difference percentage between the calculated and measured currents. NOTE: Your values for percent difference may not be as expected!

Step 5: **Graph the relationship**

Using the values recorded in below , draw a graph of the relationship between Applied Voltage and Measured Current. (V = x axis, I = y axis)

Tables for Ohm's Law Lab 2: Non-Linear Resistance

Applied Voltage, V	Calculated Current, I	Measured Current, I	% Difference
1.0			
3.0			
6.0			
9.0			
12.0			
15.0			
18.0			
21.0			
24.0			
27.0			
30.0			

Table 4: Ohm's Law Lab 2: Non-Linear Resistance

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.

Some questions to answer in your discussion:

- Does this lab experiment demonstrate the effect of a negative or positive temperature coefficient?

Ohm's Law Lab 3: Multisim and Simple Circuit Design

Components & Equipment Needed

- Bread Board
- Wire (22 AWG)
- Resistors
- Variable DC Power Supply
- DMM
- Multisim (version 10 or higher)
- Standard Resistor Table (see Additional Resources section)

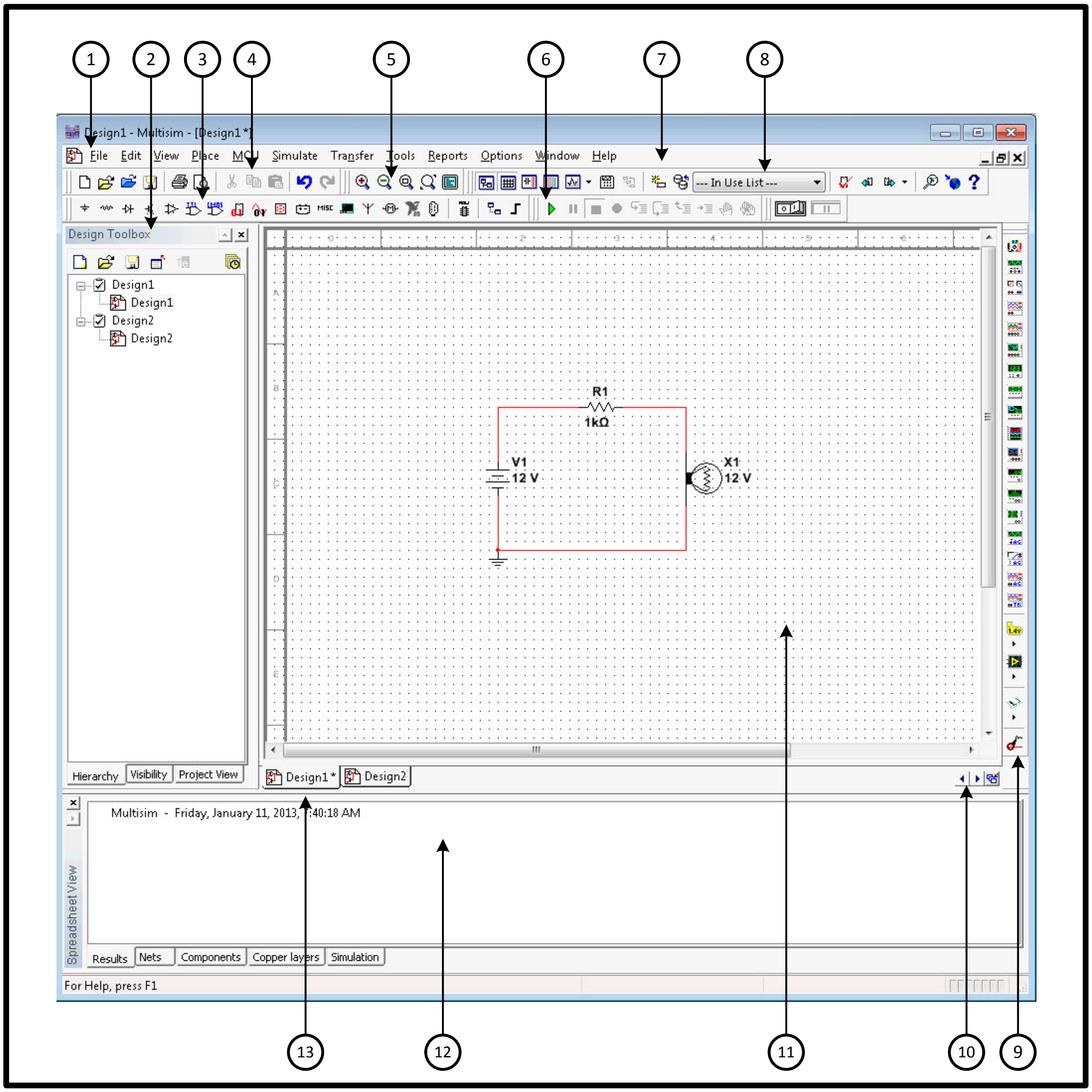
For design labs, you are asked to first design and build your circuit(s) using Multisim. In real world situations, a simulation software package, such as Multisim, will be used to build and test circuits before actual prototyping. This can help avoid expensive equipment damage when early design flaws are encountered. After you have the circuit working in Multisim, you will then need to build and demonstrate your design. Don't forget to save your circuit for submission with your lab assignments. You can select, then copy and paste your circuit from Multisim directly into Word.

One of the best ways to become familiarized with Multisim's interface is to explore it. Click the various menus and see where they go. Make up circuits and experiment with moving the components around and with attaching wires. The most commonly used items will be the Component Toolbar, the Simulation Toolbar, and the Instruments Toolbar. From these three you will be able to build your circuits, simulate them, and select instruments for measuring current, voltage, and resistance.

The tutorials which follow will walk you through the steps to get started using Multisim and how to build a circuit. When building a circuit on a breadboard, you are only worried about the positive and the negative sides of the power supply. There is no separate ground required; however, Multisim requires that a physical ground be placed on the circuit. It will not run the simulation and will give you a warning message that the circuit must be grounded.

Multisim

Getting Around in Multisim



1 Menu Bar	5 View Toolbar	8 In Use List	11 Design Window
2 Design Toolbox	6 Simulation Toolbar	9 Instruments Toolbar	12 Spreadsheet View
3 Component Toolbar	7 Main Toolbar	10 Scroll Left/Right	13 Active Tab
4 Standard Toobar			

Figure 12: Multisim Toolbar Guide

The following provides a brief description of the functions for each of the items shown in the above diagram.

1 Menu Bar	Where to find commands for all functions
2 Design Toolbox	A list of the files opened as well as additional information which may provide detail on the circuit.
3 Component Toolbar	Access to all the different components available in Multisim ordered by type
4 Standard Toolbar	The standard toolbar of commonly-used commands such as Print and Save.
5 View Toolbar	Tools for changing the view of the workspace
6 Simulation Toolbar	Access to circuit simulation controls. Includes a basic On/Off switch as well as more sophisticated controls.
7 Main Toolbar	Access to common Multisim functions.
8 In Use List	List of all components currently in use by the circuit.
9 Instruments	Access to measurement tools such as multimeter and oscilloscopes and to other specialized instruments.
10 Scroll Left/Right	Allows for scrolling the screen to the left or right.
11 Design Window	The workspace for building circuits.
12 Spreadsheet View	Provides a spreadsheet of details about the parts being used.
13 Active Tab	Allows for switching between more than one circuit design

Getting Started

1. Opening and saving a file
    a. Open Multisim
        i. On the lab computers, Select **Windows Start >> All Programs >> National Instruments >> Circuit Design Suite 12.0 >> Multisim 12.0** launch the application.
    b. Starting a New Design
        i. When you launch Multisim, it will take you to a blank workspace ready for circuit design.
    c. Opening a File
        i. Select **File >> Open**, then browse to the folder containing the Multisim file you would like to open, click it, then click "Open."
    d. Saving a File
        i. Select **File >> Save As**, then browse to the locations you would like to save the file, type a file name, then click "Save."
2. Building a Circuit
    a. Place Components
        i. Select **Place >> Component** to open the "Select a Component" box. You can also right click to **Place Component** or use **CTRL-W**.
        ii. To place a power supply, set the drop down for <u>Group</u> to *Sources*, click on Power_Sources under *Family,* and select DC_POWER under *Component*. Press OK. The dialog box will close, and then you can place the power supply on the work space by dragging it to the desired location then left click to drop. The *Select a Component* dialog box will reopen. Select GROUND from the *Component* list and place it on your work space. Don't worry about exact placement at this time. It is a simple task to move components later. To get a resistor, change the drop down <u>Group</u> to *Basic*. Select RATED_VIRTUAL then in the component column, scroll until you find RESISTOR_RATED. Select then click OK. Repeat this as many times as necessary to place the required components on the workspace. When finished, click Close in the *Select a Component* dialog box.
    b. Arrange the Components
        i. To select components for moving, click them with the mouse cursor and while depressing the left mouse button, drag the component to where you'd like it. If you need to rotate a component, right click on it and select the option for rotating it 90° to the left or right.
        ii. To add wires, click in the component's "pin" and drag the mouse. The cursor looks like a cross hairs and a wire will be seen. Drag the wire to the pin of

the next component to complete the connection. Do this until all components are attached.

   iii. The Ground – when we breadboard, there is no special ground component. It is part of the return on the power supply. However, in Multisim, it is required to place a ground. Make sure it is attached on the negative side of the power supply as shown. If not, your readings for voltage might be inconsistent with what you expect at this time. At a later date, we will be moving the ground to different places to see the effect it has on the circuit.

c. Running the simulation
   i. Once all the wires are connected, it is time to run the simulation. The circuit can be started with the "On/off" switch, or by clicking the green "Play" switch. The circuit can be Played, Paused, or Stopped.

d. Measurements
   i. At this time, we will only be using a digital multimeter. To place the meter on the design space, move the mouse to the Instrument Toolbar and select the meter at the very top. If you hover the mouse over the components, their titles will appear. Click once, then drag the meter to the design space and click a second time to drop it.
   ii. Connect the "leads" the same way you would connect wire in the circuit. Start at the "+" or "-," then drag the wire to the appropriate place on the circuit.
   iii. Double Click the meter to open it up. You can select Voltage, Ohms, Current, or decibels and either AC (curvy line) or DC (straight line).
   iv. Be aware that all the rules apply in Multisim when it comes to meters! It will NOT allow a measurement of resistance if the component is energized. It will not function correctly if not inserted into the circuit when measuring current.

Part I Designing with Multisim

Step 1: **Perform calculations based on specifications.**

Calculate the resistance required to build the circuit to the following specifications:

- V = 15 V
- I = 4 mA
- One (1) Resistor R = ____________ ohms

Step 2: **Build the circuit (follow directions!)**

Using a *single* resistor, build this circuit in Multisim. If the value you calculated is not available in the drop-down list, you may double click on the resistor and manually change the value.

Step 3: **Take measurements**

Measure and record your measurements in Table 5: Part I Designing with Multisim. Save your circuit so that it can be included in your lab report. It can be copied directly from Multisim and pasted into a Word document.

Part II Designing on the Breadboard

Step 1: **Perform calculations based on specifications.**

Calculate the resistance required to build the circuit to the following specifications:

- V = 15 V
- I = 4 mA
- One (1) Standard Value Resistor (see note below)

R = _____________ ohms

Note: To build this circuit, you may not be able to find a resistor with the exact value (Standard Resistor Values**), therefore, using the value you calculated above, select a resistor that will best work to meet the given parameters. A list of Standard Resistor Values can be found in the Additional Resources section.**

Because you will have to use a resistor that is not exact, be aware that your current value will not be 4 mA. Ensure that for whatever resistor you choose, the current is as close to 4 mA as possible.

Step 2: **Build the circuit (follow directions!)**

Build the circuit on a breadboard using **only** a single standard value ±5% resistor that best meets the specified requirements.

Step 3: **Take measurements**

Measure and record the values shown in Table 6: Part II Designing on the Breadboard. Record the nominal values and the measured values. Calculate the percent error between nominal and measured values.

Tables for Ohm's Law Lab 3: Multisim and Simple Circuit Design

	Voltage	Resistance	Current
Calculated Values	15 V		4 mA
Measured Values			
Percent Error			

Table 5: Part I Designing with Multisim

	Voltage	Resistance	Current
Calculated Values	15 V		4 mA
Measured Values			
Percent Difference			

Table 6: Part II Designing on the Breadboard

Observations and Conclusions

In your lab report, include your results from Table 5 and Table 6 as well as any observations or conclusions you may have made during this exercise.

In your discussion, include your answers to the following questions:

1. Describe the process you took to design the circuit. Support your design with calculations and include a labeled schematic.

2. Being restricted to using standard values makes design more challenging. Compare the results of the two exercises and describe the importance of understanding the difference between ideal (simulated) and approximated (real world) values.

Ohm's Law Lab 4: Critical Thinking Exercise

Solving critical thinking exercises require that you stop and methodically review what is required, what are the facts (theories, laws, etc.), and what connections exist between these things. For this exercise, the problem solving steps will be provided. Be aware that in future critical thinking exercises, this information will not be provided.

Problem

Your supervisor has asked you to design a circuit. She wants to use a light bulb that the company already uses in other products, but because this is a specialized circuit, it is important that it dissipates a very specific amount of heat, or power. She doesn'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 45 W. The only kind of power supplies that the company uses are 12 V or 24 V. In this situation, it is necessary that the voltage supply chosen be within ± 3% of the required voltage.

At first, this seems like a really hard problem. You know about Ohm's Law, but how can you calculate voltage using Ohm's Law with power and resistance? You think back on your reading and remember the Joule-Lenz Laws (also known as the Power Formulas), specifically this:

> *The rate of heat dissipation in a resistive conductor is proportional to the square of the current through it and to its resistance.*

You realize that with this formula, your knowledge of Ohm's Law and a little algebra, you can solve the problem easily!

The Steps to Solution

Form the Question – What is really being asked?

There is a tendency among students to assume that critical thinking questions are asking obscure questions. This assumption causes students to waste time with irrelevant calculations and also leads to frustration. Part of critical thinking is the evaluation of the problem to determine what is really being asked of you. The question being asked in this problem is:

- Which power supply (12 V, 24 V, or neither) should be used in this circuit?

And this question has conditions, or specifications, which must be observed:

- The calculated voltage supply must be within ± 3% of the available power supplies of 12 V or 24 V.

Gather Information – What are the facts?

Before you let yourself panic, take a moment to write down all the facts that are given. In most cases, the facts will be numerical values of resistance, voltage, current, or power. Rest assured that all the information, or data, which is required for solving the problem, has been provided.

Read through the problem and record the following values:

- R = Ω
- P = W
- Power supply choices
  - V = V
  - V = V

Additional Information – Formulas, Laws, and Theories

In electronics, you will find that nearly everything will return to a basic formula that is based on a law or theory, such as Ohm's Law. Do not fall into the trap of memorizing formulas. Sometimes, students become so fixated on a mathematical formula written a certain way that they fail to see the derivatives. A derivative is basically a change of perspective. V = IR, and also R = V/I. And as you learn other laws, such as the Joule-Lenz Laws, you will find that voltage, current, resistance, and power are interconnected.

To be truthful, the most effective way of solving critical thinking problems is to NOT memorize formulas or derivatives. Anyone can do the math. What is most important to critical thinking problems is the ***understanding*** of the laws or theories. For example, here are two of the most important laws you will need to know for now:

- **Ohm's Law:** The amount of current, I, is directly proportional to the voltage (V), and inversely proportional to the resistance, R. Expressed mathematically, I = V / R.
- **Joule-Lenz Laws** ("The Power Laws"): The rate of heat dissipation, Power (P), in a resistive conductor is proportional to the square of the current, I, through it and to its resistance, R. Expressed mathematically, $P = I^2R$.

Analysis of the Information

After gathering the data, you must analyze it. Examine the question, the data, and the other information (laws and theories), and find the connections that exist. Based on analysis, you can find many connections where derivations exist between Ohm's Law and Joule-Lenz Law.

- **The Question:** Which power supply will dissipate 45 W of power in a circuit that has 10 Ω of resistance? Is this power supply (12 V or 24 V) within ± 3% of the necessary voltage needed?
- **The Information (Data):** Values for resistance, power, and voltage of available power supplies.
- **Additional Information (Formulas):** Ohm's Law and the power formulas (Joule-Lenz Laws)

The Problem Solving Process

Step 1: **Calculations**

There are only three possible answers: 12 V, 24 V or neither. Determine what voltage, V, exists given the conditions of R = 10 Ω and P = 45 W. This will require reviewing both of the laws given and looking at them from the perspective of voltage (V).

$$V = \sqrt{PR} = \sqrt{45W * 10\Omega} = ?$$

Next, compare this voltage to the available power supplies (12 V or 24 V). Determine if the difference between the calculated voltage and the available voltage of each power supply is within ± 3%.

One way of looking at this is to determine the acceptable ranges for each power supply then comparing your calculated value with those.

Step 2: Support your answer

Support your answers with logic and reasoning. Or, more plainly, with calculations and the use of laws and theories. Don't just give the answer and show your work, ***support*** your answers by briefly explaining the reasoning ***why*** you solved the problem the way you did. Explanations must be brief and concise. This is the most important aspect of a critical thinking problem.

Calculates to include:

- The required voltage
- The acceptable voltage ranges for both power supplies

Index of Important Terms

Answers to Knowledge Checks

Introduction to Ohm's Law

2. If circuit voltage is held constant, circuit current will react in what manner as the resistance either (a) increases, or (b) decreases?

    A. (a) Current Increases (b) Current decreases
    B. (a) Current Increases (b) Current Increases
    C. (a) Current decreases (b) Current decreases
    D. (a) Current decreases (b) Current Increases [CORRECT]

3. If circuit resistance is held constant, circuit current will react in what manner as the voltage either (a) increases, or (b) decreases?

    A. (a) Voltage Increases (b) Voltage decreases [CORRECT]
    B. (a) Voltage Increases (b) Voltage Increases
    C. (a) Voltage decreases (b) Voltage decreases
    D. (a) Voltage decreases (b) Voltage Increases

Using and Manipulating Ohm's Law

1. According to Ohm's Law, what formula should be used to calculate circuit voltage if resistance and current value are known?

    A. $V = \frac{R}{I}$

    B. $V = \frac{I}{R}$

    C. $V = IR$ [CORRECT]

    D. $V = \frac{I}{IR}$

Graphical Analysis of Ohm's Law

1. Using the graph in Figure 5, what is the approximate value of current when the voltage is 12.5V? **[1.25 A]**

2. Using the graph in Figure 6, what is the approximate value of current when the resistance is 3Ω? **[4 A]**

Referring to

3. Figure 7, if the current is 15 A, what is the value of the voltage?

   A. 50 V
   B. 75 V **[CORRECT]**
   C. 100 V
   D. 150 V

Referring to

4. Figure 7, if the voltage is 200 V, what is the value of the current?

   A. 10 A
   B. 20 A
   C. 30 A
   D. 40 A **[CORRECT]**

Power in Electric Circuits

1. Which of the following terms applies to the rate at which an electrical force causes motion?

A. Power
B. Energy
C. Inertia
D. All of the above **[CORRECT]**

Introduction to the Power Formula

1. Which of the following circuit quantities can be varied ONLY by varying one of the other circuit quantities?

    A. Voltage
    B. Current **[CORRECT]**
    C. Resistance
    D. Each of the above

Using and Manipulating the Power Formula

1. Which of the following is a correct formula for determining power in an electrical circuit?

    A. $P=VI$
    B. $P=I^2R$
    C. $P = V^2/R$
    D. All of the above **[CORRECT]**

2. What is the current in a circuit with 15 ohms of resistance that uses 135 watts of power?

    A. 10 A
    B. 15 A
    C. 3 A **[CORRECT]**
    D. 9 A

3. What is the total power used by a 15-ohm resistor with 4 amps of current?

    A. 60 W
    B. 240 W **[CORRECT]**
    C. 360 W
    D. 900 W

Power Conversion and Efficiency

1. How much power is converted by a 1-horsepower motor in 12 hours? **[8.952 kWh]**

2. What is the efficiency of the motor if it actually uses 9.5 kWh in 12 hours? **[0.942]**

Power Ratings

3. What is the total power used by a 15-ohm resistor with 4 amps of current?

    A. 60 W
    B. 240 W **[CORRECT]**
    C. 360 W
    D. 900 W

4. What type of resistor should be used in question above?

    A. Carbon
    B. Wirewound **[CORRECT]**
    C. Precision
    D. Composition

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

Standard Resistor Values

Standard Resistor Values (±5%)

1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

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Ohm's Law Examples **http://www.youtube.com/watch?v=OA1I6BmeMw**
Power Formula (1 of 2): http://www.youtube.com/watch?v=jRs8ZQdhNZ0
Power Formula (2 of 2): http://www.youtube.com/watch?v=6fqWLPOtmVI
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Basic Ohm's Law **http://www.engineeringvideos.org/circuit-analysis/ohm-s-law**
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