2 Electricity

This chapter introduces the physical phenomenon of electricity. First it examines the overall structure of the atom, the most fundamental basis for studying electricity. Next, it examines the basics of electricity – charge, current, and voltage. The two types of current electricity, direct current and alternating current, are introduced, along with differences between conductors and insulators.

Next, this chapter introduces the topic of resistance, and its relation to voltage and current. The color codes for resistors are presented, and circuits using resistors in series and in parallel are examined. Potentiometers, resisters whose values can be varied, and photoresistors, resistors whose values vary based on the amount of light they receive, are introduced. Laboratory Experiments 1 and 2 correspond to the material covered in this chapter.

2.1 Electricity, Charge, and Current

2.1.1 Atomic Structure

To understand current, it is necessary to first understand the basic structure of the atom. An atom is composed of three basic types of particles. The nucleus, or center of the atom, contains some number of *protons* and *neutrons*. Protons are positively charged particles, and the number of protons in an atom determines the type of atom. For example, all hydrogen atoms have exactly one proton, and all atoms with 13 protons are aluminum. Most atoms (except for most hydrogen atoms) have one or more neutrons in their nuclei as well. Neutrons have no charge, and the number of neutrons in an atom may vary. Atoms with the same number of protons but different numbers of neutrons are called *isotopes*.

Outside of the nucleus, negatively charged particles called *electrons* orbit the nucleus. Electrons are much smaller and lighter than protons. The attraction between the positively charged protons in the nucleus and the negatively charged electrons normally keeps the electrons in orbit around the nucleus. The number of electrons is the same as the number of protons, and the positive and negative charges cancel out; the atom has no net charge. A typical atom is shown schematically in Figure 2.1.

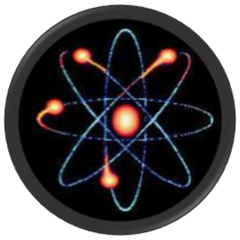


Figure 2.1: Basic atomic structure. Negative electrons orbit the positive nucleus at the center.

Sometimes an electron can escape from the orbit of its atom and be captured by another atom. The original atom now has one less electron and the atom has a net positive charge. The atom that captures the electron has one more electron than it has protons, resulting in a net negative charge. These are called *ions*, a general term that applies to all atoms with non-zero net charge, either positive or negative.

This last phenomenon, electrons moving between atoms, is the basis for electricity. Electricity is created by the flow of electrons (you will learn more about other characteristics of what we will call current in ECE 271). We'll examine this in the following subsections.

2.1.2 Charge

In the previous section we mentioned that electrons have a negative charge, but how much is this charge? To quantify charge, scientists have defined a *Coulomb* as the amount of charge contained by 6,250,000,000,000,000,000 (6.25×10^{18}) electrons. Although this sounds like a lot of electrons, keep in mind that one mole of hydrogen atoms, 6.022×10^{23} atoms, weighs only one gram, and the vast majority of that gram comes from the protons!

Charge is typically denoted as Q. Coulomb is abbreviated C; for example, a charge of 12 Coulombs is denoted as $Q = 12C$.

2.1.3 Current

Electric current is the flow of charged particles in a specific *direction*. In liquids and gases, these charged particles can be electrons or ions. In solids, such as the wire used in electrical circuits, electrons are the charged particles that cause electric current. Since the charge of a single electron is very small indeed ($q_e = 1.6 \times 10^{-19}$ C), any practical current involves flow of many electrons.

Current is typically denoted as I (for intensity). Current is the amount of charge flowing per unit time. This can be denoted by the equation:

$$I = \frac{Q}{t}$$

The same amount of charge flowing over a longer period of time would produce a smaller current, just as having a street where 20 cars pass through an intersection in one minute would be considered to have greater traffic than having the same 20 cars pass through the same intersection in an hour. The basic unit of current is the *Ampere*, or *Amp*, denoted as *A*. One Ampere is defined as the flow of one Coulomb of charge per second.

The following point is really important. *Although the electrons in a metal wire flow from the negative terminal to the positive terminal, the current flows from the positive terminal to the negative terminal.* The electrons carry a negative charge, and the current is defined by convention as the flow of positive charge. This is sort of like subtracting 1 and -1. 1 - (-1) is the same as 1 + (+1). The negative charge of the electrons flowing in one direction gives the same current as the positive charge flowing in the opposite direction. The convention of the current flow from positive to negative terminal was established before electrons were discovered and later people did not bother to change it.

2.1.4 Direct Current and Alternating Current

Two types of electric current are used in everyday life. *Direct current*, or *DC*, always flows in the same direction. This is the type of current created by batteries. The other type of current is *alternating current*, or *AC*. This is the current used to power household appliances and lights.

This type of current periodically changes direction, once every 1/120 seconds in the United States, repeating the whole process 60 times per second, hence the associated parameter 60 Hz (or once every 1/100 seconds in Europe, 50 Hz).

2.1.5 Voltage

Voltage, also called the *electromotive force* or *potential difference*, is the force that causes current to flow. It can be helpful to visualize voltage as a difference in potential energy caused by differences in charges. Consider a simple battery; it has positive and negative terminals. Chemicals inside the battery cause positive charges to congregate near the positive terminal and negative charges to collect near the negative terminal. If we connected a wire from one terminal to the other, electrons would flow from the negative terminal to the positive terminal, creating a current in the wire. Eventually the charges on each side of the battery will become more neutral, and the battery will die out.

Voltage is defined as energy per unit charge, coupled with the assignment of polarities to the terminals. The basic unit of voltage is the *Volt*, abbreviated as *V*. One volt is equal to one joule per Coulomb. The more volts a battery has, the more joules of energy it supplies per coulomb.

$$Volt(V) = \frac{Joule(J)}{Coulomb(C)}$$

$V = V_A - V_B$

2.1.6 Power

The flow of charges requires energy, and the energy per unit time, or power *P*, is proportional to both current and voltage

$$P = VI$$

Power is measured in *watts* (W). One watt is one joule per second, which is equal to one ampere times one volt.

2.1.7 Conductors and Insulators

Some materials allow electrons to flow more freely than others. *Conductors* are materials that give up electrons easily, offering little opposition (resistance) to current flow. Copper is a very good conductor; that is why house wiring is usually made of copper.

Other materials, called *insulators*, do not yield electrons easily. They offer high resistance to current flow. They are not perfect; some electrons do flow in insulators. However, the amount is so small that, for all practical purposes, virtually no current flows. Insulators are useful for wrapping wires, causing all current to flow from one end of the wire to the other and not allowing current to escape from within the wire. This is why an extension cord that is plugged into a wall outlet can be handled safely, as long as there is no break in the insulation! Rubber gloves and boots will protect you from electric shocks if you touch a live wire (out of an abundance of precaution, electricians and engineers are supposed to turn off power before working on electrical systems, but you will not need them while working on your experiments as the current is too low to cause any danger).

2.2 Resistors and Ohm's Law

2.2.1 Resistors and Resistance

Resistors are fundamental components in electric circuit design. As their name implies, they resist the flow of current in a circuit. The next several sections examine resistors, their color codes, and circuits that use resistors in series, in parallel, or in both configurations. Figure 2.2 shows several types of resistors. Potentiometers and photoresistors, resistors whose resistance can be varied, are also described.

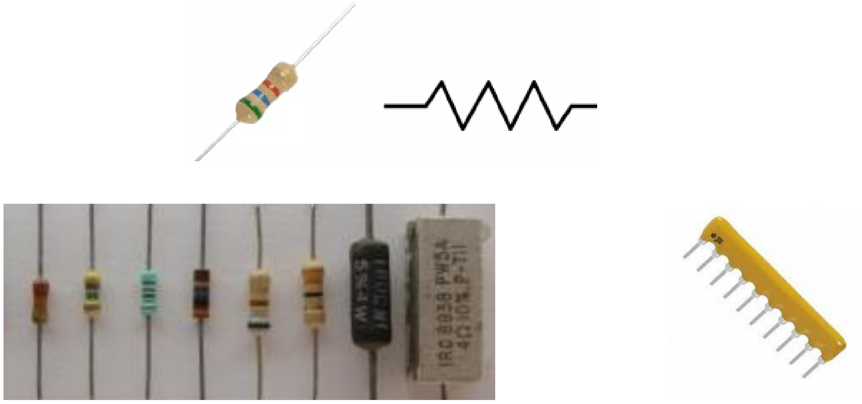


Figure 2.2: Different types of resistors

To examine the relationship between the voltage, current, and resistance in a circuit, we will start with the simple circuit shown in Figure 2.3.

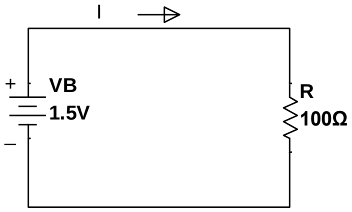


Figure 2.3: A simple 1-resistor circuit

The 4 segments (2 long, and 2 short) on the left-hand side of the figure is a battery (constant voltage source). It has a voltage of 1.5V, the voltage level of a standard battery. The positive terminal of the battery (+) is connected via a wire, represented by straight lines, to one end of a resistor, labeled R, which is denoted by the zigzag lines. The other end of the resistor is connected to the negative terminal of the battery (-) with wires, completing the circuit, that is, it forms a loop.

The value of the resistor is based on how well it resists the flow of electrons. A higher resistance allows fewer electrons to flow through the resistor in a given time, reducing the current.

The basic unit of measure of resistance is the *Ohm*, denoted by Ω, the Greek letter Omega. One Ohm is defined as the value of the resistance that lets the current of 1A flow under a voltage of 1V (one volt per ampere). The resistor in this circuit has a value of 100Ω.

2.2.2 Ohm's Law

Ohm's Law defines the relationship between voltage, current, and resistance. It was developed by German physicist Georg Ohm, for whom both Ohm's Law and the unit of measure for resistance were named. It states that the voltage (*V*) in a circuit is equal to the product of the current (*I*) and the resistance (*R*), or

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

A current flowing through a resistance leads to the dissipation of power (in form of heat).

$$P = IV = \frac{V}{R}V = \frac{V^2}{R} = I^2R$$

Now let's look back at the circuit in Figure 2.2. With a voltage of 1.5V and a resistance of 100 Ω, we can calculate its current as

$$I = \frac{V_B}{R} = \frac{1.5V}{100\Omega} = 0.015A = 15\,mA$$

The symbol *mA* stands for milli Amperes, or one-thousandth of an Ampere.

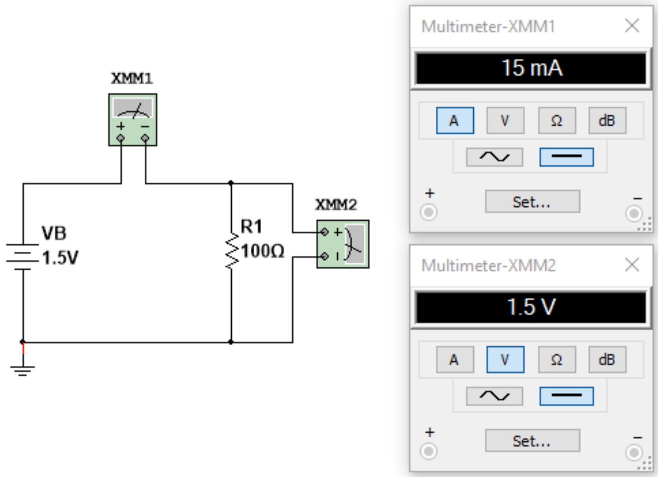


Figure 2.4: Measurements operated on a simple 1-resistor circuit

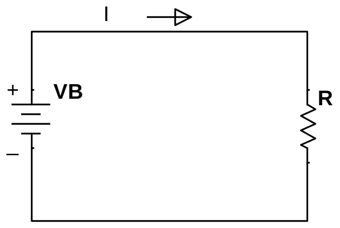
A more formal way of defining Ohm’s Law and the power dissipated by a given device:

- The voltage across a resistor, whose resistance is R, is equal to the product of the resistance R and the current that enters the positive terminal.
- The power dissipated by a given device is equal to the product of the voltage across the device and the current that enters the positive terminal.

A short circuit has zero resistance and zero voltage across it.
An open circuit has infinite resistance and zero current through it.

Worksheet 2.1 – Single-Resistor Circuit

For the circuit shown below, show the missing values for each set of given values.



V_B (V)	I (A)	R (Ω)	P (W)
10	0.5		
2		400	
	0.1	1000	
8			8

2.3 Resistor Color Codes

If you look at a resistor, you won't see a number stamped on it indicating its value. Instead, it has several colored stripes that indicate its resistance. There may be three, four, or five stripes on a resistor. In this section we'll examine how these stripes represent the resistor's value.

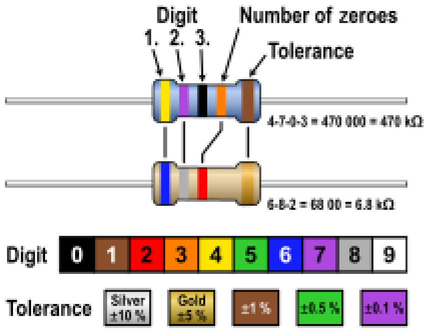


Figure 2.5: Resistor colors and digit values for resistor magnitudes (Wikipedia)

Each stripe can be one of several colors. For the first two stripes (or the first three stripes for resistors with five stripes), the colors represent digits from zero to nine. The colors corresponding to each digit are shown above where black represents 0, brown 1, all the way to white represents 9.

These digits give the base value of the resistor. For example, consider a resistor with four stripes with colors red, black, yellow, and gold, respectively. The first color, red, represents the digit 2, and black corresponds to 0. Together they give a resistance value of 20. However, the next stripe changes this value considerably. The value corresponding to yellow is 4, but this 4 is not added to the end of the 20 to create 204. Instead, it means we add 4 zeros to the right of 20, or that 20 is multiplied by 10^4, or 10,000; the actual resistance is 20×10^4, or 200,000 Ω, or 200 kΩ. There are two other colors for 5-stripe resistors when their values are very small. The 4th stripe represents the multiplier 10^{-1} when it is gold, and 10^{-2} when it is silver. Other colors exist for even smaller resistors. A program that shows the values of a resistor based on its color code is available via the ECE Department laboratory web site.

It is very unlikely that this resistor is exactly 200,000 Ω. Manufacturing processes aren't perfect, and the actual resistance may be greater than or less than its stated value. For the four and five stripe resistors, the last stripe indicates the *tolerance* of the resistor. The tolerance specifies the percentage that the actual resistance may vary from its marked value. Figure 2.5 shows some of the existing tolerance values. For our 200 kΩ resistor, the gold stripe indicates a tolerance of ±5%, so our resistor may have any value from a minimum 200 kΩ, – 5%, or 190 kΩ, up to a maximum of 200 kΩ, + 5%, or 210 kΩ.

Resistors with tolerances of 5% or 10% have four stripes. A resistor with only three stripes that does not display a tolerance explicitly, has by default a tolerance of 20%.

There are also resistors made with tighter tolerances of 1% or less, designated by the last stripes brown, green, or purple. These resistors have five stripes with the first three designating a three-digit number, the fourth stripe, a multiplier (number of zeros or power of ten), and the fifth stripe the tolerance. The reason for an additional stripe is that more digits are required to specify more precisely the values of these resistors, which are made more precisely than the four-stripe resistors.

Worksheet 2.2 – Resistor Color Codes

What are the resistances, and tolerances, of resistors with the following colored stripes?

1. Green, Blue, Red

2. White, Yellow, Green, Silver

3. Brown, Orange, Violet, Yellow, Brown

Show the colors found on resistors with the following values and tolerances.

1. 1.2 kΩ ±20%

2. 88 Ω ±5%

3. 3.14 Ω ±1%

2.4 Series Resistors

A typical circuit will have more than one resistor. Resistors in a circuit may be configured in series, in parallel, or in a combination of the two. This section examines resistors connected in series; parallel resistance is examined in the next section.

Resistors that are connected end-to-end are said to be connected in series. Figure 2.6 shows a circuit with two resistors connected in series. One hallmark of series resistance is that the **same** current that flows through one resistor must flow through the other resistor as well. There is only one path for the current to flow in this circuit.

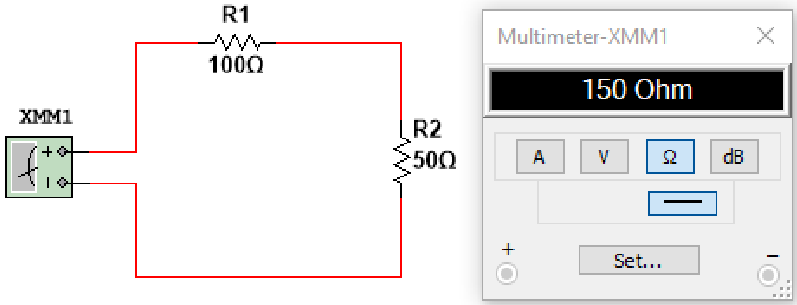


Figure 2.6: Two resistors in series

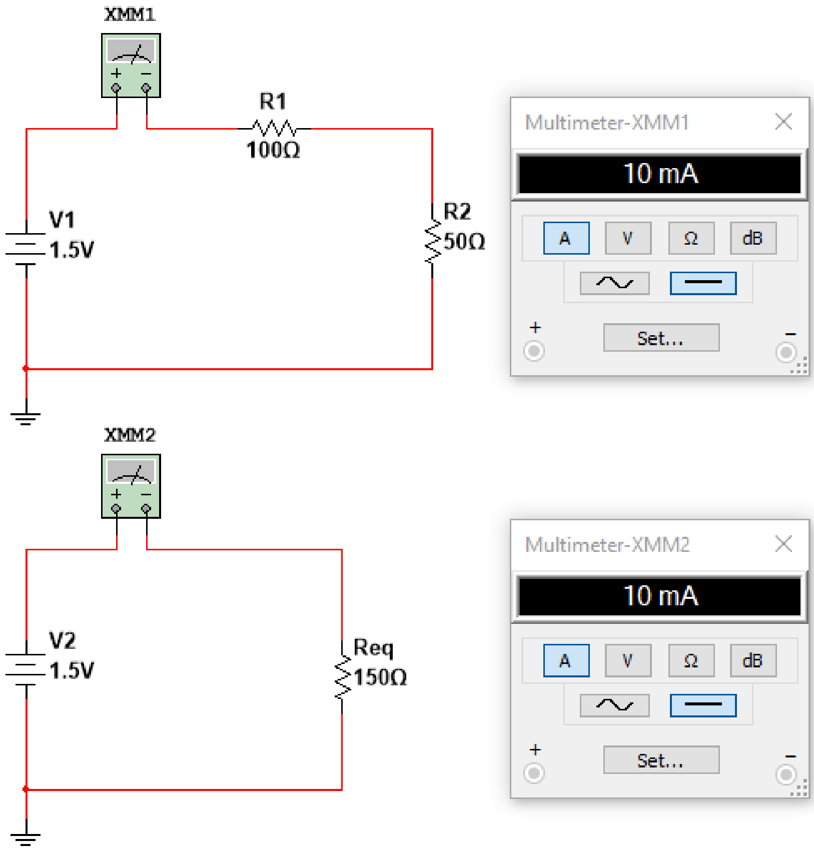


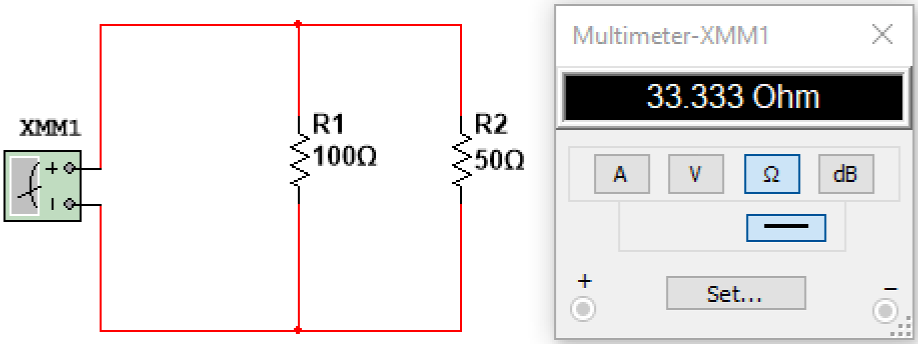
Figure 2.7: Circuit with two resistors in series and equivalent circuit

When two resistors are connected in series, their overall resistance is the sum of their individual resistances. For the circuit in Figure 2.7, the two series resistors have values of 100 Ω and 50 Ω; their overall resistance is 100 Ω + 50 Ω = 150 Ω. Using Ohm's Law, we can calculate the current in the circuit using this combined resistance.

$$I = \frac{V_B}{R_{eq}} = \frac{1.5V}{150\Omega} = 0.01A = 10mA$$

2.5 Parallel Resistors

Resistors are not always connected in series; they can also be connected in parallel. Figure 2.4 shows a circuit with two resistors connected in parallel. Notice that both terminals of the two resistors are connected together.



33.333 Ohm

Figure 2.8: Circuit with two resistors in parallel

Although it might not seem to make sense, the overall resistance of two resistors connected in parallel is *less* than the resistance of either resistor! The basic reason this is true has to do with the current flow, adding another resistor in parallel increases the amount of current flowing in the circuit. From Ohm's Law, I = V/R; as current (I) increases and the voltage (V) remains the same, the overall resistance (R) must decrease.

A standard formula, called the *reciprocal formula*, is used to calculate the net resistance of two or more resistors in parallel. The reciprocal of the overall resistance is equal to the sum of the reciprocals of the individual resistors, or

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

This formula can be simplified for circuits with only two resistors. The formula becomes

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

2.6 Series-Parallel Resistors

As their name implies, series-parallel circuits have resistors in series and in parallel. Figure 2.9 shows two series-parallel circuits.

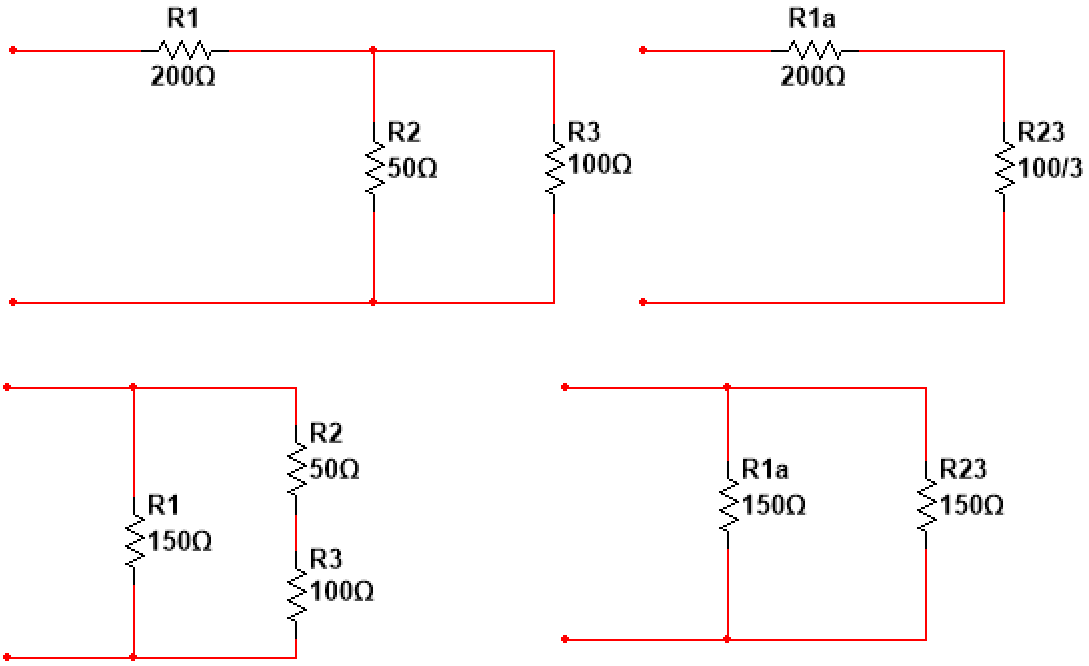


Figure 2.9: Two series-parallel circuits and their respective equivalent

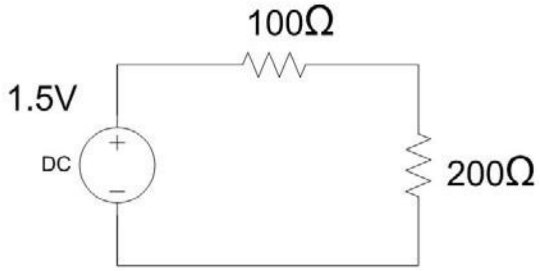
We can analyze series-parallel circuits by breaking them into their individual series and parallel components. For the first circuit in Figure 2.9, the 50 Ω and 100 Ω resistors are in parallel; their net resistance, calculated using the reciprocal formula, is 33.3 Ω. That equivalent resistance is in series with the 200 Ω resistor, producing a net resistance of 233.3 Ω in the circuit. This yields a current of 6.4mA.

For the circuit in Figure 2.9(b), we first combine the 50 Ω and 100 Ω series resistors, which results in a net resistance of 150 Ω. Combining this in parallel with the 150 Ω resistor yields a net resistance of 75 Ω, and a current of 20mA.

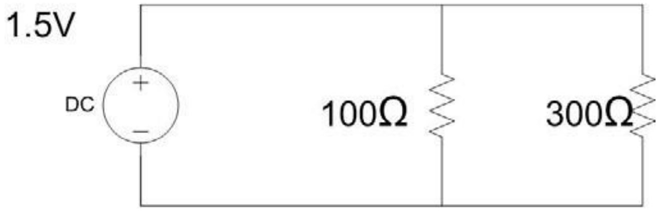
Worksheet 2.3 – Circuit Analysis

What is the net resistance and overall current for the following circuits?

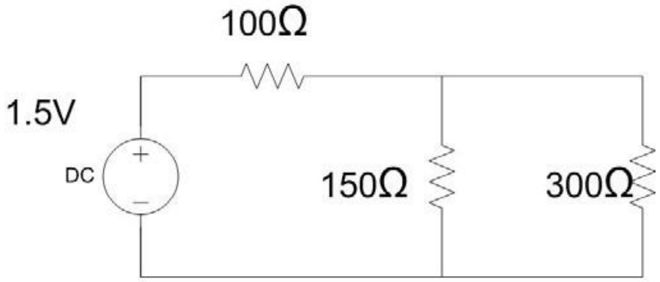
1.



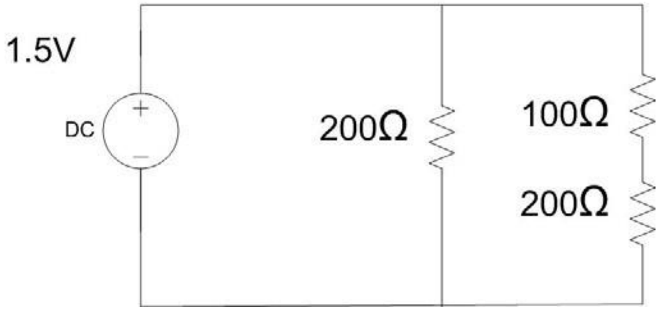
2.



3.



4.



2.7 Potentiometers and Photoresistors

For some circuits, it would be preferable to allow a user to change the value of the resistance without having to re-wire the circuit. This is the role of the *potentiometer*. It is a variable resistor whose value can be changed, typically by turning a shaft or sliding a lever.

There are several applications for potentiometers. Dimmer switches used to vary the intensity of lights are typically potentiometers, or their close relatives, *rheostats*. Volume control knobs on older radios, amplifiers and televisions are also potentiometers.

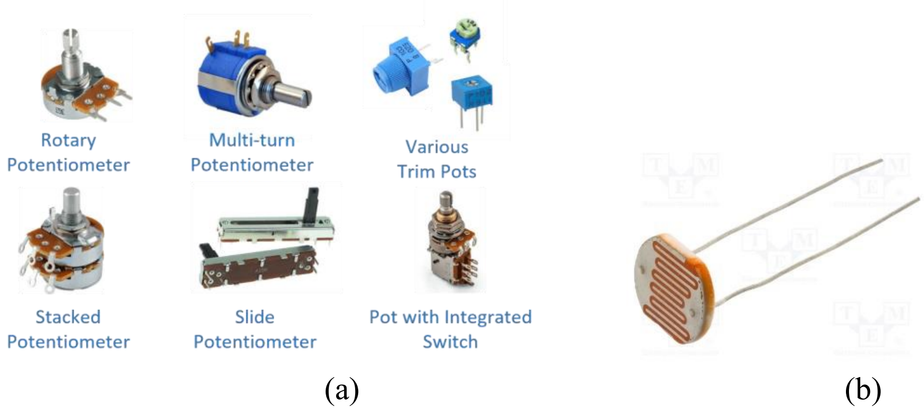


Figure 2.10: (a) Different potentiometers and (b) photoresistor

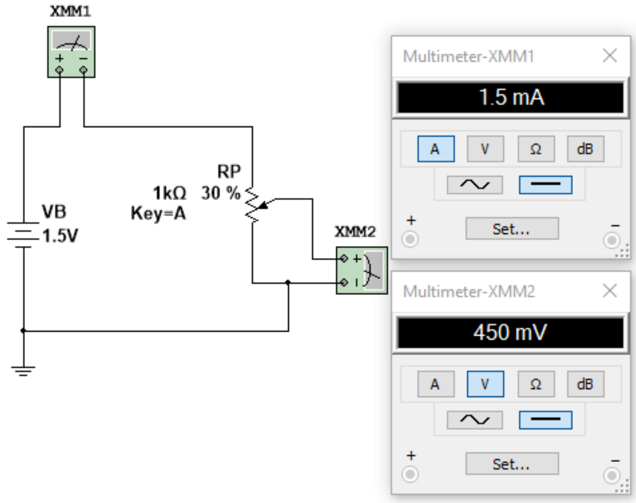
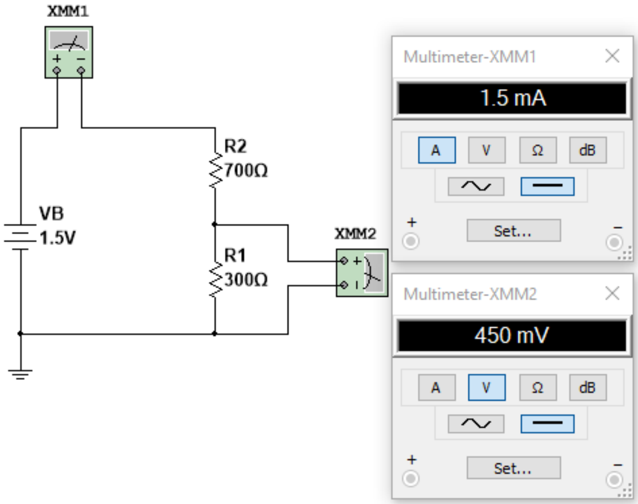


Figure 2.11: Potentiometer in a circuit



Multimeter-XMM1

1.5 mA

Multimeter-XMM2

450 mV

Figure 2.12: The equivalent of a potentiometer used as a voltage divider

Figure 2.12 shows a potentiometer through the equivalent of 2 resistors in series, with the values given corresponding to the 30% fraction (R1/(R1+R2) *100%). As we see, a potentiometer is equivalent to two resistors whose sum if fixed, but depending on the position of the arm, it allows a fraction of the entire voltage to be available at the output. In this case the fraction is 30%, or

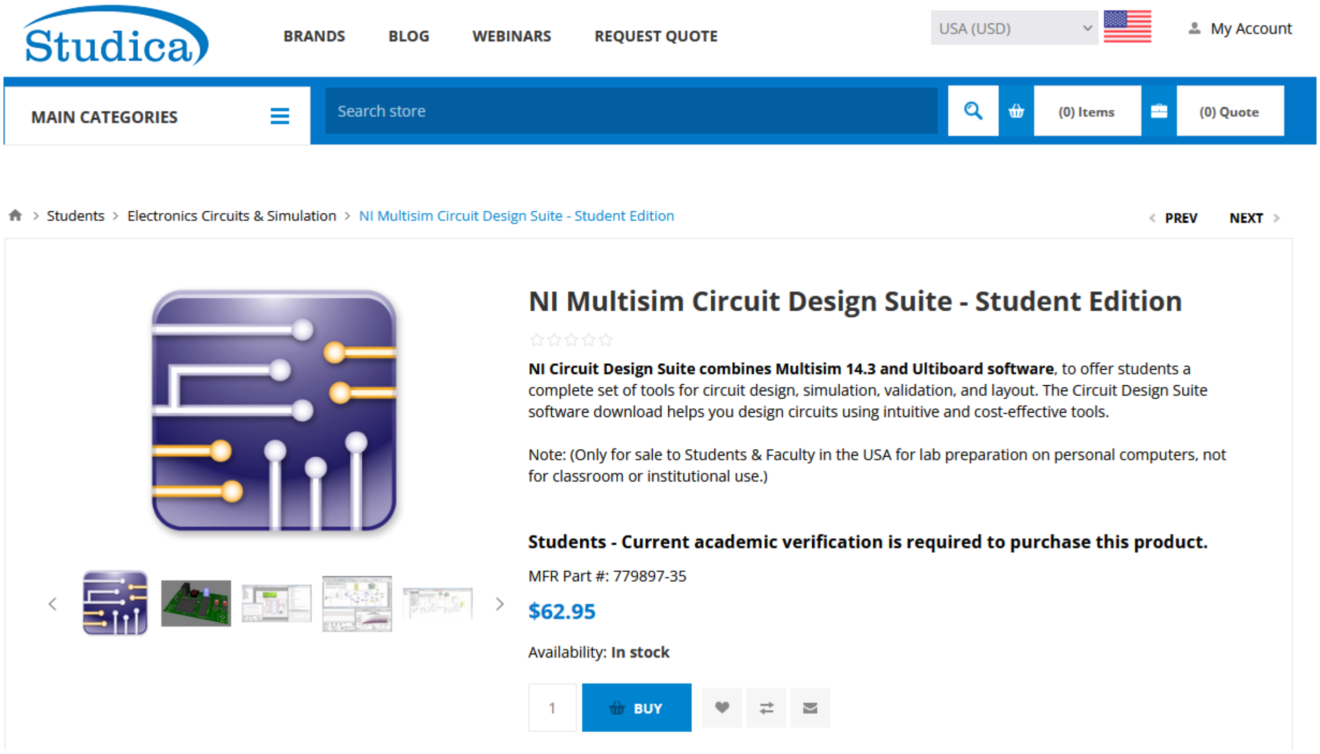
$$V_o = \frac{R_1}{R_1 + R_2} V_B = 0.3*1.5 = 0.45V = 450mV$$

If we ignore one of the outside terminals, and we use only one terminal and the arm, then the potentiometer can be used as a variable resistor.

A photoresistor also changes its value, but the user does not directly change the value of the resistance. Instead, the resistance varies depending on the amount of light sensed by the photoresistor. The photoresistor has greater resistance in dim light and darkness. If the light is bright, the resistance decreases. The photoresistor can be used as a light sensor.

2.8 Basic Introduction to Multisim

The student edition of Multisim is available through **Studica** and should be available to you for as long as you are a student at NJIT with an njit.edu email address. The student version, though powerful, is made available at a low price hoping that when you work for a particular industry, you will be ordering the professional version which is quite expensive, but very useful in high level design and manufacturing. There is also a free online version of Multisim available at at https://www.multisim.com/create/. This version is more limited, but it may be sufficient for some or all the work you do in this course. Obviously, there are a lot more simulation software packages which may appeal to different industries or engineers.



NI Multisim Circuit Design Suite - Student Edition

NI Circuit Design Suite combines Multisim 14.3 and Ultiboard software, to offer students a complete set of tools for circuit design, simulation, validation, and layout. The Circuit Design Suite software download helps you design circuits using intuitive and cost-effective tools.

Note: (Only for sale to Students & Faculty in the USA for lab preparation on personal computers, not for classroom or institutional use.)

Students - Current academic verification is required to purchase this product.

MFR Part #: 779897-35

$62.95

Availability: **In stock**

1

Figure 2.13: Studica add for the Multisim student version

Professional engineering simulation software packages have been developed to assist engineers and scientists in solving design problems using a computer. These software packages rely on mathematical models of circuits (PSpice developed by Microsim, purchased by ORCAD, which in turn was purchased by Cadence Design Systems, and Multisim created by a company named Electronics Workbench, which is now a division of National Instruments), or on the usage of a programming language (Matlab from Mathworks, Mathcad from Mathsoft) to facilitate the resolution of mathematical problems in circuit analysis. The two packages that you will be exposed to in a very limited fashion this semester will be Multisim, and Matlab. The students will be shown a limited set of the features of these software packages to have an idea of their capabilities. These and other software packages will be utilized more extensively in the future, in the various courses that require the assistance of these software tools, and the students will see how powerful these packages can be in supporting the design of engineering systems, most notably in electrical and computer engineering.

Matlab is available free of charge as part of the software package distributed to the students when they join NJIT. Follow the following link to have more information on how to have access to other software packages that NJIT makes available to the students.
https://ist.njit.edu

After you install Multisim (yours will be version 14.3 whereas the one available in the labs is version 14.01), and you have activated it, you will be able to open this program through the main menu or a short cut, or the taskbar.

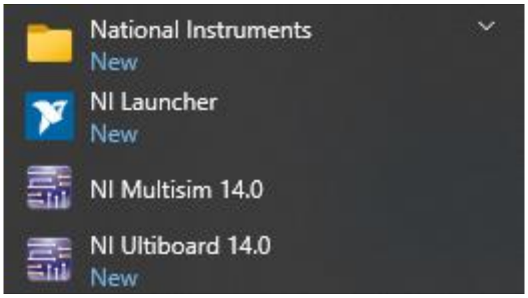
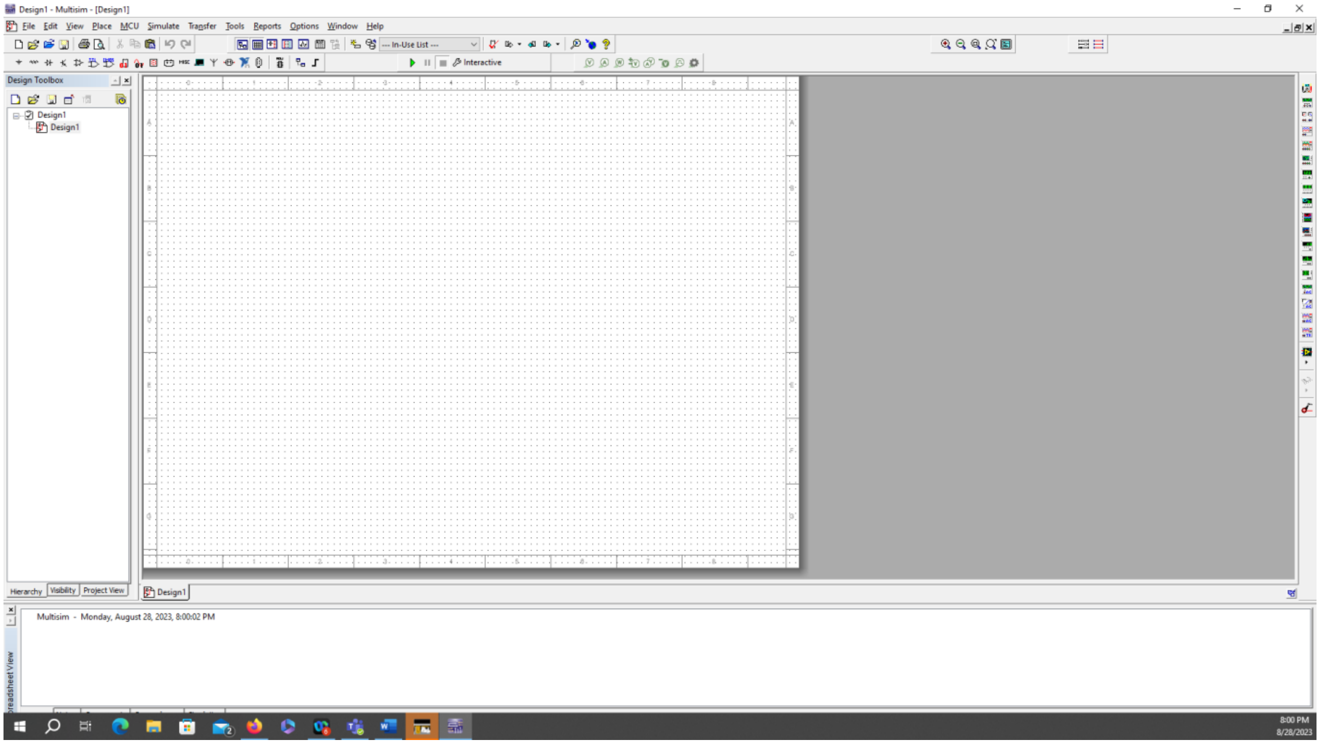


Figure 2.14: Start menu for Multisim

At the moment of the writing of this manual (2023), version 14.3 may be all contained in the National Instruments section heading on the start menu bar. The screenshots may differ slightly from version 14.3, but you are guaranteed access to more features than version 14.01.



Multisim - Monday, August 28, 2023, 8:00:02 PM

Figure 2.15: Opening window for Multisim 14.01

2.9 Kirchoff's Laws

Kirchoff's Laws are useful tools for analyzing circuits. There are two distinct laws, Kirchoff's Current Law (KCL) and Kirchoff's Voltage Law (KVL). This section examines both laws and how they can be used to analyze resistor circuits.

2.9.1 Kirchoff's Current Law

Kirchoff's Current Law can be summarized as follows.

The sum of currents entering a node = The sum of currents leaving a node

A node is a point in the circuit to which at least two elements, for example resistors, are connected. Intuitively this law makes sense if you consider that current flow is generated by electrons. The electrons flowing into a point in a circuit must come out somewhere; just like water flowing into a pipe must flow out of its other end or out of the pipe branches, if there are any.

To illustrate this point, consider the series resistor circuit shown in Figure 2.16. This is the same as the circuit of Figure 2.3, and we had previously calculated the current in this circuit to be 10 mA. For this circuit, this is the current in to and out of point A, as well as the current in to and out of point B.

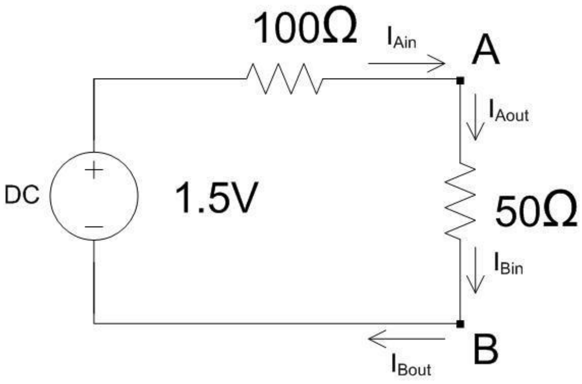


Figure 2.16: Applying Kirchoff's Current Law to a series resistor circuit

Although the KCL is valid for series resistor circuits, it isn't all that useful as an analysis tool. It is much more interesting for analyzing current flow in parallel resistors. For example, consider the circuit shown in Figure 2.17. This is the same circuit as shown in Figure 2.4, and we can see the currents flowing out of the battery or through each resistor.

$$I_{Ain} = \frac{V_B}{R_1 // R_2} = \frac{1.5}{100/3} = 45mA$$

$$I_{A1out} = \frac{V_B}{R_1} = \frac{1.5}{100} = 15mA$$

$$I_{A2out} = \frac{V_B}{R_1} = \frac{1.5}{100} = 15mA$$

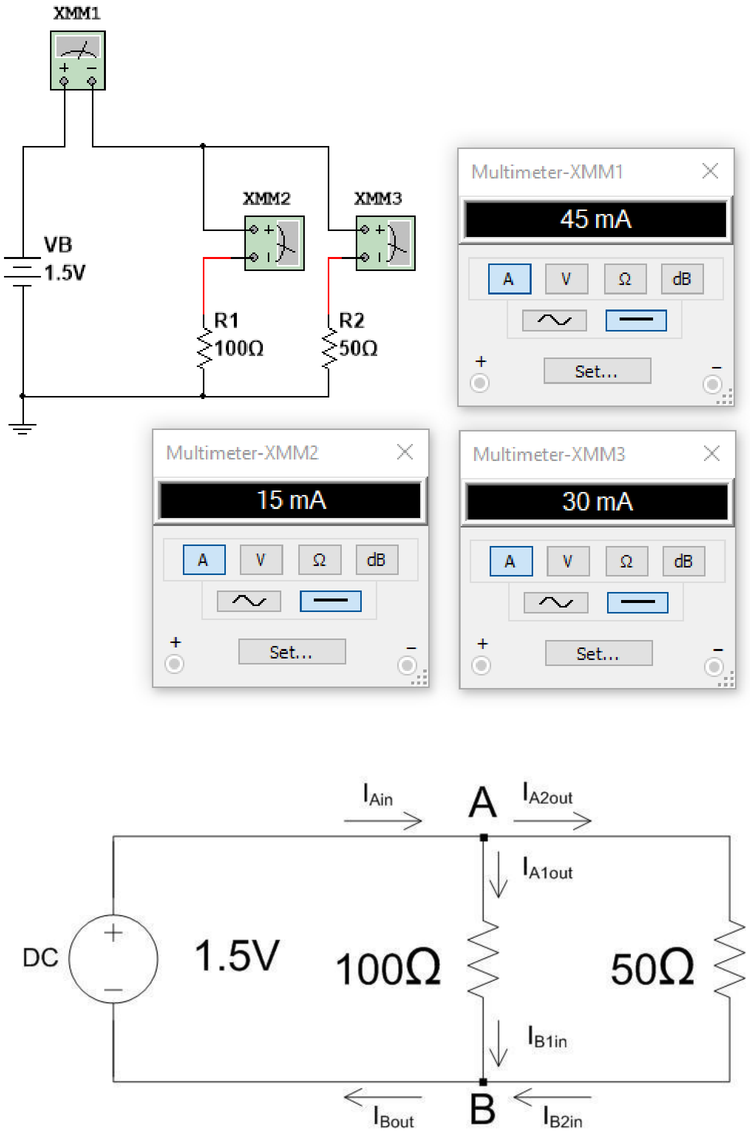


Figure 2.17: Applying Kirchoff's Current Law to a parallel resistor circuit

According to Kirchoff's Current Law, the current entering node A is equal to the current leaving the node, or

$$I_{Ain} = I_{A1out} + I_{A2out}$$

We calculated I_{A1out} = 15 mA and I_{A2out} = 30 mA, so

$$\begin{aligned} I_{Ain} = 45\text{ mA} &= I_{A1out} + I_{A2out} \\ &= 15\text{ mA} + 30\text{ mA} = 45\text{ mA} \end{aligned}$$

Similarly for node B,

$$I_{Bin} = 45 \text{ mA} = I_{B1out} + I_{B2out}$$
$$= 15 \text{ mA} + 30 \text{ mA} = 45 \text{ mA}$$

An important question remains: How do we know how much current flows through each of the parallel resistors? In this example, why did the current split up as 15 mA and 30 mA instead of, say, 40 mA and 5 mA?

Clearly the current values are not selected randomly. In this case there is a straightforward explanation. *When two resistors are connected in parallel, they both have the same voltage drop*. For the circuit of Figure 2.8, the voltage drop across each resistor is 1.5V. If two resistors are connected in parallel and one resistor has four times the resistance of the other, the larger resistor will have 1/4 the current flow of the other resistor.

2.9.2 Kirchoff's Voltage Law

The second of Kirchoff's Laws, Kirchoff's Voltage Law, is as follows.

The (algebraic) sum of all voltages in a loop is equal to zero

Before examining this law in detail, we first must define a loop. A loop is essentially a closed path within a circuit, consisting of part or the entire circuit. For example, Figure 2.18 shows a series resistor circuit and its one and only loop.

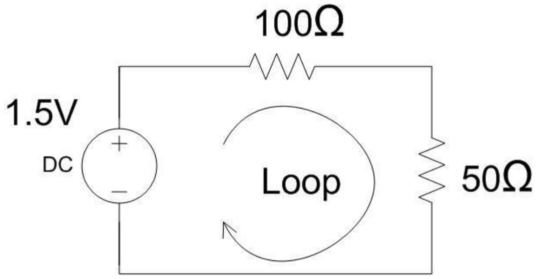


Figure 2.18: A series resistor circuit and its only loop

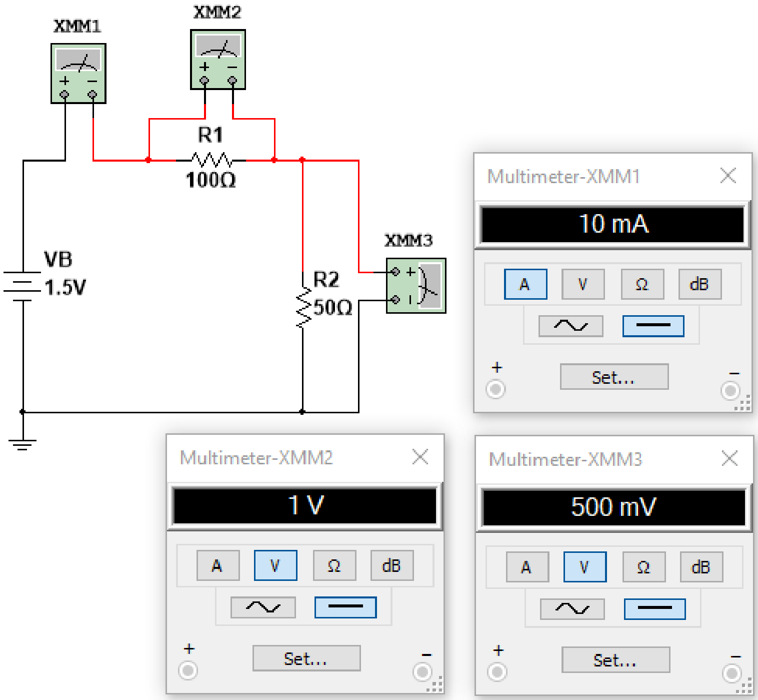


Figure 2.19: Simulation of the same series resistor circuit

There are three voltages in this loop: the voltage from the 1.5V power supply and the voltages dropped across each of the two resistors. By convention, we show voltage values as positive or negative based on the direction of the current flow. Since current flows in the same direction as the loop for this circuit, the voltage across each resistor is positive. Since the loop passes from the negative to positive terminal of the power source, its value is negative. The voltage in this loop can be expressed as

$$+V_{100\Omega} + V_{50\Omega} - 1.5V = 0$$

By Ohm's Law, the voltage drop across each resistor is equal to its current multiplied by its resistance, $V = I \times R$. We had previously calculated the current flow through each resistor as 10 mA, so $V_{100\Omega} = 10\text{ mA} \times 100\Omega = 1.0V$ and $V_{50\Omega} = 10\text{ mA} \times 50\Omega = 0.5V$, or

$$V_{100\Omega} + V_{50\Omega} - 1.5V = 1.0V + 0.5V - 1.5V = 0$$

Circuits with resistors in parallel have more than one loop. As shown in Figure 2.9, a circuit with two parallel resistors has three loops. The sum of the voltages in each of the three loops must equal zero.

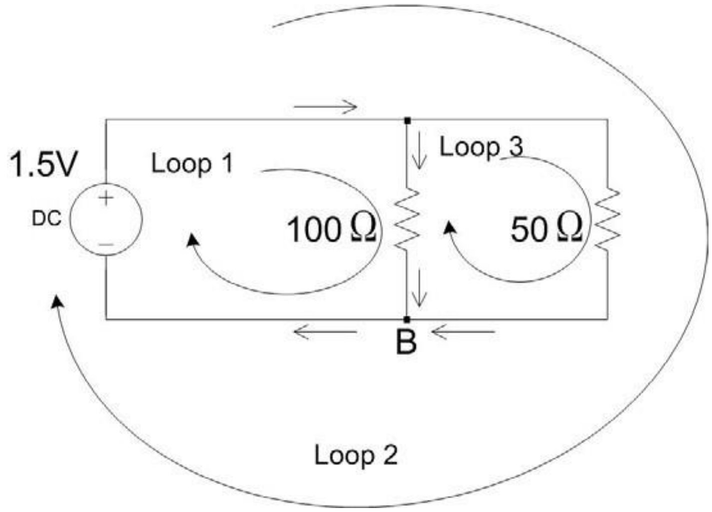


Figure 2.20: A parallel resistor circuit and its three loops

First let's look at Loop 1. It consists of the 1.5V power supply and the 100Ω resistor. We had previously calculated the current for this resistor as 15 mA, so its voltage, calculated using

Ohm's Law, is 15 mA × 100Ω = 1.5V. The voltages in this loop are

$$(15\text{ mA} \times 100\Omega) - 1.5\text{V} = 1.5\text{V} - 1.5\text{V} = 0$$

The second loop consists of the 1.5V power supply and the 50Ω resistor. Since this resistor has a current of 30 mA, the voltage equation for this loop is

$$(30\text{ mA} \times 50\Omega) - 1.5\text{V} = 1.5\text{V} - 1.5\text{V} = 0$$

The third loop, consisting of the two resistors, might appear to fail under Kirchoff's Voltage Law since all voltage drops across resistors so far have been positive. If this is true for this loop, we would be adding two positive values and could not obtain a zero result. However, this is not the case here. Note the direction of the arrow for this loop. For Loop 1, the flow of the loop for the 100Ω resistor goes in the opposite direction of the current flow. For this loop, the voltage across this resistor is treated as a negative value, and the loop equation becomes

$$-(15\text{ mA} \times 100\Omega) + (30\text{ mA} \times 50\Omega) = -1.5\text{V} + 1.5\text{V} = 0$$