Note to the Teacher

For a circuit to be considered "closed", the circuit must meet the following three requirements:

- All components in the circuit must be connected propertly
- There must be a load (resistor, lamp, etc.) in the circuit
- There must be a voltage source (battery, voltage generator, etc.) in the circuit.
- Note that the circuit students construct is closed by the inclusion of the multimeter.

When dealing with a circuit, the potential difference in the circuits is what causes electrons to flow from one point to another. As voltage sources are added to the circuit, the potential difference will either increase or decrease. Depending upon how the battery is inserted in the circuit, the total circuit potential will either increase or decrease. This concept is called the Kirchhoff's Voltage Law (KVL). The law is stated as follows:

Kirchhoff's Voltage Law: "The net voltage around a closed circuit is zero."

Formula: $$\sum_{n=1}^{N} V_n = 0$$

Where N is the number of elements in the circuit and Vn are the individual voltages in the closed circuit.

To illustrate this a little better, let's use an example.

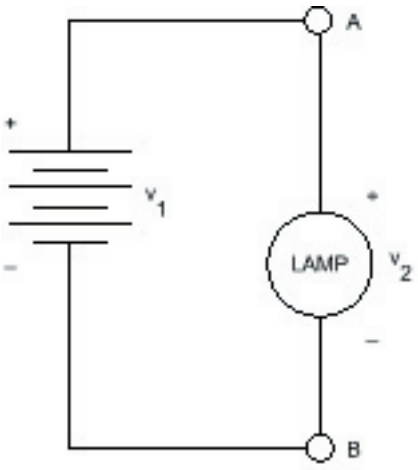
In this circuit, there's a lamp and a battery.

V1 = 1.5 volts

V2 = ? volts

Va = 1.5 volts

Vb = 0 volts



Using KVL, we know that the sum of the voltages should be equal to zero.

V1 = 1.5 volts

V2 = Vab = Va - Vb = Va - 0 = Va

With the previous equation, we know that:

V1 = V2 , V1 - V2 = 0 , 1.5v-1.5v = 0 volts

V2 = 1.5 volts

Note to the Teacher

On Completing the Lesson, Students Will Be Able to:

1. Explain and apply Kirchhoff's Voltage Law

2. Use a multimeter to measure voltage

3. Name and use the parts of a battery

4. Read and understand a simple schematic including multiple voltage sources

5. Calculate averages

Description of the Investigation

In this investigation students will:

• Measure battery voltages with a multimeter

• Put batteries in series

• Demonstrate Kirchhoff's Voltage Law

• Apply Kirchhoff's Voltage Law to solve a problem

Math versus Science

As students complete the investigations, they will begin to understand the relationship between mathematics and science. Mathematics is pure; when you plug numbers into equations, you will get the same result every time. Science, on the other hand, is dependent on multiple variables that may or may not be in control of the investigator. A good scientist will eliminate as many uncontrollable variables as possible so that they are able to analyze and measure the results of their investigation.

Experimental Error

There are many things that can cause your experimentally measured numbers to fall off-target from the predicted values. Here are a few:

- **Systematic error** is something in the experiment that always throws off the data in the exact same way. Some examples of systematic errors are a dead battery, improperly connected components, or a defective motor.
- **Random error** is caused by small factors that constantly change and affect the experimental results. In this experiment, random error may be caused by inconsistent starting points, imprecise measuring procedures, or a fluctuating battery level.

There are many things that can cause your experimentally measured numbers to fall off-target from the predicted values. Here are a few:

- Clutch Slippage: At higher torque, the clutch slips to reduce the chance of damage to the motor. This results in a shorter distance being traveled.
- Motor temperature
- Friction
- Battery power varies due to charge level

This investigation includes worksheets where students can capture data and write conclusions.

Note to the Teacher

Materials Needed

1. The testbed
2. A lifting device
3. Weights of your choice (Please note: you can use whatever lifting device and weights are most convenient. The only constraints are that the lifting device should not weigh more than 5 ounces, that it should be able to hold 15 ounces of additional weight, and that the weights used are fairly small and equal to each other, like washers or pennies.)
4. Tools
5. Vex remote control (with frequency crystal matching the crystal in the Vex controller in the testbed)

How to Use the Lesson Materials

1. Review the other lesson materials thoroughly.
2. Read the remainder of this document. It will serve as a general guide for how to teach the lesson content.
3. Have your students review the Introduction for Students, under Guide and KVL under Helper Link.
5. Modify and add to the lesson in the way that will best serve your classroom.
6. Teach the lesson, drawing on lesson materials where appropriate. The KVL Lesson Procedures document asks students to perform a simple experiment where they measure voltages from batteries, both individually and in series, and use the values they find to demonstrate Kirchhoff's Voltage Law.
7. Assign the "Checking for Understanding" Quiz/Worksheet.