Online laboratory assignment 4 – DC circuits and Kirchhoff's rules

Purpose: to study methods for analyzing DC circuit configurations.

Introduction

In a simple DC circuit containing a power supply (source of emf with known voltage (V)) and one resistor with known resistance (R), it is possible to calculate the expected current (i.e., analyze the circuit) from the applied voltage of the power supply and the known resistance using Ohm's Law.

$$V = IR$$

For circuits with multiple resistors all in series or all in parallel, we can analyze the circuit by first determining an equivalent resistance for the series combination

$$R_{\text{eq}} = \sum_{i=1}^{N} R_i$$

or the parallel combination

$$\frac{1}{R_{\text{eq}}} = \sum_{i=1}^{N} \frac{1}{R_i}$$

More complicated circuits often cannot be reduced to simple combinations of series and parallel resistors, and we must use other techniques to analyze the circuits. The most common circuit analysis technique involves applying Kirchhoff's Rules.

Loop Rule: $\sum V_i = 0$

Around any closed loop in a circuit, the sum of all changes in potential (emfs and potential drops across resistors) must equal zero. As charge carriers move around a circuit loop, they experience changes in potential, and therefore changes in potential energy. When the charge carriers move completely around a loop in the circuit, they are at the same potential as when they started, and therefore there has been no change in potential energy. This first rule is simply an expression of conservation of electric potential energy as charge carriers move around a circuit loop.

Junction Rule: $\sum I_i = 0$

At any junction point in a circuit, the sum of all currents entering (+) and leaving (−) must be zero. Since charge does not accumulate anywhere in a circuit containing only sources of emf and resistors, the rate at which charge carriers enter a junction must equal the rate at which charge carriers leave the junction. This second rule is simply an expression of conservation of electric charge at places where the circuit branches.

Procedure for using Kirchhoff's Rules to analyze a circuit

1. Identify the current in every segment of the circuit between junction points (*i.e.*, every branch) and label them as unknown currents (I_1, I_2, I_3, …). The number of unknown currents represents the number of linearly independent equations that must be generated and solved to completely analyze the circuit.
2. Assign a direction to each current. The choice of direction is arbitrary. Once you solve for all of the currents, a positive value indicates you chose the correct direction and a negative value indicates you chose the incorrect direction. The magnitudes of the currents will be correct.
3. Assign an arbitrary direction for a closed loop that traverses part of the circuit. Write an equation that adds the potential changes across every circuit element in the loop and sets the sum equal to zero. The potential change for a source of *emf* will be positive if you traverse the source from negative electrode to positive electrode, and negative if from positive to negative. The potential change associated with a

linear resistor is described by Ohm's Law ($V = IR$). Assign a negative value to the potential if you traverse the resistor in the direction of the current and positive if opposite.

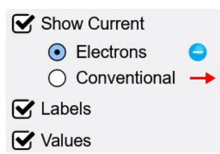
4. Write comparable loop equations for the other possible closed loops in the circuit. Every circuit element must appear in at least one equation, and every equation must have at least one new element.
5. Write junction equations that express the fact that the net current flowing into a junction point must equal the net current leaving a junction point. Currents flowing into a junction point should be labeled positive and currents flowing out should be labeled negative. For a circuit with "n" junction points there are "$n - 1$" linearly independent equations that can be written. Writing an equation for the last junction point yields no new mathematical information.
6. Combine the loop equations with the junction equations. You should have "n" equations for "n" unknown currents. Solve the equations to obtain numerical values for all of the unknown currents.
7. For negative currents, change the direction of the arrow in your drawing and the sign of the current.
8. Based on the currents, calculate the potential drop across each resistor in the circuit.

Laboratory assignment

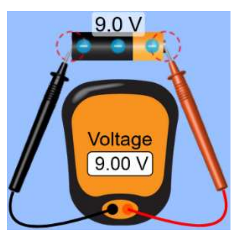
Part 1: Batteries

1. Run the "Circuit construction kit: DC" PhET simulation.
2. Select the "Intro" icon.

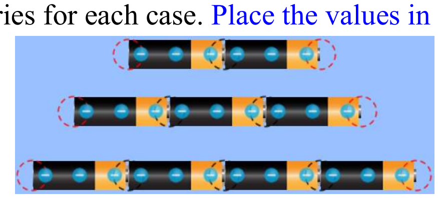
3. Check all of the boxes as shown below.



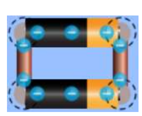
4. Drag a battery into the main area and then use the voltmeter to measure the voltage across the battery. Place the value in Table I.



5. Add two batteries in series, then three, and finally four batteries in series while measuring the end terminal voltage of the series for each case. Place the values in Table I.



6. Now attach a wire at both ends of two battery as shown below so that they are in parallel. Place the values in Table I.



7. Connect three batteries in series and then four batteries in series while measuring the voltage across the series for each case. Place the values in Table I.

Table I: Batteries in series and parallel configurations.

# of batteries	1	2	3	4
Batteries in a series configuration				
Terminal voltage (V)				
Batteries in a parallel configuration				
Terminal voltage (V)				

8. Explain what advantages there might be to add batteries in series?

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9. Explain what advantages there might be to add batteries in parallel?

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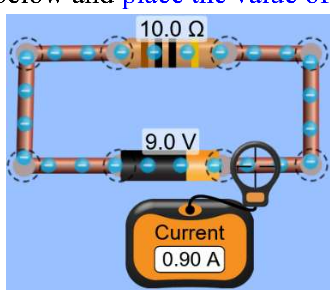
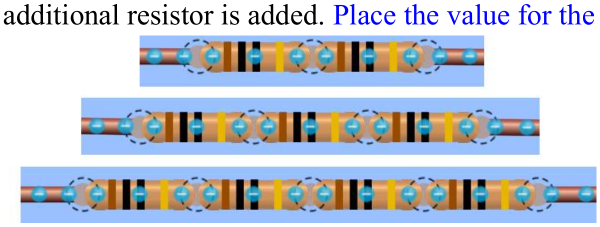
Part 2: Resistors

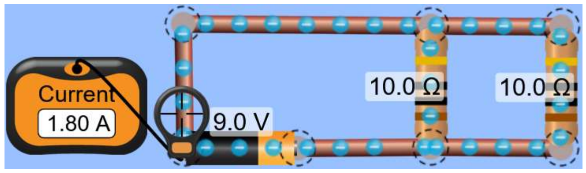
10. Place a single 10.0 Ω resistor and 9.0 V battery in a circuit. Measure the value of the current near the battery terminal as shown below and place the value of the current in Table II.



11. Calculate the value of the resistance from the voltage across the resistor and the measured current and place it in Table II for both of the 1 resistor slots in the series and parallel regions of the table.
12. Set up two, three, and four 10.0 Ω resistors in series and measure the current near the battery terminal after each additional resistor is added. Place the value for the current in Table II.



13. Calculate the equivalent resistance for the series cases using the voltage and current and place the values in Table II.
14. Set up two resistors in parallel as shown below and measure the current at the battery terminal. Place the current in Table II.



15. Set up three parallel resistors and then four parallel resistors and measure the current at the battery terminal for each case. Place the measured currents in Table II.
16. Calculate the equivalent resistance for the parallel cases using the voltage and measured current and place the values in Table II.

Table II: Series and parallel 10 Ω resistors connected to a 9.00 V battery

# of resistors	1	2	3	4
Resistors in Series				
Current (A)				
Equiv. resistance (Ω)				
Resistors in Parallel				
Current (A)				
Equiv. resistance (Ω)				

17. If you want to increase the resistance of a circuit should you add your resistors in series or in parallel? Explain.

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Part 3: Kirchhoff's rules

18. Analyze the circuit below using Kirchhoff's rules and fill in Table III with the current through each resistor and voltage across each resistor. You may use matrix solving methods after setting up the equations.

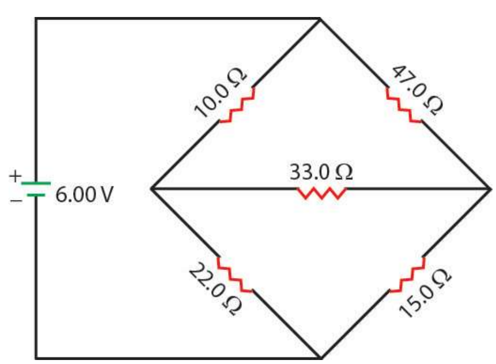
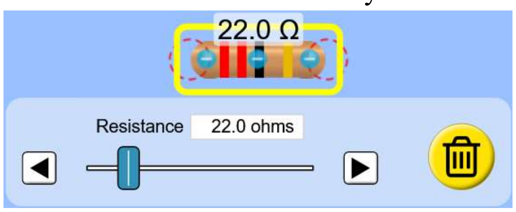
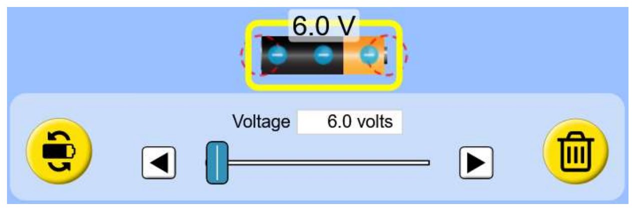


Table III: Analysis of the wheatstone bridge circuit given in the diagram.

Resistor	*I* (mA)	*V* (V)
R_1		
R_2		
R_3		
R_4		
R_5		

19. Build the circuit shown above in the simulation to check your answers given in Table III. Use the toggle at the bottom of the screen that appears after double clicking on a resistor (it will be boxed in yellow after double clicking) to change its resistance. You may have to add more than one resistor in series in the same wire to reach the desired R_i value.
20. Do the same for the battery.





21. Write a brief conclusion to this laboratory assignment.