Series and Parallel Circuits

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Introduction

This laboratory investigates direct-current series and parallel circuits using theoretical calculations and the PhET Circuit Construction Kit. The purpose is to apply Ohm's law, equivalent-resistance rules, Kirchhoff's laws, and electrical-power equations, then compare calculated values with simulated measurements. Four resistor networks are examined: two series circuits and two parallel circuits.

A simulation is valuable because it allows voltage and current to be measured without the component tolerances, wire resistance, battery internal resistance, and meter uncertainty found in a physical laboratory. Agreement between calculation and simulation therefore confirms that the circuit was assembled correctly and that the governing equations were applied consistently. It does not mean that every real circuit will produce perfectly identical values.

Theoretical Background

Ohm's Law

Ohm's law relates voltage, current, and resistance:

$V = IR$

Voltage V is measured in volts, current I in amperes, and resistance R in ohms. The equation can be rearranged as $I = V/R$ or $R = V/I$. For an ideal resistor, current increases when voltage increases and decreases when resistance increases.

Electrical Power

Electrical power is the rate at which a circuit element transfers energy:

$P = VI$

Combining this expression with Ohm's law gives $P = I^2R$ and $P = V^2/R$. Power is measured in watts. In every circuit below, the sum of power dissipated by the resistors equals the power supplied by the ideal source.

Series Circuits

Components are in series when they form one continuous path. The same current flows through every resistor. Equivalent resistance is the sum of the individual resistances:

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

The source voltage is divided among the resistors. Kirchhoff's voltage law requires the sum of the voltage drops to equal the battery voltage. (OpenStax, 2020)

Parallel Circuits

Components are in parallel when they connect across the same two nodes. Every branch has the same voltage, while the source current divides among the branches. Equivalent resistance is calculated from:

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

Kirchhoff's current law requires the total current entering a junction to equal the sum of currents leaving it. (OpenStax, 2020)

Procedure

The PhET Circuit Construction Kit was used to construct each network. (PhET Interactive Simulations, n.d.) Resistors and a battery were dragged into the workspace, and component values were set to match the assigned figures. Wires were connected only after the components and measuring instruments had been placed.

1. Calculate equivalent resistance, total current, resistor voltage, and resistor power before running the simulation.
2. Construct the circuit with the specified battery and resistor values.
3. Place an ammeter in series with the path or branch whose current is being measured.
4. Place a voltmeter in parallel across the component whose potential difference is being measured.
5. Record the simulated values and compare them with the theoretical calculations.
6. Check that voltage, current, and power satisfy conservation relationships.

An ideal ammeter has negligible resistance and must be inserted into the current path. Connecting it directly across a battery would create an effective short circuit. An ideal voltmeter has very high resistance and is connected across a component, not inserted in series.

Part I: First Series Circuit

The first circuit contains 20-ohm, 10-ohm, and 20-ohm resistors connected in series to a 10-volt source.

Calculations

The equivalent resistance is:

$R_{eq} = 20\ \Omega + 10\ \Omega + 20\ \Omega = 50\ \Omega$

The total current is:

$I = V/R_{eq} = 10\ V/50\ \Omega = 0.20\ A$

Because this is a series circuit, 0.20 A flows through every resistor. The voltage drops are calculated using V = IR. Each 20-ohm resistor has a 4-volt drop, and the 10-ohm resistor has a 2-volt drop. Their sum is 10 volts, equal to the source voltage.

Component	Resistance	Current	Voltage	Power
R_1	20 Ω	0.20 A	4 V	0.8 W
R_2	10 Ω	0.20 A	2 V	0.4 W
R_3	20 Ω	0.20 A	4 V	0.8 W
Net	50 Ω	0.20 A	10 V	2.0 W

Simulation Comparison

The simulated current is the same at every position in the loop, confirming the defining property of a series circuit. The measured voltage drops match the calculated 4 V, 2 V, and 4 V. Total power is P = VI = 10 V × 0.20 A = 2 W, which also equals 0.8 W + 0.4 W + 0.8 W.

Part II: Second Series Circuit

The second circuit contains 20-ohm, 48-ohm, and 72-ohm resistors connected in series to a 70-volt source.

Calculations

Equivalent resistance is:

$R_{eq} = 20\ \Omega + 48\ \Omega + 72\ \Omega = 140\ \Omega$

Total current is:

$I = 70\ V/140\ \Omega = 0.50\ A$

The same 0.50 A passes through each resistor. Their voltage drops are 10 V, 24 V, and 36 V. The larger resistor receives the larger voltage drop because the current is common to all components.

Component	Resistance	Current	Voltage	Power
R_1	20 Ω	0.50 A	10 V	5 W
R_2	48 Ω	0.50 A	24 V	12 W
R_3	72 Ω	0.50 A	36 V	18 W
Net	140 Ω	0.50 A	70 V	35 W

Simulation Comparison

The theoretical and simulated values agree. Kirchhoff's voltage law is satisfied because 10 V + 24 V + 36 V = 70 V. Source power is 70 V × 0.50 A = 35 W, equal to the total resistor power. This circuit also demonstrates that voltage division in series is proportional to resistance.

Part III: First Parallel Circuit

The third network contains resistors of 3 ohms, 1.5 ohms, and 1 ohm connected in parallel across a 6-volt source.

Equivalent Resistance

The reciprocal rule gives:

$1/R_{eq} = 1/3 + 1/1.5 + 1/1 = 1/3 + 2/3 + 1 = 2$

Therefore:

$R_{eq} = 0.50\ \Omega$

Each branch is connected directly across the source, so each resistor has 6 volts across it. Branch currents are:

$I_1 = 6/3 = 2$ A

$I_2 = 6/1.5 = 4$ A

$I_3 = 6/1 = 6$ A

Total current is 12 A, either by adding the branch currents or by calculating 6 V/0.50 Ω.

Component	Resistance	Current	Voltage	Power
R_1	3 Ω	2 A	6 V	12 W
R_2	1.5 Ω	4 A	6 V	24 W
R_3	1 Ω	6 A	6 V	36 W
Net	0.50 Ω	12 A	6 V	72 W

Simulation Comparison

The simulated voltage is 6 V in every branch. Current is greatest in the branch with the lowest resistance, which follows Ohm's law. Kirchhoff's current law is satisfied because 2 A + 4 A + 6 A = 12 A. Power supplied by the source is 6 V × 12 A = 72 W, equal to the total dissipated power.

Part IV: Second Parallel Circuit

The fourth network contains 15-ohm, 20-ohm, and 10-ohm resistors connected in parallel across a 90-volt source.

Equivalent Resistance

The reciprocal calculation is:

$1/R_{eq} = 1/15 + 1/20 + 1/10$

Using a common denominator of 60:

$1/R_{eq} = 4/60 + 3/60 + 6/60 = 13/60$

Therefore:

$R_{eq} = 60/13\ \Omega \approx 4.62\ \Omega$

The original table rounded this result to 4.6 ohms. Each branch receives 90 volts. The branch currents are 6 A, 4.5 A, and 9 A, giving a total current of 19.5 A.

Component	Resistance	Current	Voltage	Power
R_1	15 Ω	6 A	90 V	540 W
R_2	20 Ω	4.5 A	90 V	405 W
R_3	10 Ω	9 A	90 V	810 W
Net	4.62 Ω	19.5 A	90 V	1,755 W

Simulation Comparison

The simulation confirms that voltage is common across all parallel branches. The 10-ohm resistor carries the greatest current and dissipates the most power because it offers the least resistance. Total source power is 90 V × 19.5 A = 1,755 W, matching 540 W + 405 W + 810 W.

Comparison of Series and Parallel Behavior

The two series circuits show that current remains constant while voltage divides. Adding another series resistor increases equivalent resistance and reduces total current for a fixed source voltage. If one connection opens, the single path is broken and current stops throughout the circuit.

The parallel circuits show the opposite distribution. Voltage remains constant across branches, but current divides according to resistance. Adding a parallel branch decreases equivalent resistance and increases the total current drawn from an ideal source. One branch can be opened without necessarily stopping current in the others.

Equivalent resistance in a series circuit is always greater than any individual resistance. Equivalent resistance in a parallel circuit is always less than the smallest branch resistance. These observations provide quick checks for calculation errors. A reported parallel equivalent resistance larger than the smallest resistor would be physically inconsistent.

Sources of Experimental Difference

The ideal PhET model produces exact agreement because the battery, wires, resistors, and instruments can be treated as ideal. A physical experiment would normally show small differences. Commercial resistors have tolerance, so a labeled 20-ohm resistor may not measure exactly 20 ohms. Batteries have internal resistance and may not maintain their nominal voltage under a heavy load.

Ammeters introduce a small series resistance, voltmeters draw a small current, wires and contacts have resistance, and components may heat during operation. Heating can change resistance. Human reading, rounding, and incorrect meter placement also contribute to error. These effects should be discussed rather than labeling every difference a mistake.

The fourth circuit would require particular caution in a real laboratory because 1,755 watts is a very large power level for ordinary classroom resistors and a 90-volt source can present a serious hazard. The simulation permits ideal exploration without supplying this physical power. A real version would require properly rated components, protective equipment, and qualified supervision.

Conclusion

The calculations and simulated measurements agree for all four circuits. In series networks, resistance adds directly, current is common, and individual voltage drops sum to the source voltage. In parallel networks, reciprocal resistance determines the equivalent value, voltage is common, and branch currents sum to the source current.

Power conservation provides an additional verification method. In every circuit, the power delivered by the source equals the sum of resistor power. The activity therefore confirms Ohm’s law, Kirchhoff’s voltage law, Kirchhoff’s current law, and the standard equations for series and parallel resistance. It also demonstrates why correct meter placement and attention to component power ratings are essential when moving from simulation to physical circuits.

References

OpenStax. (2020). *Series circuits*. In *Physics*.

OpenStax. (2020). *Parallel circuits*. In *Physics*.

PhET Interactive Simulations, University of Colorado Boulder. (n.d.). *Circuit Construction Kit: DC*.