Lab 4. Series and Parallel Resistors

Goals

- To understand the fundamental difference between resistors connected in series and in parallel.
- To calculate the voltages and currents in simple circuits involving only resistors using the rules for "adding" series and parallel resistors.
- To learn to connect components correctly according to a circuit diagram and then to make valid current and voltage measurements with ammeters and voltmeters.
- To compare the predicted and measured currents and voltages for three circuits.

Introduction

Circuits are often composed of multiple resistors connected in various ways. Two general configurations that recur again and again are the so-called "series" and "parallel" combinations. Many resistor networks can be broken down into these simple units. For the sake of the following discussion, assume that the terminals of each resistor are labeled Terminal 1 at one end and Terminal 2 at the other end.

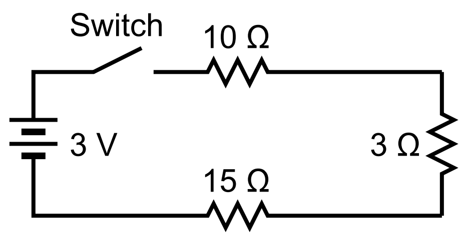
A "series" connection is when Terminal 2 of one resistor is connected to Terminal 1 of the next resistor and so on. This is like adding lengths of garden hose to reach the far corner of the yard. A battery or power supply is connected between Terminal 1 of the first resistor in the chain and Terminal 2 of the last resistor in the chain. Just like the water hose, where water flows into one end of the hose at the same rate as water flows out of the other end, the same electrical current (charge flow) flows through each of the resistors connected in series. It is important to note that in series connections, no other electrical connections can be made anywhere along the chain to add more current or take some away. If extra connections are present, even though the resistors may appear to be in a chain, our assumptions are invalid and the circuit is no longer a simple series combination. It is straightforward to show that resistances connected in series can be summed together to get the total resistance of the whole chain. In other words

$$R_{total} = R_1 + R_2 + R_3 + R_4 + \ldots \tag{4.1}$$

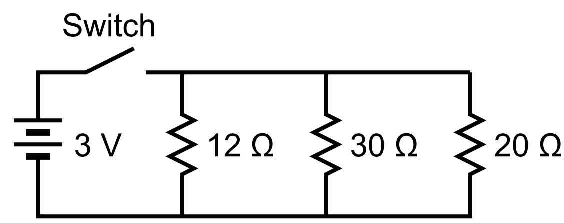
A "parallel" connection is when all of the Terminal 1's of several resistors are connected together. Likewise, all of the Terminal 2's are connected together. A battery or power supply is then connected between the combined Terminal 1 and the combined Terminal 2. In this case the applied voltage ("pressure" if you will) across each resistor is the same. Using this observation it again is straightforward to show that the total resistance of such a parallel combination is

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + ... \quad (4.2)$$

Simple series and simple parallel resistor configurations



(a) Circuit 1.



(b) Circuit 2.

Figure 4.1. Diagrams of (a) series and (b) parallel circuits for study.

Analyze Circuits 1 and 2

Answer the following questions for both Circuits 1 and 2. Be sure to explain your reasoning and show your calculations in your notes! You can summarize your numerical results in the provided table.

1. Which circuit contains the series combination and which the parallel combination?
2. What is the value of current through each resistor?
3. What is the voltage across each resistor?
4. What is the total current flowing through the power supply into the entire circuit?
5. What is the power dissipated (as heat) in each resistor? If any value exceeds 2 W, talk with your TA before proceeding to the next step.

Construct and study Circuits 1 and 2

Caution: Set the power supply to 3 V *before* connecting it to your circuit!

1. Measure the current through each resistor, showing on a circuit diagram exactly how and where the ammeter is connected in the circuit for each of the measurements.
2. Measure the voltage across each resistor, showing on a circuit diagram exactly how and where the voltmeter is connected in the circuit for each of the measurements.
3. Measure the total current flowing through the circuit, showing on a circuit diagram exactly how and where the ammeter is connected in the circuit.
4. Measure the total voltage across the whole circuit, showing on a circuit diagram exactly how and where the voltmeter is connected in the circuit.

Compare measured and predicted potential differences and currents

Compare your calculated and measured values using table at the end of the lab. (Remove this table from the manual and turn it in with your lab notes.) Percent differences are a good way to compare. Note whether the measured values are larger or smaller than the calculated ones. This is a good way to determine whether the differences are due to a systematic error or to some random process. If all the calculated values are larger than the measured ones, this suggests a systematic error, perhaps due to an non-ideal measuring device. If some values are a little high and others are a little low, the cause of variation is more likely to be random, such as variations in reading the meters.

Use these results to address the following questions. Explain your reasoning and justify your conclusions based on your data.

1. How are the currents through each resistor related to the total current flowing through the power supply in a series circuit? Look for a general rule that will apply to all series circuits.
2. How are the voltages across each resistor related to the total voltage across the power supply in a series circuit? Look for a general rule that will apply to all series circuits.
3. How are the currents through each resistor related to the total current flowing through the power supply in a parallel circuit? Again, look for a general rule that will apply to all parallel circuits.

Combined series and parallel configuration of resistors

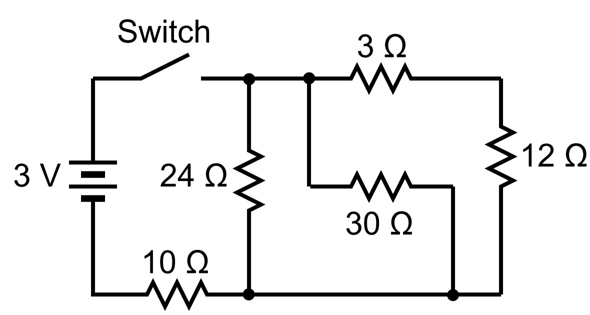


Figure 4.2. Diagram of Circuit 3.

Calculate, then measure the potential differences across and currents through each component in Circuit 3.

Before you leave the lab please: Turn off the power to all the equipment. Please put all leads and small components in the plastic tray provided. Report any problems or suggest improvements to your TA.

Resistor Color Code

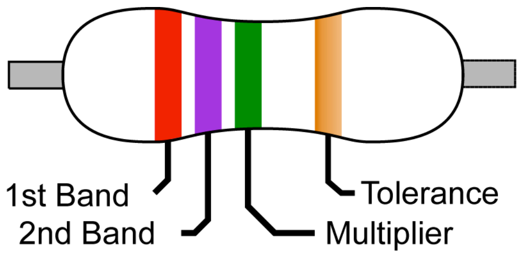


Figure 4.3. Resistor with labeled bands. To read the bands in order, orient the resistor so that the tolerance band (which is all by itself) is on the right. If the first band is red (2), the second violet (7), and the third green (10^5), the resistance is 27×10^5 ohms or 2.7 MΩ. If the tolerance band is gold, the actual resistance of a new resistor may differ from the indicated value by ±5%. Exceeding the current rating of a resistor can destroy it or change its resistance permanently. Image courtesy of Wikipedia (public domain).

Color Blank	Band 1 First Digit	Band 2 Second Digit	Band 3 Third Digit	Band 4 Tolerance
Black	0	0	$10^0 = 1$	
Brown	1	1	10^1	
Red	2	2	10^2	
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%
No Color				±20%

Series and Parallel Resistors Data Sheet

Circuit 1 — Series Resistors

		Calculated	Measured	%Difference	Power (W)
$R_{total} =$ ___ Ω	ΔV_{total} (V)				
	I_{total} (A)				
$R_1 = 10\,\Omega$	ΔV_1 (V)				
	I_1 (A)				
$R_2 = 3\,\Omega$	ΔV_2 (V)				
	I_2 (A)				
$R_3 = 15\,\Omega$	ΔV_3 (V)				
	I_3 (A)				

Circuit 2 — Parallel Resistors

		Calculated	Measured	%Difference	Power (W)
$R_{total} =$ ___ Ω	ΔV_{total} (V)				
	I_{total} (A)				
$R_1 = 12\,\Omega$	ΔV_1 (V)				
	I_1 (A)				
$R_2 = 30\,\Omega$	ΔV_2 (V)				
	I_2 (A)				
$R_3 = 20\,\Omega$	ΔV_3 (V)				
	I_3 (A)				

Circuit 3 — Combined Series and Parallel Resistors

		Calculated	Measured	%Difference	Power (W)
$R_{total} =$ ___ Ω	ΔV_{total} (V)				
	I_{total} (A)				
$R_1 = 10\,\Omega$	ΔV_1 (V)				
	I_1 (A)				
$R_2 = 24\,\Omega$	ΔV_2 (V)				
	I_2 (A)				
$R_3 = 30\,\Omega$	ΔV_3 (V)				
	I_3 (A)				
$R_4 = 3\,\Omega$	ΔV_4 (V)				
	I_4 (A)				
$R_5 = 12\,\Omega$	ΔV_5 (V)				
	I_5 (A)				

Grading Rubric

	No Effort	Progressing	Expectation	Exemplary
AA Is able to extract the information from representation correctly Labs: 1-12	No visible attempt is made to extract information from the experimental setup.	Information that is extracted contains errors such as labeling quantities incorrectly, mixing up initial and final states, choosing a wrong system, etc. Physical quantities have no subscripts (when those are needed).	Most of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers and there are no units. Or directions are missing. Subscripts for physical quantities are either missing or inconsistent.	All necessary information has been extracted correctly, and written in a comprehensible way. Objects, systems, physical quantities, initial and final states, etc. are identified correctly and units are correct. Physical quantities have consistent and informative subscripts.
AB Is able to construct new representations from previous representations Labs: 1-12	No attempt is made to construct a different representation.	Representations are attempted, but omits or uses incorrect information (i.e. labels, variables) or the representation does not agree with the information used.	Representations are constructed with all given (or understood) information and contain no major flaws.	Representations are constructed with all given (or understood) information and offer deeper insight due to choices made in how to represent the information.
AC Is able to evaluate the consistency of different representations and modify them when necessary Labs: 3-8, 10-12	No representation is made to evaluate the consistency.	At least one representation is made but there are major discrepancies between the constructed representation and the given experimental setup. There is no attempt to explain consistency.	Representations created agree with each other but may have slight discrepancies with the given experimental representation. Or there is inadequate explanation of the consistency.	All representations, both created and given, are in agreement with each other and the explanations of the consistency are provided.
AD Is able to use representations to solve problems Labs: 4, 5, 6-8, 10, 11	No attempt is made to solve the problem.	The problem is solved correctly but no representations other than math were used.	The problem is solved correctly but there are only two representations: math and words explaining the solution.	The problem is solved correctly with at least three different representations (sketch, physics representation and math or sketch, words and math, or some other combination)
AF Sketch Labs: 1, 2, 4-7, 11	No representation is constructed.	Sketch is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing.	Sketch has no incorrect information but has either a few missing labels of given quantities. Subscripts are missing or inconsistent. Majority of key items are drawn.	Sketch contains all key items with correct labeling of all physical quantities have consistent subscripts; axes are drawn and labeled correctly.

	No Effort	Progressing	Expectation	Exemplary
AJ Circuit diagram Labs: 3, 4	No representation is constructed.	Components of the circuit are missing, or connected incorrectly. Components are not clearly labelled.	Diagram is missing key features but contains no errors. It may be difficult to follow electrical pathways, but it can be determined which components are connected with sufficient scrutiny.	Circuit diagram contains minimal connecting lines, components are neatly arranged to ensure labels are readily identified to appropriate components.
CA Is able to identify the hypothesis to be tested Labs: 4-6, 9	No mention is made of a hypothesis.	An attempt is made to identify the hypothesis to be tested but is described in a confusing manner.	The hypothesis to be tested is described but there are minor omissions or vague details.	The hypothesis is clearly stated.
CC Is able to make a reasonable prediction based on a hypothesis Labs: 4-6, 9	No prediction is made. The experiment is not treated as a testing experiment.	• A prediction is made but it is identical to the hypothesis OR • Prediction is made based on a source unrelated to hypothesis being tested OR • is completely inconsistent with hypothesis being tested OR • Prediction is unrelated to the context of the designed experiment.	Prediction follows from hypothesis but is flawed because • relevant experimental assumptions are not considered and/or • prediction is incomplete or somewhat inconsistent with hypothesis and/or • prediction is somewhat inconsistent with the experiment.	A prediction is made that • follows from hypothesis, • is distinct from the hypothesis, • accurately describes the expected outcome of the designed experiment, • incorporates relevant assumptions if needed.
CD Is able to identify the assumptions made in making the prediction Labs: 4-6, 9	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but the assumptions are irrelevant or are confused with the hypothesis.	Relevant assumptions are identified but are not properly evaluated for significance in making the prediction.	Sufficient assumptions are correctly identified, and are noted to indicate significance to the prediction that is made.
CE Is able to determine specifically the way in which assumptions might affect the prediction Labs: 4-6, 9	No attempt is made to determine the effects of assumptions.	The effects of assumptions are mentioned but are described vaguely.	The effects of assumptions are determined, but no attempt is made to validate them.	The effects of the assumptions are determined and the assumptions are validated.

	No Effort	Progressing	Expectation	Exemplary
CF Is able to decide whether the prediction and the outcome agree/disagree Labs: 4-6, 9	No mention of whether the prediction and outcome agree/disagree.	A decision about the agreement/disagreement is made but is not consistent with the outcome of the experiment.	A reasonable decision about the agreement/disagreement is made but experimental uncertainty is not properly taken into account.	A reasonable decision about the agreement/disagreement is made and experimental uncertainty is taken into account.
CG Is able to make a reasonable judgment about the hypothesis Labs: 4-6, 9	No judgment is made about the hypothesis.	A judgment is made but is not consistent with the outcome of the experiment.	A judgment is made, is consistent with the outcome of the experiment, but assumptions are not taken into account.	A judgment is made, consistent with the experimental outcome, and assumptions are taken into account.
GA Is able to identify sources of experimental uncertainty Labs: 4-6, 11	No attempt is made to identify experimental uncertainties.	An attempt is made to identify experimental uncertainties, but most are missing, described vaguely, or incorrect.	Most experimental uncertainties are correctly identified. But there is no distinction between random and experimental uncertainty.	All experimental uncertainties are correctly identified. There is a distinction between experimental uncertainty and random uncertainty.
GD Is able to record and represent data in a meaningful way Labs: 1-12	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible. They are not organized in tables or the tables are not labeled properly.	All important data are present, but recorded in a way that requires some effort to comprehend. The tables are labeled but labels are confusing.	All important data are present, organized, and recorded clearly. The tables are labeled and placed in a logical order.
GE Is able to analyze data appropriately Labs: 1-12	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.
IA Is able to conduct a unit analysis to test the self-consistency of an equation Labs: 1-6, 8-12	No meaningful attempt is made to identify the units of each quantity in an equation.	An attempt is made to identify the units of each quantity, but the student does not compare the units of each term to test for self-consistency of the equation.	An attempt is made to check the units of each term in the equation, but the student either mis-remembered a quantity's unit, and/or made an algebraic error in the analysis.	The student correctly conducts a unit analysis to test the self-consistency of the equation.

EXIT TICKET:

- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Report any problems or suggest improvements to your TA.
- ☐ Have TA validate Exit Ticket Complete.