

Performance-based assessments for basic electricity competencies

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The purpose of these assessments is for instructors to accurately measure the learning of their electronics students, in a way that melds theoretical knowledge with hands-on application. In each assessment, students are asked to predict the behavior of a circuit from a schematic diagram and component values, then they build that circuit and measure its real behavior. If the behavior matches the predictions, the student then simulates the circuit on computer and presents the three sets of values to the instructor. If not, then the student then must correct the error(s) and once again compare measurements to predictions. Grades are based on the number of attempts required before all predictions match their respective measurements.

You will notice that no component values are given in this worksheet. The *instructor* chooses component values suitable for the students' parts collections, and ideally chooses different values for each student so that no two students are analyzing and building the exact same circuit. These component values may be hand-written on the assessment sheet, printed on a separate page, or incorporated into the document by editing the graphic image.

This is the procedure I envision for managing such assessments:

1. The instructor hands out individualized assessment sheets to each student.
2. Each student predicts their circuit's behavior at their desks using pencil, paper, and calculator (if appropriate).
3. Each student builds their circuit at their desk, under such conditions that it is impossible for them to verify their predictions using test equipment. Usually this will mean the use of a multimeter only (for measuring component values), but in some cases even the use of a multimeter would not be appropriate.
4. When ready, each student brings their predictions and completed circuit up to the instructor's desk, where any necessary test equipment is already set up to operate and test the circuit. There, the student sets up their circuit and takes measurements to compare with predictions.
5. If any measurement fails to match its corresponding prediction, the student goes back to their own desk with their circuit and their predictions in hand. There, the student tries to figure out where the error is and how to correct it.
6. Students repeat these steps as many times as necessary to achieve correlation between all predictions and measurements. The instructor's task is to count the number of attempts necessary to achieve this, which will become the basis for a percentage grade.
7. (OPTIONAL) As a final verification, each student simulates the same circuit on computer, using circuit simulation software (Spice, Multisim, etc.) and presenting the results to the instructor as a final pass/fail check.

These assessments more closely mimic real-world work conditions than traditional written exams:

- Students cannot pass such assessments only knowing circuit theory or only having hands-on construction and testing skills – they must be proficient at both.
- Students do not receive the “authoritative answers” from the instructor. Rather, they learn to validate their answers through real circuit measurements.
- Just as on the job, the work isn't complete until *all errors* are corrected.
- Students must recognize and correct their own errors, rather than having someone else do it for them.
- Students must be fully prepared on exam days, bringing not only their calculator and notes, but also their tools, breadboard, and circuit components.

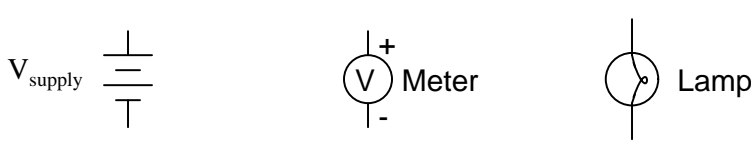
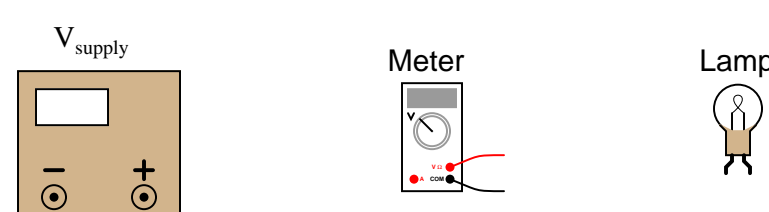
Instructors may elect to reveal the assessments before test day, and even use them as preparatory labwork and/or discussion questions. Remember that there is absolutely nothing wrong with “teaching to

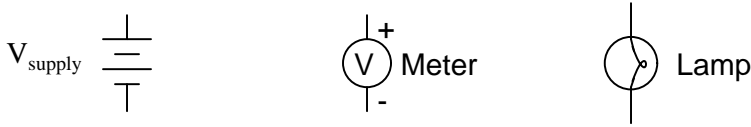
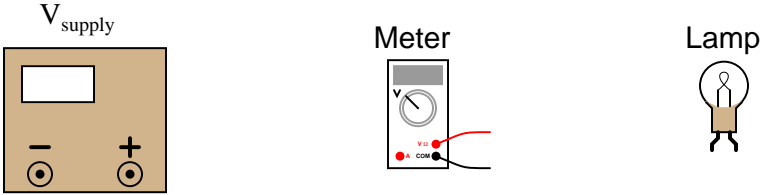
the test" *so long as the test is valid*. Normally, it is bad to reveal test material in detail prior to test day, lest students merely memorize responses in advance. With performance-based assessments, however, there is no way to pass without truly understanding the subject(s).

Competency: Soldered wire splice	Version:
<p>Description</p> <p>Strip the ends of a short length of solid copper wire, splicing the ends together so as to form a loop. Use the "Western Union" splice technique, soldering the splice as a final step.</p>	
<p>Given conditions</p> <p>Approximately 6 inches of 22-gauge (or similar) solid copper wire. 25 watt soldering iron Electrical solder Needle-nose pliers</p>	
<p>Parameters</p> <p style="text-align: right;">(Check)</p> <p>Western Union splice well-formed <input type="checkbox"/></p> <p>Even solder coverage of splice <input type="checkbox"/></p> <p>No excess solder on splice <i>(can still discern shape of splice)</i> <input type="checkbox"/></p> <p>Solder joint shiny in appearance <input type="checkbox"/></p> <p>Splice stronger than wire <input type="checkbox"/></p>	

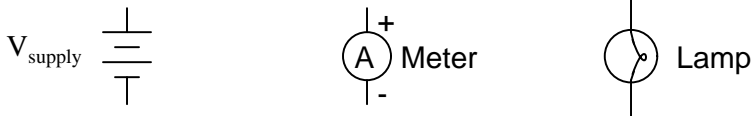
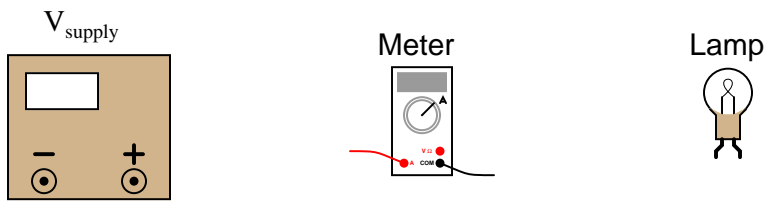
Competency: PCB soldering	Version:
Description	
Solder at least five resistors into a printed circuit board, being careful not to apply excess heat or excess solder. The resistors should lay flat on the board, with the soldered wire ends neatly trimmed.	
Given conditions	
Five resistors, 1/4 watt each Printed circuit board with copper pads 25 watt soldering iron Electrical solder, small-diameter Needle-nose pliers Miniature diagonal cutting pliers	
Parameters	(Check)
Five resistors soldered in place (flat on board)	<input type="checkbox"/>
Even solder coverage of all pads and leads	<input type="checkbox"/>
No excess solder on pads (<i>solder has concave profile</i>)	<input type="checkbox"/>
No cold solder joints	<input type="checkbox"/>
All soldering flux cleaned off	<input type="checkbox"/>
All leads neatly trimmed	<input type="checkbox"/>
No overheated or lifted pads	<input type="checkbox"/>
Good "wetting" of solder on all pads	<input type="checkbox"/>

file 01971

Competency: Voltmeter usage	Version:
Description Build a simple one-source, one-lamp circuit and use a multimeter to measure the lamp voltage.	
Schematic diagram 	
Pictorial diagram 	
Explanation Should the voltmeter be connected in <i>series</i> or in <i>parallel</i> with the lamp in order to measure voltage? What will happen if the meter is connected the wrong way (series vs. parallel)?	

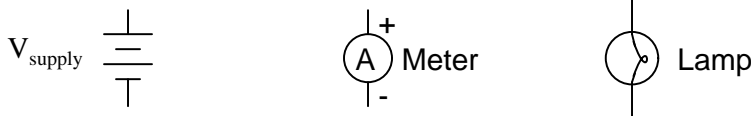
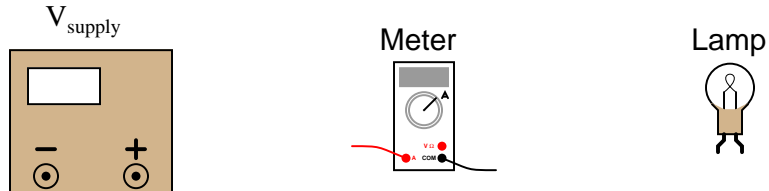
Competency: Voltmeter usage	Version:
<div data-bbox="310 212 472 254" style="border: 1px solid black; padding: 2px;">Description</div> <p data-bbox="483 289 1146 359" style="text-align: center;">Build a simple one-source, one-lamp circuit and use two multimeters to measure the lamp voltage.</p>	
<div data-bbox="310 422 586 464" style="border: 1px solid black; padding: 2px;">Schematic diagram</div> <div style="text-align: center; margin-top: 20px;">  </div>	
<div data-bbox="310 758 586 800" style="border: 1px solid black; padding: 2px;">Pictorial diagram</div> <div style="text-align: center; margin-top: 20px;">  </div>	
<div data-bbox="310 1066 500 1108" style="border: 1px solid black; padding: 2px;">Parameters</div> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;"> <p data-bbox="532 1115 667 1146">Measured</p> <p data-bbox="444 1171 509 1203">V_{lamp}</p> <div data-bbox="521 1150 691 1213" style="border: 1px solid black; width: 100px; height: 30px; margin: 0 auto;"></div> <p data-bbox="472 1220 732 1251">(with analog meter)</p> </div> <div style="text-align: center;"> <p data-bbox="938 1115 1073 1146">Measured</p> <p data-bbox="850 1171 915 1203">V_{lamp}</p> <div data-bbox="927 1150 1097 1213" style="border: 1px solid black; width: 100px; height: 30px; margin: 0 auto;"></div> <p data-bbox="889 1220 1149 1251">(with digital meter)</p> </div> </div>	
<div data-bbox="310 1283 500 1325" style="border: 1px solid black; padding: 2px;">Explanation</div> <p data-bbox="423 1339 1187 1409" style="text-align: center;">Should the voltmeter be connected in <i>series</i> or in <i>parallel</i> with the lamp in order to measure voltage?</p> <p data-bbox="423 1444 1187 1514" style="text-align: center;">What will happen if the meter is connected the wrong way (series vs. parallel)?</p>	

file 01715

Competency: Ammeter usage	Version:
<div data-bbox="310 212 472 254" style="border: 1px solid black; padding: 2px;">Description</div> <p data-bbox="483 289 1117 359" style="text-align: center;">Build a simple one-source, one-lamp circuit and use a multimeter to measure the lamp current.</p>	
<div data-bbox="310 426 586 468" style="border: 1px solid black; padding: 2px;">Schematic diagram</div> <div data-bbox="423 548 1170 663" style="text-align: center;">  </div>	
<div data-bbox="310 758 586 800" style="border: 1px solid black; padding: 2px;">Pictorial diagram</div> <div data-bbox="399 919 1159 1119" style="text-align: center;">  </div>	
<div data-bbox="310 1283 500 1325" style="border: 1px solid black; padding: 2px;">Explanation</div> <p data-bbox="423 1339 1179 1409" style="text-align: center;">Should the ammeter be connected in <i>series</i> or in <i>parallel</i> with the lamp in order to measure current?</p> <p data-bbox="423 1444 1192 1514" style="text-align: center;">What will happen if the meter is connected the wrong way (series vs. parallel)?</p>	


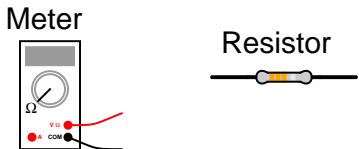
IMPORTANT NOTE: do not actually try to connect the ammeter improperly in the circuit, as the meter may be damaged in the process!

[file 01638](#)

Competency: Ammeter usage	Version:
<p>Description</p> <p>Build a simple one-source, one-lamp circuit and use two multimeters to measure the lamp current.</p>	
<p>Schematic diagram</p>  <p>The schematic diagram shows three components: a DC voltage source labeled V_{supply}, an ammeter labeled 'A Meter' with '+' and '-' terminals, and a lamp symbol labeled 'Lamp'.</p>	
<p>Pictorial diagram</p>  <p>The pictorial diagram shows a physical DC power supply labeled V_{supply}, a digital multimeter labeled 'Meter' with red and black test leads, and a light bulb labeled 'Lamp'.</p>	
<p>Parameters</p> <p style="text-align: center;">Measured</p> <p>I_{lamp} <input type="text"/> (with analog meter)</p> <p style="text-align: center;">Measured</p> <p>I_{lamp} <input type="text"/> (with digital meter)</p>	
<p>Explanation</p> <p>Should the ammeter be connected in <i>series</i> or in <i>parallel</i> with the lamp in order to measure current?</p> <p>What will happen if the meter is connected the wrong way (series vs. parallel)?</p>	

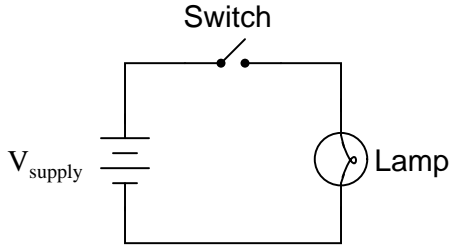
IMPORTANT NOTE: do not actually try to connect the ammeter improperly in the circuit, as the meter may be damaged in the process!

[file 01714](#)

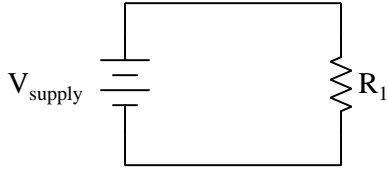
Competency: Ohmmeter usage	Version:	
Description		
Interpret the color codes for several resistors, and then compare their rated resistances with the indication given by an ohmmeter.		
Schematic diagram		
		
Pictorial diagram		
		
Given conditions and parameters		
Resistor colors: _____	Predicted	Measured
Resistor colors: _____	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
Resistor colors: _____	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
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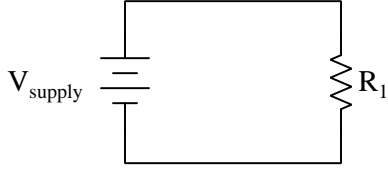
Competency: Sources of electricity	Version:								
Schematic									
Given conditions									
<p>(Descriptions of source types; i.e. <i>photovoltaic, chemical, etc.</i>)</p> <p>Source 1 =</p> <p>Source 2 =</p> <p>Source 3 =</p>									
Parameters									
	<table style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Greatest voltage produced</td> <td style="padding: 5px;"><input style="width: 80px; height: 25px;" type="text"/></td> </tr> <tr> <td style="padding: 5px;"></td> <td style="padding: 5px;"><input style="width: 80px; height: 25px;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">Least voltage produced</td> <td style="padding: 5px;"><input style="width: 80px; height: 25px;" type="text"/></td> </tr> </tbody> </table>	Predicted	Measured	Greatest voltage produced	<input style="width: 80px; height: 25px;" type="text"/>		<input style="width: 80px; height: 25px;" type="text"/>	Least voltage produced	<input style="width: 80px; height: 25px;" type="text"/>
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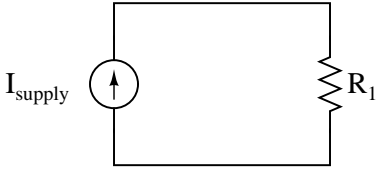
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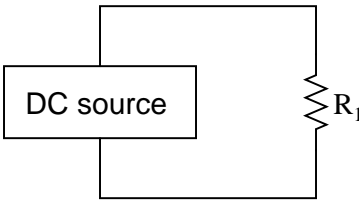
Competency: Circuit with switch	Version:														
Schematic															
															
Given conditions															
$V_{\text{supply}} =$	$I_{\text{lamp}} \text{ (nominal)} =$														
Parameters															
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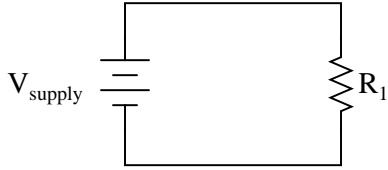
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Competency: Ohm's Law	Version:									
Schematic										
										
Given conditions										
$V_{\text{supply}} =$ $R_1 =$										
Parameters										
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I_{total}										
V_R										
Fault analysis										
<p>Suppose component R_1 fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i> <small>Write "increase", "decrease", or "no change" for each parameter.</small></p> <p>I_{total} </p> <p>V_R </p> <p>V_{supply} </p>										

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Suppose component <input style="width: 50px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i>																					

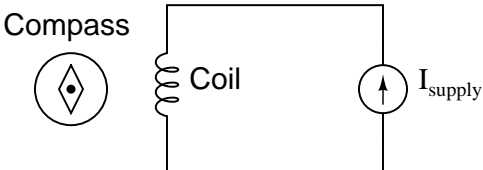
Competency: Ohm's Law	Version:																				
Schematic																					
																					
Given conditions																					
$V_{\text{supply}} =$ (see multiple values given below) $I_{\text{supply}} =$ (see multiple values given below) $R_1 =$																					
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Fault analysis																					
Suppose component <input style="width: 50px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i>																					

Competency: Current-limiting resistor	Version:	
Schematic		
		
Given conditions		
$V_{\text{supply}} =$	$I_{\text{maximum}} =$	
Description		
Choose a resistor value such that the circuit current is as close as possible to I_{maximum} without exceeding it.		
Parameters		
	Predicted	Measured
R_1	<input type="text"/>	<input type="text"/>
I	<input type="text"/>	<input type="text"/>

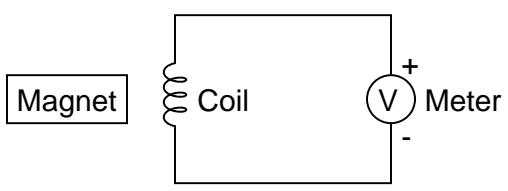
Competency: 4-wire "Kelvin" resistance measurement Version:									
Schematic									
Given conditions									
$I_{\text{supply}} =$									
Parameters									
<table style="margin-left: auto; margin-right: auto;"> <tr> <td></td> <td style="text-align: center;">Measured</td> </tr> <tr> <td style="text-align: center;">V_{meter}</td> <td style="text-align: center;"><input style="width: 100px; height: 20px;" type="text"/></td> </tr> <tr> <td style="text-align: center;">"Kelvin" Measured</td> <td style="text-align: center;">Directly Measured (or revealed by instructor)</td> </tr> <tr> <td style="text-align: center;">R_x</td> <td style="text-align: center;"><input style="width: 100px; height: 20px;" type="text"/></td> </tr> </table>			Measured	V_{meter}	<input style="width: 100px; height: 20px;" type="text"/>	"Kelvin" Measured	Directly Measured (or revealed by instructor)	R_x	<input style="width: 100px; height: 20px;" type="text"/>
	Measured								
V_{meter}	<input style="width: 100px; height: 20px;" type="text"/>								
"Kelvin" Measured	Directly Measured (or revealed by instructor)								
R_x	<input style="width: 100px; height: 20px;" type="text"/>								

Competency: Determining wire length by resistance		Version:
Schematic		
<p>The schematic shows a series circuit containing a current source labeled I_{supply} and an ammeter labeled 'Meter' with a circled 'A'. This series combination is connected to a resistor labeled R_{wire}. A voltmeter labeled 'Meter' with a circled 'V' and polarity signs (+ and -) is connected in parallel across the resistor R_{wire}.</p>		
Given conditions		
$T_{\text{room}} =$	$I_{\text{supply}} =$	
Parameters		
	Measured	
V_{meter}	<input style="width: 100px; height: 20px;" type="text"/>	
	"Kelvin" Measured	Directly Measured (or revealed by instructor)
R_{wire}	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>

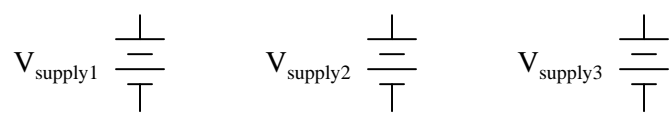
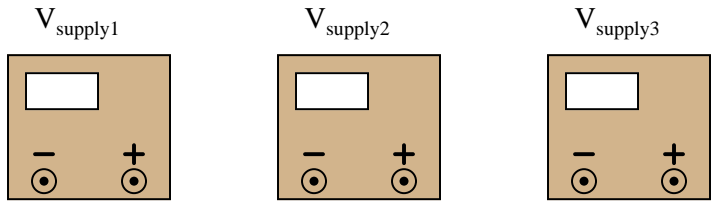
file 01695

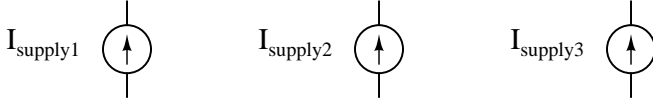
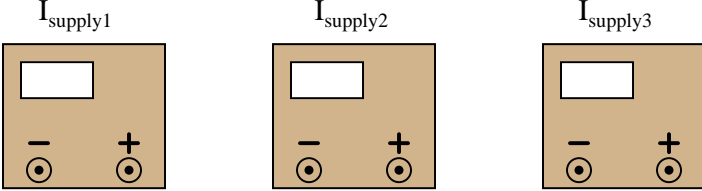
Competency: Electromagnetism	Version:															
Schematic																
 <p>The diagram shows a rectangular circuit loop. On the left side, there is a coil of wire labeled 'Coil'. On the right side, there is a power supply symbol labeled 'I_{supply}' with an upward-pointing arrow. To the left of the coil is a compass symbol, consisting of a circle with a diamond inside and a dot at the center, labeled 'Compass'.</p>																
Given conditions																
<p>Vary the power supply current, and also switch polarity, noting the effects on the compass needle.</p>																
Parameters																
<i>Qualitative answers only</i>																
	<table border="1" style="margin: auto; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 20%;">Predicted</th> <th style="width: 20%;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Low current</td> <td style="width: 60px; height: 20px;"><input type="text"/></td> <td style="width: 60px; height: 20px;"><input type="text"/></td> </tr> <tr> <td style="padding: 5px;">Higher current</td> <td style="width: 60px; height: 20px;"><input type="text"/></td> <td style="width: 60px; height: 20px;"><input type="text"/></td> </tr> <tr> <td style="padding: 5px;">Reverse polarity Low current</td> <td style="width: 60px; height: 20px;"><input type="text"/></td> <td style="width: 60px; height: 20px;"><input type="text"/></td> </tr> <tr> <td style="padding: 5px;">Reverse polarity Higher current</td> <td style="width: 60px; height: 20px;"><input type="text"/></td> <td style="width: 60px; height: 20px;"><input type="text"/></td> </tr> </tbody> </table>		Predicted	Measured	Low current	<input type="text"/>	<input type="text"/>	Higher current	<input type="text"/>	<input type="text"/>	Reverse polarity Low current	<input type="text"/>	<input type="text"/>	Reverse polarity Higher current	<input type="text"/>	<input type="text"/>
	Predicted	Measured														
Low current	<input type="text"/>	<input type="text"/>														
Higher current	<input type="text"/>	<input type="text"/>														
Reverse polarity Low current	<input type="text"/>	<input type="text"/>														
Reverse polarity Higher current	<input type="text"/>	<input type="text"/>														
Analysis																
<p>Identify the places on the coil where the field is strongest.</p>																

file 01645

Competency: Electromagnetic induction	Version:															
Schematic																
																
Given conditions																
<p>Set voltmeter to the most sensitive range possible!</p> <p>Move the magnet slowly toward the coil, and then slowly away</p> <p>Move the magnet quickly toward the coil, and then quickly away</p>																
Parameters																
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	Predicted	Measured														
V_{coil} Slowly, toward																
V_{coil} Slowly, away																
V_{coil} Quickly, toward																
V_{coil} Quickly, away																
Analysis																
<p>Does the orientation of the magnet have any effect on the polarity or magnitude of the induced voltage?</p> <p>Does the direction of approach to the coil have any effect on the magnitude of the induced voltage?</p>																

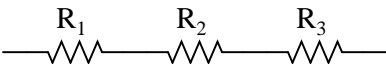
[file 01644](#)

Competency: Series DC voltages	Version:
Description	
<p>Connect three DC power sources together to achieve the specified total voltage.</p>	
Given conditions	
$V_{\text{supply1}} =$ $V_{\text{supply2}} =$ $V_{\text{supply3}} =$	$V_{\text{total}} =$
Schematic diagram	
	
Pictorial diagram	
	

Competency: Parallel DC currents	Version:
Description	
Connect three DC power sources together to achieve the specified total current.	
Given conditions	
$I_{\text{supply1}} =$ $I_{\text{supply2}} =$ $I_{\text{supply3}} =$	$I_{\text{total}} =$
Schematic diagram	
	
Pictorial diagram	
	

Caution! Consult your instructor to see how to set up each power supply to be a *safe* current source before attempting to connect them together!

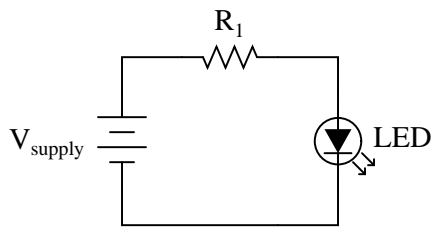
[file 01678](#)

Competency: Series resistances	Version:	
Schematic		
		
Given conditions		
$R_1 =$	$R_2 =$	$R_3 =$
Parameters		
R_{total}	Predicted	Measured
	<input type="text"/>	<input type="text"/>
Analysis		
Equation used to calculate R_{total} :		

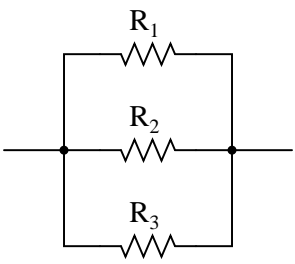
file 01634

Competency: Series DC resistor circuit	Version:																								
Schematic																									
Given conditions																									
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$																							
Parameters																									
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 20%; text-align: center;">Predicted</th> <th style="width: 20%; text-align: center;">Measured</th> <th style="width: 15%;"></th> <th style="width: 20%; text-align: center;">Predicted</th> <th style="width: 20%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td style="text-align: right;">I_{supply}</td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="text-align: right;">I_{R1}</td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">V_{R1}</td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="text-align: right;">I_{R2}</td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">V_{R2}</td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>		Predicted	Measured		Predicted	Measured	I_{supply}			I_{R1}			V_{R1}			I_{R2}			V_{R2}						
	Predicted	Measured		Predicted	Measured																				
I_{supply}			I_{R1}																						
V_{R1}			I_{R2}																						
V_{R2}																									
Analysis																									
Relationship between resistor voltage drops and total voltage:																									
Fault analysis																									
Suppose component <input style="width: 40px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted																									
What will happen in the circuit? <small>Write "increase", "decrease", or "no change" for each parameter:</small>																									
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V_{R2}		I_{R2}																							

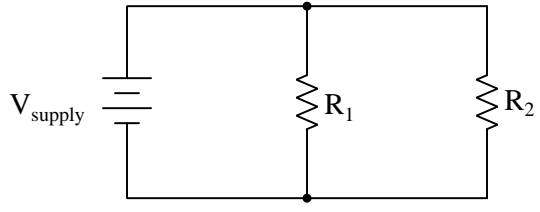
Competency: Series DC resistor circuit	Version:				
Schematic					
Given conditions					
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$		
Parameters					
	Predicted	Measured		Predicted	Measured
I_{supply}	<input type="text"/>	<input type="text"/>		I_{R1}	<input type="text"/>
V_{R1}	<input type="text"/>	<input type="text"/>		I_{R2}	<input type="text"/>
V_{R2}	<input type="text"/>	<input type="text"/>		I_{R3}	<input type="text"/>
V_{R3}	<input type="text"/>	<input type="text"/>			
Analysis					
Relationship between resistor voltage drops and total voltage:					
Fault analysis					
Suppose component <input type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____					
<input type="checkbox"/> shorted					
<i>What will happen in the circuit?</i> Write "increase", "decrease", or "no change" for each parameter:					
V_{R1}	<input type="text"/>		I_{R1}	<input type="text"/>	
V_{R2}	<input type="text"/>		I_{R2}	<input type="text"/>	
V_{R3}	<input type="text"/>		I_{R3}	<input type="text"/>	

Competency: Series dropping resistor for LED	Version:				
Schematic					
					
Given conditions					
$V_{\text{supply}} =$	$I_{\text{LED}} =$				
Parameters					
$V_{\text{LED}} @ I_{\text{LED}}$	Measured <input type="text"/>				
R_1	Predicted <input type="text"/>				
I_{total}	<table style="display: inline-table; border: none;"> <tr> <td style="padding: 0 10px;">Predicted</td> <td style="padding: 0 10px;">Measured</td> </tr> <tr> <td style="border: 1px solid black; width: 100px; height: 20px;"></td> <td style="border: 1px solid black; width: 100px; height: 20px;"></td> </tr> </table>	Predicted	Measured		
Predicted	Measured				
P_{R1}	<input type="text"/>				

file 01636

Competency: Parallel resistances	Version:	
Schematic		
		
Given conditions		
$R_1 =$ $R_2 =$ $R_3 =$		
Parameters		
Predicted Measured		
R_{total}	<input type="text"/>	<input type="text"/>
Analysis		
Equation used to calculate R_{total} :		

file 01635

Competency: Parallel DC resistor circuit		Version:	
Schematic			
			
Given conditions			
$V_{\text{supply}} =$		$R_1 =$	$R_2 =$
Parameters			
	Predicted	Measured	
I_{supply}			I_{R1}
V_{R1}			I_{R2}
V_{R2}			
Analysis			
Relationship between resistor (branch) currents and total current:			
Fault analysis			
Suppose component fails		<input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted	
<i>What will happen in the circuit?</i>		<small>Write "increase", "decrease", or "no change" for each parameter:</small>	
I_{supply}		I_{R1}	
V_{R1}		I_{R2}	
V_{R2}			

Competency: Parallel DC resistor circuit		Version:	
Schematic			
Given conditions			
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$
Parameters			
	Predicted	Measured	
I_{supply}			I_{R1}
V_{R1}			I_{R2}
V_{R2}			I_{R3}
V_{R3}			
Analysis			
Relationship between resistor (branch) currents and total current:			
Fault analysis			
Suppose component <input style="width: 40px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted			
What will happen in the circuit? <small>Write "increase", "decrease", or "no change" for each parameter:</small>			
V_{R1}		I_{supply}	
V_{R2}		I_{R1}	
V_{R3}		I_{R2}	
		I_{R3}	

Competency: Parallel loads with fuse protection	Version:					
Schematic						
<p>The schematic shows a DC power source labeled V_{supply} connected in series with a switch and a fuse. Following the fuse, the circuit splits into two parallel branches. The first branch contains a single lamp. The second branch contains a lamp and is labeled "Additional lamps ...", with dashed lines indicating further connections.</p>						
Given conditions						
$V_{\text{supply}} =$	$I_{\text{lamp}} \text{ (nominal)} =$	Fuse rating =				
Parameters						
Maximum # of lamps	<table border="1" style="display: inline-table; border-collapse: collapse;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Tested</td> </tr> <tr> <td style="width: 50px; height: 20px;"></td> <td style="width: 50px; height: 20px;"></td> </tr> </table>	Predicted	Tested			
Predicted	Tested					

file 01641

(Template)

Competency:	Version:
Schematic	
Given conditions	
Parameters	
Predicted	Measured
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>

file 01602

Answers

Answer 1

Instructor will certify quality of splice.

Answer 2

Instructor will certify quality of solder joints.

Answer 3

Connect the voltmeter in *parallel* with the component whose voltage is to be measured.

Answer 4

Connect the voltmeter in *parallel* with the component whose voltage is to be measured.

Answer 5

Connect the ammeter in *series* with the component whose current is to be measured.

Answer 6

Connect the ammeter in *series* with the component whose current is to be measured.

Answer 7

The ohmmeter's indication is the "final word" on resistance.

Answer 8

The real-life measurements you take constitute the "final word" on which sources generate the most significant voltages.

Answer 9

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 10

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 11

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 12

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 13

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 14

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 15

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 16

Measure the wire length to check your calculation!

Answer 17

I won't reveal the answer here as to what effect magnitude has on magnetic field strength, but I will suggest a way to test for strength: place the compass at a distance from the coil, where the coil's field has a relatively small effect on the needle position in relation to the ambient magnetic field.

Answer 18

The magnitude of the induced voltage is a direct function of the magnetic flux's rate of change over time ($\frac{d\phi}{dt}$).

Answer 19

Use circuit simulation software to verify schematic diagram. Your real circuit will verify the pictorial diagram.

Answer 20

Use circuit simulation software to verify schematic diagram. Your real circuit will verify the pictorial diagram.

Answer 21

Use circuit simulation software to verify schematic diagram. Your real circuit will verify the pictorial diagram.

Answer 22

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 23

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 24

Note: be careful to choose a resistor with an adequate power rating (Watts)!

Answer 25

Use circuit simulation software to verify schematic diagram. Your real circuit will verify the pictorial diagram.

Answer 26

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 27

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 28

Use circuit simulation software to verify your predicted and measured parameter values.

Answer 29

Here, you would indicate where or how to obtain answers for the requested parameters, but not actually give the figures. My stock answer here is "use circuit simulation software" (Spice, Multisim, etc.).

Notes 1

The purpose of this exercise is to ensure students can solder a good wire splice.

General concepts and principles to emphasize

- Heat transfer
- Craftsmanship
- Proper use of hand tools
- Safety (protective eyewear, handling hot soldering iron, chemical exposure to solder and flux and fumes)

Suggestions for Socratic discussion and experimentation

- Identify ways to *destructively* test the solder joint.
- Identify ways to *non-destructively* test the solder joint.

Notes 2

The purpose of this exercise is to ensure students can make good solder joints on a printed circuit board.

General concepts and principles to emphasize

- Heat transfer
- Craftsmanship
- Proper use of hand tools
- Safety (protective eyewear, handling hot soldering iron, chemical exposure to solder and flux and fumes)

Suggestions for Socratic discussion and experimentation

- Identify ways to *destructively* test the solder joint.
- Identify ways to *non-destructively* test the solder joint.:w

Notes 3

The purpose of this exercise is to make absolutely sure students can safely measure voltage with a multimeter.

A good extension of this assessment is to have students demonstrate competency using both digital and analog multimeters!

General concepts and principles to emphasize

- Voltage is a *differential* quantity: always measured between two points
- The relationship between the mathematical sign of the measured voltage (on the DMM display) versus the orientation of the red and black test leads

Suggestions for Socratic discussion and experimentation

- Try setting the voltmeter to a different *range* and re-measuring the same voltage sources. What practical purpose does the range of a meter serve?
- Can a metal frame (e.g. the steel frame of a lab workbench) be used as an electrical conductor to allow powering of the lamp with just one copper wire between the lamp and battery?

Notes 4

The purpose of this exercise is to make absolutely sure students can safely measure voltage with a multimeter.

General concepts and principles to emphasize

- Voltage is a *differential* quantity: always measured between two points
- The relationship between the mathematical sign of the measured voltage (on the DMM display) versus the orientation of the red and black test leads
- The relationship between the needle movement (on the analog meter's display) versus the orientation of the red and black test leads

Suggestions for Socratic discussion and experimentation

- Try setting the voltmeter to a different *range* and re-measuring the same voltage sources. What practical purpose does the range of a meter serve?
- Can a metal frame (e.g. the steel frame of a lab workbench) be used as an electrical conductor to allow powering of the lamp with just one copper wire between the lamp and battery?

Notes 5

The purpose of this exercise is to make absolutely sure students can safely measure current with a multimeter.

A good extension of this assessment is to have students demonstrate competency using both digital and analog multimeters!

General concepts and principles to emphasize

- The relationship between the mathematical sign of the measured current (on the DMM display) versus the orientation of the red and black test leads

Suggestions for Socratic discussion and experimentation

- Try setting the ammeter to a different *range* and re-measuring the same current. What practical purpose does the range of a meter serve?
- Can a metal frame (e.g. the steel frame of a lab workbench) be used as an electrical conductor to allow powering of the lamp with just one copper wire between the lamp and battery?

Notes 6

The purpose of this exercise is to make absolutely sure students can safely measure current with a multimeter.

General concepts and principles to emphasize

- The relationship between the mathematical sign of the measured current (on the DMM display) versus the orientation of the red and black test leads
- The relationship between the needle movement (on the analog meter's display) versus the orientation of the red and black test leads

Suggestions for Socratic discussion and experimentation

- Try setting the ammeter to a different *range* and re-measuring the same current. What practical purpose does the range of a meter serve?
- Can a metal frame (e.g. the steel frame of a lab workbench) be used as an electrical conductor to allow powering of the lamp with just one copper wire between the lamp and battery?

Notes 7

The purpose of this exercise is to make absolutely sure students can accurately measure resistance with a multimeter, and also that they can interpret resistor color codes. Select resistors that span a wide range, from less than 10 ohms to millions of ohms.

I recommend the following resistor color codes for students to try (all 5% tolerance):

- Blk, Brn, Grn, Gld
- Brn, Red, Brn, Gld
- Blu, Gry, Blk, Gld
- Red, Red, Org, Gld
- Brn, Grn, Yel, Gld
- Org, Org, Red, Gld

A good extension of this assessment is to have students demonstrate competency using both digital and analog multimeters!

General concepts and principles to emphasize

- Resistance, like voltage, is a *differential* quantity: always measured two points
- Meter test lead wire resistance, and its effects on resistance measurement

Suggestions for Socratic discussion and experimentation

- Suppose one of your ohmmeter's test leads were to fail open. How would that affect your meter's ability to measure resistance?
- Demonstrate how to measure your ohmmeter's test lead resistance so that you have an exact quantity to use when compensating for this lead resistance.
- Once you know how many ohms of resistance are in your ohmmeter's test leads, what can you do with this number to derive a more accurate measurement of any component's resistance?

Notes 8

In this performance assessment, different electricity sources are suggested by way of conversion phenomena. In other words, the instructor will list such things as *photovoltaic* and *piezoelectric*, and students will have to choose the correct components to demonstrate conversion of energy into electrical form. Then, students will demonstrate each conversion for the instructor, ranking them in order of the voltage magnitude generated by each demonstration.

The purpose of this exercise is not only for students to obtain a practical understanding of electricity sources, but also to understand the relative magnitudes of each one. It is important for students to know, for instance, that thermoelectricity is a rather weak effect compared to piezoelectricity. This will help them understand the relative sensitivity of sensors and other electrical devices in the future.

Possible sources to list for student demonstration are:

- Photovoltaic
- Piezoelectric
- Electromagnetic
- Chemical
- Thermoelectric

Of course, your selection of sources for student demonstration depends on the parts and equipment available to them.

Use a variable-voltage, regulated power supply to supply a suitable DC voltage for the incandescent lamp.

General concepts and principles to emphasize

- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive “loop”)
- Any break in a circuit, anywhere in that circuit, prevents the continuous flow of electricity everywhere in that circuit
- The distinction between electrical *sources* and electrical *loads*

Suggestions for Socratic discussion and experimentation

- Try relocating the switch to some other point in the circuit. Does it still perform the same function? Are any of the voltage or current readings affected by this alteration?
- Identify some of the various switch types available in your parts kit. How do their functions differ from one another?
- Explain how you can use a multimeter to test the function of a switch before it is connected to a circuit with a power supply and load.
- Sketch the direction of current in this simple circuit when the switch is closed (“on”). Also sketch the + and – symbols marking voltage polarity across each component in the circuit when the switch is closed. Explain why the relationship between the power supply’s voltage polarity and current direction is different than the relationship between the lamp’s voltage polarity and current direction. Which of these components is an electrical *source* and which of these is an electrical *load*?
- Sketch the + and – symbols marking voltage polarity across the switch when it is open (“off”). Does the switch’s polarity of voltage match the power supply’s polarity or not?
- Demonstrate how you can measure current in this circuit without ever disconnecting a single wire (i.e. “breaking” the circuit), just by connecting the ammeter across the switch terminals.

Notes 10

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify a standard resistor value, somewhere between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

If using this question as a lab exercise rather than an assessment, I recommend specifying a voltage that is standard for batteries, so students don't necessarily have to have an adjustable power supply available to do this lab.

For example, specify V_{supply} as 6 volts and R_1 as 33 k Ω . The resulting current is sufficient to provide a nice, strong needle deflection on most cheap analog ammeters, too!

General concepts and principles to emphasize

- Resistor color codes
- Multimeter usage: measuring voltage, current, and resistance
- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive "loop")
- Any break in a circuit, anywhere in that circuit, prevents the continuous flow of electricity everywhere in that circuit
- The distinction between electrical *sources* and electrical *loads*
- Qualitative analysis using Ohm's Law (i.e. how to analyze *increases* and *decreases* without the use of numerical quantities)

Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this simple circuit. Also sketch the + and - symbols marking voltage polarity across each component in the circuit. Explain why the relationship between the power supply's voltage polarity and current direction is different than the relationship between the resistor's voltage polarity and current direction. Which of these components is an electrical *source* and which of these is an electrical *load*?
- If voltage increases while resistance remains constant in a simple circuit, what happens to current?
- If current increases while resistance remains constant in a simple circuit, what happens to voltage?
- If resistance increases while voltage remains constant in a simple circuit, what happens to current?
- If resistance increases while current remains constant in a simple circuit, what happens to voltage?

Notes 11

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify a standard resistor value, somewhere between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

Notes 12

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify a standard resistor value, somewhere between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

When students set their power supplies for a certain amount of current, it is often helpful to have them do so while it is powering the resistor (rather than connecting their ammeter directly across the power supply to set its current output). This helps avoid the possibility of blowing the fuse in their ammeter!

Notes 13

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify a standard resistor value, somewhere between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

An interesting "twist" on this exercise is to specify the value of resistor R_1 in colors. For example: Red, Vio, Red, Gld instead of 2.7 k Ω .

When students set their power supplies for a certain amount of current, it is often helpful to have them do so while it is powering the resistor (rather than connecting their ammeter directly across the power supply to set its current output). This helps avoid the possibility of blowing the fuse in their ammeter!

General concepts and principles to emphasize

- Resistor color codes
- Multimeter usage: measuring voltage, current, and resistance
- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive "loop")
- Any break in a circuit, anywhere in that circuit, prevents the continuous flow of electricity everywhere in that circuit
- The distinction between electrical *sources* and electrical *loads*
- Qualitative analysis using Ohm's Law (i.e. how to analyze *increases* and *decreases* without the use of numerical quantities)

Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this simple circuit. Also sketch the + and - symbols marking voltage polarity across each component in the circuit. Explain why the relationship between the power supply's voltage polarity and current direction is different than the relationship between the resistor's voltage polarity and current direction. Which of these components is an electrical *source* and which of these is an electrical *load*?
- If voltage increases while resistance remains constant in a simple circuit, what happens to current?
- If current increases while resistance remains constant in a simple circuit, what happens to voltage?
- If resistance increases while voltage remains constant in a simple circuit, what happens to current?
- If resistance increases while current remains constant in a simple circuit, what happens to voltage?
- Demonstrate how to measure voltage across different pairs of points in the circuit. Do you get different measured values, or the same value? Explain the results.

Notes 14

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. If using this question as a lab exercise rather than an assessment, I recommend specifying a voltage that is standard for batteries, so students don't necessarily have to have an adjustable power supply available to do this lab.

In this exercise, the student must both quantitatively and qualitatively analyze the circuit, because the ideal resistor value probably does not exist. As the instructor, it is your task to choose voltage and current specifications that preclude exact solutions with common resistor values.

Notes 15

You will need to provide some low-resistance specimens for your students to measure using this technique. Motor armature coils work well for this purpose, as do large power resistors with the labels scratched off.

When students set their power supplies for a certain amount of current, it is often helpful to have them do so while it is powering the resistor (rather than connecting their ammeter directly across the power supply to set its current output). This helps avoid the possibility of blowing the fuse in their ammeter!

Notes 16

You will need to provide some spools of wire for your students to measure using this technique. Your students will need to find wire tables correlating length with resistance (at different temperatures, if the room temperature is significantly different from the standard temperature given in the table).

When students set their power supplies for a certain amount of current, it is often helpful to have them do so while it is powering the wire (rather than connecting their ammeter directly across the power supply to set its current output). This helps avoid the possibility of blowing the fuse in their ammeter!

Notes 17

Electromagnetism is a fundamental “first principle” with a wide range of applications including electric motors, relays, and solenoid actuators.

Old solenoid valve coils work very well for this exercise, as do spools of wire with large steel bolts passed through the center. Students may also wind their own coils using small-gauge magnet wire and a steel bolt. If the coils are hollow, you may experiment with and without ferrous cores, to demonstrate the effects of a ferromagnetic flux path on the field strength produced.

General concepts and principles to emphasize

- The “right-hand rule” for relating direction of current, geometry of wire, and direction of magnetic field

Suggestions for Socratic discussion and experimentation

- Identify ways to increase the magnetic field strength without altering the amount of electric current through the wire coil.
- Will a reversal of current affect how well the electromagnet coil attracts plain iron and steel objects, or does this reversal only affect how a compass reads the field?
- Will a reversal in the direction the wire is wound in a coil affect how well the electromagnet coil attracts plain iron and steel objects, or does this reversal only affect how a compass reads the field?

Electromagnetic induction is a fundamental “first principle” with a wide range of applications including electric generators, sensors, and power transformers.

Old solenoid valve coils work very well for this exercise, as do spools of wire with large steel bolts passed through the center. Students may also wind their own coils using small-gauge magnet wire and a steel bolt.

Please note that students will not be able to *predict* the polarity of the induced voltage unless they know the rotation of the coil windings and the polarity of their magnet. This will only be possible if the windings are exposed to view or if the students wind their own coils, and if the magnet has its poles labeled “North” and “South” (or if this is determined experimentally by using the magnet as a compass).

Use magnets that are as strong as possible, and that have their poles on the physical ends. This may seem like a strange request, but I’ve seen students bring some unusual magnets to class for this experiment, whose poles are *not* located on the ends. One type of magnet that works well is the so-called “cow magnet,” used by cattle ranchers to protect cows’ multiple stomachs from injury from ingestion of fence staples and other ferromagnetic objects. These are a few inches long, cylindrical in shape (so the cow can swallow it like a big pill), and quite strong.

If students are using analog multimeters to measure the coil’s induced voltage, be sure to keep the multimeter far away from the magnet. Analog meter movements are generally quite sensitive to external magnetic fields and may register falsely if positioned too close to a strong magnet.

General concepts and principles to emphasize

- Faraday’s Law of electromagnetic induction: $E = N \frac{d\phi}{dt}$
- Lenz’s Law (that the direction of induced current tends to oppose the instigating change)

Suggestions for Socratic discussion and experimentation

- Identify ways to increase the induced voltage without using a stronger magnet.
- Will a reversal in the direction the wire is wound in a coil affect the polarity of the induced voltage, the magnitude of the induced voltage, or both?
- A technique used in making wire-wound resistors is something called a *bifilar winding*. Bifilar windings have nearly zero inductance. Research how a bifilar winding is made, and then explain how it works to minimize induction and also why this might be important for making resistors.

Use variable-voltage, regulated power supplies to supply any amount of DC voltage below 30 volts.

Use regulated power supplies with adjustable current limits to act as current sources (voltage adjustments set to “full” while current adjustments set the desired output current for each). Keep the currents less than one amp for each supply.

Specify standard resistor values, all between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

General concepts and principles to emphasize

- How to use a multimeter to accurately measure resistance
- How to read resistor color codes
- The effect of adding resistances in series with each other

Suggestions for Socratic discussion and experimentation

- Does the polarity of the ohmmeter matter when measuring the resistance of a network such as this? Why or why not?
- What would the total resistance formula look like for a 4-resistor series network? How about a 5-resistor series network?
- Does an “open” fault in a resistor result in its resistance increasing or decreasing?
- Does a “shorted” fault in a resistor result in its resistance increasing or decreasing?

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k, 47k, 68k, etc.).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

General concepts and principles to emphasize

- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive “loop”)
- Any break in a circuit, anywhere in that circuit, prevents the continuous flow of electricity everywhere in that circuit
- The distinction between electrical *sources* and electrical *loads*
- Continuous current must be the same at all points in a series circuit
- Qualitative analysis using Ohm's Law (i.e. how to analyze *increases* and *decreases* without the use of numerical quantities)

Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this simple circuit. Also sketch the + and – symbols marking voltage polarity across each component in the circuit. Explain why the relationship between the power supply's voltage polarity and current direction is different than the relationship between each resistor's voltage polarity and current direction. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load*.
- If just one of these resistor's resistance happens to increase, how will this change affect all the other electrical quantities in the circuit?
- If just one of these resistor's resistance happens to decrease, how will this change affect all the other electrical quantities in the circuit?
- If the power supply's voltage happens to increase, how will this change affect all the other electrical quantities in the circuit?
- Demonstrate how to measure current at different points in the circuit. Do you get different measured values, or the same value? Explain the results.

Notes 23

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 8k2, 10k, 22k, 33k, 39k, 47k, 68k, 82k, etc.).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

General concepts and principles to emphasize

- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive “loop”)
- Any break in a circuit, anywhere in that circuit, prevents the continuous flow of electricity everywhere in that circuit
- The distinction between electrical *sources* and electrical *loads*
- Continuous current must be the same at all points in a series circuit
- Qualitative analysis using Ohm's Law (i.e. how to analyze *increases* and *decreases* without the use of numerical quantities)

Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this simple circuit. Also sketch the + and – symbols marking voltage polarity across each component in the circuit. Explain why the relationship between the power supply's voltage polarity and current direction is different than the relationship between each resistor's voltage polarity and current direction. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load*.
- If just one of these resistor's resistance happens to increase, how will this change affect all the other electrical quantities in the circuit?
- If just one of these resistor's resistance happens to decrease, how will this change affect all the other electrical quantities in the circuit?
- If the power supply's voltage happens to increase, how will this change affect all the other electrical quantities in the circuit?
- Demonstrate how to measure voltage across different pairs of points in the circuit. Do you get different measured values, or the same value? Explain the results.
- Demonstrate how to measure current at different points in the circuit. Do you get different measured values, or the same value? Explain the results.

Notes 24

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. For added challenge, set the power supply voltage high enough (at least 15 volts) that a 1/4 watt resistor will be inadequately rated for the power dissipation.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Specify standard resistor values, all between $1\text{ k}\Omega$ and $100\text{ k}\Omega$ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

General concepts and principles to emphasize

- How to use a multimeter to accurately measure resistance
- How to read resistor color codes
- The effect of adding resistances in parallel with each other

Suggestions for Socratic discussion and experimentation

- Does the polarity of the ohmmeter matter when measuring the resistance of a network such as this? Why or why not?
- What would the total resistance formula look like for a 4-resistor parallel network? How about a 5-resistor parallel network?
- Does an “open” fault in a resistor result in its resistance increasing or decreasing?
- Does a “shorted” fault in a resistor result in its resistance increasing or decreasing?

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

General concepts and principles to emphasize

- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive “loop”)
- The distinction between electrical *sources* and electrical *loads*
- Voltage must be the same across all components in a parallel circuit
- Qualitative analysis using Ohm's Law (i.e. how to analyze *increases* and *decreases* without the use of numerical quantities)

Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this simple circuit. Also sketch the + and – symbols marking voltage polarity across each component in the circuit. Explain why the relationship between the power supply's voltage polarity and current direction is different than the relationship between each resistors' voltage polarity and current direction. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load*.
- If just one of these resistor's resistance happens to increase, how will this change affect all the other electrical quantities in the circuit?
- If just one of these resistor's resistance happens to decrease, how will this change affect all the other electrical quantities in the circuit?
- If the power supply's voltage happens to increase, how will this change affect all the other electrical quantities in the circuit?
- Demonstrate how to measure voltage across different pairs of points in the circuit. Do you get different measured values, or the same value? Explain the results.
- Demonstrate how to measure current at different points in the circuit. Do you get different measured values, or the same value? Explain the results.

Notes 27

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 k Ω and 100 k Ω (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 8k2, 10k, 22k, 33k, 39k, 47k, 68k, 82k, etc.).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

General concepts and principles to emphasize

- Electricity can only travel continuously when there is a *complete circuit* (i.e. a conductive “loop”)
- The distinction between electrical *sources* and electrical *loads*
- Voltage must be the same across all components in a parallel circuit
- Qualitative analysis using Ohm's Law (i.e. how to analyze *increases* and *decreases* without the use of numerical quantities)

Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this simple circuit. Also sketch the + and – symbols marking voltage polarity across each component in the circuit. Explain why the relationship between the power supply's voltage polarity and current direction is different than the relationship between each resistor's voltage polarity and current direction. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load*.
- If just one of these resistor's resistance happens to increase, how will this change affect all the other electrical quantities in the circuit?
- If just one of these resistor's resistance happens to decrease, how will this change affect all the other electrical quantities in the circuit?
- If the power supply's voltage happens to increase, how will this change affect all the other electrical quantities in the circuit?
- Demonstrate how to measure voltage across different pairs of points in the circuit. Do you get different measured values, or the same value? Explain the results.
- Demonstrate how to measure current at different points in the circuit. Do you get different measured values, or the same value? Explain the results.

Notes 28

Use a variable-voltage, regulated power supply to supply a suitable DC voltage for the incandescent lamp. Set the power supply current limit such that it outputs enough to blow the fuse, but not enough to damage anything else. The fuse needs to be rated for a current value practical for a reasonable number of parallel-connected lamps.

Notes 29

Any relevant notes for the assessment activity go here.