

## Performance-based assessments for DC circuit 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

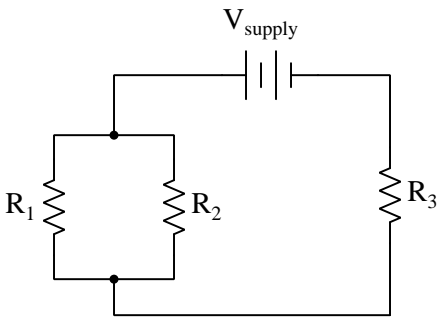
the test" *so long as the test is valid*. Normally, it is bad to reveal test material in detail prior to test day, lest students merely memorize responses in advance. With performance-based assessments, however, there is no way to pass without truly understanding the subject(s).

<b>Competency: Voltage divider circuit</b>		Version:	
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$		$V_{\text{out}} =$	
<b>Parameters</b>			
	Predicted	Measured	
$I_{\text{supply}}$	<input type="text"/>	<input type="text"/>	
$V_{R1}$	<input type="text"/>	<input type="text"/>	
$V_{R2}$	<input type="text"/>	<input type="text"/>	
	Predicted	Measured	
$I_{R1}$	<input type="text"/>	<input type="text"/>	
$I_{R2}$	<input type="text"/>	<input type="text"/>	
	Predicted	Calculated (from measurements)	
$\frac{V_{\text{out}}}{V_{\text{supply}}}$ (Ratio)	<input type="text"/>	<input type="text"/>	
<b>Fault analysis</b>			
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? Write "increase", "decrease", or "no change" for each parameter:</i>			
$V_{R1}$	<input type="text"/>		$I_{R1}$
$V_{R2}$	<input type="text"/>		$I_{R2}$

Competency: <b>Current divider circuit</b>	Version:																														
<b>Schematic</b>																															
<b>Given conditions</b>																															
$I_{supply} =$	$I_{out} =$																														
<b>Parameters</b>																															
<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 15%;"></td> <td style="width: 20%; text-align: center;">Predicted</td> <td style="width: 20%; text-align: center;">Measured</td> <td style="width: 15%;"></td> <td style="width: 20%; text-align: center;">Predicted</td> <td style="width: 20%; text-align: center;">Measured</td> </tr> <tr> <td><math>V_{supply}</math></td> <td><input type="text"/></td> <td><input type="text"/></td> <td></td> <td><math>V_{R1}</math></td> <td><input type="text"/></td> </tr> <tr> <td><math>I_{R1}</math></td> <td><input type="text"/></td> <td><input type="text"/></td> <td></td> <td><math>V_{R2}</math></td> <td><input type="text"/></td> </tr> <tr> <td><math>I_{R2}</math></td> <td><input type="text"/></td> <td><input type="text"/></td> <td></td> <td></td> <td></td> </tr> </table>		Predicted	Measured		Predicted	Measured	$V_{supply}$	<input type="text"/>	<input type="text"/>		$V_{R1}$	<input type="text"/>	$I_{R1}$	<input type="text"/>	<input type="text"/>		$V_{R2}$	<input type="text"/>	$I_{R2}$	<input type="text"/>	<input type="text"/>				<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 15%;"></td> <td style="width: 20%; text-align: center;">Predicted</td> <td style="width: 20%; text-align: center;">Calculated (from measurements)</td> </tr> <tr> <td><math>\frac{I_{out}}{I_{supply}}</math> (Ratio)</td> <td><input type="text"/></td> <td><input type="text"/></td> </tr> </table>		Predicted	Calculated (from measurements)	$\frac{I_{out}}{I_{supply}}$ (Ratio)	<input type="text"/>	<input type="text"/>
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<i>What will happen in the circuit?</i> Write "increase", "decrease", or "no change" for each parameter:																															
$I_{R1}$ <input type="text"/>	$V_{R1}$ <input type="text"/>																														
$I_{R2}$ <input type="text"/>	$V_{R2}$ <input type="text"/>																														





<b>Competency: Series-parallel DC resistor circuit</b>		Version:	
<b>Schematic</b>			
			
<b>Given conditions</b>			
$V_{\text{supply}} =$ $R_1 =$ $R_2 =$ $R_3 =$			
<b>Parameters</b>			
	Predicted	Measured	
$I_{\text{supply}}$			$I_{R1}$
$V_{R1}$			$I_{R2}$
$V_{R2}$			$I_{R3}$
$V_{R3}$			
<b>Fault analysis</b>			
Suppose component <span style="border: 1px solid black; display: inline-block; width: 30px; height: 15px;"></span> 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>	
$V_{R1}$		$I_{R1}$	
$V_{R2}$		$I_{R2}$	
$V_{R3}$		$I_{R3}$	





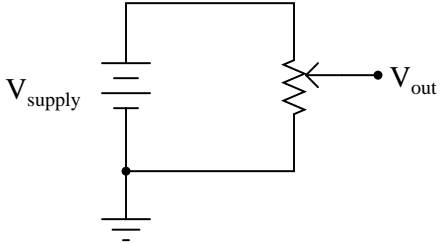
Competency: <b>Series-parallel DC resistor circuit</b>		Version:	
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$
<b>Parameters</b>			
	Predicted	Measured	
$I_{\text{supply}}$			$I_{R1}$
$V_{R1}$			$I_{R2}$
$V_{R2}$			$I_{R3}$
$V_{R3}$			$I_{R4}$
$V_{R4}$			
<b>Fault analysis</b>			
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>			
$V_{R1}$		$V_{R3}$	
$V_{R2}$		$V_{R4}$	
$I_{R1}$		$I_{R3}$	
$I_{R2}$		$I_{R4}$	

Competency: <b>Series-parallel DC resistor circuit</b>		Version:	
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$
$R_4 =$			
<b>Parameters</b>			
	Predicted	Measured	
$I_{\text{supply}}$			$I_{R1}$
$V_{R1}$			$I_{R2}$
$V_{R2}$			$I_{R3}$
$V_{R3}$			$I_{R4}$
$V_{R4}$			
<b>Fault analysis</b>			
Suppose component <input style="width: 40px; height: 20px;" type="text"/> 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>	
$V_{R1}$		$V_{R3}$	
$V_{R2}$		$V_{R4}$	
$I_{R1}$		$I_{R3}$	
$I_{R2}$		$I_{R4}$	

Competency: <b>Series-parallel DC resistor circuit</b>		Version:	
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$
$R_4 =$			
<b>Parameters</b>			
	Predicted	Measured	
$I_{\text{supply}}$			$I_{R1}$
$V_{R1}$			$I_{R2}$
$V_{R2}$			$I_{R3}$
$V_{R3}$			$I_{R4}$
$V_{R4}$			
<b>Fault analysis</b>			
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>			
$V_{R1}$		$V_{R3}$	
$V_{R2}$		$V_{R4}$	
$I_{R1}$		$I_{R3}$	
$I_{R2}$		$I_{R4}$	

Competency: <b>Custom rheostat range</b>	Version:																							
<b>Schematic</b>																								
<p>The schematic shows a circuit with two input terminals on the left. The first terminal is connected to a node that splits into two parallel branches. The top branch contains resistor <math>R_1</math>. The bottom branch contains a potentiometer <math>R_{pot}</math>. These two branches recombine at a second node. From this second node, a single branch containing resistor <math>R_2</math> leads to the final output terminal on the right.</p>																								
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$R_{total}$ (minimum) =	$R_{total}$ (maximum) =																							
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$R_{total}$ (minimum)																								
$R_{total}$ (maximum)																								

file 01754

Competency: <b>Potentiometer as voltage divider</b>	Version:
<b>Description</b>	
<p>You must set the potentiometer to the correct position to achieve <math>V_{out}</math> given <math>V_{supply}</math> <i>before</i> it is connected to <math>V_{supply}</math> for testing.</p>	
<b>Schematic</b>	
	
<b>Given conditions</b>	
$V_{supply} =$	$V_{out} =$
<b>Parameters</b>	
<b>Measured</b> $V_{out}$ <input style="width: 80px; height: 20px;" type="text"/>	
<b>Calculated</b> Error (%) <input style="width: 80px; height: 20px;" type="text"/>	$\frac{V_{out(actual)} - V_{out(ideal)}}{V_{out(ideal)}} \times 100\%$

file 01925

Competency: <b>Kirchhoff's Voltage Law</b>	Version:																																				
<b>Schematic</b>																																					
<b>Given conditions</b>																																					
$V_{\text{supply}} = \text{Any whole-number value evenly divisible by 4}$ $R_1 = R_2 = R_3 = R_4 =$																																					
<b>Parameters</b>																																					
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<p><i>Note: "<math>V_{BD}</math>" means voltage measured with the red lead touching <b>B</b> and the black lead touching <b>D</b>.</i></p>																																					

file 03294

Competency: <b>Kirchhoff's Current Law</b>	Version:																		
<b>Schematic</b>																			
<b>Given conditions</b>																			
$I_{\text{supply}} = \text{Any whole-number milliamp value evenly divisible by 4}$ $R_1 = R_2 = R_3 = R_4 = R_5 =$																			
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$I_{R1}$	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	$I_{R3}$	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>														
$I_{R2}$	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	$I_{R4}$	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>														
<p style="text-align: center;">Sketch directions and magnitudes of currents at these nodes:</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <p><b>A</b></p> </div> <div style="text-align: center;"> <p><b>B</b></p> </div> <div style="text-align: center;"> <p><b>C</b></p> </div> <div style="text-align: center;"> <p><b>D</b></p> </div> </div>																			

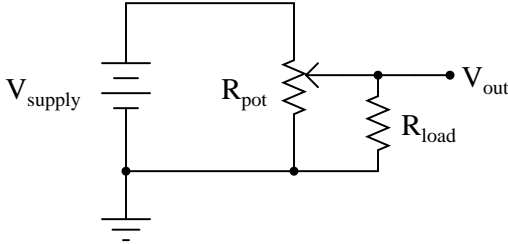
file 03593





Competency: <b>Loaded voltage divider</b>		Version:	
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$
$R_{\text{load1}} =$	$R_{\text{load2}} =$	$R_{\text{load3}} =$	
<b>Parameters</b>			
	Predicted	Measured	
$I_{\text{supply}}$	<input type="text"/>	<input type="text"/>	$I_{\text{load1}}$
$V_A$	<input type="text"/>	<input type="text"/>	$I_{\text{load2}}$
$V_B$	<input type="text"/>	<input type="text"/>	$I_{\text{load3}}$
			$I_{\text{bleed}}$
<b>Fault analysis</b>			
Suppose component <input type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted What will happen in the circuit?			

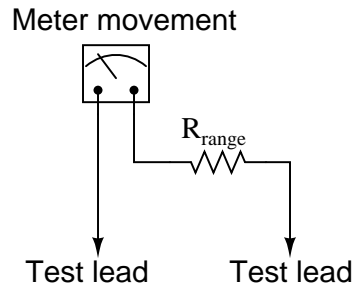
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Competency: <b>Potentiometer as loaded voltage divider</b> Version:	
<b>Description</b>	
<p>You must set the potentiometer to the correct position to achieve <math>V_{out}</math> given <math>V_{supply}</math> <i>before</i> it is connected to <math>V_{supply}</math> for testing.</p>	
<b>Schematic</b>	
	
<b>Given conditions</b>	
$V_{supply} =$	$V_{out} =$
$R_{pot} =$	$R_{load} =$
<b>Parameters</b>	
<b>Measured</b> $V_{out}$ <input style="width: 80px; height: 25px;" type="text"/>	
<b>Calculated</b> <b>Error (%)</b> <input style="width: 80px; height: 25px;" type="text"/>	$\frac{V_{out(actual)} - V_{out(ideal)}}{V_{out(ideal)}} \times 100\%$

file 01926

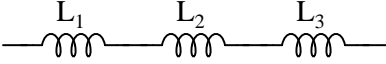
<b>Competency: Wheatstone bridge</b>	<b>Version:</b>		
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$	$R_3 =$
<b>Parameters</b>			
	Predicted	Measured	
$R_{\text{pot}}$ (balance)	<input type="text"/>	<input type="text"/>	
$I_{\text{supply}}$	<input type="text"/>	<input type="text"/>	
<b>Fault analysis</b>			
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> <small>Write "increase", "decrease", or "no change" for each parameter:</small>			
$V_{R1}$	<input type="text"/>	$I_{\text{supply}}$	<input type="text"/>
$V_{R2}$	<input type="text"/>		
$V_{R3}$	<input type="text"/>		
$V_{R4}$	<input type="text"/>		

Competency: <b>Bridge resistance measurement</b>	Version:	
<b>Schematic</b>		
<b>Given conditions</b>		
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$
$R_{\text{pot}} =$ Decade resistance box		
<b>Parameters</b>		
$R_x$	Measured by bridge <input style="width: 80px; height: 20px;" type="text"/>	Measured by ohmmeter <input style="width: 80px; height: 20px;" type="text"/>
<b>Calculations</b>		

Competency: <b>DC voltmeter circuit</b>	Version:	
<b>Schematic</b>		
 <p style="text-align: center;">Meter movement</p> <p style="text-align: center;">Test lead      Test lead</p>		
<b>Given conditions</b>		
$I_{F.S.} =$	$R_{movement} =$	Full-scale range =
<b>Parameters</b>		
$R_{range}$	Predicted <input style="width: 100px; height: 20px;" type="text"/>	
Meter indication with full-scale voltage applied	Predicted <input style="width: 100px; height: 20px;" type="text"/>	Measured <input style="width: 100px; height: 20px;" type="text"/>
<b>Calculations</b>		

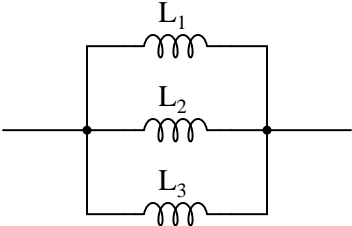
Competency: <b>Voltmeter loading</b>	Version:	
<b>Schematic</b>		
<b>Given conditions</b>		
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$
<b>Explanation</b>		
<p>Due to the effects of the voltmeter "loading" the voltage divider circuit, there will be a significant difference between <math>V_{R_2}</math> predicted and <math>V_{R_2}</math> measured.</p>		
<b>Parameters</b>		
$V_{R_2}$	Predicted <input style="width: 80px; height: 25px;" type="text"/> (Ideal, with no meter connected)	
$V_{R_2}$	Measured <input style="width: 80px; height: 25px;" type="text"/> (Real measurement with voltmeter)	
$R_{\text{input}}$ (Meter)	Calculated      Advertised <input style="width: 80px; height: 25px;" type="text"/> <input style="width: 80px; height: 25px;" type="text"/>	

Competency: <b>Self-induction</b>	Version:	
<b>Schematic</b>		
<b>Given conditions</b>		
$V_{\text{supply}} =$		
<b>Parameters</b>		
<i>Yes/no answers only</i>		
	Predicted	Tested
Lamp across $L_1$ Lamp flashes?	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
Lamp across switch Lamp flashes?	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
Lamp across battery Lamp flashes?	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>

Competency: <b>Series inductances</b>		Version:
Schematic		
		
Given conditions		
$L_1 =$	$L_2 =$	$L_3 =$
Parameters		
	Predicted	Measured
$L_{\text{total}}$	<input type="text"/>	<input type="text"/>
Analysis		
Equation used to calculate $L_{\text{total}}$ :		

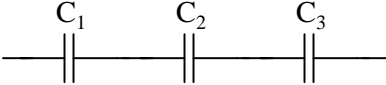
file 01650



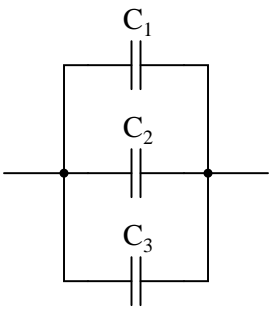
Competency: <b>Parallel inductances</b>	Version:	
<b>Schematic</b>		
		
<b>Given conditions</b>		
$L_1 =$ $L_2 =$ $L_3 =$		
<b>Parameters</b>		
Predicted              Measured		
$L_{\text{total}}$	<input type="text"/>	<input type="text"/>
<b>Analysis</b>		
Equation used to calculate $L_{\text{total}}$ :		

file 01651

Competency: <b>Series coupled inductors</b>	Version:				
<b>Schematic</b>					
<b>Given conditions</b>					
$L_1 =$	$L_2 =$				
<b>Parameters</b>					
$L_{total}$	<table style="margin: auto;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Measured</td> </tr> <tr> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> </table>	Predicted	Measured		
Predicted	Measured				
<b>Analysis</b>					
Equation used to calculate $L_{total}$ :					

Competency: <b>Series capacitances</b>		Version:
Schematic		
		
Given conditions		
$C_1 =$	$C_2 =$	$C_3 =$
Parameters		
	Predicted	Measured
$C_{\text{total}}$	<input type="text"/>	<input type="text"/>
Analysis		
Equation used to calculate $C_{\text{total}}$ :		

file 01652

Competency: <b>Parallel capacitances</b>	Version:
<b>Schematic</b>	
	
<b>Given conditions</b>	
$C_1 =$ $C_2 =$ $C_3 =$	
<b>Parameters</b>	
Predicted              Measured	
$C_{\text{total}}$	<input type="text"/> <input type="text"/>
<b>Analysis</b>	
Equation used to calculate $C_{\text{total}}$ :	

file 01653

Competency: <b>RC discharge circuit</b>	Version:	
<b>Schematic</b>		
<b>Given conditions</b>		
$V_{\text{supply}} =$	$C_1 =$	$R_1 =$
$t_1 =$	$t_2 =$	$t_3 =$
<b>Parameters</b>		
	Predicted	Measured
$V_{t1}$		
$V_{t2}$		
$V_{t3}$		
<b>Calculations</b>		

Competency: <b>Time-delay relay</b>	Version:				
<b>Schematic</b>					
<b>Given conditions</b>					
$V_{\text{supply}} =$	$C_1 =$	$R_{\text{coil}} =$	$V_{\text{dropout}} =$		
<b>Parameters</b>					
$t_{\text{delay}}$	<table border="1" style="margin: auto;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Measured</td> </tr> <tr> <td style="width: 60px; height: 20px;"></td> <td style="width: 60px; height: 20px;"></td> </tr> </table>	Predicted	Measured		
Predicted	Measured				
<b>Calculations</b>					

file 01647

Competency: <b>RC charge/discharge circuit</b>	Version:			
<b>Schematic</b>				
<b>Given conditions</b>				
$V_{\text{supply}} =$	$C_1 =$	$R_1 =$		
$t_1 =$	$t_2 =$	$t_3 =$		
<b>Parameters</b>				
<i>Charging from 0 volts</i>	<i>Discharging from <math>V_{\text{supply}}</math></i>			
Predicted	Measured	Predicted	Measured	
$V_{t1}$			$V_{t1}$	
$V_{t2}$			$V_{t2}$	
$V_{t3}$			$V_{t3}$	
<b>Calculations</b>				

Competency: <b>Rate of change indicator circuit</b>	Version:		
<b>Schematic</b>			
<b>Given conditions</b>			
$V_{\text{supply}} =$	$R_{\text{pot}} =$	$C_1 =$	$R_1 =$
<b>Parameters</b>			
<i>Qualitative answers only</i>			
	Predicted	Measured	
$V_{\text{out}}$ Wiper up, slowly	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	
$V_{\text{out}}$ Wiper down, slowly	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	
$V_{\text{out}}$ Wiper up, rapidly	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	
$V_{\text{out}}$ Wiper down, rapidly	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	
<b>Analysis</b>			
<p>Explain <i>why</i> the output voltage polarity is related to the wiper motion as measured.</p>			

file 03178



(Template)

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

file 01602

## Answers

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Answer 1

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

---

Answer 2

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

---

Answer 3

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

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Answer 4

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

---

Answer 5

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

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Answer 6

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

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Answer 7

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

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Answer 8

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

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Answer 9

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

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Answer 10

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

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Answer 11

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

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Answer 12

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

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Answer 13

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

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Answer 14

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

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Answer 15

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

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Answer 16

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

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Answer 17

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

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Answer 18

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

---

Answer 19

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

---

Answer 20

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

---

Answer 21

The neon bulb will likely give you more reliable confirmation of your predictions than simulation software.

---

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

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

You might be surprised to find that  $L_{total} \neq L_1 + L_2$ . This is due to the *mutual inductance* between inductors  $L_1$  and  $L_2$ .

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Answer 25

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

---

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.

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Answer 28

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

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Answer 29

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

---

Answer 30

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

---

Answer 31

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

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### Notes 1

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Students will have to choose resistor values appropriate to the task.

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.

---

### Notes 2

Use a variable-current, regulated power supply to supply any amount of DC current below a few milliamps. Students will have to choose resistor values appropriate to the task. I recommend low-value resistors so as to keep the voltage drop (and power dissipation!) low.

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.

---

### Notes 3

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 $\Omega$  and 100 k $\Omega$  (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.

---

### Notes 4

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 $\Omega$  and 100 k $\Omega$  (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.

---

### Notes 5

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 $\Omega$  and 100 k $\Omega$  (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.

---

### Notes 6

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 $\Omega$  and 100 k $\Omega$  (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.

---

## Notes 7

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 $\Omega$  and 100 k $\Omega$  (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.

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## Notes 8

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 $\Omega$  and 100 k $\Omega$  (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.

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## Notes 9

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 $\Omega$  and 100 k $\Omega$  (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

- Voltage is a *differential* quantity: always measured between two points
- Continuous current must be the same through all series-connected components
- Voltage must be the same across all parallel-connected components
- 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)
- Calculating the total resistance of a series-parallel resistor network

### Suggestions for Socratic discussion and experimentation

- Sketch the direction of current in this 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?

---

## Notes 10

Be sure to remind your students that resistances  $R_1$  and  $R_2$  may need to be series-parallel networks in themselves, to achieve the necessary values. An alternative you may wish to permit is the use of 10-turn (precision) potentiometers connected as rheostats for  $R_1$  and  $R_2$ . This way the circuit's minimum and maximum values may be precisely calibrated. The main potentiometer,  $R_{pot1}$ , should be a 3/4 turn unit, to allow fast checking of minimum and maximum total resistance, and it should be some common value such as 1 k $\Omega$  or 10 k $\Omega$ .

---

## Notes 11

Students need not measure potentiometer shaft angles in order to do this exercise. Rather, all they need to do is measure resistance between the wiper and the two outer terminals to set the potentiometer to a position where it will produce the specified division of voltage.

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.

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## Notes 12

Kirchhoff's Voltage Law ("KVL") is one of the fundamental "first principles" of electric circuit analysis. It is imperative that students master this principle and apply it regularly to the circuits they encounter. Not only is KVL useful for quantitative circuit analysis, but also for determining qualitative changes in circuits (e.g. analyzing faults in circuits, as part of circuit troubleshooting).

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**

- Voltage is a *differential* quantity: always measured between two points
- Kirchhoff's Voltage Law: *the algebraic sum of all voltages in any loop is equal to zero*
- 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**

- Demonstrate Kirchhoff's Voltage Law by using your voltmeter to "step around" any arbitrary loop in this circuit, summing all the voltage readings to show that they algebraically add to zero. For example, stepping around loop **ABCA**:
  - Measure voltage between **B** (red lead) and **A** (black lead)
  - Measure voltage between **C** (red lead) and **B** (black lead)
  - Measure voltage between **A** (red lead) and **C** (black lead)
- You will notice that the given conditions in this circuit call for equal-valued resistors, as well as a power supply voltage that is evenly divisible by four. Explain why these conditions make the circuit easier to analyze.

---

## Notes 13

I recommend students use a normal regulated (voltage) power supply, adjusting the output voltage until the output current is at 4 mA. 1 k $\Omega$  resistors work well for this circuit, requiring only 6.4 volts from the power supply to achieve 4 mA total current.

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.

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## Notes 14

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 $\Omega$  and 100 k $\Omega$  (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 8k2, 10k, 22k, 33k, 39k, 47k, 68k, 82k, etc.).

I have used this circuit as both a "quick" lab exercise and a troubleshooting exercise, using values of 10 k $\Omega$  for R1, R2, and R3; 15 k $\Omega$  for R(load1); 22 k $\Omega$  for R(load2); and 6 volts for the power supply. Of course, these component values are not critical, but they do provide easy-to-measure voltages and currents without incurring excessive impedances that would cause significant voltmeter loading problems.

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

- Voltage is a *differential* quantity: always measured between two points
- Continuous current must be the same through all series-connected components
- Voltage must be the same across all parallel-connected components
- 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 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 the load resistor's resistance happens to increase, how will this change affect the voltage seen by the other load?
- If just one of the voltage divider resistor's resistance happens to increase, how will this change affect the voltage seen by the two loads?
- If the power supply's voltage happens to increase, how will this change affect all the other electrical quantities in the circuit?
- Not all voltage divider circuits behave the same when loaded. For example two different divider circuits, each one dividing the source voltage into thirds (i.e. 66%, 33%), may yield the exact same output voltages with no loads attached, but as soon as equal loads are attached to them their output voltages "sag" to different degrees. Explain why this happens, and what is it about the more "stout" voltage divider circuit that allows it to better maintain its ideal output voltage under load.

---

Notes 15

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 $\Omega$  and 100 k $\Omega$  (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.

---

Notes 16

Students need not measure potentiometer shaft angles in order to do this exercise. Rather, all they need to do is measure resistance between the wiper and the two outer terminals to set the potentiometer to a position where it will produce the specified division of voltage.

$R_{pot}$  refers to the potentiometer's nominal full-range value (for example, 1 k $\Omega$  or 5 k $\Omega$ ), and not to its particular setting. The setting is what the student must figure out to achieve  $V_{out}$ .

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.



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 $\Omega$  and 100 k $\Omega$  (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k, 47k, 68k, etc.), and be sure to specify a potentiometer value in excess of the amount required to balance the bridge.

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**

- Voltage is a *differential* quantity: always measured between two points
- Continuous current must be the same through all series-connected components
- Voltage must be the same across all parallel-connected components
- The concept of “balancing” a Wheatstone bridge circuit
- 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**

- Wheatstone bridge circuits have traditionally been used to measure unknown resistances, by comparing them against known resistances. This is analogous to a laboratory balance-scale, where a sample of unknown weights is compared against a set of brass cylinders of known weight, the beam achieving equilibrium only when the sum total of the brass weights equals the sample weight. Explain how you could use a Wheatstone bridge circuit in the same way, given a collection of precision resistors of known value.
- How would the operation of this bridge circuit be affected if the potentiometer were relocated to a different “arm” of the bridge?
- The meter symbol in the center of the bridge (marked with the letter “G”) is supposed to represent a *galvanometer*: a highly sensitive electrical meter. Demonstrate how to set up your multimeter to be as sensitive as possible for use as a galvanometer.
- A galvanometer used in a Wheatstone bridge circuit only has to be accurate at one point in its measurement range: *zero*. Explain why accuracy at other points along the galvanometer's range is irrelevant.

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Use precision resistors for  $R_1$  and  $R_2$ , and use any standard resistor value for  $R_x$  between 1 k $\Omega$  and 100 k $\Omega$ .

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.

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Notes 19

Students may use potentiometers in their range resistance networks to achieve precise values. However, they are not allowed to adjust those potentiometers after connecting them to the meter movement – they must set their potentiometer(s) during the "prediction" step of the assessment before the circuit is completely built.

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.

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Notes 20

Be sure to specify resistor values for the voltage divider that will show a marked impact when measured with the type of voltmeter you expect your students to use. If you size the resistors for a modest impact measured with an analog voltmeter ( $20,000 \Omega/\text{Volt}$ ), your students may not see much of an impact when using a modern digital voltmeter ( $Z_{in} > 10 \text{ M}\Omega$ ).

New students often have a difficult time grasping the main idea of this activity, due to the assumption of the voltmeter's indication always being taken as true. The purpose of this activity is to shatter that assumption: to teach students that electrical measurements are never truly passive – rather, they invariably impact the circuit being measured in some way. Usually, the impact is so small it may be safely ignored. Here, due to the large resistor values used in the divider circuit, the impact of voltmeter usage on the circuit is non-trivial.

Another aspect of this activity that escapes some students' attention is that the circuit must be analyzed twice: once with the meter connected and once without. The point here is that the meter *becomes a component of the circuit when it is connected across  $R_2$ , and thus changes all the voltages and currents.*

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Notes 21

Students may either use ready-made inductors for this experiment (the larger the value, the more impressive the light flash!) or inductors of their own making (using old solenoid valve coils, or hand-wound coils around steel bolts). Power transformer primary windings also work well for this.

You will need an inductance meter in your lab to do this exercise. If you don't have one, you should get one right away!

**General concepts and principles to emphasize**

- Self-induction (i.e. how a single coil is able to experience induction as a consequence of a changing current passing through it)
- 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)
- The relationship between inductor coil geometry, core material, and inductance

**Suggestions for Socratic discussion and experimentation**

- Identify ways to modify each inductor so as to create more total inductance.
- Explain *why* total inductance relates to individual inductor values, basing your explanation strictly on an analysis of voltages and currents in this network.
- Suppose these inductors were built such that their magnetic fields were not contained within their structures, but rather were "open" and could thereby interact with the magnetic fields from other inductors. What would happen if we placed two of these series-connected inductors close together so that their magnetic fields opposed each other? What would happen if we placed two of these series-connected inductors close together so that their magnetic fields aided each other?
- 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.

You will need an inductance meter in your lab to do this exercise. If you don't have one, you should get one right away!

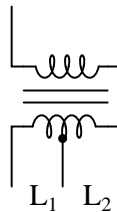
**General concepts and principles to emphasize**

- Self-induction (i.e. how a single coil is able to experience induction as a consequence of a changing current passing through it)
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- The relationship between inductor coil geometry, core material, and inductance

**Suggestions for Socratic discussion and experimentation**

- Identify ways to modify each inductor so as to create more total inductance.
- Explain *why* total inductance relates to individual inductor values, basing your explanation strictly on an analysis of voltages and currents in this network.
- Suppose these inductors were built such that their magnetic fields were not contained within their structures, but rather were "open" and could thereby interact with the magnetic fields from other inductors. What would happen if we placed two of these series-connected inductors close together so that their magnetic fields opposed each other? What would happen if we placed two of these series-connected inductors close together so that their magnetic fields aided each other?
- 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.

In case students don't have access to a pair of inductors on a common core, they may either make their own by winding wire around a long ferromagnetic core, or use a center-tapped inductor (or transformer winding). The latter solution is probably the easiest:



Inexpensive audio output transformers (with center-tapped 1000  $\Omega$  primary windings) work very well for this. Your students' parts kits should contain at least one of these transformers anyway if they are to do audio coupling experiments later.

You will need an inductance meter in your lab to do this exercise. If you don't have one, you should get one right away!

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Notes 25

Many modern digital multimeters come equipped with capacitance measurement built-in. If your students do not have these meters, you will either need to provide one for them to use, or provide an LCR meter. If you don't have either one of these instruments, you should get one right away!

**General concepts and principles to emphasize**

- The relationship between capacitor plate geometry, dielectric material, and capacitance

**Suggestions for Socratic discussion and experimentation**

- Identify ways to modify each capacitor so as to create more total capacitance.
- Explain *why* total capacitance relates to individual capacitor values, basing your explanation strictly on an analysis of voltages and currents in this network.

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Notes 26

Many modern digital multimeters come equipped with capacitance measurement built-in. If your students do not have these meters, you will either need to provide one for them to use, or provide an LCR meter. If you don't have either one of these instruments, you should get one right away!

**General concepts and principles to emphasize**

- The relationship between capacitor plate geometry, dielectric material, and capacitance

**Suggestions for Socratic discussion and experimentation**

- Identify ways to modify each capacitor so as to create more total capacitance.
- Explain *why* total capacitance relates to individual capacitor values, basing your explanation strictly on an analysis of voltages and currents in this network.

RC charging and discharging circuits are tremendously useful in electronics, being applied to everything from timers to power converters. LR circuits are technically just as useful, but the size, weight, and expense of inductors capable of mimicking the same behavior as readily-available capacitors makes LR circuits less common than RC circuits.

A tremendously important concept in electric circuit analysis is the distinction between a *source* and a *load*. Reactive components such as capacitors and inductors have the unique ability to act as both, depending on the conditions impressed upon these components. In some situations, a capacitor or inductor may absorb energy from the circuit (i.e. act as a load). In other situations, a capacitor or inductor may release energy into the circuit (i.e. act as a source).

I recommend choosing resistor and capacitor values that yield time constants in the range that may be accurately tracked with a stopwatch. I also recommend using resistor values significantly less than the voltmeter's input impedance, so that voltmeter loading does not significantly contribute to the decay rate.

Good time values to use ( $t_1$ ,  $t_2$ ,  $t_3$ ) would be in the range of 5, 10, and 15 seconds, respectively.

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

- How to manipulate algebraic equations containing exponential terms
- The distinction between electrical *sources* and electrical *loads*

#### Suggestions for Socratic discussion and experimentation

- Identify multiple ways to modify this circuit so as to achieve a longer (slower) discharge time.
- Identify multiple ways to modify this circuit so as to achieve a shorter (faster) discharge time.
- Modify this circuit to make the *charging* time slow as well.
- Sketch the direction of current in this circuit while the pushbutton switch is being pressed. Also sketch the + and - symbols marking voltage polarity across each component in the circuit. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load* during this time period.
- Sketch the direction of current in this circuit while the pushbutton switch is not being pressed. Also sketch the + and - symbols marking voltage polarity across each component in the circuit. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load* during this time period.

Two very important “given” parameters are the relay coil resistance ( $R_{coil}$ ) and the relay dropout voltage ( $V_{dropout}$ ). These are best determined experimentally.

Many students fail to grasp the purpose of this exercise until it is explained. The idea here is to predict *when* the relay will “drop out” after the switch is opened. This means solving for  $t$  in the time-constant (decay) equation given the initial capacitor voltage, time constant ( $\tau$ ), and the capacitor voltage at time  $t$ . Because this involves the use of logarithms, students may be perplexed until given assistance.

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**

- The purpose for and operation of an electromechanical relay
- RC time-constant calculations

**Suggestions for Socratic discussion and experimentation**

- Identify at least one way to modify this circuit so as to achieve a longer time delay to the relay’s operation.
- Identify at least one way to modify this circuit so as to achieve a shorter time delay to the relay’s operation.
- Is it possible to achieve a similar time-delay effect without using a relay at all?
- Sketch the direction of current in this circuit while the pushbutton switch is being pressed. Also sketch the + and – symbols marking voltage polarity across each component in the circuit. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load* during this time period.
- Sketch the direction of current in this circuit while the pushbutton switch is not being pressed. Also sketch the + and – symbols marking voltage polarity across each component in the circuit. Identify whether each of the components in this circuit is an electrical *source* or an electrical *load* during this time period.

I recommend choosing resistor and capacitor values that yield time constants in the range that may be accurately tracked with a stopwatch. I also recommend using resistor values significantly less than the voltmeter’s input impedance, so that voltmeter loading does not significantly contribute to the decay rate.

Good time values to use ( $t_1, t_2, t_3$ ) would be in the range of 5, 10, and 15 seconds, respectively.

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.

I recommend a supply voltage of 12 volts, a potentiometer value of 10 k $\Omega$ , a capacitor value of 0.1  $\mu$ F, and a loading resistor ( $R_1$ ) of 1 M $\Omega$ . Use a DMM so as to not load the circuit any more than necessary. If you wish to choose different capacitor/resistor values, I strongly suggest choosing them such that the time constant ( $\tau$ ) of the circuit significantly faster than 1 second.

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.

Any relevant notes for the assessment activity go here.