Performance-based assessments for DC circuit competencies

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:

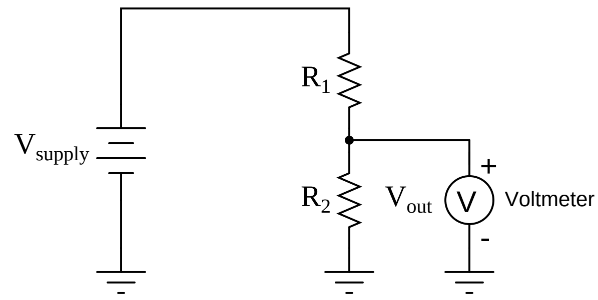
- Students cannot pass such assessments only knowing circuit theory or only having hands-on construction and testing skills – they must be proficient at both.
- Students do not receive the "authoritative answers" from the instructor. Rather, they learn to validate their answers through real circuit measurements.
- 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).

Question 1

Competency: **Voltage divider circuit** Version:

Schematic



Given conditions

V_{supply} =

V_{out} =

Parameters

	Predicted	Measured
I_{supply}		
V_{R1}		
V_{R2}		

	Predicted	Measured
I_{R1}		
I_{R2}		

	Predicted	Calculated (from measurements)
$\frac{V_{out}}{V_{supply}}$ (Ratio)		

Fault analysis

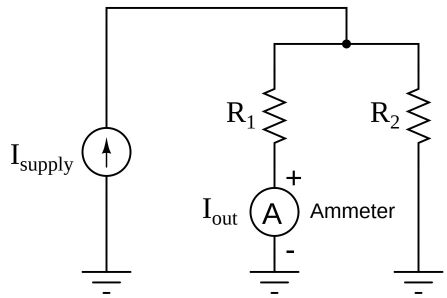
Suppose component [ ] fails [ ] open [ ] shorted [ ] other ______

What will happen in the circuit?

file 03176

Competency: **Current divider circuit** Version:

Schematic



Given conditions

I_{supply} = I_{out} =

Parameters

	Predicted	Measured
V_{supply}		
I_{R1}		
I_{R2}		

	Predicted	Measured
V_{R1}		
V_{R2}		

	Predicted	Calculated (from measurements)
$\frac{I_{out}}{I_{supply}}$ (Ratio)		

Fault analysis

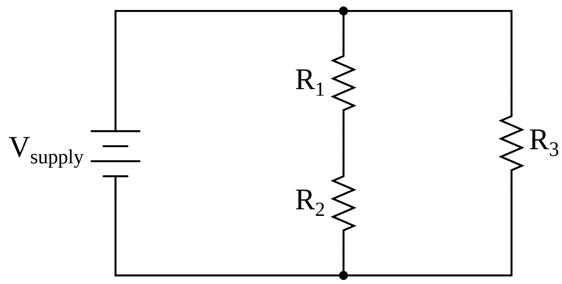
Suppose component ☐ fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 03177

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{R1}		
V_{R1}			I_{R2}		
V_{R2}			I_{R3}		
V_{R3}					

Fault analysis

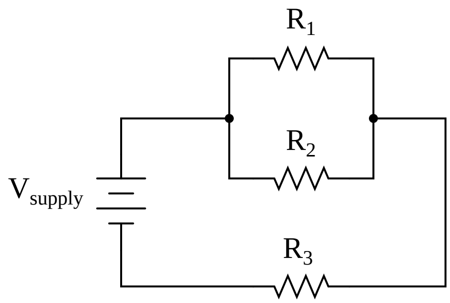
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ________

What will happen in the circuit?

file 01633

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{R1}		
V_{R1}			I_{R2}		
V_{R2}			I_{R3}		
V_{R3}					

Fault analysis

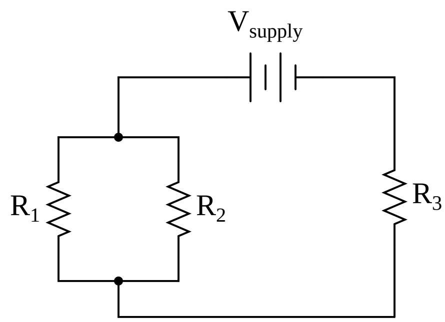
Suppose component ☐ fails ☐ open ☐ shorted ☐ other __________

What will happen in the circuit?

file 01631

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{R1}		
V_{R1}			I_{R2}		
V_{R2}			I_{R3}		
V_{R3}					

Fault analysis

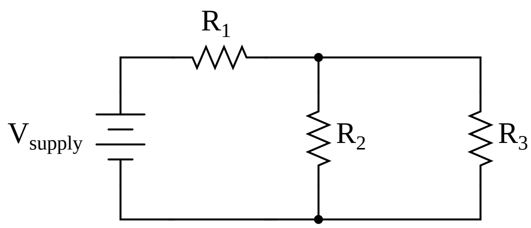
Suppose component ☐ fails ☐ open ☐ other ________ ☐ shorted

What will happen in the circuit?

file 01632

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{R1}		
V_{R1}			I_{R2}		
V_{R2}			I_{R3}		
V_{R3}					

Fault analysis

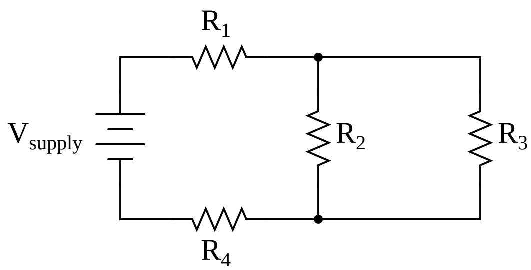
Suppose component ☐ fails ☐ open ☐ other ______________ ☐ shorted

What will happen in the circuit?

file 01630

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 = R_4 =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{R1}		
V_{R1}			I_{R2}		
V_{R2}			I_{R3}		
V_{R3}			I_{R4}		
V_{R4}					

Fault analysis

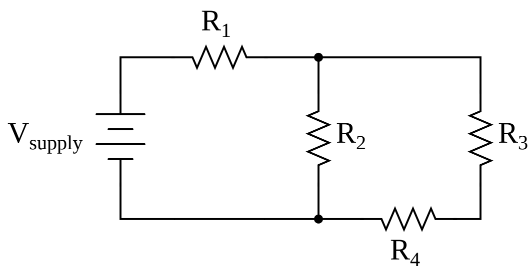
Suppose component ☐ fails ☐ open ☐ shorted ☐ other __________

What will happen in the circuit?

file 01606

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 = R_4 =

Parameters

	Predicted	Measured
I_{supply}		
V_{R1}		
V_{R2}		
V_{R3}		
V_{R4}		

	Predicted	Measured
I_{R1}		
I_{R2}		
I_{R3}		
I_{R4}		

Fault analysis

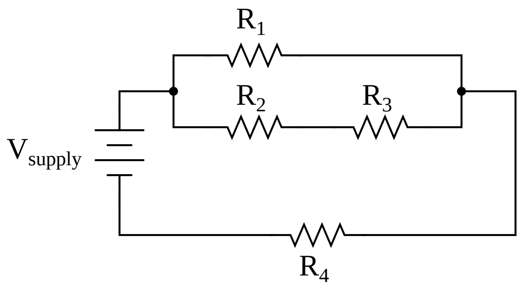
Suppose component ☐ fails ☐ open ☐ other ________
☐ shorted

What will happen in the circuit?

file 01607

Competency: **Series-parallel DC resistor circuit** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 = R_4 =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{R1}		
V_{R1}			I_{R2}		
V_{R2}			I_{R3}		
V_{R3}			I_{R4}		
V_{R4}					

Fault analysis

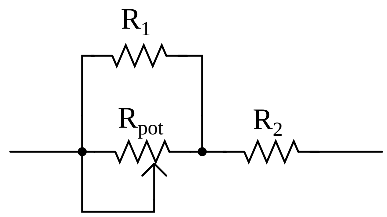
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ______

What will happen in the circuit?

file 01608

Competency: **Custom rheostat range** Version:

Schematic



Given conditions

R_{total} (minimum) = R_{total} (maximum) =

R_{pot} =

Parameters

	Ideal	Attained
R_1		
R_2		

Resistors R_1 and R_2 may need to be series-parallel networks in order to achieve the necessary values.

	Measured
R_{total} (minimum)	
R_{total} (maximum)	

Fault analysis

Suppose component [ ] fails
- [ ] open
- [ ] shorted
- [ ] other ____________

What will happen in the circuit?

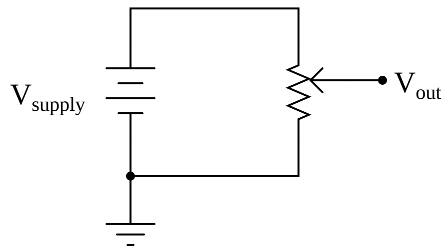
file 01754

Competency: **Potentiometer as voltage divider** Version:

Description

You must set the potentiometer to the correct position to achieve V_{out} given V_{supply} *before* it is connected to V_{supply} for testing.

Schematic



Given conditions

V_{supply} = V_{out} =

Parameters

Measured

V_{out} [ ]

Calculated

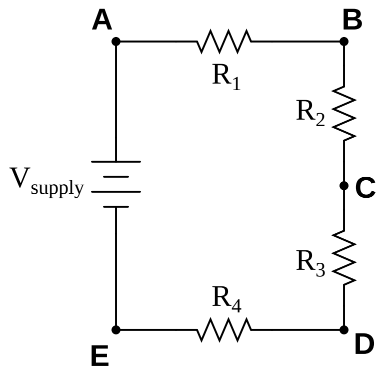
Error (%) [ ]

$$\frac{V_{out(actual)} - V_{out(ideal)}}{V_{out(ideal)}} \times 100\%$$

file 01925

Competency: **Kirchhoff's Voltage Law** Version:

Schematic



Given conditions

V_{supply} = Any whole-number value evenly divisible by 4

$R_1 = R_2 = R_3 = R_4 =$

Parameters

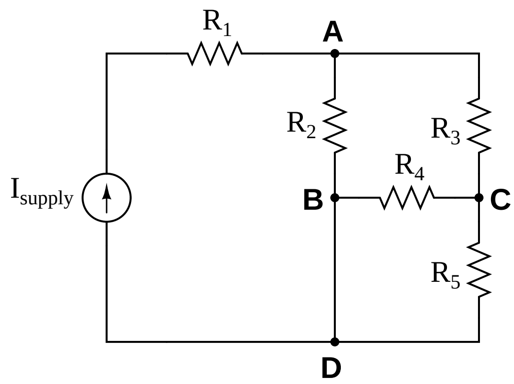
	Predicted	Measured		Predicted	Measured
V_{R1}			V_{R3}		
V_{R2}			V_{R4}		
V_{BD}			V_{DA}		
V_{BE}			V_{DC}		
V_{AC}			V_{CE}		

Note: "V_{BD}" means voltage measured with the red lead touching **B** and the black lead touching **D**.

file 03294

Competency: **Kirchhoff's Current Law** Version:

Schematic



Given conditions

I_{supply} = Any whole-number milliamp value evenly divisible by 4

$R_1 = R_2 = R_3 = R_4 = R_5 =$

Parameters

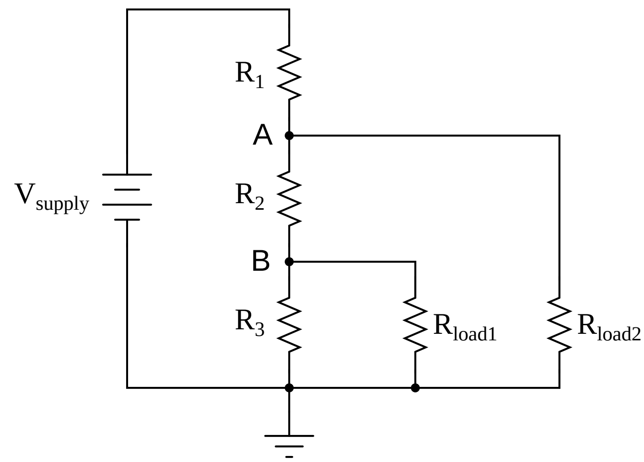
	Predicted	Measured		Predicted	Measured
I_{R1}			I_{R3}		
I_{R2}			I_{R4}		

Sketch directions and magnitudes of currents at these nodes:

file 03593

Competency: **Loaded voltage divider** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 = R_{load1} = R_{load2} =

Parameters

	Predicted	Measured		Predicted	Measured
I_{supply}			I_{load1}		
V_A			I_{load2}		
V_B			I_{bleed}		

Fault analysis

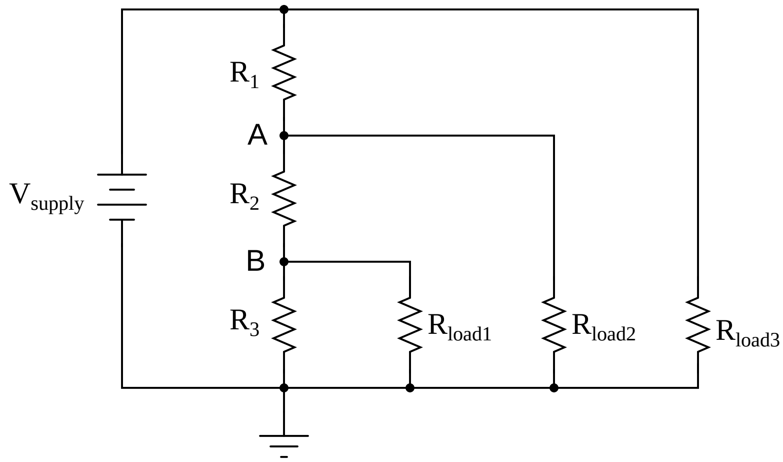
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ______

What will happen in the circuit?

file 01609

Competency: **Loaded voltage divider** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 =

R_{load1} = R_{load2} = R_{load3} =

Parameters

	Predicted	Measured
I_{supply}		
V_A		
V_B		

	Predicted	Measured
I_{load1}		
I_{load2}		
I_{load3}		
I_{bleed}		

Fault analysis

Suppose component ______ fails ☐ open ☐ shorted ☐ other ______

What will happen in the circuit?

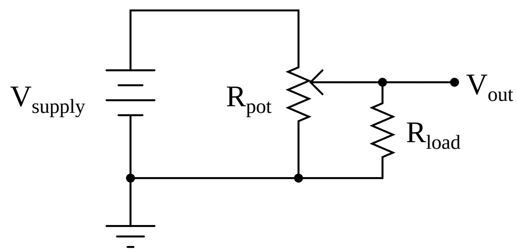
file 01642

Competency: **Potentiometer as loaded voltage divider** Version:

Description

You must set the potentiometer to the correct position to achieve V_{out} given V_{supply} *before* it is connected to V_{supply} for testing.

Schematic



Given conditions

V_{supply} = V_{out} = R_{pot} = R_{load} =

Parameters

Measured

V_{out} [ ]

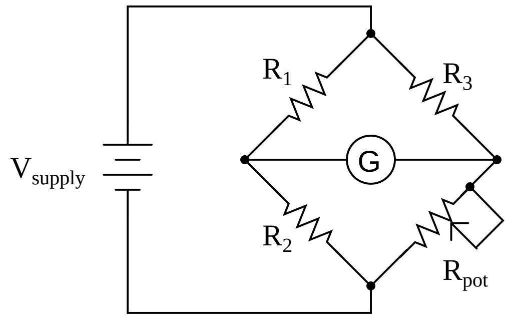
Calculated

Error (%) [ ] $$\frac{V_{out(actual)} - V_{out(ideal)}}{V_{out(ideal)}} \times 100\%$$

file 01926

Competency: **Wheatstone bridge** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 = R_3 =

Parameters

	Predicted	Measured
R_{pot} (balance)		
I_{supply}		

Fault analysis

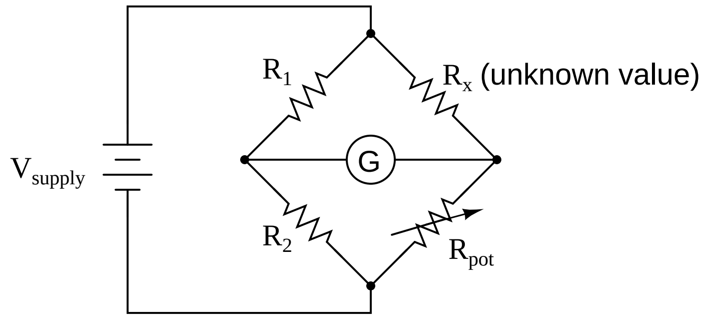
Suppose component ______ fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 01618

Competency: **Bridge resistance measurement** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 =

R_{pot} = Decade resistance box

Parameters

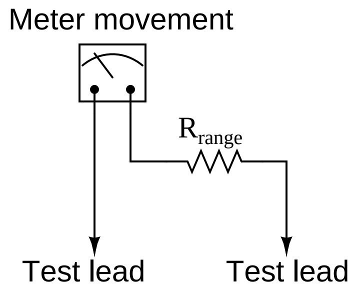
	Measured by bridge	Measured by ohmmeter
R_x		

Calculations

file 01643

Competency: **DC voltmeter circuit** Version:

Schematic



Given conditions

$I_{F.S.}$ = $R_{movement}$ = Full-scale range =

Parameters

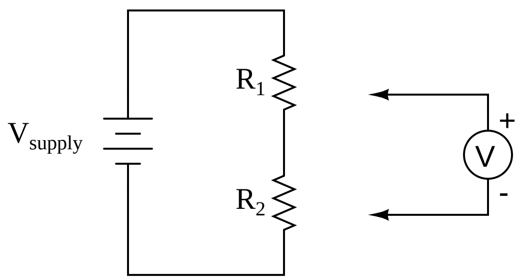
	Predicted	Measured
R_{range}		
Meter indication with full-scale voltage applied		

Calculations

file 01649

Competency: **Voltmeter loading** Version:

Schematic



Given conditions

V_{supply} = R_1 = R_2 =

Explanation

Due to the effects of the voltmeter "loading" the voltage divider circuit, there will be a significant difference between V_{R2} predicted and V_{R2} measured.

Parameters

	Predicted	
V_{R2}		(Ideal, with no meter connected)

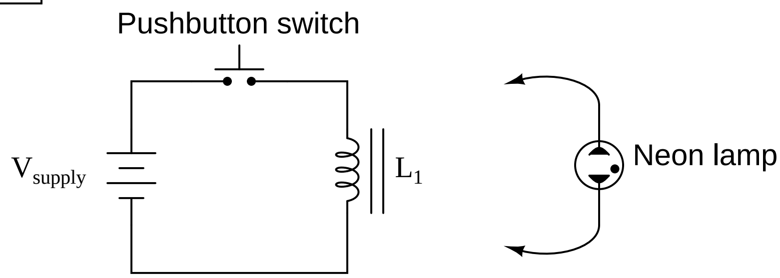
	Measured	
V_{R2}		(Real measurement with voltmeter)

	Calculated	Advertised
R_{input} (Meter)		

file 01694

Competency: **Self-induction** Version:

Schematic



Given conditions

V_{supply} =

Parameters

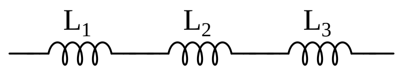
Yes/no answers only

	Predicted	Tested
Lamp across L_1 Lamp flashes?		
Lamp across switch Lamp flashes?		
Lamp across battery Lamp flashes?		

file 01646

Competency: **Series inductances** Version:

Schematic



Given conditions

$L_1 =$ $L_2 =$ $L_3 =$

Parameters

	Predicted	Measured
L_{total}		

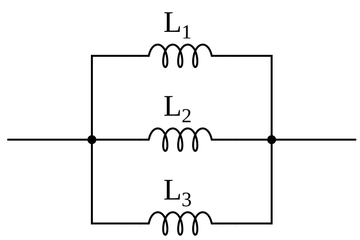
Analysis

Equation used to calculate L_{total} :

file 01650

Competency: **Parallel inductances** Version:

Schematic



Given conditions

L_1 = L_2 = L_3 =

Parameters

	Predicted	Measured
L_{total}		

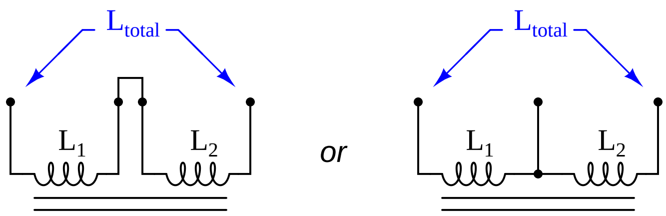
Analysis

Equation used to calculate L_{total} :

file 01651

Competency: **Series coupled inductors** Version:

Schematic



Given conditions

L_1 =

L_2 =

Parameters

	Predicted	Measured
L_{total}		

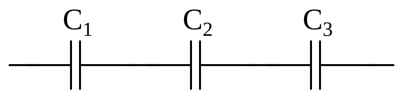
Analysis

Equation used to calculate L_{total} :

file 01989

Competency: **Series capacitances** Version:

Schematic



Given conditions

$C_1 =$ $C_2 =$ $C_3 =$

Parameters

	Predicted	Measured
C_{total}		

Analysis

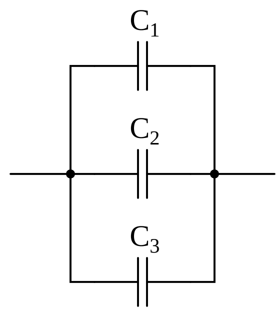
Equation used to calculate C_{total} :

file 01652

Question 26

Competency: **Parallel capacitances** Version:

Schematic



Given conditions

C_1 = C_2 = C_3 =

Parameters

	Predicted	Measured
C_{total}		

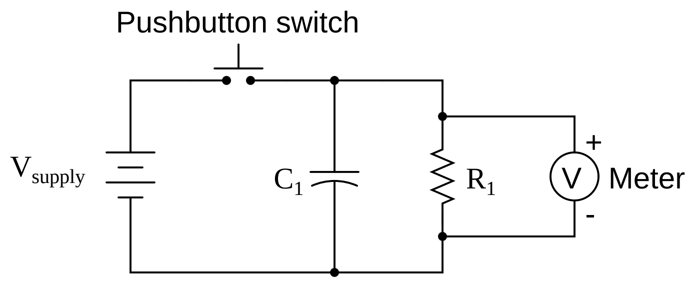
Analysis

Equation used to calculate C_{total} :

file 01653

Competency: **RC discharge circuit** Version:

Schematic



Given conditions

V_{supply} = C_1 = R_1 =

t_1 = t_2 = t_3 =

Parameters

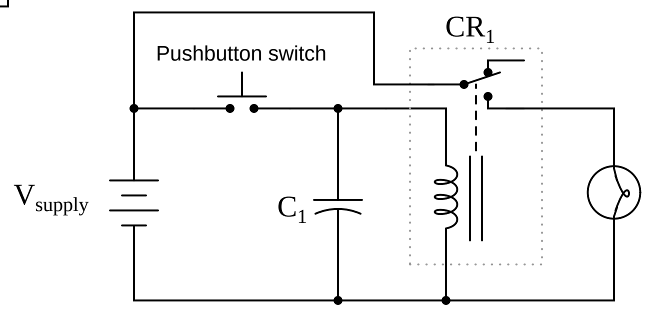
	Predicted	Measured
V_{t1}		
V_{t2}		
V_{t3}		

Calculations

file 01648

Competency: **Time-delay relay** Version:

Schematic



Given conditions

V_{supply} = C_1 = R_{coil} = $V_{dropout}$ =

Parameters

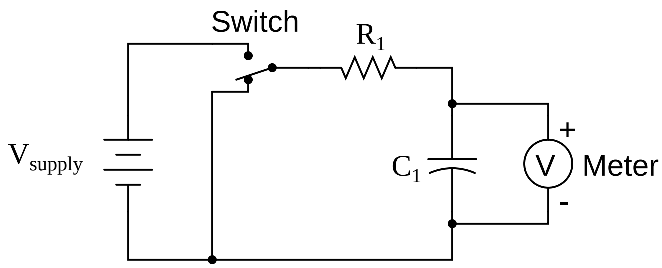
	Predicted	Measured
t_{delay}		

Calculations

file 01647

Competency: **RC charge/discharge circuit** Version:

Schematic



Given conditions

V_{supply} = C_1 = R_1 =

t_1 = t_2 = t_3 =

Parameters

Charging from 0 volts

	Predicted	Measured
V_{t1}		
V_{t2}		
V_{t3}		

Discharging from V_{supply}

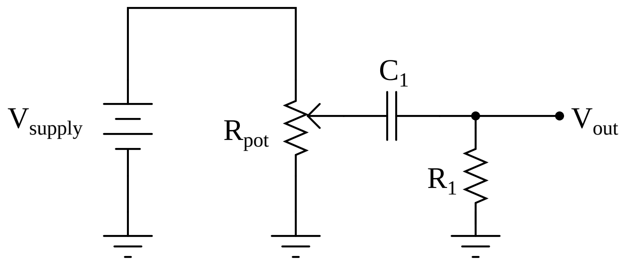
	Predicted	Measured
V_{t1}		
V_{t2}		
V_{t3}		

Calculations

file 01657

Competency: **Rate of change indicator circuit** Version:

Schematic



Given conditions

V_{supply} = R_{pot} = C_1 = R_1 =

Parameters

Qualitative answers only

	Predicted	Measured
V_{out} Wiper up, slowly		
V_{out} Wiper down, slowly		
V_{out} Wiper up, rapidly		
V_{out} Wiper down, rapidly		

Analysis

Explain *why* the output voltage polarity is related to the wiper motion as measured.

file 03178

(Template)

Competency: Version:

Schematic

Given conditions

Parameters

Predicted	Measured

file 01602

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.

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.

Answer 6

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

Answer 7

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

Answer 8

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

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

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

Answer 17

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

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.

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.

Answer 28

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

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 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 kΩ and 100 kΩ (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 kΩ and 100 kΩ (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 kΩ and 100 kΩ (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 kΩ and 100 kΩ (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 kΩ and 100 kΩ (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.

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 kΩ and 100 kΩ (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.

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 kΩ and 100 kΩ (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.

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 kΩ or 10 kΩ.

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.

Notes 12

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 13

I recommend students use a normal regulated (voltage) power supply, adjusting the output voltage until the output current is at 4 mA. 1 kΩ 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.

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 kΩ and 100 kΩ (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 kΩ for R1, R2, and R3; 15 kΩ for R(load1); 22 kΩ 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.

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 kΩ and 100 kΩ (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 kΩ or 5 kΩ), 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.

Notes 17

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (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.

Notes 18

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 kΩ and 100 kΩ.

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 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.

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 Ω/Volt), your students may not see much of an impact when using a modern digital voltmeter ($Z_{in} > 10$ MΩ).

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.*

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.

Notes 22

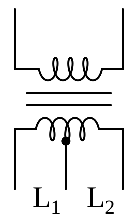
You will need an inductance meter in your lab to do this exercise. If you don't have one, you should get one right away!

Notes 23

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!

Notes 24

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 Ω 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!

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!

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!

Notes 27

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.

Notes 28

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 (τ), 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.

Notes 29

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.

Notes 30

I recommend a supply voltage of 12 volts, a potentiometer value of 10 kΩ, a capacitor value of 0.1 μF, and a loading resistor (R_1) of 1 MΩ. 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 (τ) 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.

Notes 31

Any relevant notes for the assessment activity go here.