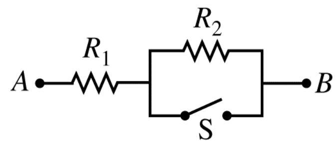


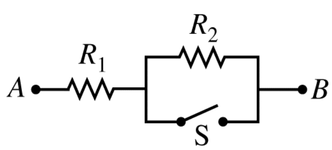
2. (12 points, suggested time 25 minutes)

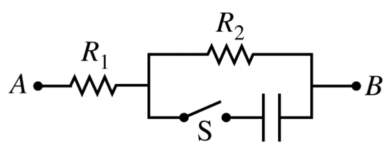
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points *A* and *B*. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

Complete the Diagram

Describe the Experiment





A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

(b)

i. Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

ii. Calculate the values of R_1 and R_2.

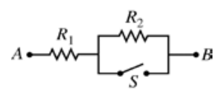
iii. Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

Question 2

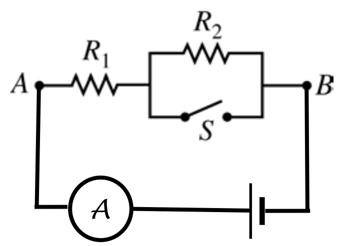
12 points total **Distribution of points**



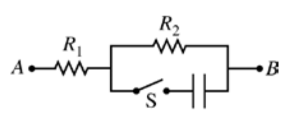
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2 , as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2 .

(a) LO 4.E.5.3, SP 2.2, 4.2, 5.1; LO 5.B.9.5, SP 6.4; LO 5.C.3.4, SP 6.4
4 points

Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2 .



For a diagram with an ammeter and battery in series with the resistor combination		1 point
For indicating that the current should be measured with the switch closed and open		1 point
For correctly indicating that with the switch closed $R_1 = V/I_1$		1 point
For correctly indicating that with the switch open $R_2 = (V/I_2) - R_1$		1 point



A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

Question 2 (continued)

Distribution of points

(b)

i. LO 4.E.5.2, SP 6.1, 6.4; LO 5.B.9.5, SP 6.4; LO 5.C.3.7, SP 1.4
3 points

Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

For indicating that the current through resistor 1 immediately after the switch is closed is greater than the current a long time after the switch is closed		1 point
For indicating that the current through resistor 2 is zero immediately after the switch is closed and nonzero a long time after the switch is closed		1 point
For indicating that the current through the switch is nonzero immediately after the switch is closed and zero a long time after the switch is closed		1 point

ii. LO 4.E.5.1, SP 2.2, 6.4
2 points

Calculate the values of R_1 and R_2.

For using the correct value of current and correctly calculating R_1		1 point
$9\text{ V} = (0.9\text{ A})R_1$		
$R_1 = 10\ \Omega$		
For using the correct value of current and correctly calculating R_2, consistent with the calculated value of R_1		1 point
$9\text{ V} = (0.3\text{ A})(R_1 + R_2) = (0.3\text{ A})(10\ \Omega + R_2)$		
$R_2 = 20\ \Omega$		

iii. LO 4.E.5.1, SP 2.2; LO 5.B.9.6, SP 2.2, LO 5.C.3.7, SP 1.4, 2.2
1 point

Determine the potential difference across the capacitor a long time after the switch is closed.

For correctly calculating the potential difference across the capacitor, including correct units, consistent with part (b)(ii)		1 point
$V_C = V_{\text{battery}} - V_{\text{resistor 1}} = 9\text{ V} - (0.3\text{ A})(10\ \Omega)$		
$V_C = 6\text{ V}$		

Question 2 (continued)

Distribution of points

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) LO 5.B.9.7, SP 5.3
2 points

How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

For correctly explaining that the third group's measured current is smaller		1 point
For correctly indicating that the third group's value of R_1 is higher than the second group's or the resistance they will determine is actually $R_1 + r$		1 point

Learning Objectives (LO)

LO 4.E.5.1: The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 2.2, 6.4]

LO 4.E.5.2: The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 6.1, 6.4]

LO 4.E.5.3: The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [See Science Practices 2.2, 4.2, 5.1]

LO 5.B.9.5: The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See Science Practice 6.4]

LO 5.B.9.6: The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]

LO 5.B.9.7: The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [See Science Practices 4.1, 4.2, 5.1, 5.3]

LO 5.C.3.4: The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. [See Science Practices 6.4, 7.2]

LO 5.C.3.7: The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [See Science Practice 1.4, 2.2]