2018

AP® CollegeBoard

# AP Physics 2: Algebra-Based

## Sample Student Responses and Scoring Commentary

**Inside:**

Free Response Question 2

☑ Scoring Guideline

☑ Student Samples

☑ Scoring Commentary

# AP® PHYSICS
# 2018 SCORING GUIDELINES

## General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

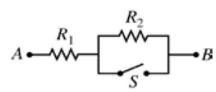
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of $10 \text{ m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

## Question 2

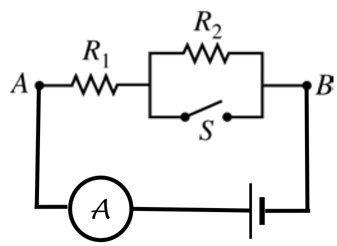
**12 points total** **Distribution of points**



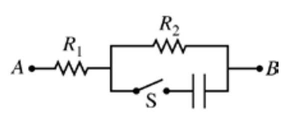

Students are given resistor 1 with resistance $R_1$ connected in series with the parallel combination of a switch S and resistor 2 with resistance $R_2$, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. 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]

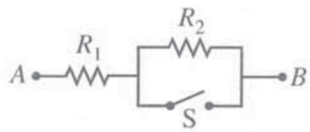
**LO 5.B.9.5**: The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See Science Practice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

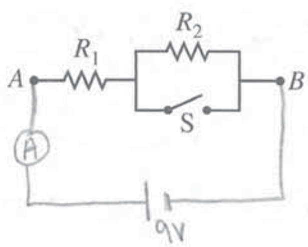



2. (12 points, suggested time 25 minutes)

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



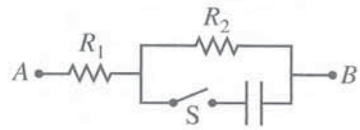

Describe the Experiment

With the switch open, record the current read on the ammeter. This current should equal the total Voltage (battery) divided by (Resistor 1 + Resistor 2). From the read current they can find what the total resistance is.

Now with the switch closed, record the current read on ammeter. This should equal total Voltage (battery) divided by Resistor 1, since current follows the path of least resistance. From the read current they can find what Resistance in Resistor 1 is equal to. Knowing the total resistance and resistance in Resistor 1, resistance in Resistor 2 can also be found from the difference, since they are in series.



GO ON TO THE NEXT PAGE.




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.

The current through resistor 1 immediately after the Switch is closed would be .9 A, while in resistor 2 and the Switch the current would add up to .9A since the current Split. After a long time current would stop flowing through the switch since the capacitor is fully charged and the Current in resistor 1 would be .3A as well as resistor 2 since they are practically in series.

ii. Calculate the values of $R_1$ and $R_2$.

$9V = (.3A)(R_T)$ $\quad$ $9V = (.9A)(R_1)$

$R_T = 30\Omega$ $\quad$ $\boxed{R_1 = 10\Omega}$

$R_T = R_1 + R_2$

$30 = 10 + R_2$

$\boxed{R_2 = 20\Omega}$

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

$Q = VC \quad V = IR$

$V = (.3A)(20\Omega)$

$\boxed{V = 6V}$

Question 2 continues on the next page.

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.

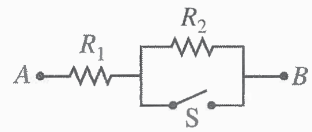
(c) How does the third group's value of $R_1$ calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

$V = \downarrow I R \uparrow$

The third group's value of $R_1$ would calculate out to be larger than of the second group's calculation of $R_1$. Because there is internal resistance within the battery, the circuit would then technically have a higher total resistance. Because a higher total resistance is present, a lower current will be present and read on the ammeter. Because they do not accaunt for the internal resistance, it will make it seem as if there is more resistance in $R_1$ and $R_2$ than there actually is. So the 3rd group will have a higher calculated $R_1$ than $R_1$ of the second group.



GO ON TO THE NEXT PAGE.

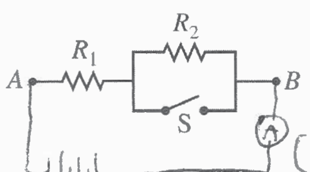


2. (12 points, suggested time 25 minutes)

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



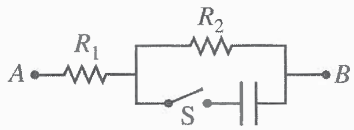
Describe the Experiment

First close switch S and take a measurement on the ammeter. No current will go through $R_2$ because its in parallel with a wire of no resistance. Knowing voltage and current use the equation $V=IR$ to find the resistance of $R_1$. Then, open the switch S, now $R_1$ and $R_2$ are in series and are the only places for current to flow. measure the current, set up $V=IR$ and solve for R, R will be a combination of $R_1$ and $R_2$ since they are in series, so subtract $R_1$ from R to get $R_2$.



GO ON TO THE NEXT PAGE.

$V=IR$




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.

Initially the current through $R_1$ is ,9A, after a long time it is ,3A, The current of $R_2$ stays constant at .3A.

ii. Calculate the values of $R_1$ and $R_2$.

$V=IR$

$9=(.3)(R_1+R_2)$

$30=R_1+R_2$

$9=(.9)(R_1)$

$8.1=R_1$

$21.9=R_2$

$30-8.1=R_2$

$21.9=R_2$

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

0 V

Question 2 continues on the next page.



GO ON TO THE NEXT PAGE.

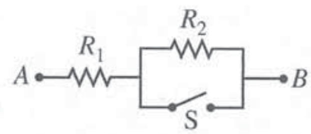
A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(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.

The third group would have a value of $R_1$ that is higher than that of the seconds group. This is because their total resistance is higher due to the resistors being the same but they have a battery with resistance. They would attribute this extra resistance to the resistors ~~the~~ so they would get a higher value than the second group.



GO ON TO THE NEXT PAGE.



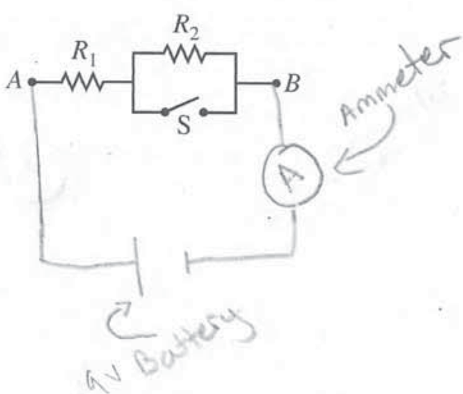

2. (12 points, suggested time 25 minutes)

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

V / IR




Describe the Experiment

The battery is placed arcoss from the Resistors and switch. The Ammeter is to the right of the battery so electricity flows to it last. You'll want it there so you get the correct Current of the whole System* (current is constant in series) (switch open)

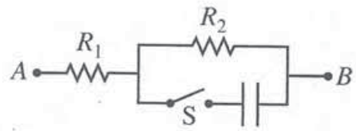
1.) Measure Amps + Find total resistance using V = IR (switch open)

2.) This time, close the switch + measure Current. It will be different because it is now a parallel ciruit

3.) You can now use the difference in currents to find the resistance of $R_1$ + $R_2$.



GO ON TO THE NEXT PAGE.




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.

Resistor 1 will have the largest current. This is because it doesn't ~~have the~~ have a resistor before it & is directly linked to the battery. Resistor 2 will have a small current that continues to get smaller as the capacitor is allowed current. The switch will have a low current but it will continue to rise the longer the switch is closed. (Eventually, it will be constant.)

ii. Calculate the values of $R_1$ and $R_2$.

$V = IR$

$9 = .9R$

$\Delta R = 10$

$9 = .3R$

$R = 30$

$\Delta R = 10$

$R_1 =$

$R_2 =$

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

The potential difference is still 9 volts. This is because voltage stays constant over a parallel circuit. Once the switch is closed it becomes a parallel circuit.

Question 2 continues on the next page.



GO ON TO THE NEXT PAGE.

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.

The value of $R_1$ as measured by the 3rd group would be larger. This is because when calculating the initial resistance that of the battery's internal resistance will be added to it because its existance was not known. Thus, it would be added on to the first resistor's resistance.



GO ON TO THE NEXT PAGE.

## Question 2

**Overview**

This question assessed learning objectives 4.E.5.1, 4.E.5.2, 4.E.5.3, 5.B.9.5, 5.B.9.6, 5.B.9.7, 5.C.3.4, and 5.C.3.7.

The responses to this question were expected to demonstrate the following:

- The ability to complete a working circuit diagram with the given materials as described.
- The ability to apply Ohm's law throughout a given circuit.
- The ability to explain the behavior of current in an RC Circuit.
- How to calculate and determine resistances and potential differences in a given circuit.
- The ability to describe the effects of internal resistance on the current and total resistance in a circuit.

**Sample: P2 Q2 A**
**Score: 11**

Part (a) earned full credit of 4 points. It has a correct diagram, indicates measuring the current with the switch both open and closed, and correctly identifies the data analysis necessary to determine each of the resistances $R_1$ and $R_2$. Part (b)(i) earned 2 points for correctly comparing the currents in resistor 1 and the switch before and after the switch is closed. The exact value for resistor 2 immediately after the switch is closed is not specified in the first sentence; therefore, a clear comparison with the value of 0.3 A after the switch is closed is not made. Part (b)(ii) earned 2 points for correctly calculating resistances $R_1$ and $R_2$. Part (b)(iii) earned 1 point for the correct calculation of the potential difference across the capacitor a long time after the switch is closed and the inclusion of the correct units (volts). Part (c) earned 2 points for referencing the lower current and for a correct description of the higher calculated resistance.

**Sample: P2 Q2 B**
**Score: 7**

Part (a) earned full credit of 4 points. It has a correct diagram, indicates measuring the current with the switch both open and closed and correctly identifies the data analysis necessary to determine the resistances $R_1$ and $R_2$. Part (b)(i) earned 1 point for saying the current in resistor 1 goes from 0.9A to 0.3A. The response incorrectly says that the current in $R_2$ stays the same and does not discuss the current in the switch. Part (b)(ii) earned 1 point for a consistent calculation of $R_2$ from an incorrect value of $R_1$ that is the result of a mathematical error. Correct units were not required in this part. Part (b)(iii) earned no points. The response incorrectly indicates that the potential difference across the capacitor is 0 V. Part (c) earned 1 point for stating the total resistance would be higher, but there is no mention of current decreasing.

**Sample: P2 Q2 C**
**Score: 3**

Part (a) earned 2 points for the correct diagram and for measuring the current when the switch is open and closed. However, it is not clear exactly which resistances can be determined with each measurement. Part (b)(i) earned no points. The response never makes a comparison for resistor 1 and never clearly states that resistor 2 and the switch ever have zero currents. Part (b)(ii) earned no points because it is unclear which resistor has a resistance of 10 ohms. Part (b)(iii) earned no points because the response provides an incorrect potential

## Question 2 (continued)

difference across the capacitor a long time after the switch has been closed. Part (c) received 1 point for stating the resistance would be higher. The response does not provide an explanation of the current.