2019

AP® CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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General Notes About 2019 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 $g = 9.8\ \text{m}/\text{s}^2$, but the use of $10\ \text{m}/\text{s}^2$ 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.

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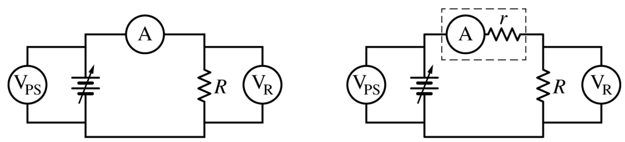
Question 2

12 points



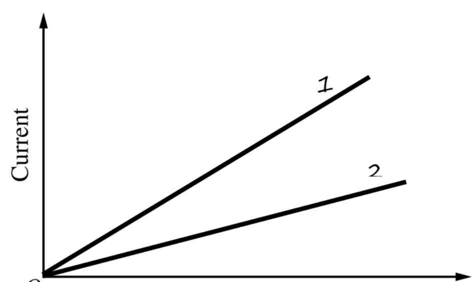
Circuit 1 Circuit 2

The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) LO 4.E.5.1, SP 6.4
2 points

The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.



For graph 1 a straight line with a positive slope through origin		1 point
For graph 2 a straight line with a positive slope through origin with a smaller slope than line 1		1 point

(b) LO 5.B.9.6, SP 2.2; LO 5.C.3.4, SP 6.4
2 points

Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

<u>Circuit 1</u> <u>Circuit 2</u>

For a correct equation for circuit 1		1 point
$\Delta V_{PS} - IR = 0$		
For a correct equation for circuit 2		1 point
$\Delta V_{PS} - I(R + r) = 0$		

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Question 2 (continued)

(c) LO 5.B.9.8, SP 1.5
2 points

Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

For indicating that the slope is inversely proportional to the resistance		1 point
For explaining that the equations in part (b) show that a larger total resistance corresponds to a smaller slope or smaller current		1 point
Example: Claim: The equations in part (b) account for the differences between graphs 1 and 2 in part (a). Evidence: The graphs show a linear relationship between current and potential difference. The equations are linear functions, which when graphed would have a slope that is the inverse of the total resistance. Reasoning: The difference between the equations is the value of the total resistance, so the equations account for the difference in slopes. The larger the total resistance, the smaller the slope.		

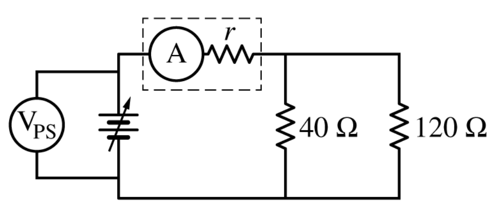
(d) LO 5.B.9.6, SP 2.2; LO 5.C.3.4, SP 6.4, 7.2
2 points

In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

Ohm's law solution:		
For correctly calculating the current in the circuit		1 point
$I = \Delta V_R / R = 2.5\ \text{V}/40\ \Omega = 0.0625\ \text{A}$		
For using Ohm's law with the calculated current and correct potential difference		1 point
$r = \Delta V_r / I = (3\ \text{V} - 2.5\ \text{V})/0.0625\ \text{A}$		
$r = 8\ \Omega$		

(e)

Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

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Question 2 (continued)

(e) (continued)

i. LO 4.E.5.1, SP 2.2
2 points

Calculate the equivalent resistance R_{eq} of the circuit.

For calculating the equivalent resistance of the parallel branches		1 point
$\dfrac{1}{40\ \Omega} + \dfrac{1}{120\ \Omega} = \dfrac{4}{120\ \Omega}$		
$R_{\parallel} = 30\ \Omega$		
For adding the value of r from part (d) to $R_{\parallel}$		1 point
$R_{eq} = 30\ \Omega + 8\ \Omega = 38\ \Omega$		

ii. LO 5.B.9.6, SP 2.2
2 points

Calculate the current in each of the resistors that are in parallel.

For substituting the correct potential difference and the resistance from part (e)(i) into Ohm's law to determine the current through the battery		1 point
$I_{tot} = 3\ \text{V}/38\ \Omega = 0.079\ \text{A}$		
For calculating two currents that are in the correct ratio ($I_{40\ \Omega} = 3I_{120\ \Omega}$)		1 point
$\Delta V_{\text{parallel}} = (3\ \text{V}) - (8\ \Omega)(0.079\ \text{A}) = 2.36\ \text{V}$ $I_{40\ \Omega} = \dfrac{2.36\ \text{V}}{40\ \Omega} = 0.059\ \text{A}$ $I_{120\ \Omega} = \dfrac{2.36\ \text{V}}{120\ \Omega} = 0.020\ \text{A}$		

Learning Objectives

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 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.9.8: The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [See Science Practices 1.5]

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

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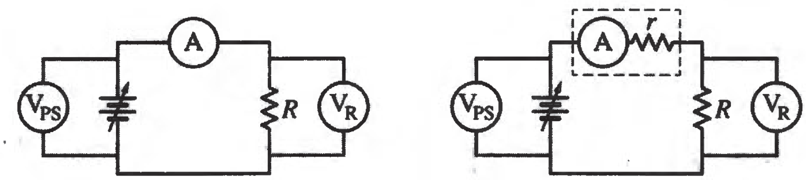


Circuit 1 Circuit 2

2. (12 points, suggested time 25 minutes)

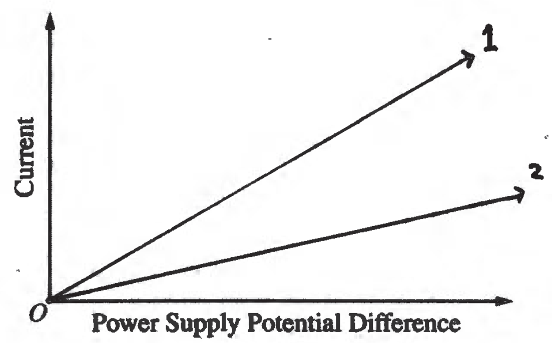
The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.

$V = IR$

$I/V = \frac{1}{R}$



(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

Circuit 1

$\Delta V_{PS} = IR$

Circuit 2

$\Delta V_{PS} = Ir + IR$

$I = \frac{\Delta V}{rR}$

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

Circuit 1's equation can be written as $I = \frac{1}{R} \cdot V$, and Circuit 2's equation as $I = \frac{1}{r+R} \cdot V$. If the equations are looked at using the $y = mx + b$ format, circuit 2 will have a smaller m, leading to the smaller slope as seen in part a

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(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

$V_{PS} = IR + Ir = 3.0V = 2.5V + (0.0625)r$

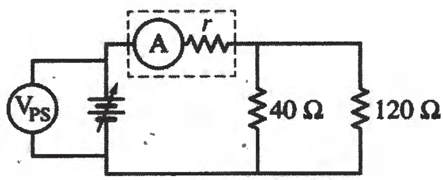
$r = \dfrac{0.5}{0.0625} \Rightarrow 8$

$V_R = I(40\Omega) = 2.5V$

$I = 0.0625A$

$\boxed{r = 8\Omega}$

(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance 120 Ω to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

$R_{eq} = r + \left(\left(\frac{1}{40} + \frac{1}{120}\right)^{-1}\right) = 8 + 30$

$\boxed{R_{eq} = 38\Omega}$

ii. Calculate the current in each of the resistors that are in parallel.

$V_{PS} = I(R_{eq}) \Rightarrow I = \frac{V}{R} = 0.07895$

$V_r = 0.6316$

$V/R_{40} = I$

$3 - 0.6316 = 2.3684$

$V/R_{120} = I$

$\boxed{I_{40\Omega} = 0.059\ A \quad I_{120\Omega} = 0.0197\ A}$

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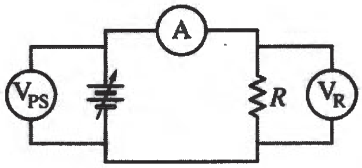
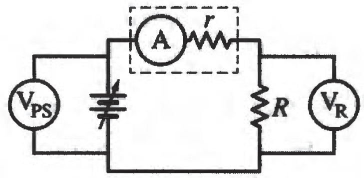


Circuit 1



Circuit 2

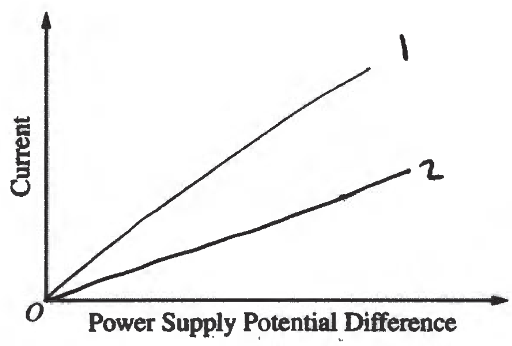
2. (12 points, suggested time 25 minutes)

The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.

direct relationship



(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

Circuit 1

$\Delta V_{ps} = IR$

Circuit 2

$\Delta V_{ps} = I(R+r)$

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

My equations show that in Circuit 2 the addition of the resistance r will affect the potential difference.

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(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

$V = IR$

$2.5 = (I)40$

$I = 0.0625$

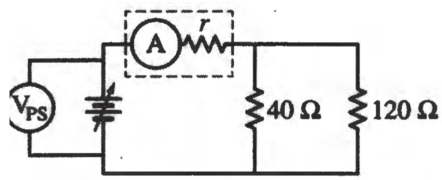
$3.0 = (0.0625)R$

$R = 48$

$R_{Total} = R_1 + R_2 + R_3$

$48 - 40 = \boxed{8\ \Omega}$

(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

$r = 8\Omega$

$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$ $\quad (40^{-1} + 120^{-1})^{-1} = \boxed{30\ \Omega}$

$30 + 8 = R_{eq} =$

$\boxed{38\ \Omega}$

ii. Calculate the current in each of the resistors that are in parallel.

[redacted]

$C_T = C_1 + C_2 + C_3 + \ldots$

$(0.208334) + (0.416667) = \boxed{0.0625\text{ Amp}}$

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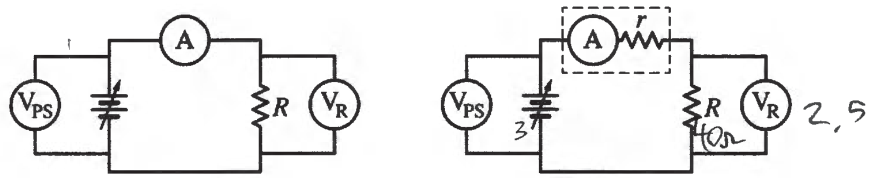


Circuit 1 Circuit 2

2. (12 points, suggested time 25 minutes)

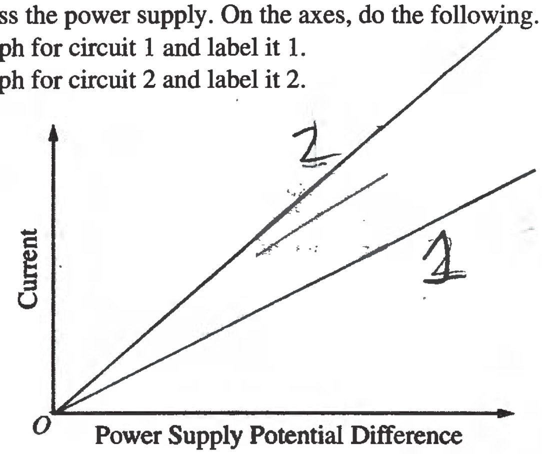
The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.

$V = IR$

$R = \frac{V}{I}$



(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

$\cancel{\Delta V_{ps}} \; V_{ps} - V_R$

Circuit 1

$\Delta V_{ps} = IR$

Circuit 2

$\Delta V_{ps} = I\left(\frac{1}{r} + \frac{1}{R}\right)$

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

Graph 2 has a greater slope because it has more resistance than Graph 1.

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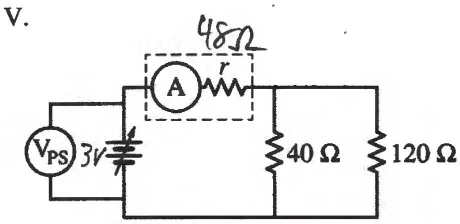
(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

$V = IR$ $\quad 2.5 = I(40)$

$3 = Ir$ $\quad I = .0625$

$\frac{3}{.0625} = r = \boxed{48\Omega}$

(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

$\frac{1}{R_{eq}} = \frac{1}{r} + \frac{1}{(40+120)}$

$\frac{1}{48} + \frac{1}{160}$

$\frac{160}{7680} + \frac{48}{7680}$

$\frac{1}{R_{eq}} = \frac{208}{7680}$

$R_{eq} = \boxed{36.92\Omega}$

ii. Calculate the current in each of the resistors that are in parallel.

$3 = 48(.0625)$

$V = IR$

$.0625$

$\boxed{\begin{array}{l} I_{40\Omega} = 0.0625A \\ I_{120\Omega} = 0.0208A \end{array}}$

$2.5 = I(40)$

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Question 2

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

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

- An understanding of Ohm's law such that the correct linear relationship between current and potential difference, as well as a y-intercept of zero, was graphed.
- Recognition that for the given axes, the graph of Circuit 2 should have a slope less than Circuit 1.
- A statement of Kirchhoff's loop rule that satisfies the Law of Conservation of Energy in terms of the given variables.
- The ability to translate between the qualitative graph and the quantitative equations and show how they are related.
- Proper use of Ohm's law to determine the current through the circuit, as well as recognizing that the potential difference across the ammeter would be the difference between the given potential difference values for use with Ohm's law a second time to determine the internal resistance of the ammeter.
- Recognizing which resistors are in parallel and which resistor is in series and being able to calculate the equivalent resistance of the full circuit.
- Understanding that the addition of the resistor in parallel changed the circuit and the potential difference across the various elements in Circuit 3 is different from what they were in Circuit 2.
- Proper application of Ohm's law to the new circuit.

Sample: P2 Q2 A
Score: 12

Part (a) earned 2 points for two lines drawn through the origin and with positive slope, with line 2 having a smaller slope than line 1. Part (b) earned 2 points for two correct equations that obey Kirchhoff's loop rule, thereby satisfying conservation of energy. Part (c) earned 2 points for relating the equations in part (b) to the graph in part (a) and noting how the slopes are the inverse of the total resistance. Part (d) earned 2 points for correctly calculating the current in the circuit and for using the calculated current with the correct potential difference. Part (e)(i) earned 2 points for correctly calculating the equivalent resistance of the resistors in parallel and correctly adding the internal resistance of the ammeter. Part (e)(ii) earned 2 points for determining the current in the circuit using the correct potential difference and resistance and then determining the current in each of the resistors in parallel.

Sample: P2 Q2 B
Score: 8

Part (a) earned 2 points for two lines drawn through the origin and with positive slope, with line 2 having a smaller slope than line 1. Part (b) earned 2 points for two correct equations that obey Kirchhoff's loop rule, thereby satisfying conservation of energy. Part (c) earned no points for not relating the equations to the slopes of the lines. Part (d) earned 2 points for correctly calculating the current in the circuit and for using the calculated current with the correct potential difference. Part (e)(i) earned 2 points for correctly calculating the equivalent resistance of the resistors in parallel and correctly adding the resistance of the ammeter. Part (e)(ii) earned no points for apparently attempting to calculate capacitance.

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Question 2 (continued)

Sample: P2 Q2 C
Score: 4

Part (a) earned 1 point for the graph of Circuit 1 but did not earn the point for Circuit 2 because the slope is larger. Part (b) earned 1 point for the correct equation for Circuit 1. Part (c) earned no points for an incorrect relationship between the slopes and the equations. Part (d) earned 1 point for correctly calculating the current in the circuit. Part (e)(i) earned no points because the expression that is used for the equivalent resistance is incorrect.
Part (e)(ii) earned 1 point for recognizing that the potential difference across the resistors in parallel is the same (even though the value is incorrect) and using it to calculate currents through each of the resistors that are in the correct ratio.

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