AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2016 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**

(a) 2 points

For selecting "It is the same through both." 1 point
For a correct justification 1 point
Example: The sample of wire and the resistor are in series with each other and therefore will have the same current.
Note: Because the voltmeter is ideal, it will have no effect on the result.
No points are earned if the wrong answer is selected.

(b) 2 points

For selecting "It will depend on the resistance of the sample." 1 point
For a correct justification including argument using Ohm's law, voltage drop across resistors, etc. 1 point
Example: Because the sample of wire has resistance, it cannot be known whether the wire of the resistor has the greatest resistance and which has the higher potential difference across it. Therefore, it will depend on the resistance of the wire sample.
No points are earned if the wrong answer is selected.

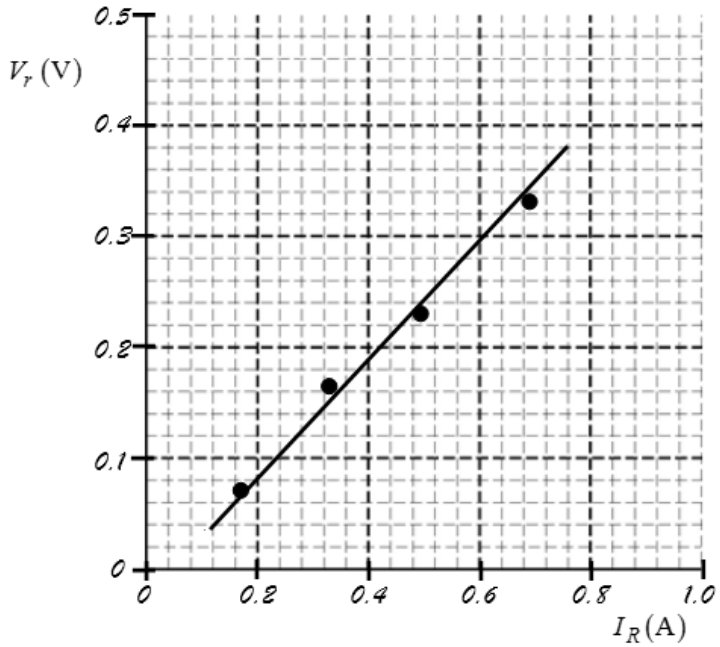
(c) 1 point

For indicating the correct quantities for each axis 1 point
Horizontal axis: I_R
Vertical axis: $V_r = \mathcal{E} - V_R$
Note: Credit is received if the axes are reversed.

Question 2 (continued)

Distribution of points

(d) 3 points



For a correct scale that uses more than half the grid and for correctly labeling the axes including units — 1 point

For correctly plotting given data — 1 point

For drawing a straight line consistent with the given data — 1 point

(e) 2 points

For correctly calculating slope using the best-fit straight line and not data points — 1 point

$$\text{slope} = \frac{(V_2 - V_1)}{(I_2 - I_1)} = \frac{(0.30 - 0.10)\ \text{V}}{(0.60 - 0.22)\ \text{A}} = 0.526\ \text{V/A}$$

Note: Linear regression gives $\text{slope} = 0.485\ \text{V/A}$. (Student must indicate that the value comes from a linear regression from the calculator, and the equation of the line must be present.)

For correctly relating r to the slope — 1 point

$V_r = I_R r$, therefore the slope equals r

$r = 0.526\ \Omega$

Note: Linear regression gives $r = 0.485\ \Omega$.

Question 2 (continued)

Distribution of points

(f) 1 point

For using the equation relating resistance to resistivity with the correct or consistent substitutions — 1 point

$$R = \frac{\rho L}{A} \quad \text{so} \quad \rho = \frac{AR}{L}$$

$$\rho = \frac{(\pi)\left(1.00 \times 10^{-3}\ \text{m}\right)^2 (0.526\ \Omega)}{(3.00\ \text{m})}$$

$$\rho = 5.51 \times 10^{-7}\ \Omega\text{•m}$$

Note: Linear regression gives $\rho = 5.08 \times 10^{-7}\ \Omega\text{•m}$.

(g)

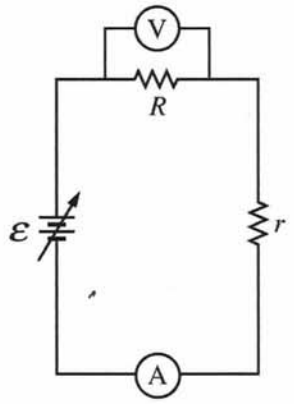
i. 2 points

For selecting "Less than" with an attempt at a justification — 1 point
For a correct justification — 1 point
Example: The resistance calculated from the graph is the sum of the sample resistance plus the ammeter resistance because it is not ideal. The actual resistance is the calculated resistance minus the ammeter resistance, and therefore less than the calculated resistance.
No points are earned if the wrong answer is selected.

ii. 2 points

For selecting "Greater than" with an attempt at a justification — 1 point
For a correct justification — 1 point
Example: If the voltmeter is not ideal, that would add an additional resistor in parallel. A parallel resistor reduces the total resistance of the circuit. This would lead to an increase in current and a higher reading on the ammeter.
No points are earned if the wrong answer is selected.

E Q2 A1



E&M.2.

The circuit shown above consists of a source of variable emf $\mathcal{E}$, an ideal ammeter A, an ideal voltmeter V, a resistor of resistance R, and a sample of wire with resistance r.

(a) How does the current through the wire sample compare with the current through the resistor R ?

_____ It is greater through R.
_____ It is greater through the sample.
✓ It is the same through both.
_____ It depends on the resistance of the sample.

Justify your answer.

In a series circuit, the amount of current going through each component in the series is the same.

(b) How does the potential difference across the wire sample compare with the potential difference across the resistor R ?

_____ It is greater across R.
_____ It is greater across the sample.
_____ It is the same across both.
✓ It depends on the resistance of the sample.

Justify your answer.

Based on the Law that $V=IR$, since I is the same through R and r. in the series circuit, the potential difference across each segment depends on R and r.

With the sample of wire in place, the emf of the source is set to a given value. The current through and potential difference across the resistor R are measured. This is repeated for several values of emf, and the data are recorded in the table below.

$\mathcal{E}$(V)	V_R(V)	I_R(A)	$\mathcal{E} - V_R$ (V)	
0.250	0.179	0.162	0.071	
0.500	0.335	0.327	0.165	
0.750	0.520	0.490	0.230	
1.000	0.670	0.687	0.330	

(c) Indicate below which quantities should be graphed to yield a straight line that could be used to calculate a numerical value for the resistance of the wire sample.

Horizontal axis: I_R

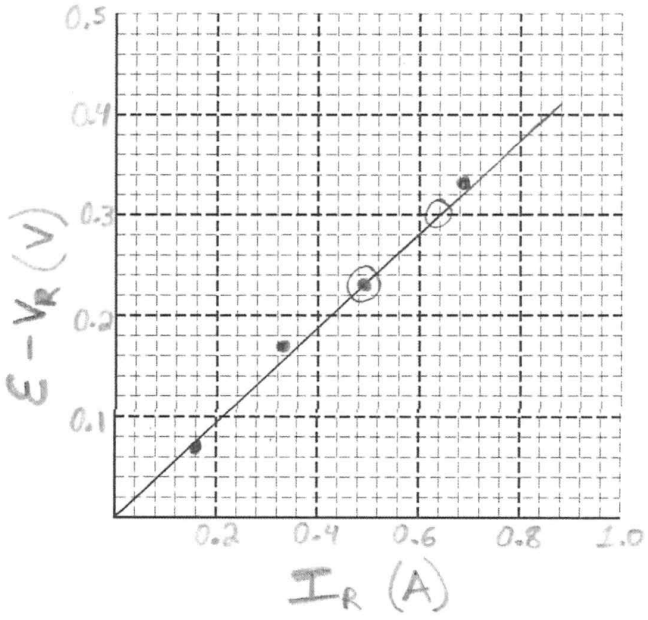
Vertical axis: $\mathcal{E} - V_R$

$\mathcal{E} - V_R - I_R \cdot r = 0$

$\frac{\mathcal{E} - V_R}{I_R} = r$

You may use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given.

(d) On the grid below, plot the straight line data points from part (c). Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(e) Use your straight line to calculate the value of the resistance of the wire sample.

slope $= \frac{0.3 - 0.23}{0.64 - 0.49} = \frac{0.07}{0.15} =$ 0.4667 Ω $= \frac{\mathcal{E} - V_R}{I_R} = r$

Question 2 continues on next page.

(f) The wire sample has a length of 3.00 m and a radius of 1.00×10^{-3} m . Calculate the resistivity of the material from which the wire sample is made.

$r = \frac{\rho \ell}{A}$ $\rho = \frac{r \cdot A}{\ell} = \frac{(0.4667)(\pi \cdot (1 \times 10^{-3})^2)}{3}$

$\rho = 4.88 \times 10^{7}\ \Omega m$

(g)

i. Suppose the ammeter used to collect these data was not ideal. Would the actual value of the resistance of the wire sample be greater than, less than, or equal to that calculated in part (e) ?

____ Greater than ✓ Less than ____ Equal to

Justify your answer.

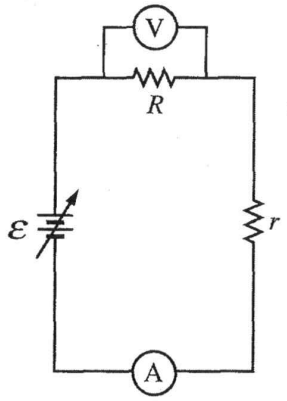
If the ammeter was not ideal, it would have a resistance greater than zero, but we assumed all of the resistance from the wire came from the wire sample, so actually some of the resistance belongs to the ammeter, not completely to the wire sample.

ii. If the ideal voltmeter is replaced by a voltmeter that is not ideal and the experiment is repeated, would the readings of the ideal ammeter be greater than, less than, or equal to those in the data chart before part (c) ?

✓ Greater than ____ Less than ____ Equal to

Justify your answer.

A non-ideal voltmeter would decrease the resistance in the circuit (due to the parallel structure) so there would be more current drawn from the battery.



E&M.2.

The circuit shown above consists of a source of variable emf $\mathcal{E}$, an ideal ammeter A, an ideal voltmeter V, a resistor of resistance R, and a sample of wire with resistance r.

(a) How does the current through the wire sample compare with the current through the resistor R ?

_____ It is greater through R.
_____ It is greater through the sample.
__✓__ It is the same through both.
_____ It depends on the resistance of the sample.

Justify your answer.

In a series arrangement, the current is constant along the circuit.

(b) How does the potential difference across the wire sample compare with the potential difference across the resistor R ?

_____ It is greater across R.
_____ It is greater across the sample.
_____ It is the same across both.
__✓__ It depends on the resistance of the sample.

Justify your answer.

The potential difference is directly proportional to the resistance ($V=IR$), so the potential difference across the wire sample is dependent on the resistance of the sample.

With the sample of wire in place, the emf of the source is set to a given value. The current through and potential difference across the resistor R are measured. This is repeated for several values of emf, and the data are recorded in the table below.

$V = \mathcal{E} - IR$

$\mathcal{E} - V_R = IR$

$\mathcal{E}$ (V)	V_R (V)	I_R (A)	$\mathcal{E} - V_R$ (V)	
0.250	0.179	0.162	.071	
0.500	0.335	0.327	.165	
0.750	0.520	0.490	.23	
1.000	0.670	0.687	.33	

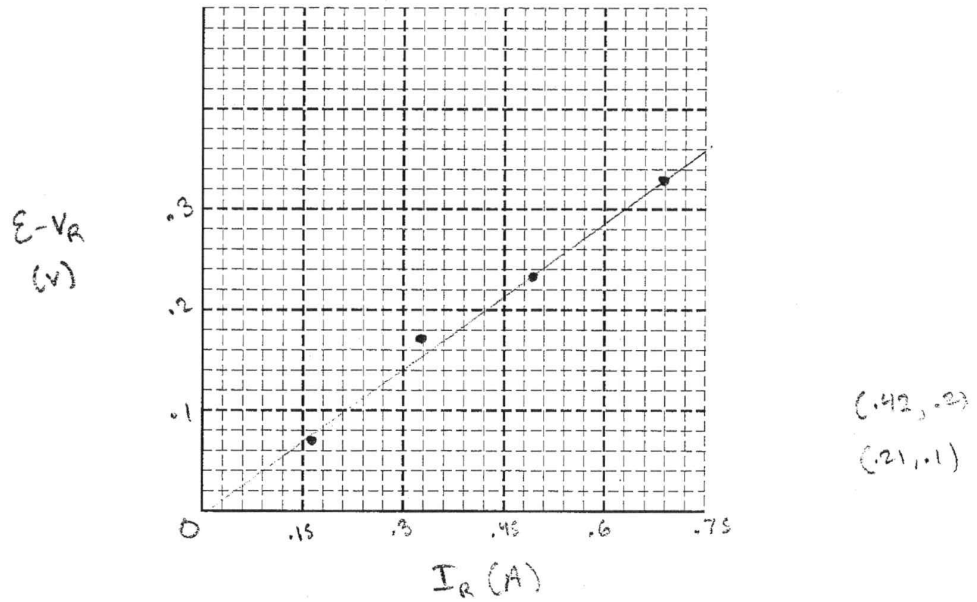
(c) Indicate below which quantities should be graphed to yield a straight line that could be used to calculate a numerical value for the resistance of the wire sample.

Horizontal axis: I_R

Vertical axis: $\mathcal{E} - V_R$

You may use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given.

(d) On the grid below, plot the straight line data points from part (c). Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(e) Use your straight line to calculate the value of the resistance of the wire sample.

$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{.2 - .1}{.42 - .21} = \frac{.1}{.21} = .48\,\Omega$

Question 2 continues on next page.

(f) The wire sample has a length of 3.00 m and a radius of 1.00×10^{-3} m . Calculate the resistivity of the material from which the wire sample is made.

$R = \frac{\rho l}{A}$ $\rho = \frac{RA}{l} = \frac{\pi (1 \cdot 10^{-3} m)^2 (.46 \Omega)}{3m} =$

$1.6 \cdot 10^{-7} \Omega m$

(g)

i. Suppose the ammeter used to collect these data was not ideal. Would the actual value of the resistance of the wire sample be greater than, less than, or equal to that calculated in part (e) ?

✓ Greater than ____ Less than ____ Equal to

Justify your answer.

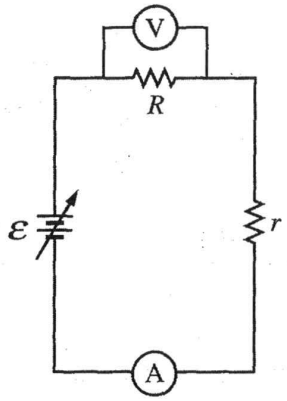
Some of the voltage would be lost when the current travels through the ammeter, so the voltage drop across the wire will be greater than the calculated value.

ii. If the ideal voltmeter is replaced by a voltmeter that is not ideal and the experiment is repeated, would the readings of the ideal ammeter be greater than, less than, or equal to those in the data chart before part (c) ?

____ Greater than ____ Less than ✓ Equal to

Justify your answer.

The voltmeter is in parallel so even if it is not ideal, the current before entering this parallel portion must equal the current leaving the parallel portion, so the ammeter reading will remain the same.



E&M.2.

The circuit shown above consists of a source of variable emf $\mathcal{E}$, an ideal ammeter A, an ideal voltmeter V, a resistor of resistance R, and a sample of wire with resistance r.

(a) How does the current through the wire sample compare with the current through the resistor R ?

_____ It is greater through R.
_____ It is greater through the sample.
__X__ It is the same through both.
_____ It depends on the resistance of the sample.

Justify your answer.

(b) How does the potential difference across the wire sample compare with the potential difference across the resistor R ?

_____ It is greater across R.
_____ It is greater across the sample.
_____ It is the same across both.
__X__ It depends on the resistance of the sample.

Justify your answer.

$V = \frac{kq}{r} = IR$

Since the same current goes through both, the potential is dependent on the resistance.

With the sample of wire in place, the emf of the source is set to a given value. The current through and potential difference across the resistor R are measured. This is repeated for several values of emf, and the data are recorded in the table below.

ε (V)	V_R (V)	I_R (A)		
0.250	0.179	0.162		
0.500	0.335	0.327		
0.750	0.520	0.490		
1.000	0.670	0.687		

(c) Indicate below which quantities should be graphed to yield a straight line that could be used to calculate a numerical value for the resistance of the wire sample.

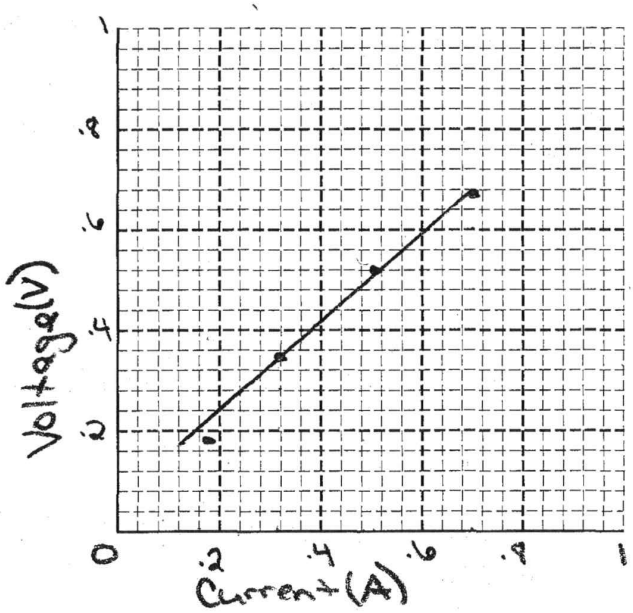
$R = \frac{V}{I}$

Horizontal axis: Current

Vertical axis: Voltage

You may use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given.

(d) On the grid below, plot the straight line data points from part (c). Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(e) Use your straight line to calculate the value of the resistance of the wire sample.

$R = \frac{\Delta V}{\Delta I} = \frac{.670 - .179}{.687 - .162} = .935\,\Omega$

Question 2 continues on next page.

(f) The wire sample has a length of 3.00 m and a radius of 1.00×10^{-3} m . Calculate the resistivity of the material from which the wire sample is made.

$E = \rho J$

(g)

i. Suppose the ammeter used to collect these data was not ideal. Would the actual value of the resistance of the wire sample be greater than, less than, or equal to that calculated in part (e) ?

__X__ Greater than ____ Less than ____ Equal to $V = IR$ $I = \frac{V}{R}$ $R = \frac{V}{I}$

Justify your answer.

If the ammeter is not ideal, the value for current will decrease. If current decreases, resistance increases since $R = \frac{V}{I}$.

ii. If the ideal voltmeter is replaced by a voltmeter that is not ideal and the experiment is repeated, would the readings of the ideal ammeter be greater than, less than, or equal to those in the data chart before part (c) ?

____ Greater than __X__ Less than ____ Equal to $I = \frac{V}{R}$

Justify your answer.

If the voltmeter is not ideal, the recorded voltage will decrease. If voltage decreases, current decreases since $I = \frac{V}{R}$.

AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2016 SCORING COMMENTARY

Question 2

Overview

This problem explored the relationship between resistance, voltage, and current in a simple circuit, and the means of experimentally verifying the relationships. The concepts stressed are the relationship between voltage, current, and resistance; the relationship between resistance and resistivity; the effects of a nonideal voltmeter and a nonideal ammeter on a circuit; and the experimental means to determine the resistance of an unknown resistor in a circuit.

Sample: E Q2 A
Score: 15

Part (a) earned 2 points for selecting "It is the same through both" and explaining that resistors in series will have the same current. Part (b) earned 2 points for selecting "It depends on the resistance of the sample," a correct justification using Ohm's law, and the voltage drop across resistors. Part (c) earned 1 point for listing the correct quantities to graph. Part (d) earned 3 points for the proper scale, labels, and units; correctly plotting the data; and for an appropriate best-fit straight line. Part (e) earned 2 points for calculating the slope of the line (and not using data points) and relating the slope to "r." Part (f) earned 1 point for correctly substituting into the formula for resistivity. Part (g)(i) earned 2 points for selecting "less than" and a justification describing how the resistance of the ammeter affects the circuit. Part (g)(ii) earned 2 points for selecting "greater than" and a justification describing how the resistance of the voltmeter affects the circuit.

Sample: E Q2 B
Score: 10

Parts (a), (b), (c), and (d) earned full credit. Part (e) earned 1 point for calculating the slope of the line, but there is no indication that the slope is related to "r." Part (f) earned 1 point for correctly substituting the answer from part (e) into the formula for resistivity. Both parts (g)(i) and (g)(ii) earned no credit for selecting the wrong answers.

Sample: E Q2 C
Score: 6

Part (a) earned 1 point for selecting "It is the same through both," but there is no justification. Part (b) earned full credit. Part (c) earned no credit for indicating incorrect quantities to graph. Part (d) earned full credit (even though the quantities chosen are not correct, all three graphing points can still be earned). Part (e) earned no credit for calculating the slope because data points are used, and the slope is not related to "r." Part (f) earned no credit because there is no substitution into the formula for resistivity. Both parts (g)(i) and (g)(ii) earned no credit for selecting the wrong answers.