Question 3: Quantitative/Qualitative Translation — 12 points

(a)(i) For correctly determining the total resistance R_{total} of the circuit — **1 point**

Example Response

$$R_{\text{total}} = \frac{5R}{3}$$

For a multi-step derivation that includes correct substitutions of $\mathcal{E}$ and R_{total} into the equation that describes Ohm's law, consistent with the first point of part (a)(i) — **1 point**

Example Response

$$I_1 = \frac{3\mathcal{E}}{5R}$$

Example Solution

Determine the total resistance of the circuit.

The resistance of the right-most branch containing resistors connected in series:

$$R_s = \sum_i R_i$$
$$R_s = R + R$$
$$R_s = 2R$$

The resistance of parallel branches that contain resistors:

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$
$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{2R} = \frac{3}{2R}$$
$$R_p = \frac{2R}{3}$$

The total resistance of the circuit:

$$R_s = \sum_i R_i$$
$$R_{\text{total}} = R + \frac{2R}{3} = \frac{5R}{3}$$

The total current in the circuit:

$$I = \frac{\Delta V}{R} = \frac{3\mathcal{E}}{5R}$$

(a)(ii) For applying a result of Kirchhoff's law and/or Ohm's law that relates the current in R_3 to **one** of the following: **1 point**

- The current in or potential difference across R_1
- The current in or potential difference across R_2
- The potential difference across R_3

Example Responses

One-third of the total current in the circuit is in R_3*:* $I_3 = \frac{I_1}{3}$

OR

$I_1 = I_2 + I_3$

OR

$\Delta V_2 = \Delta V_3 + \Delta V_4$

For a correct expression from a multi-step derivation that is consistent with the final expression in part (a)(i) **1 point**

Example Response

$I = \frac{\mathcal{E}}{5R}$

Example Solutions

$I_1 = I_2 + I_3$

$\Delta V_2 = \Delta V_3 + \Delta V_4$
$I_2 R_2 = I_3(R_3 + R_4)$
$I_2 R = I_3(2R)$
$I_2 = 2I_3$

$I_1 = 2I_3 + I_3$
$I_3 = \frac{I_1}{3}$

$I_3 = \frac{\left(\frac{3\mathcal{E}}{5R}\right)}{3}$
$I_3 = \frac{\mathcal{E}}{5R}$

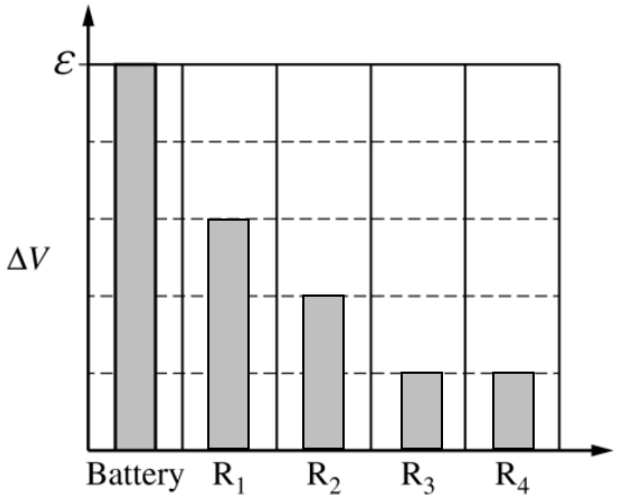
OR

One-third of the total current in the circuit is in R_3*. Therefore,* $I_3 = \frac{\mathcal{E}}{5R}$.

Total for part (a) 4 points

(b)	For drawing a bar that indicates that the potential difference across R_3 is nonzero and is equal to the potential difference across R_4	**1 point**
	For drawing a bar that indicates that the potential difference across R_2 is nonzero and is equal to the sum of the potential differences across R_3 and R_4	**1 point**
	For drawing all bars correctly	**1 point**

Example Response



Total for part (b) 3 points

(c) For indicating that the equation is correct or incorrect, consistent with the derivations in part (a) or the bar chart from part (b), with an attempt at a relevant justification **1 point**

For a justification that correctly relates P to at least **one** of the following: **1 point**

- The potential difference across the battery
- The current in the battery
- R_1, R_2, R_3, and R_4

For a justification that relates the equation $P = \frac{3\mathcal{E}^2}{5R}$ to at least **one** of the following: **1 point**

- The bar chart from the response in part (b)
- The derivations in the responses to parts (a)(i) and (a)(ii)

Scoring Note: The justification must be consistent with the derivations in part (a) or the bar chart from part (b).

Example Solution

The equation is correct. The equation for P, which is power, can be written as $P = \frac{(\Delta V)^2}{R}$. According to the bar chart in part (b), the potential difference across the battery is $\mathcal{E}$. The total resistance of the circuit is $\frac{5R}{3}$, according to the derivation from part (a)(i). Therefore, $P = \frac{(\Delta V)^2}{R} = \frac{(\mathcal{E})^2}{\left(\frac{5R}{3}\right)} = \frac{3\mathcal{E}^2}{5R}$.

Total for part (c) 3 points

(d) For selecting that $P_{\text{new}} < P_{\text{original}}$ with an attempt at a relevant justification **1 point**

For a correct justification that indicates at least **one** of the following: **1 point**

- The current in R_1 is less in the new circuit than in the original circuit
- The potential difference across R_1 is less in the new circuit than in the original circuit

Example Response

$P_{\text{new}} < P_{\text{original}}$. Since the emf *of the battery is the same in the new circuit and the total resistance of the new circuit is greater, the current in R_1 is less in the new circuit. Therefore, P_{new} is less than P_{original}.*

Total for part (d) 2 points

Total for question 3 12 points

Question 3: Quantitative/Qualitative Translation — 12 points

(a)	For indicating that the magnetic field needs to double in order to double the force (since the force equals qvB)	**1 point**
	For correctly explaining why the magnitude of the current must double, without any incorrect statements	**1 point**
	For indicating that the current must go in the opposite direction, i.e. be negative	**1 point**
	Example response for part (a) *The current must change direction and double in magnitude. The graph shows that when the current doubles the magnetic field doubles. When the magnetic field doubles, the magnetic force doubles. Reversing the direction of the current will reverse the direction of the magnetic field, and therefore the direction of the force.*	
	Total for part (a)	**3 points**
(b)	For indicating that the emf is the same	**1 point**
	For indicating that larger resistance and/or less current means less power, without making any incorrect statements	**1 point**
	For indicating that the slope between t_1 and t_3 is less, or the horizontal line segment at right would be below the one shown	**1 point**
	Example response for part (b) *The slope of the energy vs. time graph represents power. Because the induced emf is the same, but resistance is higher, power is lower. Therefore, the slope would be smaller.*	
	Total for part (b)	**3 points**
(c)	For indicating that the greater change in magnetic field means a greater change in magnetic flux or a larger emf	**1 point**
	For indicating that power increases with increasing emf so the power and thus the energy dissipated is greater, or for an answer that is consistent with the response to the previous point in (c).	**1 point**
	For indicating that the slope between t_1 and t_3 is greater, or the horizontal line segment at right would be above the one shown, or for an answer that is consistent with the response to the first point in (c)	**1 point**
	Example response for part (c) *The induced emf is larger than it was before because the magnetic field changed by a larger amount in the same time period. Power is proportional to the square of the emf, so the power is larger. Power is the slope of energy vs time, so the slope is greater for the new graph.*	
	Total for part (c)	**3 points**
(d)	For any indication the cumulative energy dissipated depends on the time elapsed	**1 point**
	For indicating that the emf depends on the rate of change of the magnetic flux, i.e., it is inversely proportional to the time elapsed	**1 point**
	For indicating that the power is proportional to the square of the emf and the energy dissipated is power times time, so energy is inversely proportional to the time	**1 point**
	Total for part (d)	**3 points**
	Total for question 3	**12 points**

AP® Physics 2
2015 Scoring Guidelines

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2015 SCORING GUIDELINES

Question 1

10 points total **Distribution of points**

(a) 5 points

For explaining that the light that results in spot X reflects at the glass-liquid interface — 1 point

For explaining that the light that results in spot Y is refracted both as it leaves the glass and reenters the glass (direction of refraction need not be correct) — 1 point

For explaining that the light that results in spot Y is reflected at the liquid-air interface — 1 point

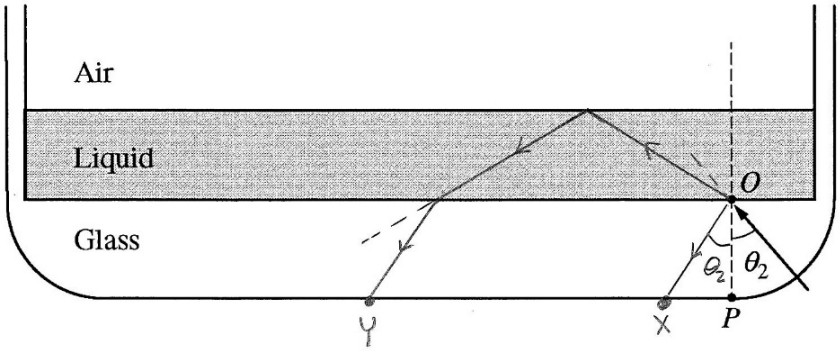
For explaining that Y is farther from P than X in terms of the geometry of the path — 1 point

For explaining that at each interface the brightness is affected by reflection, and by transmission and/or refraction as appropriate — 1 point

Students may reference a diagram to support the reasoning, but it cannot supplant the written reasoning.

(b)

i) 2 points



For drawing a reasonably accurate path for the rays that form spot X — 1 point

For drawing a reasonably accurate path for the rays that form spot Y, including correct directions of refraction, with no rays in the air — 1 point

ii) 1 point

For indicating that Y becomes brighter in terms of the distribution of energy with and without total internal reflection — 1 point

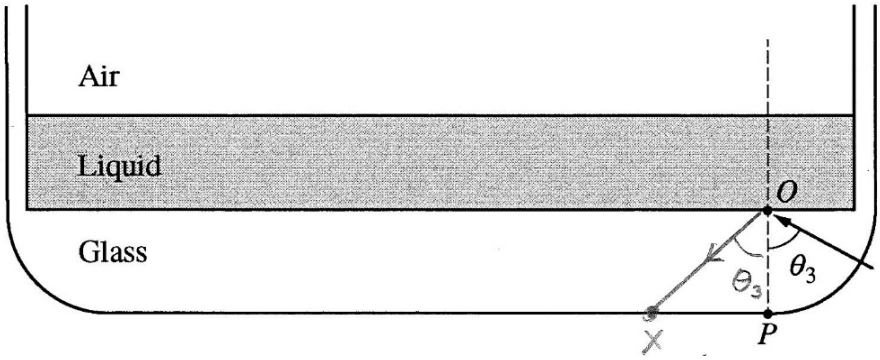
2015 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(c)

i) 1 point



For drawing rays to show reflection at the glass-liquid interface — 1 point
One point will be deducted for drawing any rays above the glass-liquid interface.

ii) 1 point

For indicating that Y disappears and indicating that total internal reflection takes place at the glass-liquid interface — 1 point

2015 SCORING GUIDELINES

Question 2

12 points total **Distribution of points**

(a)

i) 3 points

For indicating that R_{eq} of the entire circuit or the combination of bulbs 2 and 3 decreases — 1 point

For indicating a change in I_{tot} or the potential difference across bulb 1 consistent with Ohm's law and the change in R_{eq} stated in the response — 1 point

For indicating a change in brightness consistent with the current or potential difference change stated in the response — 1 point

ii) 3 points

For indicating that $P_1 = \frac{1}{4}\left(\varepsilon^2/R\right)$ — 1 point

For indicating that the new equivalent resistance of the circuit is $R_{eq,new} = (3/2)R$ — 1 point

Note: Credit is earned if calculation is done in part (i) and used here.

For manipulating equations to show that the power expended by bulb 1 is $P_{new} = \frac{16}{9}P_1$ — 1 point

iii) 1 point

For using or referring to the expression from part (a)(ii) to support the claim made in (a)(i) regarding the brightness of bulb 1: e.g., $16/9 > 1$, and indicating an understanding that brightness is related to power consumption — 1 point

(b)

i) 1 point

For explaining that the brightness of bulb 2 decreases after the switch is closed because it expends less power (or the current through bulb 2 decreases, or the potential difference across bulb 2 decreases) — 1 point

ii) 1 point

For a calculation that supports the reasoning in part i — 1 point

2015 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(c) 3 points

For indicating in either part (c)i or part (c)ii that brightness is dependent on potential difference across the bulb OR on current through the bulb — 1 point

i)

For a reasonable explanation for why bulb 1 is brighter than bulb 2 — 1 point

Example: Immediately after the switch is closed, the potential difference across the capacitor will be zero (like a short in the circuit), so the current through bulb 2 would be zero, which is less than the current through bulb 1.

Note: No points will be awarded for indicating that bulb1 is brighter than bulb 2 with no justification.

ii)

For a reasonable explanation for why bulb 1 is the same brightness as bulb 2 — 1 point

Example: The current through bulb 2 increases as the potential difference across the capacitor increases (becomes like an open circuit), so a long time after the switch is closed, the current through bulb 2 will be equal to the full current through bulb 1.

Note: No points will be awarded for indicating that bulb 1 is the same brightness as bulb 2 without a justification.

2015 SCORING GUIDELINES

Question 3

12 points total **Distribution of points**

(a) 2 points

For indicating that the ideal gas law ($PV = nRT$ or $PV = NkT$) gives the relevant relationship between pressure and temperature of a gas and attempting to use it to support some reasoning — 1 point

For indicating that the volume and number of moles (or particles) of gas are held constant — 1 point

Note: The student will not be penalized for not specifying that pressure and temperature are only directly proportional when the temperature is measured in Kelvin.

Alternate Solution — *Alternate Points*

For indicating that the density of a sample of gas increases as its temperature decreases (if the pressure and number of moles or molecules of gas are held constant), and a sample of denser gas will sink below samples of gas that are less dense — *1 point*

For indicating that the gas near the North Pole is not a closed system and its pressure will increase as additional sinking gas molecules are added to it — *1 point*

(b) 4 points

For selecting one of the cylinders and indicating or implying that volume is held constant — 1 point

For selecting all the equipment described in the procedure and no extraneous equipment — 1 point

For describing a method of measuring the temperature of the enclosed gas — 1 point

For describing a method for measuring the pressure at more than just two temperatures — 1 point

Example: Insert the thermometer and pressure sensor in the gasket to measure the gas temperature and pressure. Place the cylinder in the bath with hot (cold) water. Take measurements periodically as the bath water cools (heats) over time.

2015 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(c) 2 points

For selecting a set of trials in which volume is held constant and explaining that the volume must be held constant to test the relationship between pressure and temperature — 1 point

For selecting trials in which volume is $5.0\ \text{cm}^3$, and explaining that there are the most trials for this volume, and the most trials will result in the most reliable test — 1 point

Alternate Solution — *Alternate points*

For selecting the full set of trials and explaining that the effect of changing volume on the relationship between pressure and temperature can be taken into account by multiplying pressure by volume (or plotting P/T as a function of $1/V$, etc.) — *1 point*

For explaining that selecting the most trials will result in the most reliable test OR that selecting the widest range of pressure values will result in the most precise determination of the proportionality constant relating pressure and temperature — *1 point*

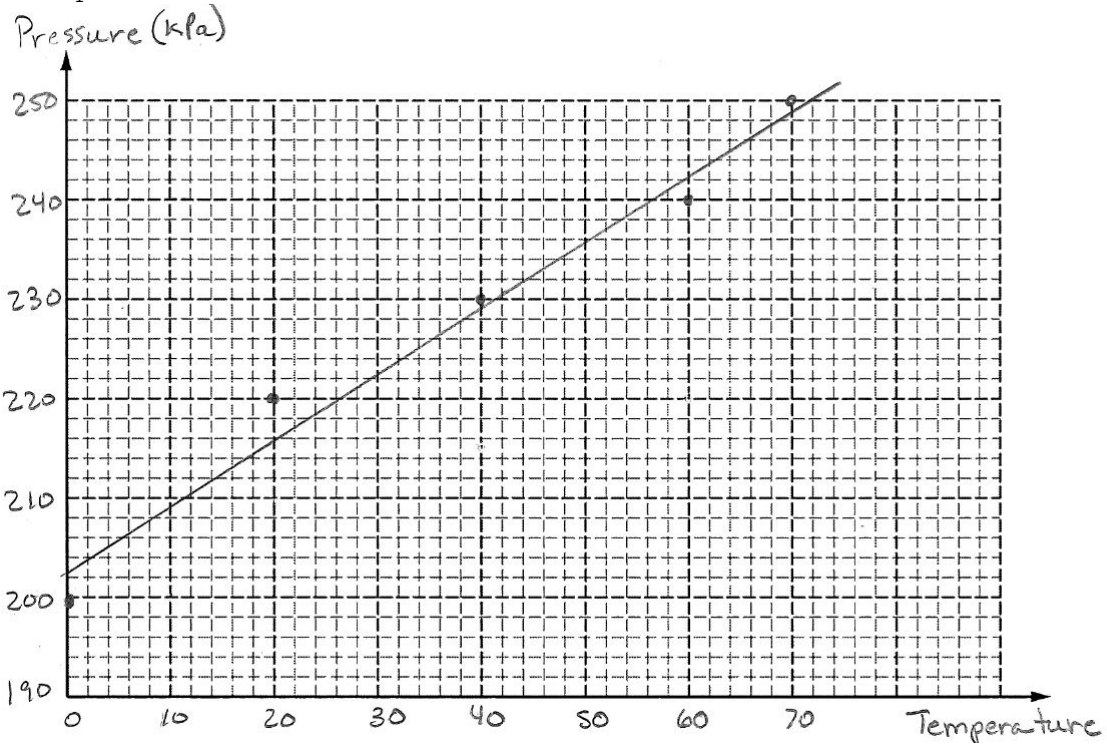
(d) 3 points

For plotting P as a function of T (or T as a function of $1/P$, etc.) OR plotting PV as a function of T (or P as a function of V/T, etc.) for each trial selected in part (c) — 1 point

For appropriate axis labels with units and appropriate scales — 1 point

For drawing an appropriate best-fit line or curve — 1 point

Example:



2015 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(e) 1 point

For correctly describing the relationship depicted in part (d) 1 point

Examples:

The relationship between P and T is linear.

The relationship between P and V/T is hyperbolic.

2015 SCORING GUIDELINES

Question 4

10 points total **Distribution of points**

(a) 2 points

The top plate is negative.
For relating the direction of force or acceleration to the direction of the field — 1 point
For relating the direction of the electric field to the sign of the charge on the top plate — 1 point
No points are awarded for identifying that the top plate is negative with no attempt to explain why.

(b) 4 points

For using an appropriate kinematic relation to determine the acceleration of the electron while it is between the plates — 1 point

$a = (v_f - v_i)/t$

For using Newton's second law to determine an expression for the magnitude of the force needed to give the electron the calculated acceleration — 1 point

$F = ma = m(v_f - v_i)/t$

For setting eE equal to the force calculated from Newton's second law — 1 point

For correctly manipulating equations to solve for the magnitude of the electric field and arriving at a correct numerical answer with units — 1 point

$E = m(v_f - v_i)/et$

$$E = \frac{(9.11 \times 10^{-31}\ \text{kg})(8.02 \times 10^{6}\ \text{m/s} - 5.40 \times 10^{6}\ \text{m/s})}{(1.6 \times 10^{-19}\ \text{C})(1.49 \times 10^{-9}\text{s})} = 10{,}000\ \text{N/C}$$

Alternate Solution *Alternate Points*

For applying conservation of energy for the time the electron is between the plates — *1 point*

$\Delta K = \Delta U$

For using the correct relationship between potential energy and potential difference — *1 point*

$\Delta U = e\,\Delta V$

$\frac{1}{2} m_e (v_f^2 - v_i^2) = e\,\Delta V$

For using the relation between potential difference, electric field, and plate separation — *1 point*

$\Delta V = Ed$

$\frac{1}{2} m_e (v_f^2 - v_i^2) = eEd$

For correctly manipulating equations to solve for the magnitude of the electric field and arriving at a correct numerical answer with units — *1 point*

$E = m_e (v_f^2 - v_i^2)/2ed$

$$E = \frac{(9.11 \times 10^{-31})\left((8.02 \times 10^{6}\ \text{m/s})^2 - (5.40 \times 10^{6}\ \text{m/s})^2\right)}{2(1.6 \times 10^{-19}\ \text{C})(0.010\ \text{m})} = 10{,}000\ \text{N/C}$$

2015 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(c) 1 point

$E = Q/\varepsilon_0 A$

$Q = \varepsilon_0 AE$

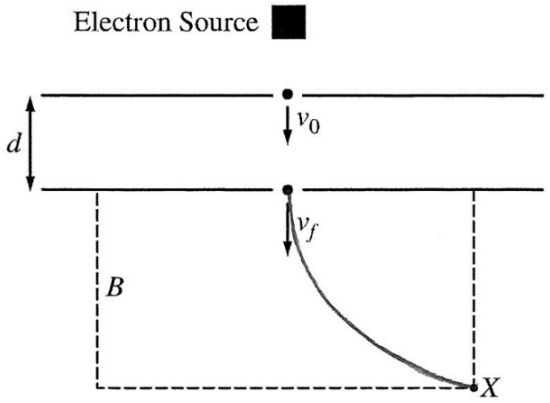
For correct substitution of values into the equation to calculate the magnitude of charge on each parallel plate — 1 point

$Q = \left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(0.25\ \text{m}^2\right)(10{,}000\ \text{N/C})$

$Q = 2.2 \times 10^{-8}\ \text{C}$

(d)

i. 2 points



Note: Figure not drawn to scale.

For drawing a reasonably circular path from the point where the electrons leave the bottom plate to point X — 1 point

Note: There is no penalty for starting the path at the tip of the arrow.

For explaining that the field is always perpendicular to the velocity, so the force is also always perpendicular to the velocity which creates a curved (circular) path — 1 point

ii. 1 point

In order for the electron to reach point X, the magnetic field must exert a centripetal force on the electron toward the top right corner of the dashed box.

For using the right hand rule and reasoning that the force on a negatively charged object is in the opposite direction from the force exerted on a positively charged object (or using the "left hand rule") to conclude that the direction of the magnetic field is directed out of the page — 1 point

Notes:

No points are awarded for identifying that the direction of the magnetic field is out of the page without explaining why.

Credit can be earned for a correct analysis at any individual point on the path.