Question 3: Experimental Design and Analysis (LAB) — 10 points

A

For a procedure that includes **both** of the following measurements: — **Point A1**

- The dimensions of the capacitor
- A current

For a procedure that indicates an appropriate method of reducing experimental uncertainty (e.g., Repeat the procedure multiple times.) — **Point A2**

Example Responses

Measure the length of one side of a capacitor plate. Measure the separation distance between the plates. Construct a circuit that includes the battery and the resistor. Measure the current in the resistor. Repeat measurements of current in the resistor for the described closed circuit.

Measure the length of one side of a capacitor plate. Measure the separation distance between the plates. Construct a circuit that includes the battery, resistor, and capacitor. Measure the initial current in the resistor after the closed circuit is constructed. Disconnect the capacitor from the circuit, discharge the capacitor, and repeat the procedure.

B

For indicating that $\tau = R_{eq}C_{eq}$ can be used to calculate τ — **Point B1**

For **both** of the following: — **Point B2**

- A correct relationship between resistance, the emf of the battery, and current (e.g., $R_{eq} = \frac{\mathcal{E}}{I}$)
- A correct relationship between capacitance, the area of a capacitor plate, and the distance between the capacitor plates (e.g., $C_{eq} = \varepsilon_0 \frac{A}{d}$)

Example Responses

$\tau = R_{eq}C_{eq}$ can be used to determine τ. R_{eq} can be determined by using $R_{eq} = \frac{\mathcal{E}}{I}$, where I is the current in the resistor when the resistor is connected to the battery. C_{eq} can be determined by using $C_{eq} = \varepsilon_0 \frac{A}{d}$, where d is the distance between the capacitor plates and A is the square of the length of a capacitor plate.

$\tau = R_{eq}C_{eq}$ can be used to determine τ. R_{eq} can be determined by using $R_{eq} = \frac{\mathcal{E}}{I}$, where I is the initial current in the resistor when the resistor is connected in series with the battery and the capacitor. C_{eq} can be determined by using $C_{eq} = \varepsilon_0 \frac{A}{d}$, where d is the distance between the capacitor plates and A is the square of the length of a capacitor plate.

C	**(i)**	For indicating appropriate quantities that can be plotted to produce a linear graph to determine C **Scoring Note:** Any response that correctly identifies the functional dependence between varied quantities earns this point, regardless of any coefficients that contain numbers or physical/fundamental constants, or which axis is chosen to graph each of those quantities.	**Point C1**

Example Responses

q *as a function of* $|\Delta V|$

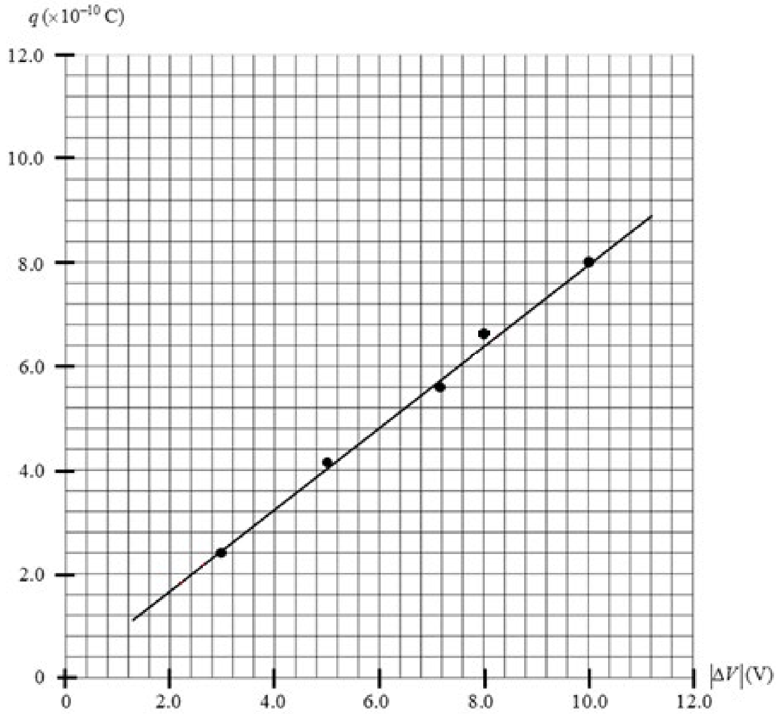
$|\Delta V|$ *as a function of* q

$\dfrac{1}{q}$ *as a function of* $\dfrac{1}{|\Delta V|}$

$\dfrac{1}{|\Delta V|}$ *as a function of* $\dfrac{1}{q}$

(ii)	For labeling the axes (including units) with a linear scale	**Point C2**
	For correctly plotting the data points, consistent with **one** of the following: • The quantities indicated in part C (i) • The quantities provided in the table • The axes indicated in point C2	**Point C3**
(iii)	For drawing a line or curve that approximates the trend of the plotted data	**Point C4**

Example Response



D

For correctly relating the slope of the straight line graph to $q = C|\Delta V|$ or a correct equation that is consistent with an appropriate graph that can be used to determine C (e.g., $\frac{\Delta q}{\Delta|\Delta V|} = \text{slope} = C$) **Point D1**

Example Responses

The slope of q *as a function of* $|\Delta V|$ *is C.*

The slope of $|\Delta V|$ *as a function of q is* $\frac{1}{C}$.

The slope of $\frac{1}{q}$ *as a function of* $\frac{1}{|\Delta V|}$ *is* $\frac{1}{C}$.

The slope of $\frac{1}{|\Delta V|}$ *as a function of* $\frac{1}{q}$ *is C.*

For a value for C that is approximately equal to 8×10^{-11} F, within the range $7 \times 10^{-11}\ \text{F} \le C \le 9 \times 10^{-11}\ \text{F}$ **Point D2**

Scoring Notes:

- If the slope of the plotted data points is equal to the quantity that is supposed to be determined, a correct, isolated final value earns points D1 and D2.
- If the slope of the plotted data points is not equal to the quantity that is supposed to be determined, a correct, isolated final value earns point D2 only.

Example Response

$$\text{slope} = \frac{\Delta q}{\Delta|\Delta V|}$$

$$\frac{\Delta q}{\Delta|\Delta V|} = \frac{(6.4 \times 10^{-10}\ \text{C}) - (2.0 \times 10^{-10}\ \text{C})}{8.0\ \text{V} - 2.4\text{V}}$$

$$\frac{\Delta q}{\Delta|\Delta V|} = 7.9 \times 10^{-11}\ \frac{\text{C}}{\text{V}}$$

$$C = \frac{Q}{\Delta V}$$

$$q = C|\Delta V|$$

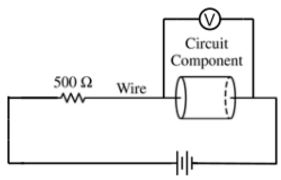
$$\text{slope} = C$$

$$C \approx 8 \times 10^{-11}\ \text{F}$$

Question 2: Experimental Design **12 points**

(a)(i)	For a diagram including a source of potential difference (e.g., battery, power supply) that is in a complete circuit that results in a current in the unknown circuit component	**1 point**
	For a diagram including a measurement device that is appropriately connected in the circuit (e.g., voltmeter, ammeter) **Scoring Note:** A lightbulb that is connected in series with the circuit component is an acceptable alternative for an ammeter.	**1 point**

Example Responses



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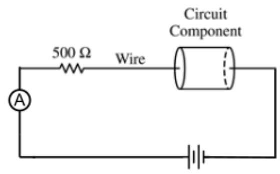

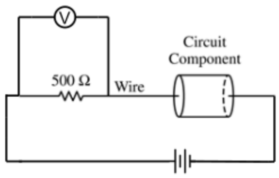

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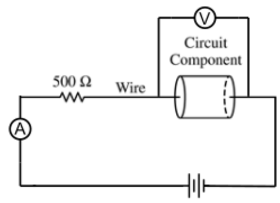

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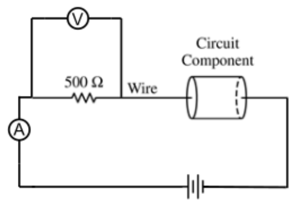


(a)(ii)	For describing a procedure that includes a measurement of **one** of the following: • The potential difference across the circuit component • The current in the circuit • The potential difference across the known resistor	**1 point**
	For taking measurements at two different times after the circuit is closed or taking one measurement a long time after the circuit is closed, consistent with the procedure described	**1 point**

Example Responses

Measure the current in the ammeter immediately after the circuit is closed and a long time after the circuit is closed.

OR

Measure the potential difference across the circuit component immediately after the circuit is closed and a long time after the circuit is closed.

OR

Measure the potential difference across the circuit component a long time after the circuit is closed.

OR

Measure the potential difference across the $500\ \Omega$ *resistor immediately after the circuit is closed and a long time after the circuit is closed.*

(a)(iii)	For describing a correct result of the experiment that indicates the current in the circuit decreases to zero over time or that the charge of the plates of the capacitor increases over time	**1 point**
	For describing a correct result of the experiment that indicates that the electric potential difference across the capacitor increases from zero over time	**1 point**

Example Response

Immediately after the circuit has been closed, a current should be measured. A long time after the circuit has been closed, a current of zero should be measured. This is because the initially uncharged capacitor becomes fully charged. This results in a potential difference across the capacitor that is equal to the potential difference across the battery a long time after the circuit has been closed. Therefore, according to Kirchhoff's loop rule, a potential difference will not be measured across any other circuit components.

Total for part (a) 6 points

(b)(i)	For an equation that correctly applies the loop rule	**1 point**

Example Response

$0 = +\varepsilon - Ir - IR_{\text{var}}$

(b)(ii)	For indicating appropriate quantities that, when graphed, result in a linear graph that allow students to determine emf ε	**1 point**

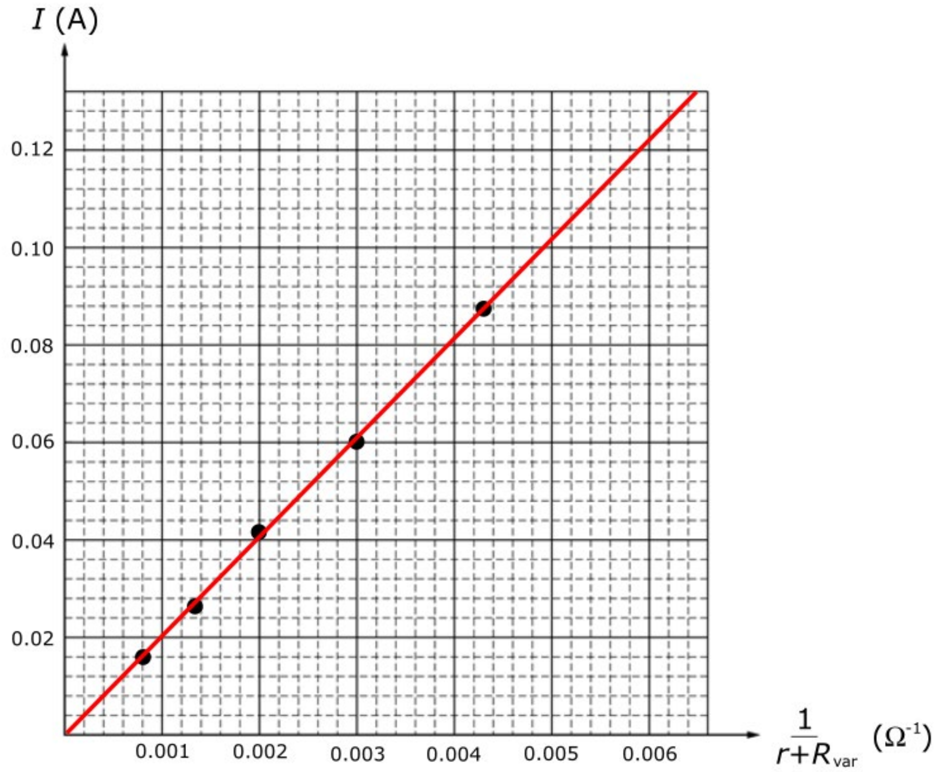
Example Responses

- $\dfrac{1}{r + R_{\text{var}}}$ *vs.* I
- I *vs.* IR_{var}
- R_{var} *vs.* $\dfrac{1}{I}$

(b)(iii)	For including numerical values on both axes with a linear scale and labeling the axes with appropriate labels and units	**1 point**
	For a graph in which data are plotted within at least half of the grid area	**1 point**

For drawing a best-fit line that approximates the trend of the data **1 point**

Example Responses



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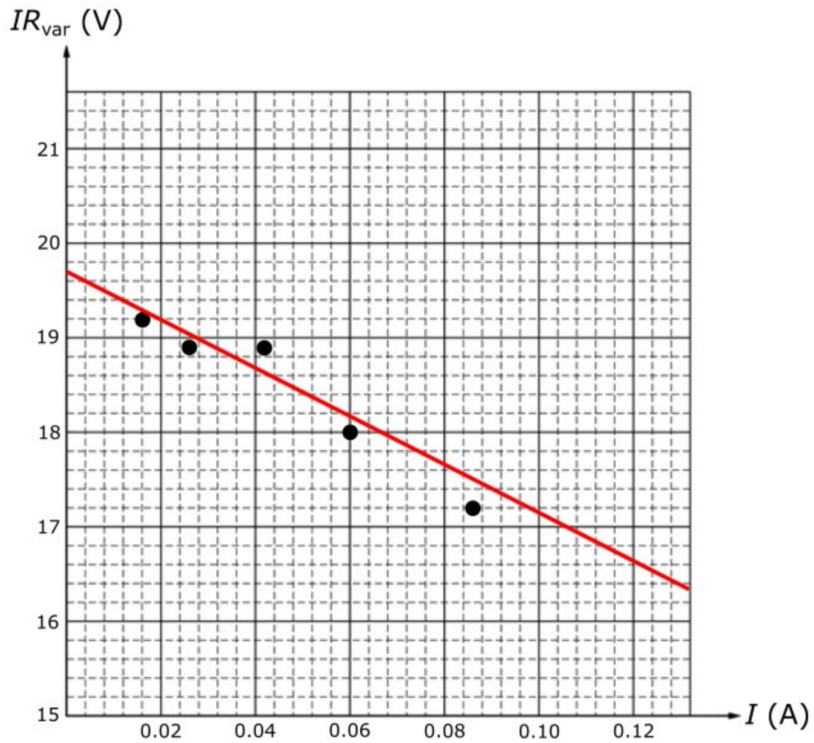


(b)(iv) For correctly using the graph to determine an experimental value for emf ε, including correct units, between 18.0 V and 22.0 V **1 point**

Example Solutions

I as a function of $\dfrac{1}{r + R_{\text{var}}}$

$$\varepsilon - Ir - IR_{\text{var}} = 0$$
$$\varepsilon - I(r + R_{\text{var}}) = 0$$
$$I(r + R_{\text{var}}) = \varepsilon$$
$$I = \varepsilon\left(\frac{1}{r + R_{\text{var}}}\right)$$
$$I = \varepsilon\left(\frac{1}{30\ \Omega + R_{\text{var}}}\right)$$
$$\text{Slope} = \varepsilon$$
$$\frac{\Delta y}{\Delta x} = \varepsilon$$
$$\frac{(0.08\text{ A} - 0.04\text{ A})}{\left(0.004\ \Omega^{-1} - 0.002\ \Omega^{-1}\right)} \approx \varepsilon$$
$$\varepsilon \approx 20\text{ V}$$

OR

IR_{var} as a function of I

$$\varepsilon - Ir - IR_{\text{var}} = 0$$
$$\varepsilon - Ir = IR_{\text{var}}$$
$$IR_{\text{var}} = -Ir + \varepsilon$$
$$y\text{-intercept} = \varepsilon$$
$$\varepsilon \approx 20\text{ V}$$

Total for part (b) 6 points

Total for question 2 12 points

Question 2: Experimental Design — 12 points

(a) For a correct ranking — **1 point**

__1__ ΔV_A __1__ ΔV_B __3__ ΔV_C __2__ ΔV_D

For indicating that the resistors in parallel will have the same potential difference — **1 point**

For a justification that indicates $\Delta V_D > \Delta V_C$ because $R_D = 2R_C$ — **1 point**

Total for part (a) — 3 points

(b)(i) For calculating the correct value of the charge on the $200\,\mu\text{F}$ capacitor, including units — **1 point**

Example Response

$$\Delta V = \frac{Q}{C}$$

$$Q = C\Delta V = (200\,\mu\text{F})(0.91\text{ V})$$

$$Q = 1.82 \times 10^{-4}\text{ C}$$

(b)(ii) For indicating one of the following as evidence that the capacitors are in series: — **1 point**

- the potential differences across the capacitors are different
- the sum of the potential differences across the capacitors is constant
- the sum of the potential differences across the capacitors is approximately equal to the potential difference across the battery

(b)(iii) For an explanation that correctly addresses one of the following: — **1 point**

- that the potential differences across the known and unknown capacitor will always be the same
- that the charge on the unknown capacitor cannot be determined

Example Response

Both charge and potential difference across the capacitor are needed to determine C. Arranging the capacitors in parallel will mean both capacitors will have the same potential difference. However, capacitors in parallel will have differing amounts of charge, making it impossible to determine the charge, and, therefore, the capacitance of the unknown capacitor.

Total for part (b) — 3 points

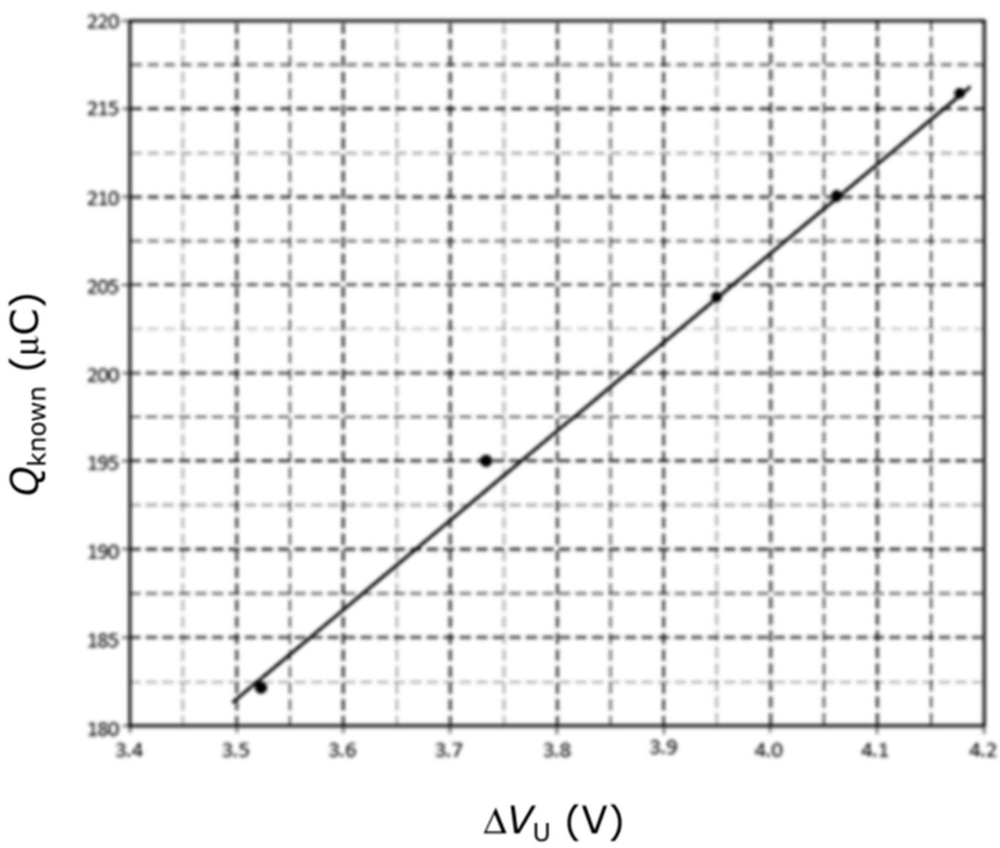
(c)(i)	For choosing two quantities that will produce a linear plot that can be used to find C_U	**1 point**

Example Responses

- Q_{known} ($C_{known}\Delta V_{known}$) and ΔV_U
- Q_U and ΔV_U
- C_{known} and $\dfrac{\Delta V_U}{\Delta V_{known}}$

(c)(ii)	For labeling the axes and including appropriate units consistent with Part (c)(i)	**1 point**
	For correctly plotting points (with valid scaling consistent with units) so that the plotted points cover at least half of the grid's width and height	**1 point**
	For drawing an appropriate linear best-fit line	**1 point**

Example Response



(c)(iii)	For using points on the best-fit line to calculate the slope of the line	**1 point**
	For correctly determining the capacitance from the slope of the line	**1 point**

Example Response

Capacitance is equal to slope

$$C_U = \frac{212\ \mu C - 190\ \mu C}{4.10\ V - 3.67\ V}$$
$$C_U = 51.2\ \mu F$$

Total for part (c) **6 points**

Total for question 2 **12 points**

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Question 1

10 points total | **Distribution of points**

(a)

i. 2 points

For showing the calculation of the force on the piston and a correct answer with units — 1 point

$$F = PA = \left(1.0 \times 10^5 \text{ Pa}\right)\left(5 \times 10^{-3} \text{ m}^2\right) = 500 \text{ N}$$

For explaining the force in terms of gas atom collisions — some change in the atoms' momentum or velocity must be identified to justify a force between atoms and piston — 1 point

Example: The collisions of the gas atoms with the container walls cause a change in the momentum of the gas atoms, which means forces are exerted between the atoms and the piston. Each gas molecule colliding with a wall experiences a force from the wall that changes the molecule's velocity or momentum.

ii. 2 points

For showing the calculation of the temperature and a correct answer with units — 1 point

$$PV = nRT$$

$$T = PV/nR = \left(1.0 \times 10^5 \text{ Pa}\right)\left(0.10 \text{ m}^3\right)/(2)(8.31 \text{ J/mol•K}) = 602 \text{ K}$$

For indicating that temperature characterizes the average speed or average kinetic energy or RMS velocity of the molecules — 1 point

(b)

i. 2 points

For identifying that the temperature increases due to increasing volume and constant pressure — 1 point

For relating temperature change with internal energy change — 1 point

Example: Because the volume increases at a constant pressure, the temperature goes up because $PV = nRT$. Increasing temperature means increasing average kinetic energy or total internal energy.

ii. 3 points

For calculating the work done in process ABC (i.e., the area under the line) — 1 point

$$W_{AB} = -\left(1.0 \times 10^5 \text{ Pa}\right)\left(0.10 \text{ m}^3 - 0.04 \text{ m}^3\right) = -6000 \text{ J} \text{ and } W_{BC} = 0$$

For calculating T_A and T_C (or ΔT between the states) and using them to determine internal energy change — 1 point

$$T_A = P_A V_A / nR = \left(1.0 \times 10^5 \text{ Pa}\right)\left(0.04 \text{ m}^3\right)/(2 \text{ mol})(8.31 \text{ J/mol•K}) = 241 \text{ K}$$

$$T_C = P_C V_C / nR = \left(0.5 \times 10^5 \text{ Pa}\right)\left(0.10 \text{ m}^3\right)/(2 \text{ mol})(8.31 \text{ J/mol•K}) = 301 \text{ K}$$

$$\Delta U = \Delta K_{\text{per molecule}} nN_0 = (3/2) k_B \Delta T nN_0$$

$$\Delta U = (3/2)\left(1.38 \times 10^{-23} \text{ J/K}\right)(301 \text{ K} - 241 \text{ K})(2 \text{ mol})\left(6.02 \times 10^{23}\right) = 1500 \text{ J}$$

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Question 1 (continued)

Distribution of points

(b)

ii. (continued)

Alternately, ΔU can be calculated directly from the given data

$\Delta U = (3/2)nR\Delta T = (3/2)(P_C V_C - P_A V_A)$

$= (3/2)\left(\left(0.5 \times 10^5\ \text{Pa}\right)\left(0.10\ \text{m}^3\right) - \left(1.0 \times 10^5\ \text{Pa}\right)\left(0.04\ \text{m}^3\right)\right) = 1500\ \text{J}$

For substituting ΔU and W (whether correct or incorrect) into some form of the first law of thermodynamics to find Q and for including units in a numerical answer — 1 point

$Q = \Delta U - W = 1500\ \text{J} - (-6000\ \text{J})$

$Q = 7500\ \text{J}$

(c) 1 point

For recognizing that the change in kinetic energy for process CA has the same numerical value as ΔU from (b)ii but with the opposite sign OR for calculating ΔK using the correct temperature change or $\Delta K_{\text{total}} = (3/2)nR\,\Delta T$ as shown below — 1 point

$\Delta K_{\text{total}} = (3/2)k_B \Delta T\, nN_0$ or $\Delta K_{\text{total}} = (3/2)nR\,\Delta T$

$\Delta K_{\text{total}} = (3/2)\left(1.38 \times 10^{-23}\ \text{J/K}\right)(241\ \text{K} - 301\ \text{K})(2\ \text{mol})\left(6.02 \times 10^{23}\ \text{mol}^{-1}\right)$

$\Delta K_{\text{total}} = -1500\ \text{J}$

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Question 2

12 points total | **Distribution of points**

(a) 3 points

For graphing angles or functions of angles on the axes	1 point
For plotting sines of angles on the axes and indicating or implying that the index of refraction of air is 1	1 point
For indicating a method to determine the index of refraction of the glass that is consistent with the graph described	1 point

Example: If 1 refers to air and 2 to the glass, use $n_1 \sin\theta_1 = n_2 \sin\theta_2$ and graph $\sin\theta_1$ as a function of $\sin\theta_2$. Because $n_1 = 1$, the slope of the line is n_2.

(b) 4 points

For indicating that the light from the lamp needs to be a beam when it enters the glass (either referring to a beam, explicitly describing how to create a beam, or showing a beam in a diagram)	1 point
For describing some method of determining angles with a protractor (or equivalent tool) in both media at an appropriate boundary	1 point
For using angles with respect to the normal (can measure any angles as long as reference is made to converting them to the correct ones)	1 point
For repeating the measurement at three or more different incidence angles to obtain sufficient data	1 point

(c) 2 points

For indicating that when light travels across the boundary from air to glass, the ray bends toward the normal	1 point
For indicating that the speed of light is slower in glass than in air (or an answer consistent with response for bending of the ray)	1 point

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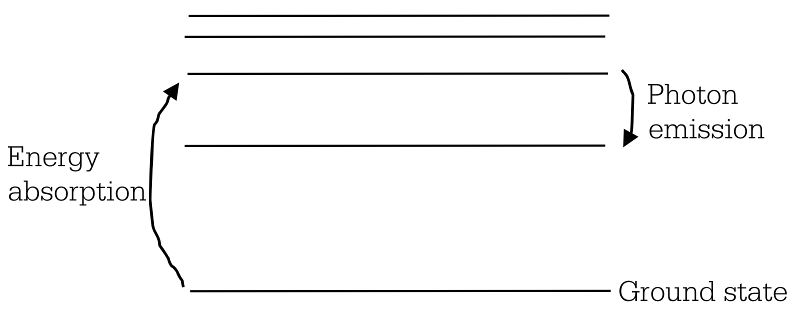
Question 2 (continued)

Distribution of points

(d) 3 points

For an appropriate energy-level diagram showing absorption from the lowest level and emission	1 point
For indicating that a hydrogen atom can be excited from the ground state to a higher energy state by absorbing energy	1 point
For indicating that transitions to lower energy levels cause emission of photons	1 point

Example:



Atoms in the ground state absorb energy from the electricity delivered to the lamp. The atoms enter an excited state. Then the atoms emit photons as they drop to a lower energy state.

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Question 3

12 points total — **Distribution of points**

(a) 1 point

For correctly labeling the magnitude of lines ($A = 60\text{ V}$ and $B = 80\text{ V}$, units not required) and for having the correct signs on each line (either explicit positive signs or no negative signs) — 1 point

(b)

i. 2 points

For indicating that Y has more charge than X with a correct explanation, such as the nearest potential of the same value is farther from Y — 1 point

For indicating X and Y must be the same sign with a correct explanation — 1 point

Examples:

- Field vectors are perpendicular to equipotentials, and the pattern of field vectors indicates that both must have the same sign.
- There is no zero potential line between the spheres, so the potentials from the two charges do not cancel anywhere.

ii. 1 point

For a correct explanation that addresses the charge to mass ratio and distance relationship — 1 point

Example: Both spheres would gravitationally attract a third sphere just like two charges of the same sign would attract a third charge of the opposite sign because both forces are dependent on the distance and also dependent on the product of the charges or masses.

(c) 2 points

For a similarity that does not generally apply to all forces — 1 point

Example: The forces have the same dependence on the distance and are both functions of $1/r^2$.

For a difference that does not generally apply to all forces — 1 point

Examples:

The proton is the same sign as the spheres, so it is electrostatically repelled, but gravity is always attractive. Therefore, the directions of the forces are different.

The forces are different in magnitude.

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Question 3 (continued)

Distribution of points

(d)

i. 2 points

The proton is repelled by both spheres, so it will move toward point A.

For some attempt to apply $\Delta U_E = q\Delta V$ using the given variables — 1 point

For using the correct variables and getting $\Delta U = q(V_A - V_B)$ (no credit for using numeric values of electric potential) — 1 point

ii. 2 points

For using a correct expression for work — 1 point

$W = Fd$ or $-\Delta U_E = q\Delta V$

For a correct expression for F or ΔV in terms of E_{avg} — 1 point

$F_{avg} = qE_{avg}$ or $\Delta V = E_{avg}d$

$W = qE_{avg}d$ (full credit is awarded for just writing the correct expression)

iii. 2 points

For indicating that student 1 is correct and a correct discussion of why — 1 point

Example: Student 1 is correct. Because the system contains all the objects, the energy is transferred from one form to another within the system due to the law of conservation of energy.

For indicating that student 2 is correct and a correct discussion of why — 1 point

Example: Student 2 is correct. Because the system is just the proton, there must be a force external to the system due to the electric field of the two spheres. That force does work on the proton which changes the kinetic energy of the proton.

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Question 4

10 points total — **Distribution of points**

(a)

i. 1 point

For indicating that $I = \mathcal{E}/R$ and $V_C = 0$ — 1 point

Because there is no charge on the capacitor, there is no potential difference across it. Therefore, entire battery potential is across the resistor, so the current is that potential divided by the resistance.

ii. 1 point

For indicating that $I = 0$ and $V_C = \mathcal{E}$ — 1 point

Once the capacitor is fully charged, it allows no current to pass. Because all the components are in series, there is no current at all in the circuit. With no current, there is no potential difference across the resistor, so the entire battery potential is across the capacitor.

(b)

i. 2 points

For a calculation that indicates one of the following: — 1 point

- The potential difference across each capacitor in the new circuit is half that across the single capacitor in the original circuit
- The equivalent capacitance of the new circuit is one-half the capacitance of the original circuit

$U_1 = (1/2)C\mathcal{E}^2$

$U_2 = 2\left[(1/2)C(\mathcal{E}/2)^2\right]$ or $(1/2)(C/2)\mathcal{E}^2$, which both equal $C\mathcal{E}^2/4$

For correctly calculating the ratio — 1 point

$U_1/U_2 = \left(C\mathcal{E}^2/2\right)/\left(C\mathcal{E}^2/4\right) = 2$

ii. 1 point

For any combination of area and spacing that is consistent with the student's answer for the ratio in part (b)(i), with a proper principle or model as support — 1 point

Example: $U = (1/2)CV^2$. The potential difference across each of the single capacitors is the same. For the energy stored in the single new capacitor to be half that of the original single capacitor, the new capacitor must have half the capacitance. $C = \varepsilon_0 A/d$, so half the plate area with the same distance between the plates will accomplish this.

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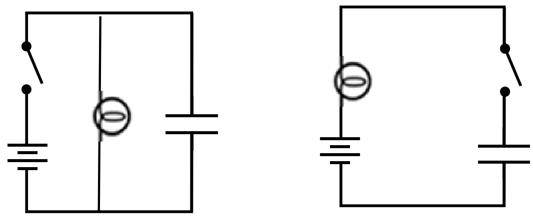
Question 4 (continued)

Distribution of points

(c) 5 points



For two correct circuit diagrams, each matched with the correct situation — arrangement 1 has lightbulb and capacitor in parallel, and arrangement 2 has them in series — 1 point

For indicating that the lightbulb is brightest when the current through it is maximum and that the capacitor eventually stops current from flowing in its branch when the potential difference across its plates is equal in magnitude to the emf of the battery (or something similar) — 1 point

Response using current	Response using potential difference	
For indicating that in the series circuit (where the same current flows through both components) the most current flows right after the switch is closed and decreases as the capacitor charges	For indicating that in the series circuit (where the potential is shared) the resistor has its maximum potential difference right after the switch is closed, because the capacitor starts out uncharged (no potential difference) and then charges until it has the same potential as the battery	1 point
For indicating that in the parallel circuit (where the current is shared between the components) the most current flows through the lightbulb a long time after the switch is closed, because the full current initially goes through the capacitor branch because it acts like a wire (very low potential difference), then ends up all through the lightbulb once the fully charged capacitor acts like an open circuit (same potential difference as battery)	For indicating that in a parallel circuit (where both components have the same potential difference) the bulb starts out with the same zero potential difference as the capacitor and ends up with the total battery potential	1 point

For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph-length response — 1 point

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Question 1

10 points total | **Distribution of points**

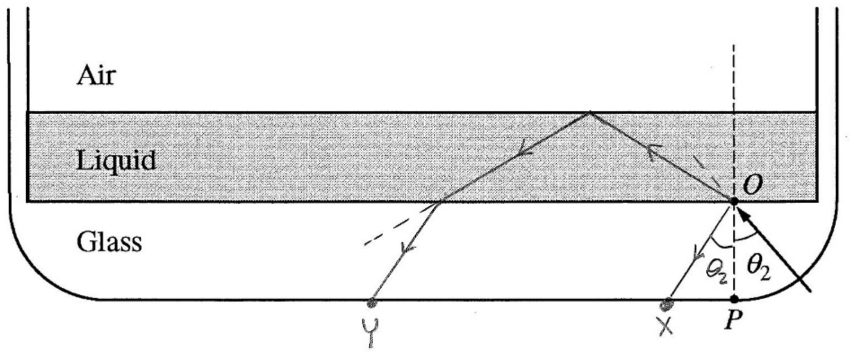
(a) 5 points

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

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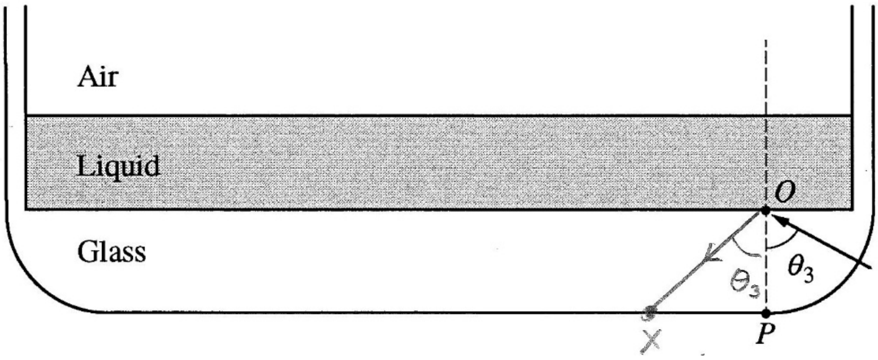
Question 1 (continued)

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

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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 — 1 point

$$P_{new} = \frac{16}{9}P_1$$

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

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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 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.	1 point
ii)		
	For a reasonable explanation for why bulb 1 is the same brightness as bulb 2 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.	1 point

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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.

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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*

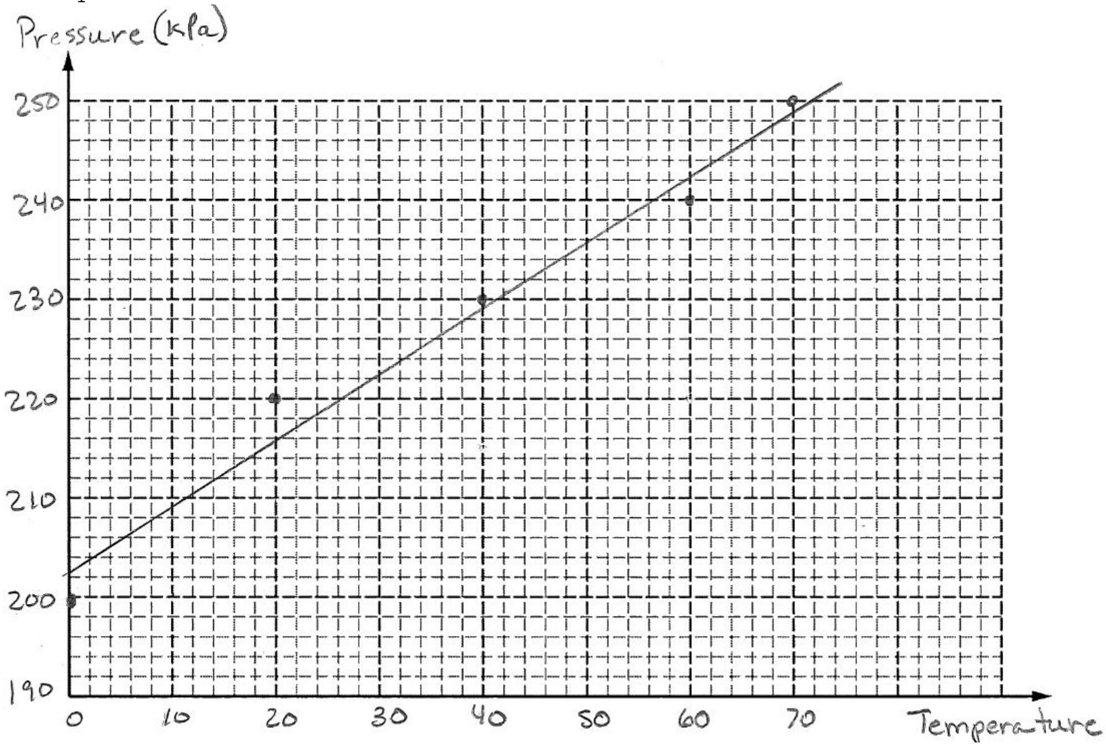
(d) 3 points

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:



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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.

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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

$a = \left(v_f - v_i\right)/t$

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

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

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

$E = m\left(v_f - v_i\right)/et$

$$E = \frac{\left(9.11\times10^{-31}\ \text{kg}\right)\left(8.02\times10^{6}\ \text{m/s} - 5.40\times10^{6}\ \text{m/s}\right)}{\left(1.6\times10^{-19}\ \text{C}\right)\left(1.49\times10^{-9}\text{s}\right)} = 10{,}000\ \text{N/C}$$

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*

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

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

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

$\Delta V = Ed$

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

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

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

$$E = \frac{\left(9.11\times10^{-31}\right)\left(\left(8.02\times10^{6}\ \text{m/s}\right)^2 - \left(5.40\times10^{6}\ \text{m/s}\right)^2\right)}{2\left(1.6\times10^{-19}\ \text{C}\right)(0.010\ \text{m})} = 10{,}000\ \text{N/C}$$

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Question 4 (continued)

Distribution of points

(c) 1 point

$E = Q/\varepsilon_0 A$

$Q = \varepsilon_0 AE$

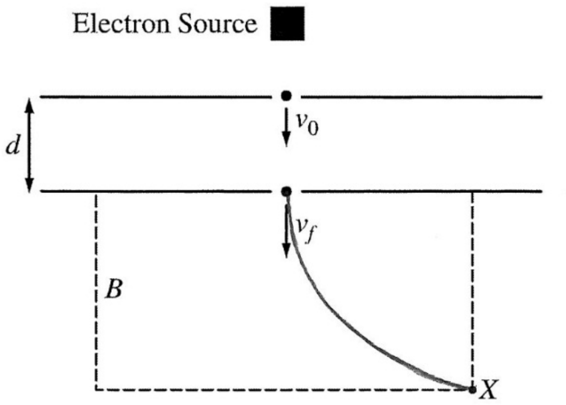
For correct substitution of values into the equation to calculate the magnitude of charge on each parallel plate — 1 point

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

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

(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.