2024

AP® Physics 2: Algebra-Based

Scoring Guidelines

Question 1: Paragraph-Length Response — 10 points

(a)

For indicating that f_B is least and f_C is greatest — **1 point**

For correctly relating the frequency of a photon to the energy of the photon — **1 point**

For indicating that the kinetic energy or speed of an ejected electron is inversely related to the de Broglie wavelength of the electron — **1 point**

For indicating **one** of the following: — **1 point**

- That a greater photon energy or frequency results in a greater kinetic energy for an ejected electron
- That the lowest photon energy or frequency is below the work function or threshold frequency which results in no ejected electron

For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response — **1 point**

Example Response

An electron will be ejected if the incident photon has an energy greater than the work function of the metal. Because no electrons were ejected using f_B, the corresponding photon energy, and, therefore, frequency must be the least. A photon with greater frequency will result in an ejected electron with more kinetic energy; the kinetic energy of an electron is inversely related to the de Broglie wavelength of the electron. Because the de Broglie wavelength of electrons ejected by light of frequency f_A is greater than those ejected by light of frequency f_C, f_A must be less than f_C. Therefore, f_C is the greatest.

Total for part (a) 5 points

(b) For **one** of the following: **1 point**

- Correctly relating electron de Broglie wavelength to a correct expression that includes h, m, and v
- Relating kinetic energy to a correct expression that includes momentum and mass

Example Responses

$\lambda_e = \frac{h}{mv}$

OR

$K = \frac{p^2}{2m}$

For correctly substituting an algebraic expression in terms of λ_e for the electron speed or momentum into a relevant equation for kinetic energy **1 point**

Scoring Note: This point can be earned for substituting a numerical value for electron speed or momentum into a relevant equation for kinetic energy.

Example Responses

$K = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2$ **OR** $K = \frac{\left(\frac{h}{\lambda_e}\right)^2}{2m}$

For a correct answer with units **1 point**

Example Response

$K = 5 \times 10^{-19}\ \text{J}$

Example Solution

$\lambda_e = \frac{h}{p} = \frac{h}{mv}$

$v = \frac{h}{m\lambda_e}$

$K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2$

$K = \frac{h^2}{2m\lambda_e^2}$

$K = \frac{\left(6.63 \times 10^{-34}\ \text{J} \cdot \text{s}\right)^2}{2\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(6.9 \times 10^{-10}\ \text{m}\right)^2} = 5 \times 10^{-19}\ \text{J}$

Scoring Note: An answer of $3\ \text{eV}$ also earns the final point.

Total for part (b) 3 points

(c)	For indicating that the work function of Metal 1 is less than the work function of Metal 2 with an attempt at a relevant justification	**1 point**
	For indicating at least **two** of the following: • The correct relationship between the work function and the difference between hf and $K_{\max}$ • The frequency or energy of the incident photons is the same • The de Broglie wavelength is inversely related to the energy of the ejected electrons	**1 point**
	Example Response *The work function of Metal 1 is less than the work function of Metal 2. When light of the same frequency is incident on both metals, the electron ejected by Metal 1 has a smaller de Broglie wavelength than that of Metal 2, so an electron ejected from Metal 1 has more kinetic energy. The work function is the difference between the photon energy and the maximum kinetic energy. Since the photon energy is the same but the maximum kinetic energy is larger for Metal 1, the difference between the energies, and thus the work function, is smaller for Metal 1.*	
	Total for part (c)	**2 points**
	Total for question 1	**10 points**

Question 2: Experimental Design — 12 points

(a)

For indicating measurements that could be used to determine the volume of the gas — **1 point**

Scoring Note: Responses that include the volume of the heater may earn full credit.

For indicating that the sensors should be used to record the temperature and pressure of the gas — **1 point**

For indicating that multiple different temperature and pressure measurements should be recorded — **1 point**

Example Response

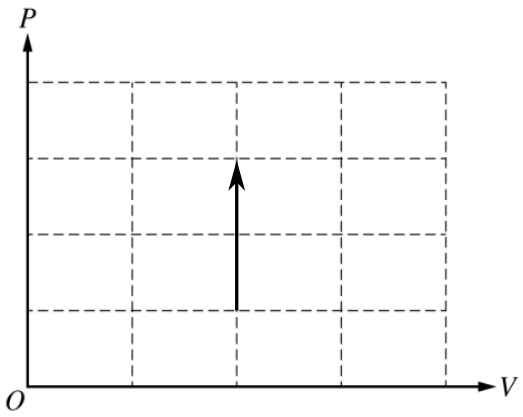
Measure the length, width, and height of the chamber. Activate the heater. Starting at time $t = 0$*, use the sensors to record the temperature and pressure of the gas every* $10\ \text{s}$ *until* $t = 60\ \text{s}$.

Total for part (a) — **3 points**

(b)(i)

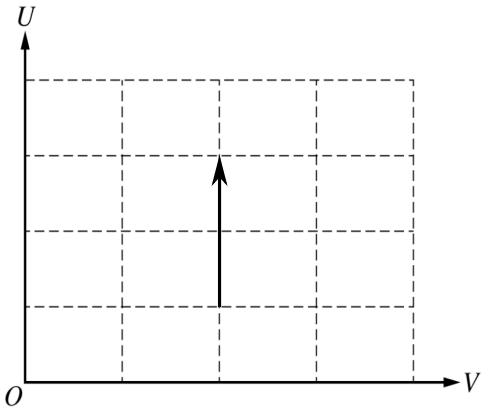
For sketching an upward vertical line that never touches the horizontal or vertical axes — **1 point**

Example Response



(b)(ii)	For sketching an upward vertical line that never touches the horizontal or vertical axes	**1 point**

Example Response



(b)(iii)	For a justification that correctly relates the volume of the chamber to the sketch or relates the energy transferred to the gas by the heater to the sketch that is consistent with the sketch in part (b)(ii)	**1 point**

Example Responses

The heater transfers energy to the gas by heating, so the internal energy of the gas increases.

OR

The gas has a constant volume.

	Total for part (b)	**3 points**

(c)(i)	For indicating quantities that can be plotted on the graph to calculate an experimental value for k	**1 point**

Example Response

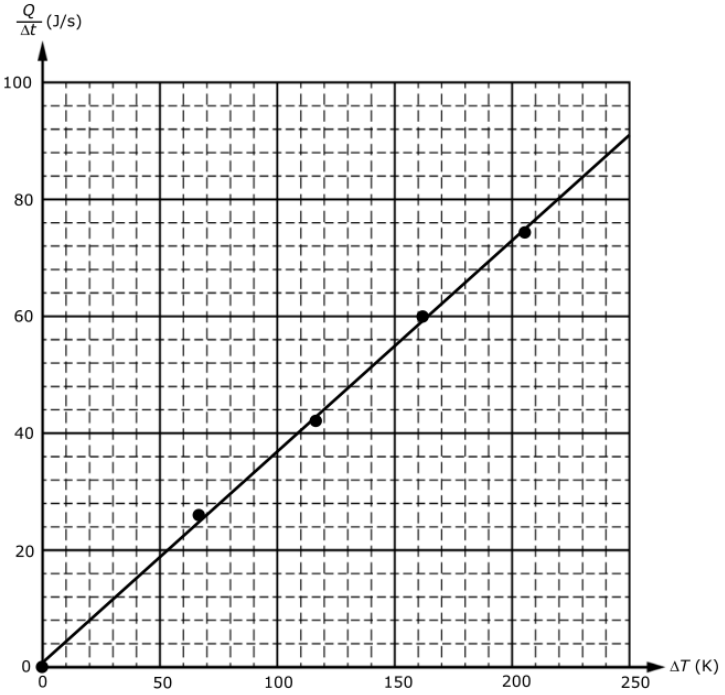
Vertical Axis: $\frac{Q}{\Delta t}$

Horizontal Axis: $\Delta T = T_G - T_L$

(c)(ii)	For labeling the axes correctly (including units) with a linear scale such that the data fill half the area of the graph	**1 point**
	For plotting the data points correctly	**1 point**

(c)(iii) For drawing a straight line that approximates the trend of the data **1 point**

Example Response



Total for part (c) **4 points**

(d) For correctly relating the slope of the straight line of the graph to the equation **1 point**

$$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$$

Example Response

$$\text{slope} = \frac{kA}{L}$$

For calculating an experimental value for k that is approximately equal to $0.06 \ \frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$ **1 point**

Example Response

$$k = 0.06 \ \frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$$

Example Solution

$$\text{slope} = \frac{\Delta y}{\Delta x}$$

$$\text{slope} = \frac{\Delta\left(\frac{Q}{\Delta t}\right)}{\Delta(\Delta T)}$$

$$\text{slope} = \frac{\left(\frac{Q}{\Delta t}\right)_2 - \left(\frac{Q}{\Delta t}\right)_1}{\Delta T_2 - \Delta T_1}$$

$$\text{slope} = \frac{(80 - 44)\,\frac{\text{J}}{\text{s}}}{(220 - 120)\,\text{K}}$$

$$\text{slope} = 0.36\,\frac{\text{J}}{\text{s} \cdot \text{K}}$$

$$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$$

$$\frac{Q}{\Delta t} = \left(\frac{kA}{L}\right)\Delta T$$

$$\text{slope} = \frac{kA}{L}$$

$$k = \frac{L}{A}(\text{slope})$$

$$k = \frac{0.01\,\text{m}}{0.06\,\text{m}^2}\left(0.36\,\frac{\text{J}}{\text{s} \cdot \text{K}}\right)$$

$$k = 0.06\,\frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$$

Total for part (d) 2 points

Total for question 2 12 points

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

$I_1 = I_2 + I_3$

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

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

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

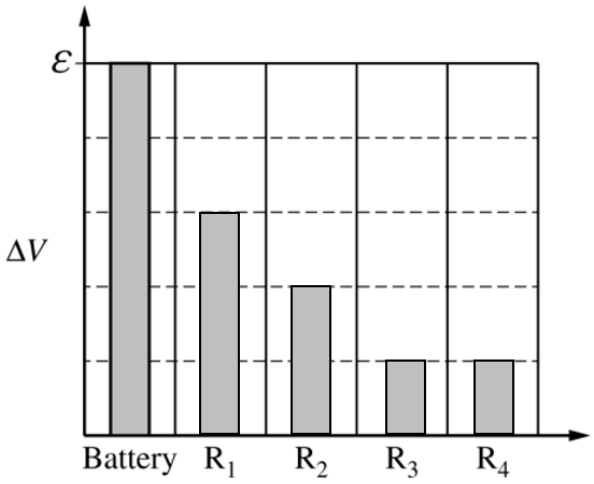
OR

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 4: Short Answer/Other — 10 points

(a) For indicating that the final kinetic energy of a particle is equal to $|q\Delta V|$ — **1 point**

Scoring Note: Explicit indication of an absolute value is not required for this point to be earned.

Example Response

$|q\Delta V| = K$

For $\frac{K_2}{K_1} = 2$ — **1 point**

Example Solution

$E_0 = E_f$

$\Delta U + \Delta K = 0$

$-\Delta U_E = \Delta K$

$|q\Delta V| = K$

$K_1 = |-Q\Delta V| = Q\Delta V$

$K_2 = |+2Q\Delta V| = 2Q\Delta V$

$\frac{K_2}{K_1} = \frac{2Q\Delta V}{Q\Delta V}$

$\frac{K_2}{K_1} = 2$

Total for part (a) — **2 point**

Scoring Note: Parts (b)(i) and (b)(ii) can be scored together.

(b)(i) For a correct expression for the speed of Particle 2 in terms of K_2 and M — **1 point**

Example Response

$v = 2\sqrt{\frac{K_2}{M}}$

Example Solution

$K = \frac{1}{2}mv^2$

$K_2 = \frac{1}{2}\left(\frac{M}{2}\right)v^2$

$v = 2\sqrt{\frac{K_2}{M}}$

(b)(ii) For substituting an appropriate expression for the magnetic force exerted on a moving charged particle in a magnetic field into a Newton's second law equation **1 point**

Example Response

$$\vec{a}_c = \frac{q\vec{v} \times \vec{B}}{m}$$

For correct substitutions of the mass, charge, and speed of Particle 2 from the response in part (b)(i) into an appropriate expression **1 point**

Example Response

$$r = \frac{\left(\frac{M}{2}\right)\left(2\sqrt{\frac{K_2}{M}}\right)}{2QB_0}$$

For indicating that $\Delta x = 2r$ **1 point**

Example Solution

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

$$\vec{a}_c = \frac{q\vec{v} \times \vec{B}}{m}$$

$$\frac{v^2}{r} = \frac{qvB}{m}$$

$$r = \frac{mv}{qB}$$

$$r = \frac{\left(\frac{M}{2}\right)\left(2\sqrt{\frac{K_2}{M}}\right)}{2QB_0}$$

$$r = \frac{\sqrt{K_2 M}}{2QB_0}$$

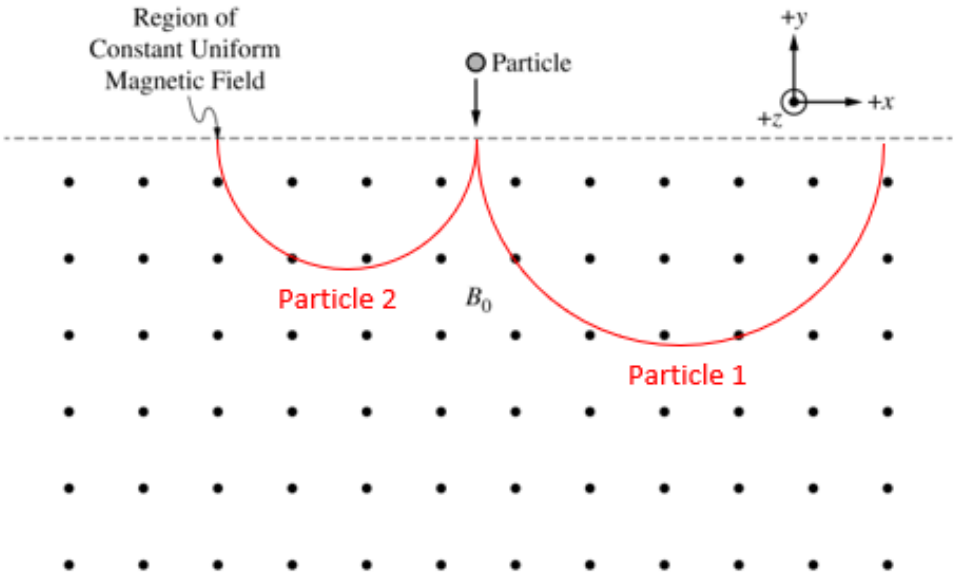
$$\Delta x = 2r$$

$$\Delta x = \frac{\sqrt{K_2 M}}{QB_0}$$

Total for part (b) 4 points

(c)	For drawing a path for Particle 1 that is concave up and to the right	**1 point**
	For drawing a path for Particle 2 that is concave up and in the opposite direction of Particle 1	**1 point**
	For drawing the path for Particle 1 with a larger radius of curvature than the path for Particle 2	**1 point**

Example Response



Total for part (c) **3 points**

(d)	For indicating **one** of the following: • That the electric field is directed in the $+x$-direction • A direction of the electric field that is consistent with the path of Particle 1 drawn in part (c)	**1 point**

Example Response

$+x$-direction

Total for part (d) **1 point**

Total for question 4 **10 points**