

10 points

Question 4: Short Answer/Other

(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

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

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

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

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

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

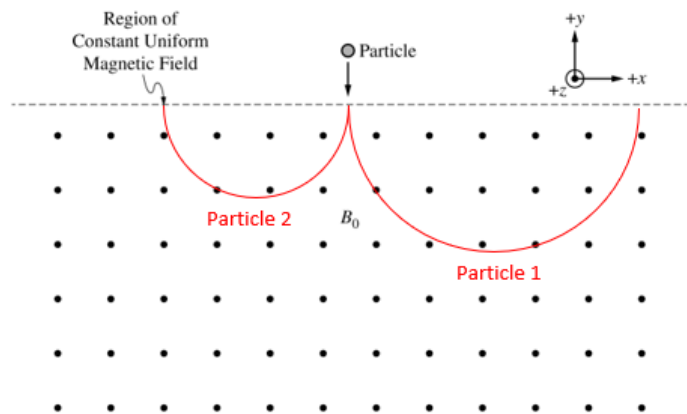
$$r = \frac{\sqrt{K_2 M}}{2QB_0}$$

$$\Delta x = 2r$$

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

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:	1 point
	- 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)	

Example Response $+x$ -direction**Total for part (d) 1 point****Total for question 4 10 points****Question 4: Short Answer Paragraph Argument****10 points**

(a)	For an evaluation of Student Y's statement that correctly includes the vector nature of electric field	1 point
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For indicating that Student Y should have stated that the third particle must have charge $+Q$ for the electric field at Point P to be zero **1 point**

OR

For a statement indicating what the resultant magnitude of the electric field at Point P would be for a particle with charge $+2Q$

	For an evaluation of Student Z's statement that correctly includes the scalar nature of electric potential	1 point
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For indicating that zero electric potential at Point P would require the third particle having charge $-2Q$ **1 point**

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

Student Y is incorrect. Before the third particle is placed at the bottom-right vertex, the electric field from particles A and B at Point P is down and to the right. The electric field from a positively charged particle placed at the bottom-right vertex is up and to the left. The third particle needs to have charge $+Q$, rather than $+2Q$, in order to have the correct magnitude to make the resultant field zero at Point P.

Student Z is incorrect. Before the third particle is placed at the bottom-right vertex, the value of the electric potential at Point P is positive. Because Point P is equidistant from all three particles, the electric potential at Point P is proportional to the total charge of the system. If the total charge of the system is zero, the electric potential at Point P will be zero. This requires the third particle to have charge $-2Q$.

OR

Student Y is incorrect that a particle with charge $+2Q$ placed at the bottom-right vertex will result in no electric field at Point P. The horizontal component of the electric field from Particle A is less than the horizontal component of the electric field from the particle with charge $+2Q$. The sum of the vertical components of the fields from particles A and B is less than the vertical component of the field from the particle with charge $+2Q$. Therefore, the resulting electric field at Point P is nonzero and points in a direction between particles A and B.

Student Z is incorrect. Before the third particle is placed at the bottom-right vertex, the value of the electric potential at Point P is positive. Electric potential is a scalar quantity, so if the third particle has charge $-2Q$ rather than $-Q$, the electric potential at Point P will be zero.

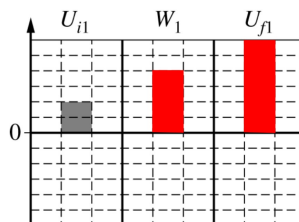
Total for part (a) 5 points

(b)(i) For drawing a bar on the grid that shows a positive value for W_1 1 point

For drawing a bar on the grid that shows $U_{f1} = 3U_{i1}$ 1 point

For drawing bars on the grid so that the work done on the system is equal to the change in energy, $U_{i1} + W_1 = U_{f1}$ 1 point

Example Response

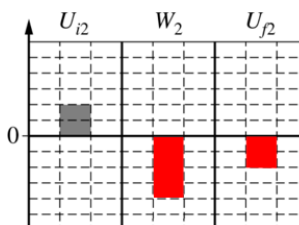


Scenario 1

(b)(ii) For drawing a bar on the grid that shows $U_{f2} = -U_{i2}$ 1 point

For drawing a bar on the grid that shows a negative value of W_2 so that the work done on the system is equal to the change in energy $U_{i2} + W_2 = U_{f2}$ 1 point

Example Response



Scenario 2

Total for part (b) 5 points

Total for question 4 10 points

Question 3: Quantitative/Qualitative Translation

12 points

(a) For indicating that the electrostatic force is equal to the net (centripetal) force on the electron, with a correct expression for each 1 point

Example Response

$$\Sigma \vec{F} = m\vec{a}$$

$$F_E = F_C$$

$$\frac{kq^2}{r^2} = \frac{mv^2}{r}$$

Scoring Note: An incorrect mass label is acceptable to earn this point.

For using the expressions for the electrostatic and net forces to determine the speed v of the electron (responses must indicate that the mass in the expression represents the mass of the electron and the charge in the expression represents the charge of the electron) 1 point

Example Response

$$\frac{ke^2}{r^2} = \frac{m_e v^2}{r}$$

$$v^2 = \frac{ke^2}{m_e r}$$

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

Scoring Note: q_e and q_p are acceptable.

Total for part (a) 2 points

(b) For a correct expression for electric potential energy, using charges consistent with charges from part (a) 1 point

Example Response

$$U = -\frac{ke^2}{r}$$

For a correct expression for kinetic energy of the electron, including a substitution consistent with the expression from part (a) to eliminate speed from the equation 1 point

Example Response

$$K = \frac{1}{2} m_e \left(\frac{ke^2}{m_e r} \right) = \frac{1}{2} \frac{ke^2}{r}$$

For indicating that the total energy of the atom is the sum of the electric potential energy and the kinetic energy of the electron **1 point**

Example Response

$$E = U + K$$

$$E = -\frac{ke^2}{r} + \frac{1}{2} \frac{ke^2}{r}$$

$$E = -\frac{ke^2}{2r}$$

Total for part (b) 3 points

(c) For correctly indicating consistency between the equation in part (b) and the description with an explanation that references the equation in part (b) **1 point**

For correctly addressing functional dependence of the energy equation from part (b) to the orbital radius of the electron **1 point**

Example Response

The equation from part (b) indicates that as the radius increases, the total energy of the atom becomes less negative, which is an increase in the total energy. This is consistent with the given description of the atom absorbing a photon.

Total for part (c) 2 points

(d)(i) For a correct calculation of the energy of the photon **1 point**

Example Response

$$E = hf$$

$$E = (6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.2 \times 10^{15} \text{ Hz})$$

$$E = 2.12 \times 10^{-18} \text{ J}$$

(d)(ii) For a correct calculation of the mass-energy of an electron **1 point**

Example Response

$$E = mc^2$$

$$E = (9.11 \times 10^{-31} \text{ kg})(3.00 \times 10^8 \text{ m/s})^2$$

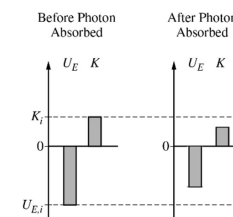
$$E = 8.20 \times 10^{-14} \text{ J}$$

For correctly indicating that the photon energy is negligible compared to the mass energy of the electron (or an answer that is consistent with the energies calculated in part (d)(i) and part (d)(ii)) **1 point**

Scoring Note: The energy comparison must be from the unit of joules to joules or the unit of electron volts to electron volts in order for this point to be earned.

(d)(iii) For U smaller in magnitude but still negative **1 point**

For K smaller in magnitude but still positive **1 point**

Example Response

Total for part (d) 5 points

Total for question 3 12 points

2019

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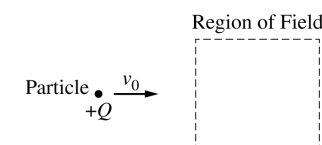
General Notes About 2019 AP Physics Scoring Guidelines

- The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.
- The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at <https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf>.
- Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.
- Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as “derive” and “calculate” on the exams, and what is expected for each, see “The Free-Response Sections — Student Presentation” in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or “Terms Defined” in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.
- The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.
- Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

2019 SCORING GUIDELINES

Question 1

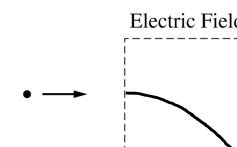
10 points



The figure above shows a particle with positive charge $+Q$ traveling with a constant speed v_0 to the right and in the plane of the page. The particle is approaching a region, shown by the dashed box, that contains a constant uniform field. The effects of gravity are negligible.

- (a)
- LO 2.C.1.1, SP 6.4
2 points

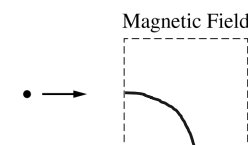
On the figure below, draw a possible path of the particle in the region if the region contains only an electric field directed toward the bottom of the page.



For a curved path that is initially horizontal and does not have a component of velocity toward the left	1 point
For a path that deflects toward the bottom of the page and reaches an edge of the region	1 point

- LO 3.C.3.1, SP 1.4
2 points

On the figure below, draw a possible path of the particle in the region if the region contains only a magnetic field directed out of the page.



For a curved path that is initially horizontal, is not more than a semicircle, and reaches an edge of the region	1 point
For a path that deflects toward the bottom of the page	1 point

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Question 1 (continued)

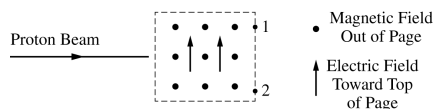
(a) (continued)

- iii. LO 2.C.5.3, SP 1.1, 7.1
1 point

For which of the previous situations is the motion more similar to that of a projectile in only a gravitational field near Earth's surface, and why?

For indicating that the motion in the electric field is more similar to a projectile because the force or acceleration is always down or constant, or the shape is parabolic	1 point
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- (b) LO 2.D.1.1, SP 2.2; LO 3.A.3.4, SP 6.1, 6.4; LO 3.B.1.4, SP 6.4, 7.2; LO 3.B.2.1, SP 1.1, 1.4, 2.2
5 points



Another region of space contains an electric field directed toward the top of the page and a magnetic field directed out of the page. Both fields are constant and uniform. A horizontal beam of protons with a variety of speeds enters the region, as shown above. Protons exit the region at a variety of locations, including points 1 and 2 shown on the figure. In a coherent, paragraph-length response, explain why some protons exit the region at point 1 and others exit at point 2. Use physics principles to explain your reasoning.

For indicating that initially the electric and magnetic forces act in opposite directions	1 point
For indicating or implying that the magnetic force is affected by speed, but the electric force is not	1 point
For indicating that different paths occur as a result of the addition of forces	1 point
For indicating that slower protons exit higher than faster protons (i.e., slower protons exit at point 1 and faster protons exit at point 2)	1 point
For a logical, relevant, and internally consistent argument that addresses the question asked and follows the guidelines described in the published requirements for the paragraph-length response	1 point
Example: For a charged particle to travel through the region undeflected, the net force on it must be zero. This means that the upward electric force and the downward magnetic force must be equal and opposite to each other. This occurs for a particular speed. The electric force is independent of the particle's velocity, but the magnetic force will be larger for greater velocities and less for smaller velocities. If a particle is moving faster than the particular speed, it will experience a greater magnetic force and be deflected downward. If it is moving more slowly than the particular speed, it will be deflected upward.	

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Question 1 (continued)

(b) (continued)

Claim: Slower protons exit higher than faster protons (i.e., slower protons exit at point 1 and faster protons exit at point 2). Evidence: The electric and magnetic forces act in opposite directions. The magnetic force is affected by speed, but the electric force is not. Reasoning: Different paths occur as a result of the addition of forces.		
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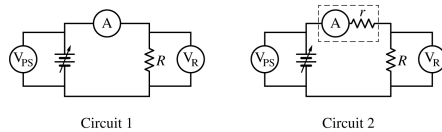
Learning Objectives

- LO 2.C.1.1:** The student is able to predict the direction, and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation. [See Science Practices 6.4, 7.2]
- LO 2.C.5.3:** The student is able to represent the motion of an electrically-charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in Earth's gravitational field. [See Science Practices 1.1, 2.2, 7.1]
- LO 2.D.1.1:** The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See Science Practices 2.2]
- LO 3.A.3.4:** The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. [See Science Practices 6.1, 6.4]
- LO 3.B.1.4:** The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]
- LO 3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
- LO 3.C.3.1:** The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [See Science Practices 1.4]

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Question 2

12 points

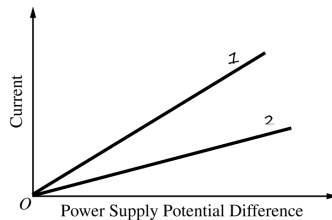


The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R , an ammeter A , and two voltmeters V_{PS} and V_R . In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r . The potential difference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

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

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

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



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

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

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

Circuit 1

Circuit 2

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

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Question 2 (continued)

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

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

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

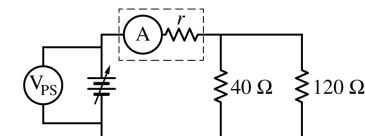
- (d) LO 5.B.9.6, SP 2.2; LO 5.C.3.4, SP 6.4, 7.2
2 points

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

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

- (e)

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



Circuit 3

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Question 2 (continued)

(e) (continued)

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

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

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

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

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

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

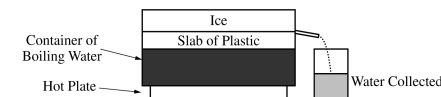
Learning Objectives

- LO 4.E.5.1:** The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 2.2, 6.4]
- LO 5.B.9.6:** The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]
- LO 5.B.9.8:** The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [See Science Practices 1.5]
- LO 5.C.3.4:** The student is able to predict or describe current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and explain the relationship of the rule to the law of charge conservation. [See Science Practices 6.4, 7.2]

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Question 3

12 points



A group of students use the apparatus shown above to determine the thermal conductivity of a certain type of plastic. A hot plate is used to keep water in a container boiling at a temperature of 100°C . They place a slab of the plastic with area 0.025 m^2 and thickness 0.010 m above the container so that the bottom surface of the slab is at a temperature of 100°C . They put a large block of ice with temperature 0°C on top of the plastic slab. Some of the ice melts, and the students measure the amount of water collected during a time Δt . The students correctly calculate the amount of energy Q delivered to the ice and thus determine $Q/\Delta t$. They repeat this experiment several times, each time adding an identical slab to increase the total thickness L of plastic. Their results are shown in the table below.

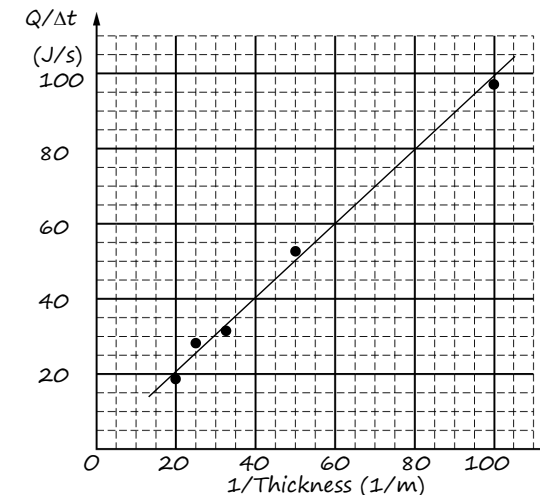
Table with sample entries for part (a)(ii)

Energy Flow Rate $Q/\Delta t$ (J/s)	97	53	31	27	18
Total Thickness of Plastic (m)	0.01	0.02	0.03	0.04	0.05
$1/\text{Thickness}$ ($1/\text{m}$)	100	50	33.3	25	20

(a)

The students want to create a graph to yield a straight line whose slope could be used to calculate the thermal conductivity of the plastic.

Sample graph using above data



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Question 3 (continued)

(a) (continued)

- i. LO 1.E.3.1, SP 4.1, 5.1
1 point

Label the axes below to indicate a pair of quantities that could be graphed to yield a straight line. Include units for the quantities.

$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$		
For labeling the axes with two quantities that would produce a linear graph, including units		1 point
Example: $Q/\Delta t$ and $1/\text{thickness}$		

- ii. LO 1.E.3.1, SP 4.1, 5.1
3 points

On the grid on the previous page, create a linear graph using the values for the quantities indicated in part (a)(i). Be sure to do the following:

- Add to the data table the values of any quantities to be plotted that are not already given.
- Scale the axes.
- Plot the data from the table.
- Draw a line that best represents the data.

For scaling the axes linearly so the data extends over at least half of each axis		1 point
For accurately plotting the data		1 point
For a best-fit curve or line that fits the trend in the data		1 point

- iii. LO 1.E.3.1, 5.1
2 points

Use the graph to calculate the thermal conductivity of the plastic.

For a correct method for calculating the slope using points on the best-fit line		1 point
For the graph above, slope = $\frac{(80 - 20)(\text{J/s})}{(80 - 20)(1/\text{m})} = 1.0 \text{ J}\cdot\text{m/s}$		
For determining the thermal conductivity k , with or without units using the slope found above		1 point
$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$ so slope = $kA\Delta T$		
Using slope above: $k = \text{slope}/A\Delta T = 1(\text{J}\cdot\text{m/s})/(0.025 \text{ m}^2)(100^\circ \text{C}) = 0.40 \text{ J/s}\cdot\text{m}^\circ\text{C}$		

2019 SCORING GUIDELINES

Question 3 (continued)

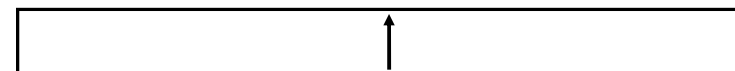
- (b) LO 5.B.6.1, SP1.2
2 points

Indicate one potential problem with the setup that could lead to an experimental value for the thermal conductivity that is different from the actual value. Use physics principles to explain the effect this problem could have on the experimental value.

For any valid indication of an additional thermal interaction with the environment		1 point
For a reasonable explanation of how additional energy added or lost could change the experimental value of conductivity		1 point
Example 1: The given setup allows energy to be transferred to the ice from the air around it. This means the values of $Q/\Delta t$ contain energy that did not go through the plastic slab, resulting in a value of k that is too large.		
Example 2: The given setup allows energy to be lost out the sides of the plastic slab. This means the values of $Q/\Delta t$ do not contain all the energy that went through the plastic slab, resulting in a value of k that is too small.		
Claim: The problem leads to a value of k that is too small/large. Evidence: The problem allows energy transfer into/out of the system that is not accounted for. Reasoning: The values of $Q/\Delta t$ contain less/more energy than went through the plastic slab, resulting in a value of k that is too small/large.		

- (c) LO 4.C.3.1, SP 6.4
1 point

The rectangle below represents a side view of the plastic slab. Draw a single arrow on the diagram representing the direction of the net flow of energy through the plastic.



For drawing an arrow toward the top of the page		1 point
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- (d) LO 4.C.3.1, SP 6.4; LO 5.B.6.1, SP 1.2; LO 5.D.1.6, SP 6.4
2 points

Describe what occurs in the plastic at the microscopic level that explains the energy flow you indicated in part (c).

For indicating that particles at the bottom (or a location consistent with part (c)) have a higher temperature or kinetic energy, so they vibrate faster		1 point
For indicating that particles collide with neighboring particles, transferring energy from faster to slower particles in the process		1 point
Example: Energy absorbed at the lower surface makes particles jiggle faster, they jiggle particles above them, and so forth until energy reaches the other side.		

2019 SCORING GUIDELINES

Question 3 (continued)

- (e) LO 1.E.3.1, SP 4.1, 4.2
1 point

An extra plastic slab sits on a wood surface, with both the plastic slab and the wood surface at room temperature. A student touches each and finds that the plastic slab feels cooler than the wood surface. Explain what causes this observation.

For indicating that the slab and wood have different thermal conductivities or that energy is transferred into the plastic and wood at different rates, with no incorrect statements	1 point
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Learning Objectives

- LO 1.E.3.1:** The student is able to design an experiment and analyze data from it to examine thermal conductivity. [See Science Practices 4.1, 4.2, 5.1]
- LO 4.C.3.1:** The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [See Science Practices 6.4]
- LO 5.B.6.1:** The student is able to describe the models that represent processes by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation. [See Science Practices 1.2]
- LO 5.D.1.6:** The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [See Science Practices 6.4]

2019 SCORING GUIDELINES

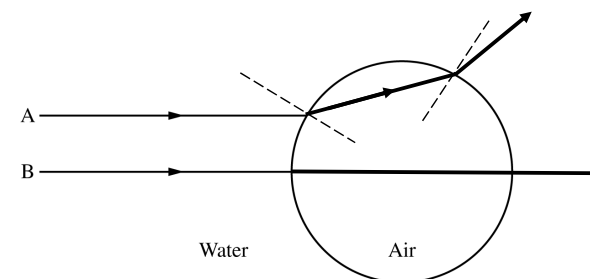
Question 4

10 points

A student notices many air bubbles rising through the water in a large fish tank at an aquarium.

- (a) LO 6.E.3.1, SP 1.1, 1.4
3 points

In the figure below, the circle represents one such air bubble, and two incoming rays of light, A and B, are shown. Ray B points toward the center of the circle. On the diagram, draw the paths of rays A and B as they go through the bubble and back into the water. Your diagram should clearly show what happens to the rays at each interface.



For ray B going straight through	1 point
For ray A bending away from the normal as it enters the air from the water	1 point
For ray A bending the opposite direction in relationship to the normal as it exits the air and enters the water compared to the refraction entering the air from the water	1 point
Note: The normals need not be shown.	

- (b) LO 5.B.4.1, SP 6.4, 7.2; LO 5.B.4.2, SP 1.4, 7.2; LO 5.B.5.4, SP 6.4, 2.2; LO 5.B.5.5, SP 2.2, 6.4
3 points

The bubble has a volume V_1 , the air inside it has density ρ_A , and the water around it has density ρ_W .

The bubble starts at rest and has a speed v_f when it has risen a height h . Assume that the change in the bubble's volume is negligible. Derive an expression for the mechanical energy dissipated by drag forces as the bubble rises this distance. Express your answer in terms of the given quantities and fundamental constants, as appropriate.

For a valid application of the work-energy theorem	1 point
$\Delta K = W_{\text{net}} = W_b - W_g - W_{\text{diss}} $	
For finding the work done by the buoyant force $W_b = \rho_W V_1 g h$	1 point
For correct substitutions into an equation with consistent relative signs for the terms $\frac{1}{2} \rho_A V_1 v_f^2 = \rho_W V_1 g h - \rho_A V_1 g h - W_{\text{diss}} $	1 point
$ W_{\text{diss}} = \rho_W V_1 g h - \rho_A V_1 g h - \frac{1}{2} \rho_A V_1 v_f^2$	

2019 SCORING GUIDELINES

Question 4 (continued)

(c)

At a particular instant, one bubble is 4.5 m below the water's surface. The surface of the water is at sea level, and the density of the water is 1000 kg/m^3 .

- i. LO 5.B.10.1, SP 2.2
1 point

Determine the absolute pressure in the bubble at this location.

$P_{4.5\text{m}} = P_{\text{atm}} + \rho_w g d$		
$P_{4.5\text{m}} = (1.0 \times 10^5 \text{ Pa}) + (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(4.5 \text{ m})$		
For a correct answer with units		1 point
$P_{4.5\text{m}} = 1.44 \times 10^5 \text{ Pa}$ (or $1.45 \times 10^5 \text{ Pa}$ using $g = 10 \text{ m/s}^2$)		

- ii. LO 7.A.3.3, SP 5.1
2 points

The bubble has a volume V_1 when it is 4.5 m below the water's surface. Assume that the temperature of the air in the bubble remains constant as it rises. In terms of V_1 , calculate the volume of the bubble when it is just below the surface of the water.

For applying the ideal gas law at two locations in an attempt to determine the new bubble volume		1 point
$P_{4.5\text{m}} V_1 = P_{\text{atm}} V_{\text{surface}}$		
$V_{\text{surface}} = P_{4.5\text{m}} V_1 / P_{\text{atm}}$		
For substituting pressures consistent with part (i)		1 point
$V_{\text{surface}} = (1.44 \times 10^5 \text{ Pa}) V_1 / (1 \times 10^5 \text{ Pa})$		
$V_{\text{surface}} = 1.44 V_1$ (or $1.45 V_1$ using $g = 10 \text{ m/s}^2$)		

- iii. LO 7.A.3.3, SP 5.1
1 point

If the air in the bubble cooled as it rose, the volume of the bubble would be less than the value calculated in part (c)(ii). Use physics principles to briefly explain why.

For a correct explanation		1 point
<u>Note:</u> The explanation may be qualitative or quantitative. The explanation may also be macroscopic or microscopic.		

2019 SCORING GUIDELINES

Question 4 (continued)

(c) (continued)

iii. (continued)

Example 1: By the ideal gas law, $P_{4.5\text{m}} V_1 / T_1 = P_{\text{atm}} V_{\text{surface}} / T_{\text{surface}}$, so $V_{\text{surface}} = P_{4.5\text{m}} V_1 T_{\text{surface}} / P_{\text{atm}} T_1$. The two pressures still have their previous values. $T_{\text{surface}} < T_1$, so the volume at the surface will be smaller.		
Example 2: As the bubble cools, the air molecules move slower. Slower molecules exert less force on the inner surface of the bubble. The unbalanced force, due to the difference in the forces on the inside and outside of the bubble, causes the bubble to expand less than it did in the constant temperature situation or contract.		
Claim (given): The volume of the bubble will decrease Example 1 evidence: $P_{4.5\text{m}} V_1 / T_1 = P_{\text{atm}} V_{\text{surface}} / T_{\text{surface}}$, so $V_{\text{surface}} = P_{4.5\text{m}} V_1 T_{\text{surface}} / P_{\text{atm}} T_1$ Example 1 reasoning: The two pressures still have their previous values. $T_{\text{surface}} < T_1$, so the volume at the surface will be smaller. Example 2 evidence: As the bubble cools, the air molecules move slower. Slower molecules exert less force on the inner surface of the bubble. Example 2 reasoning: The unbalanced force, due to the difference in the forces on the inside and outside of the bubble, causes the bubble to contract.		

Learning Objectives:

- LO 5.B.4.1:** The student is able to describe and make predictions about the internal energy of systems. [See Science Practices 6.4, 7.2]
- LO 5.B.4.2:** The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [See Science Practices 1.4, 2.1, 2.2]
- LO 5.B.5.4:** The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [See Science Practices 6.4, 7.2]
- LO 5.B.5.5:** The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [See Science Practices 2.2, 6.4]
- LO 5.B.10.1:** The student is able to make calculations related to a moving fluid using Bernoulli's equation. [See Science Practices 2.2]
- LO 6.E.3.1:** The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. [See Science Practices 1.1, 1.4]
- LO 7.A.3.3:** The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law $PV = nRT$. [See Science Practices 5.1]

AP Physics 2: Algebra-Based Scoring Guidelines

2018 SCORING GUIDELINES

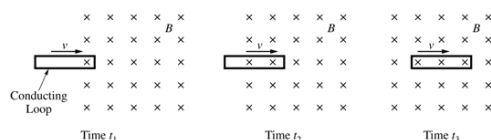
General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.
2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at <https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf>.
3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics*; *Physics C: Mechanics*, *Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.
5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.
6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

2018 SCORING GUIDELINES

Question 1

10 points total

Distribution
of points

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

- (a) LO 2.D.1.1, SP 2.2; LO 4.E.2.1, SP 6.4
5 points

In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1 , t_2 , and t_3 . Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

For indicating that the currents at t_1 and t_2 have equal nonzero magnitudes and are in the same direction	1 point
For indicating that there is no current at t_3	1 point
For correctly indicating that the currents depend on the change in flux through the loop or the forces on the charges moving in the field	1 point
For correctly identifying the direction of the current as counter-clockwise and either explaining that the direction of the current generates a magnetic field that opposes the change in flux <u>or</u> analyzing the force on the charge carriers in each segment of the loop	1 point
For an on-topic response that has sufficient paragraph structure, as described in the published requirements for the paragraph length response	1 point

- (b)

The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



2018 SCORING GUIDELINES

Question 1 (continued)

Distribution
of points

- (b) (continued)

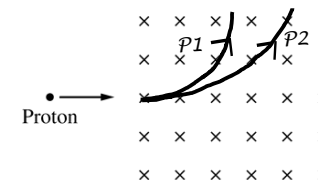
- i. LO 2.D.1.1, SP 2.2
1 point

Calculate the magnitude of the force on the proton as it enters the field.

For correct substitutions into a correct expression and correct units on the final answer	1 point
$F = qvB$	
$F = (1.6 \times 10^{-19} \text{ C})(3.0 \times 10^5 \text{ m/s})(0.03 \text{ T})$	
$F = 1.4 \times 10^{-15} \text{ N}$	

- ii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4; LO 3.C.3.1, SP 1.4
1 point

On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



For drawing a curved arc through the field, curved upward where the proton enters	1 point
Anything greater than a semi-circle or a path that does not reach the edge of the field does <u>not</u> earn credit. Any path after exiting the field is ignored.	

- iii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4
1 point

A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

For drawing a path with a larger radius that is consistent with answer to (b)(ii)	1 point
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2018 SCORING GUIDELINES

Question 1 (continued)

Distribution
of points

(b) (continued)

- iv. LO 2.C.1.1, SP 6.4; LO 2.C.1.2, SP 2.2; LO 3.B.2.1, SP 1.4, 2.2
2 points

Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

For indicating a direction of the electric field that is consistent with the response to (b)(ii)		1 point
Given the correct response to (b)(ii) illustrated above, the electric field must be directed in the $-y$ direction (or toward the bottom of the page)		
For equating the electric and magnetic forces and substituting into the correct expression using values consistent with the response to (b)(i)		1 point
$qE = qvB$ (Implicitly equating the calculated magnetic force to the electric force is acceptable.)		
$E = vB$		
$E = (3.0 \times 10^5 \text{ m/s})(0.03 \text{ T})$		
$E = 9000 \text{ N/C}$		

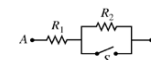
Learning Objectives (LO)

- LO 2.C.1.1:** The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation. [See Science Practices 6.4, 7.2]
- LO 2.C.1.2:** The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. [See Science Practice 2.2]
- LO 2.D.1.1:** The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See Science Practice 2.2]
- LO 3.B.1.4:** The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]
- LO 3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
- LO 3.C.3.1:** The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [See Science Practice 1.4]
- LO 4.E.2.1:** The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [See Science Practice 6.4]

2018 SCORING GUIDELINES

Question 2

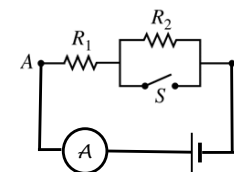
12 points total

Distribution
of points

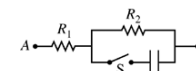
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2 , as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2 .

- (a) LO 4.E.5.3, SP 2.2, 4.2, 5.1; LO 5.B.9.5, SP 6.4; LO 5.C.3.4, SP 6.4
4 points

Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2 .



For a diagram with an ammeter and battery in series with the resistor combination		1 point
For indicating that the current should be measured with the switch closed and open		1 point
For correctly indicating that with the switch closed $R_1 = V/I_1$		1 point
For correctly indicating that with the switch open $R_2 = (V/I_2) - R_1$		1 point



A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between A and B is maintained at 9 V. The students close the switch and immediately begin to record the current through point B. The initial current is 0.9 A, and after a long time the current is 0.3 A.

2018 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

- (b)
- i. LO 4.E.5.2, SP 6.1, 6.4; LO 5.B.9.5, SP 6.4; LO 5.C.3.7, SP 1.4
3 points

Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

For indicating that the current through resistor 1 immediately after the switch is closed is greater than the current a long time after the switch is closed	1 point
For indicating that the current through resistor 2 is zero immediately after the switch is closed and nonzero a long time after the switch is closed	1 point
For indicating that the current through the switch is nonzero immediately after the switch is closed and zero a long time after the switch is closed	1 point

- ii. LO 4.E.5.1, SP 2.2, 6.4
2 points

Calculate the values of R_1 and R_2 .

For using the correct value of current and correctly calculating R_1	1 point
$9 \text{ V} = (0.9 \text{ A})R_1$	
$R_1 = 10 \Omega$	
For using the correct value of current and correctly calculating R_2 , consistent with the calculated value of R_1	1 point
$9 \text{ V} = (0.3 \text{ A})(R_1 + R_2) = (0.3 \text{ A})(10 \Omega + R_2)$	
$R_2 = 20 \Omega$	

- iii. LO 4.E.5.1, SP 2.2; LO 5.B.9.6, SP 2.2, LO 5.C.3.7, SP 1.4, 2.2
1 point

Determine the potential difference across the capacitor a long time after the switch is closed.

For correctly calculating the potential difference across the capacitor, including correct units, consistent with part (b)(ii)	1 point
$V_C = V_{\text{battery}} - V_{\text{resistor 1}} = 9 \text{ V} - (0.3 \text{ A})(10 \Omega)$	
$V_C = 6 \text{ V}$	

2018 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

- (c) LO 5.B.9.7, SP 5.3
2 points

How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

For correctly explaining that the third group's measured current is smaller	1 point
For correctly indicating that the third group's value of R_1 is higher than the second group's or the resistance they will determine is actually $R_1 + r$	1 point

Learning Objectives (LO)

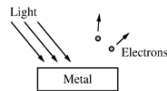
- LO 4.E.5.1:** The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 2.2, 6.4]
- LO 4.E.5.2:** The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 6.1, 6.4]
- LO 4.E.5.3:** The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [See Science Practices 2.2, 4.2, 5.1]
- LO 5.B.9.5:** The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See Science Practice 6.4]
- LO 5.B.9.6:** The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]
- LO 5.B.9.7:** The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [See Science Practices 4.1, 4.2, 5.1, 5.3]
- LO 5.C.3.4:** The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. [See Science Practices 6.4, 7.2]
- LO 5.C.3.7:** The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [See Science Practice 1.4, 2.2]

2018 SCORING GUIDELINES

Question 3

Distribution
of points

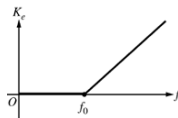
12 points total



Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

- (a) i. LO 5.B.4.2, SP 1.4, 2.1, 2.2; LO 6.F.3.1, SP 6.4
3 points

Based on conservation of energy, the relationship between K_e and f is predicted to be $Af = B + K_e$ when $f > f_0$ and $K_e = 0$ when $f \leq f_0$, where A and B are positive constants. A graph of this relationship is shown below. Indicate which aspects of the graph correspond to A and B . Also, explain the physical meaning of A , B , and f_0 .



For indicating that A represents the slope or the rate of change of K_e as a function of f and equals Planck's constant	1 point
For indicating that $-B$ is the intercept with the K_e axis and equals the minimum energy needed to release an electron from the metal (the work function)	1 point
For indicating that f_0 is the minimum frequency that will release an electron from the metal (the cutoff or threshold frequency)	1 point

- ii. LO 6.F.3.1, SP 6.4
1 point

Explain the physical meaning of the horizontal section of the graph between the origin and f_0 .

For indicating that the horizontal portion of the graph represents frequencies of light whose energy is insufficient to eject an electron	1 point
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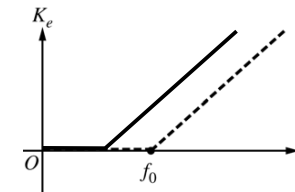
2018 SCORING GUIDELINES

Question 3 (continued)

Distribution
of points

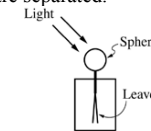
- (a) (continued)
iii. LO 6.F.3.1, SP 6.4
3 points

A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



For drawing a line that is parallel to the given line	1 point
For drawing the horizontal intercept on either side of f_0 with the line ending at the horizontal axis (The horizontal segment does not have to be drawn.)	1 point
For indicating that the K_e or f intercept changes because the work function or the frequency at which electrons can be emitted is different	1 point

- (b) The figure below shows an electroscope. A sphere is connected by a vertical bar to the leaves, which are thin, light strips of material. The sphere, leaves, and bar are all made of metal. The electroscope initially has a negative charge, so the leaves are separated.



- i. LO 1.B.1.2, SP 6.4, 7.2, LO 4.E.3.3, SP 6.4; LO 6.F.3.1, SP 6.4
2 points

Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

For indicating that the UV light causes electrons to be ejected from the electroscope	1 point
For indicating that the electroscope becomes less negatively charged, causing the leaves to move closer together	1 point

2018 SCORING GUIDELINES

Question 3 (continued)

Distribution
of points

(b) (continued)

- ii. LO 6.F.1.1, SP 6.4, 7.2, LO 6.F.3.1, SP 6.4
1 point

Green light then shines on an identical negatively charged electroscope. No movement of the leaves is observed. Explain why the green light does not make the leaves move, while the UV light does.

For indicating that the green light frequency or energy per photon is too low to eject electrons	1 point
--	---------

(c) LO 6.F.3.1, SP 6.4
2 points

The brightness of the green light is increased until the intensity (power per unit area) is the same as that of the UV light. What aspect of the green light changes when its brightness is increased? Would shining the brighter green light on the electroscope result in movement of the leaves? Explain why or why not.

For indicating that the increase in brightness causes an increase in the number of photons in the beam or increases the amplitude of the wave	1 point
For indicating that the leaves would not separate because the energy per photon or frequency of the light remains the same	1 point
The particle nature of light (photons) must be discussed to receive full credit.	

Learning Objectives (LO)

- LO 1.B.1.2:** The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [See Science Practices 6.4, 7.2]
- LO 4.E.3.3:** The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [See Science Practices 1.1, 1.4, 6.4]
- LO 5.B.4.2:** The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [See Science Practices 1.4, 2.1, 2.2]
- LO 6.F.1.1:** The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [See Science Practices 6.4, 7.2]
- LO 6.F.3.1:** The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [See Science Practice 6.4]

2018 SCORING GUIDELINES

Question 4

10 points total

Distribution
of points

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b . The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel} . The boat owners want to be able to carry as many beams as possible.

- (a) LO 1.E.1.2, SP 6.4; LO 3.B.2.1, SP 1.1, 1.4, 2.2; LO 5.B.10.1, SP 2.2
4 points

Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

For equating the correct forces acting on the boat-steel system: gravity (weight) and the buoyant force	1 point
For correctly calculating the weight of the boat-steel system $W_{\text{system}} = (M_b + N\rho_{\text{steel}}V_{\text{steel}})g$, where N is the number of steel beams (must clearly use mass of boat)	1 point
For correctly calculating the buoyant force $F_b = \rho_{\text{water}}gV_b$	1 point
For algebraic manipulation of the equations to get an expression for the number of beams consistent with the equations for weight and buoyant force $(M_b + N\rho_{\text{steel}}V_{\text{steel}})g = \rho_{\text{water}}gV_b$ $N = (\rho_{\text{water}}V_b - M_b)/\rho_{\text{steel}}V_{\text{steel}}$	1 point

- (b) LO 6.C.1.1, SP 6.4, 7.2; LO 6.E.1.1, SP 6.4, 7.2; LO 6.E.3.3, SP 6.4, 7.2
4 points

The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

The constructive interference is between light reflected from the air-oil interface and light reflected from the oil-water interface.	
For indicating that the green appearance is the result of interference of light from two waves	1 point
For indicating that there is a phase shift due to one of the reflections	1 point
For indicating that the wavelength of the light is different in air and oil	1 point
For indicating that there is a path-length difference of the light reflected from the two surfaces	1 point

2018 SCORING GUIDELINES

Question 4 (continued)

Distribution
of points

- (c) LO 5.F.1.1, SP 2.2, 7.2
2 points

Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

For an attempting to apply the principle of continuity		1 point
$A_{\text{wide}}v_{\text{wide}} = A_{\text{narrow}}v_{\text{narrow}}$		
$(60 \text{ m})(\text{depth})(5 \text{ km/hr}) = (30 \text{ m})(\text{depth})(v_{\text{narrow}})$		
For correctly calculating the speed		1 point
$v_{\text{narrow}} = 10 \text{ km/hr}$		

Learning Objectives (LO)

- LO 1.E.1.2:** The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [See Science Practices 4.1, 6.4]
- LO 3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
- LO 5.B.10.1:** The student is able to use Bernoulli's equation to make calculations related to a moving fluid. [See Science Practice 2.2]
- LO 5.F.1.1:** The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [See Science Practices 2.1, 2.2, 7.2]
- LO 6.C.1.1:** The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [See Science Practices 6.4, 7.2]
- LO 6.E.1.1:** The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [See Science Practices 6.4, 7.2]
- LO 6.E.3.3:** The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [See Science Practices 6.4, 7.2]

2017

AP Physics 2: Algebra-Based Scoring Guidelines

**AP® PHYSICS
2017 SCORING GUIDELINES**

General Notes About 2017 AP Physics Scoring Guidelines

- The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.
- The requirements that have been established for the paragraph length response in Physics 1 and Physics 2 can be found on AP Central at <https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf>.
- Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.
- Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.
- The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.
- Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

2017 SCORING GUIDELINES

Question 1

10 points total

**Distribution
of points**

- (a)
- 1 point

For indicating that student Y is correct in stating that the water moves faster at point B , and not indicating any other aspect 1 point
 - 2 points

Student Y's statement that P_B is greater than P_A is not correct.
For a correct indication of how height affects pressure using the Bernoulli equation (i.e., conservation of energy principles) 1 point
For correct indication of how the speed affects pressure using the Bernoulli equation (i.e., conservation of energy principles) 1 point
Example: The pressure at point B is not greater. Because the water at B is moving faster and is higher than at point A , the kinetic energy and the gravitational potential energy terms in Bernoulli's equation are both greater. Because the sum of pressure and these energy terms is a constant, the pressure must be less.
 - 1 point

For indicating one of the following: 1 point
 - Student Z is correct in stating that the potential energy of the water-Earth system has increased.
 - Student Z is correct in stating that conservation of energy applies.
 - Stating that nothing is correct or giving no response, with a justification in (iv).
 - 1 point

For indicating that student Z is incorrect in stating that the speed is less at point B , not indicating any other aspect, and using continuity or the Bernoulli equation (i.e., conservation of energy principles) to show that it is greater
OR
if third bullet for (iii) applies, indicating that work is done on the water due to the pressure difference, so the energy is not constant 1 point

2017 SCORING GUIDELINES

Question 1 (continued)

Distribution
of points

- (b)
- i. 2 points
- For a correct application of the continuity equation including substitutions 1 point
- $$A_A v_A = A_B v_B$$
- $$v_B = A_A v_A / A_B = r_A^2 v_A / r_B^2 = (2.5 \text{ cm})^2 (0.5 \text{ m/s}) / (1.5 \text{ cm})^2$$
- For a correct answer with units 1 point
- $$v_B = 1.4 \text{ m/s}$$
- ii. 1 point
- For an application of Bernoulli's equation to this situation and substitutions consistent with (b)(i) 1 point
- $$P_A + \rho g y_A + \frac{1}{2} \rho v_A^2 = P_B + \rho g y_B + \frac{1}{2} \rho v_B^2$$
- $$P_B = P_A + \rho g (y_A - y_B) + \frac{1}{2} \rho (v_A^2 - v_B^2)$$
- $$P_B = 2 \times 10^5 + (1000)(10)(-5) + \frac{1}{2}(1000)(0.5^2 - 1.4^2) = 2 \times 10^5 - 50000 - 855$$
- $$P_B = 1.5 \times 10^5 \text{ Pa}$$
- (c)
- i. 1 point
- For substituting correctly in an appropriate equation for determining the pressure 1 point
- $$P = P_0 + \rho g h_A = 1 \times 10^5 \text{ Pa} + (1000 \text{ kg/m}^3)(10 \text{ m/s}^2)(6 \text{ m})$$
- $$P = 1.6 \times 10^5 \text{ Pa}$$
- ii. 1 point
- For indicating that the buoyant force is toward the top of the page and gravity is toward the bottom of the page, with the buoyant force longer 1 point
- Student can draw lots of pressure forces around the dot instead of one buoyant force, as long as there is no buoyant force labeled and they add up to a net buoyant force that is longer than the gravitational force.

2017 SCORING GUIDELINES

Question 2

12 points total

Distribution
of points

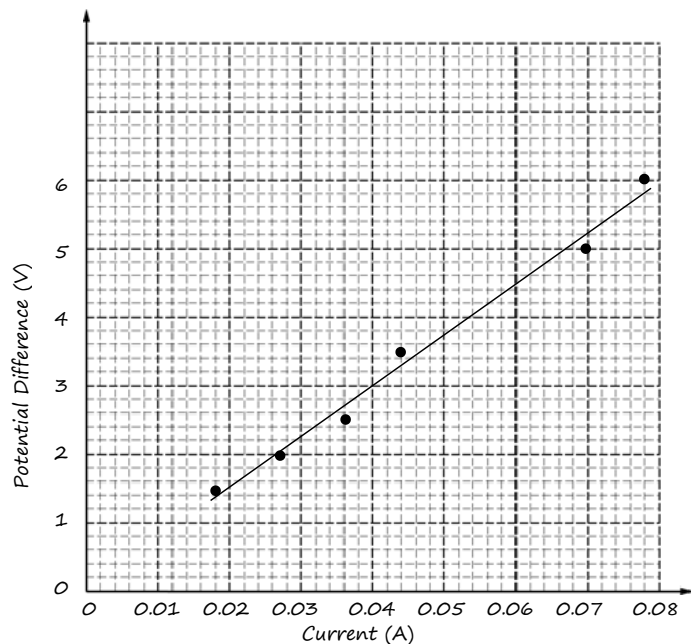
- (a)
- i. 5 points
- For drawing a circuit with the battery, rod, and ammeter in series (rods can be drawn to look like rods, or schematically as resistors) 1 point
- For drawing the voltmeter parallel to the rod, or indicating that the setting on the power supply will be used 1 point
- For measuring potential difference and current for a rod 1 point
- For measuring the length and diameter of a rod 1 point
- For including multiple trials with appropriate controls 1 point
- Examples: 1) Use one rod and apply different potential differences
2) Use different rods
- ii. 2 points
- For graphing appropriate quantities whose slope can be used to calculate resistance directly or indirectly 1 point
- For correctly stating how the slope relates to the resistivity 1 point

2017 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

(b) 3 points



For plotting the data on the graph with potential difference on one axis and current on the other, labeled with units, using a reasonable scale

1 point

For a clearly shown calculation of slope from a reasonable best-fit line

1 point

For a correct answer with units

1 point

Acceptable range is $70 - 79 \Omega$.

For a graph of I as a function of V , the slope should end up near $0.013 \Omega^{-1}$ and the resistance is the inverse

For a graph of V as a function of I , the slope should end up near 74Ω and equals the resistance

For the example shown above

$$\text{slope} = \frac{(5.8 - 2.4) \text{ V}}{(0.078 - 0.032) \text{ A}} = 73.9 \Omega$$

2017 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

(c)

i. 1 point

For indicating that the internal resistance of the power supply will not affect the data acquired, with correct reasoning

1 point

Example: Because potential difference is measured across each rod, $\Delta V/I$ is not affected by the internal resistance of the battery.

ii. 1 point

For indicating either:

The students should be concerned because a change in temperature causes a change in the resistance or resistivity.

1 point

OR

The students should not be concerned because any change in resistivity as the temperature increases is small compared to measurement error.

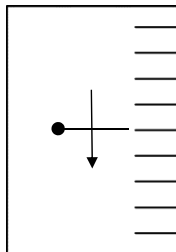
2017 SCORING GUIDELINES

Question 3

Distribution
of points

12 points total

- (a) 2 points



For the arrow drawn upside down relative to the object
 For bar/circle drawn left-to-right reversed relative to the object or consistent with an (incorrect) upright arrow

1 point
1 point

- (b) i. 1 point

For correctly showing a calculation of the focal length and a correct answer with units

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{20 \text{ cm}} + \frac{1}{30 \text{ cm}}$$

$$f = 12 \text{ cm}$$

1 point

- ii. 1 point

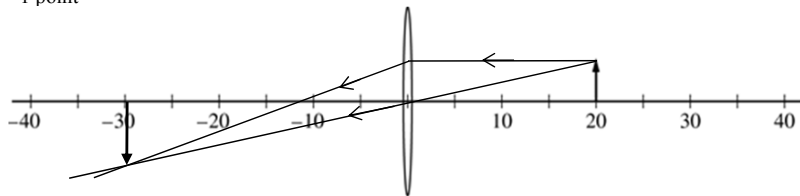
For correctly showing a calculation of the magnitude of the magnification (with or without sign) and a correct answer

$$M = d_i/d_o = 30 \text{ cm}/20 \text{ cm}$$

$$M = 1.5$$

1 point

- (c) i. 1 point



For two reasonably correctly drawn rays consistent with the calculated focal length, and inclusion of an inverted image

1 point

2017 SCORING GUIDELINES

Question 3 (continued)

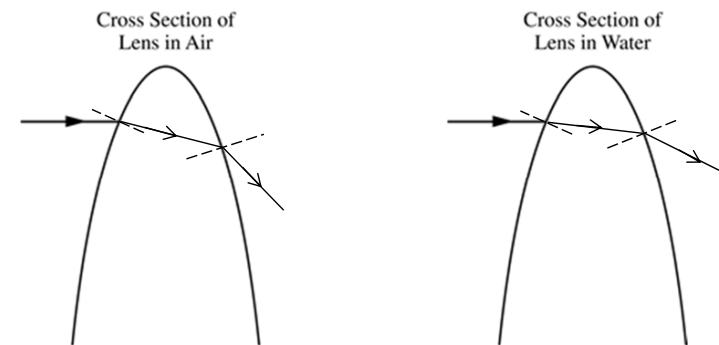
Distribution
of points

- (c) (continued)
-
- ii. 2 points

For a correct explanation of how the rays drawn relate to the focal length
 For a correct explanation of how the image relates to the magnification
 Example: The horizontal ray from the object bends to cross the axis at 12 cm from the middle of the lens, which is the focal length. The image arrow is about 1.5 times the height of the object, which is the magnification.

1 point
1 point

- (d) i. 2 points



For showing the downward refraction of the rays at each surface of the lens in air (i.e., toward the normal entering the lens and away from the normal leaving the lens)
 For the rays refracted by the lens in water at greater angles to the normal than the corresponding angles for the lens in air — i.e., less bending (can be earned even if first point was not, scoring is relative to whatever is drawn for the lens in air)

1 point
1 point

- ii. 3 points

For describing a greater focal length when the lens is in water or a comparison consistent with part (d)(i)
 For describing a larger image distance and image size or a comparison consistent with part (d)(i)
 For describing how the rays drawn in (d)(i) support the descriptions
 Example: The rays do not bend as much as they pass from water to glass as when they pass from air to glass (and vice versa). This means parallel rays coming into the lens will converge at a farther distance, so the focal length is longer. Rays from an object also will converge farther from the lens, so the new image is farther and larger.

1 point
1 point
1 point

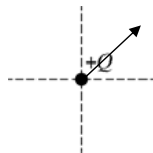
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Question 4

10 points total

Distribution
of points

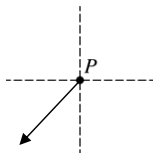
- (a) 1 point



For an arrow pointing outward from the object, along a diagonal of the square and away from the object with charge $-2Q$, with no other arrows

1 point

- (b)
-
- i. 3 points



For correctly determining magnitudes of the field from individual objects
The fields from the $+2Q$ objects cancel. This can be implicit or explicit in the calculations.

1 point

For the $-2Q$ object, $E = 2kQ/d^2$

For the $+Q$ object, $E = kQ/d^2$

For correctly adding the individual fields

1 point

$$E = 3kQ/d^2$$

For showing the correct direction on the diagram, along a diagonal of the square and toward the object with charge $-2Q$

1 point

- ii. 1 point

For showing a correct scalar potential summation

1 point

A final answer is not required; however, no credit is given if an incorrect final answer is included.

$$V = (k/d)(+2Q + Q + 2Q - 2Q) = 3kQ/d$$

2017 SCORING GUIDELINES

Question 4 (continued)

Distribution
of points

- (c) 5 points

For indicating that electric potential energy is the energy stored in a configuration of charged objects

1 point

For indicating that the change in potential energy is equal to the work done by an external force to create a particular configuration

1 point

For indicating that moving the object with $+2Q$ charge results in an increase in energy and indicating that moving the object with $+Q$ charge results in a decrease in energy (i.e., for showing understanding that moving charges of the same sign closer together increases the energy and/or moving charges of opposite sign closer together decreases the energy, with some support such as $U = kqQ/r$ or a description of doing work against forces)

1 point

For indicating that the net result is an increase in the energy with some explanation

1 point

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

1 point

AP[®] Physics 2

2016 Scoring Guidelines

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2016 SCORING GUIDELINES

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

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

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

$$PV = nRT$$

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

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

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

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

1 point

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

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

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

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

2016 SCORING GUIDELINES

Question 1 (continued)

Distribution
of points

(b)

ii. (continued)

Alternately, ΔU can be calculated directly from the given data

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

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

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

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

$$Q = 7500 \text{ J}$$

1 point

(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

$$\Delta K_{\text{total}} = (3/2)k_B \Delta T n N_0 \quad \text{or} \quad \Delta K_{\text{total}} = (3/2)nR \Delta T$$

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

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

1 point

2016 SCORING GUIDELINES

Question 2

Distribution
of points

12 points total

(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

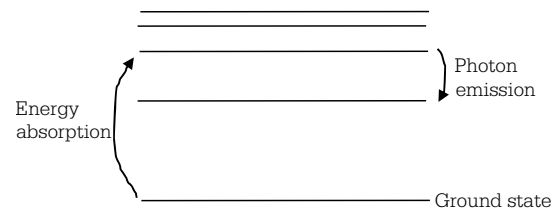
2016 SCORING GUIDELINES

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.

2016 SCORING GUIDELINES

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

1 point

1 point

ii. 2 points

For using a correct expression for work

$$W = Fd \quad \text{or} \quad -\Delta U_E = q\Delta V$$

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

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

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

1 point

1 point

iii. 2 points

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

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.

1 point

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

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.

1 point

2016 SCORING GUIDELINES

Question 4

Distribution
of points

10 points total

(a)

i. 1 point

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

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.

1 point

ii. 1 point

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

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.

1 point

(b)

i. 2 points

For a calculation that indicates one of the following:

- 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

1 point

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

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

For correctly calculating the ratio

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

1 point

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

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. $C = \epsilon_0 A/d$, so half the plate area with the same distance between the plates will accomplish this.

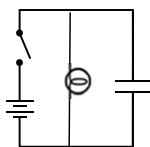
1 point

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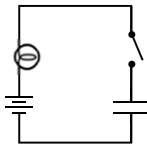
Question 4 (continued)

Distribution
of points

(c) 5 points



Arrangement 1



Arrangement 2

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

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

Response using potential difference

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

AP[®] Physics 2

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2015 SCORING GUIDELINES

Question 1

10 points total

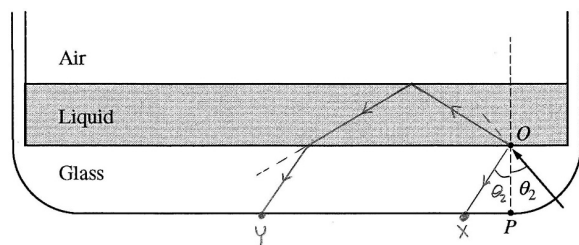
Distribution
of points

(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 $P_1 = \frac{1}{4}(\mathcal{E}^2/R)$ 1 point
- For indicating that the new equivalent resistance of the circuit is $R_{\text{eq,new}} = (3/2)R$ 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 $P_{\text{new}} = \frac{16}{9}P_1$ 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 bulb 1 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 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

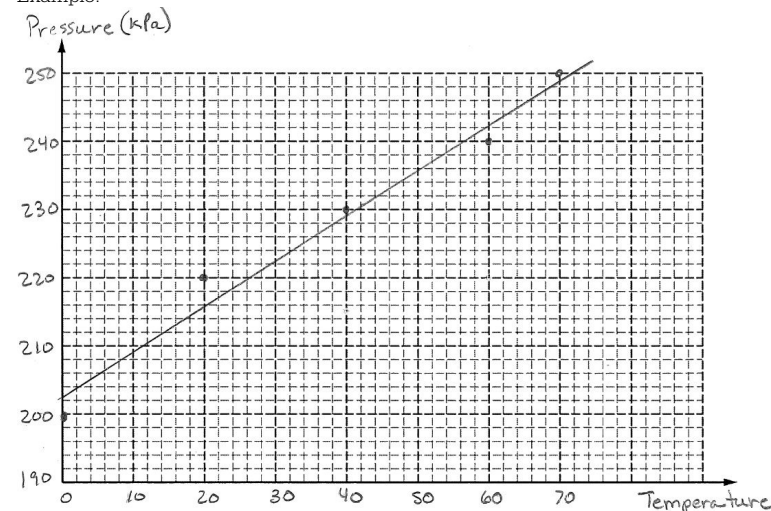
(d) 3 points

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.

2015 SCORING GUIDELINES

Question 4

Distribution
of points

10 points total

(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

$$\Delta V = Ed$$

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

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

1 point

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

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

2015 SCORING GUIDELINES

Question 4 (continued)

Distribution
of points

(c) 1 point

$$E = Q/\epsilon_0 A$$

$$Q = \epsilon_0 A E$$

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

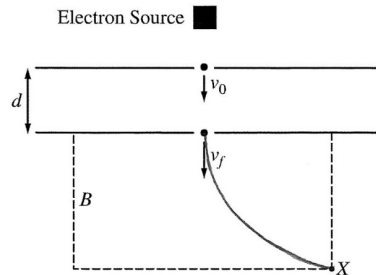
1 point

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

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

(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.