Question 4: Short Answer/Other — 10 points

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

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

Example Response

$|q\Delta V| = K$

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

Example Solution

$$E_0 = E_f$$
$$\Delta U + \Delta K = 0$$
$$-\Delta U_E = \Delta K$$
$$|q\Delta V| = K$$

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

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

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

Total for part (a) — **2 point**

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

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

Example Response

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

Example Solution

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

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

Example Response

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

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

Example Response

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

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

Example Solution

$$\vec{a} = \frac{\sum \vec{F}}{m}$$
$$\vec{a}_c = \frac{q\vec{v} \times \vec{B}}{m}$$
$$\frac{v^2}{r} = \frac{qvB}{m}$$
$$r = \frac{mv}{qB}$$

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

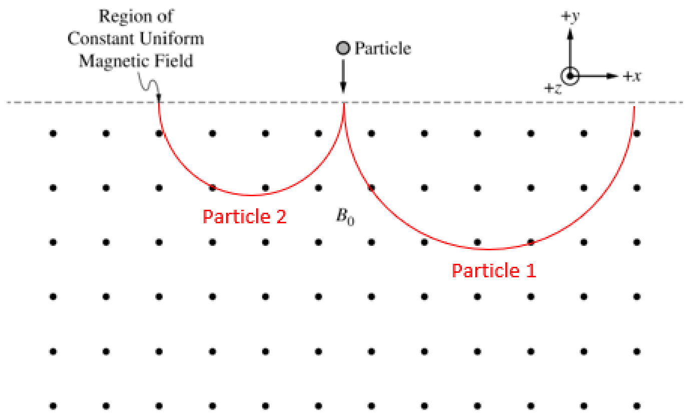
$$r = \frac{\sqrt{K_2 M}}{2QB_0}$$

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

Total for part (b) — **4 points**

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

Example Response



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

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

Example Response

$+x$ -direction

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

Total for question 4 **10 points**

Question 4: Short Answer — 10 points

(a)	For an appropriate use of Newton's laws to set the magnetic force equal to the electric force	**1 point**
	For using correct expressions for the magnetic and electric forces	**1 point**
	For substituting an expression for the magnetic field to yield a correct expression that includes v and the given quantities	**1 point**

Example Response

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

$F_M - F_E = 0$

$F_M = F_E$

$qvB = qE$

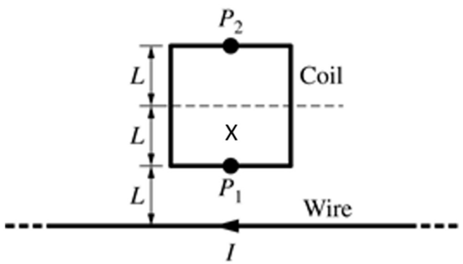
$v\left(\dfrac{\mu_0 I}{2\pi d}\right) = E$

$v = \dfrac{2\pi d E}{\mu_0 I}$

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

(b)(i)	For an "X" between point P_1 and the dashed line	**1 point**

Example Response



	For indicating that the magnetic field strength is inversely proportional to the distance from the wire	**1 point**

Example Response

Magnetic field is inversely proportional to the distance from a long, straight current carrying wire: $B = \dfrac{\mu_0 I}{2\pi r}$ *. Doubling the distance from the wire from* L *to* $2L$ *would reduce the magnetic field from* $3B_0$ *to* $1.5B_0$*. Therefore, the magnetic field would be equal to* $2B_0$ *somewhere between* L *and* $2L$ *.*

(b)(ii)	For using the change in flux, with correct substitutions, to determine the emf	**1 point**
	For correctly applying Ohm's law with correct substitutions	**1 point**

Scoring Note: It is not necessary to independently calculate a numerical value for the emf.

Example Response

$$|\mathcal{E}| = \left|-\frac{\Delta\Phi_B}{\Delta t}\right| = \frac{\left(5.0\times10^{-5} - 1.0\times10^{-5}\right)\ \text{T}\bullet\text{m}^2}{2.0\ \text{s}} = 2.0\times10^{-5}\ \text{V}$$

$$I = \frac{|\mathcal{E}|}{R} = \frac{2.0\times10^{-5}\ \text{V}}{10\ \Omega} = 2.0\times10^{-6}\ \text{A}$$

Total for part (b) 4 points

(c)	For indicating that the current in the round coil produces a magnetic field	**1 point**
	For indicating that the magnetic field from the round coil produces a flux through the square coil	**1 point**
	For indicating that the changing flux produces an emf or current in the square coil circuit	**1 point**

Scoring Note: A response that indicates that the magnetic flux only changes during a portion of the entire time interval does not earn this point.

Example Response

The current in the round coil produces a magnetic field. The magnetic field from the round coil passes through the square coil, producing a flux. As the current in the power supply increases, so does the current in the round coil, and, therefore, the magnetic field created by the current increases. Since the magnetic field changes, the flux through the square coil changes. The constantly changing magnetic flux through the square coil produces an emf and, therefore, current in the square coil to light the lightbulb.

Total for part (c) 3 points

Total for question 4 10 points

Question 3: Quantitative/Qualitative Translation — 12 points

(a)	For indicating that the magnetic field needs to double in order to double the force (since the force equals qvB)	**1 point**
	For correctly explaining why the magnitude of the current must double, without any incorrect statements	**1 point**
	For indicating that the current must go in the opposite direction, i.e. be negative	**1 point**

Example response for part (a)

The current must change direction and double in magnitude. The graph shows that when the current doubles the magnetic field doubles. When the magnetic field doubles, the magnetic force doubles. Reversing the direction of the current will reverse the direction of the magnetic field, and therefore the direction of the force.

Total for part (a) 3 points

(b)	For indicating that the emf is the same	**1 point**
	For indicating that larger resistance and/or less current means less power, without making any incorrect statements	**1 point**
	For indicating that the slope between t_1 and t_3 is less, or the horizontal line segment at right would be below the one shown	**1 point**

Example response for part (b)

The slope of the energy vs. time graph represents power. Because the induced emf is the same, but resistance is higher, power is lower. Therefore, the slope would be smaller.

Total for part (b) 3 points

(c)	For indicating that the greater change in magnetic field means a greater change in magnetic flux or a larger emf	**1 point**
	For indicating that power increases with increasing emf so the power and thus the energy dissipated is greater, or for an answer that is consistent with the response to the previous point in (c).	**1 point**
	For indicating that the slope between t_1 and t_3 is greater, or the horizontal line segment at right would be above the one shown, or for an answer that is consistent with the response to the first point in (c)	**1 point**

Example response for part (c)

The induced emf is larger than it was before because the magnetic field changed by a larger amount in the same time period. Power is proportional to the square of the emf, so the power is larger. Power is the slope of energy vs time, so the slope is greater for the new graph.

Total for part (c) 3 points

(d)	For any indication the cumulative energy dissipated depends on the time elapsed	**1 point**
	For indicating that the emf depends on the rate of change of the magnetic flux, i.e., it is inversely proportional to the time elapsed	**1 point**
	For indicating that the power is proportional to the square of the emf and the energy dissipated is power times time, so energy is inversely proportional to the time	**1 point**

Total for part (d) 3 points

Total for question 3 12 points

2019

AP® CollegeBoard

AP® Physics 2: Algebra-Based
Scoring Guidelines

2019 SCORING GUIDELINES

General Notes About 2019 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.

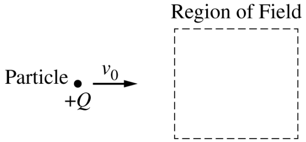
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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.

Question 1

10 points



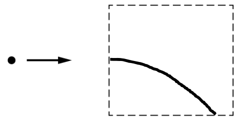
The figure above shows a particle with positive charge $+Q$ traveling with a constant speed v_0 to the right and in the plane of the page. The particle is approaching a region, shown by the dashed box, that contains a constant uniform field. The effects of gravity are negligible.

(a)

i. 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.

Electric Field

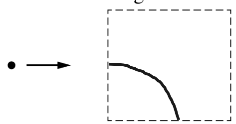


For a curved path that is initially horizontal and does not have a component of velocity toward the left		1 point
For a path that deflects toward the bottom of the page and reaches an edge of the region		1 point

ii. 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.

Magnetic Field



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

Question 1 (continued)

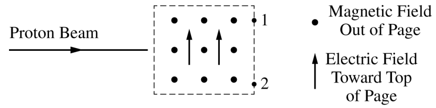
(a) (continued)

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

(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.		

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.		

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]

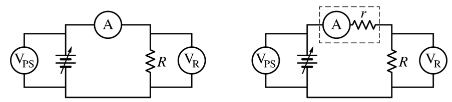
LO 3.B.1.4: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]

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]

Question 2

12 points



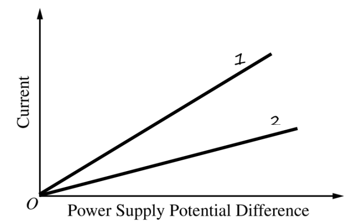
Circuit 1 Circuit 2

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.

<u>Circuit 1</u> <u>Circuit 2</u>

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

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.		

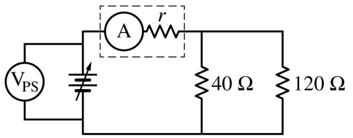
(d) LO 5.B.9.6, SP 2.2; LO 5.C.3.4, SP 6.4, 7.2
2 points

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

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
$\dfrac{1}{40\ \Omega} + \dfrac{1}{120\ \Omega} = \dfrac{4}{120\ \Omega}$		
$R_{\parallel} = 30\ \Omega$		
For adding the value of r from part (d) to $R_{\parallel}$		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
$\Delta V_{\text{parallel}} = (3\ \text{V}) - (8\ \Omega)(0.079\ \text{A}) = 2.36\ \text{V}$ $I_{40\ \Omega} = \dfrac{2.36\ \text{V}}{40\ \Omega} = 0.059\ \text{A}$ $I_{120\ \Omega} = \dfrac{2.36\ \text{V}}{120\ \Omega} = 0.020\ \text{A}$		

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]

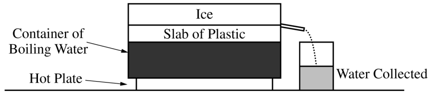
LO 5.B.9.6: The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]

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]

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.

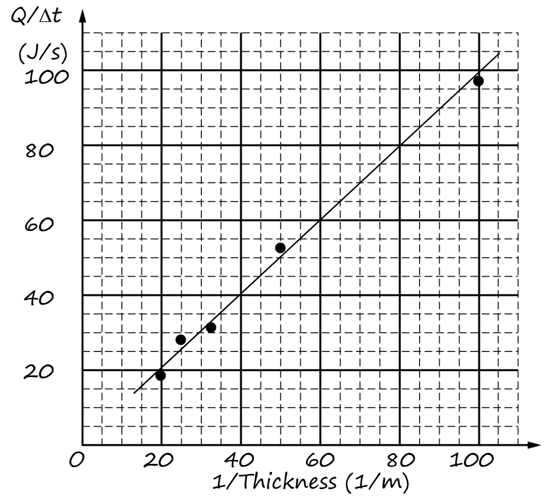
Table with sample entries for part (a)(ii)

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/Thickness (1/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



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.

$\dfrac{Q}{\Delta t} = \dfrac{kA\Delta T}{L}$		
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 $= \dfrac{(80-20)(\text{J/s})}{(80-20)(1/\text{m})} = 1.0\ \text{J}\bullet\text{m/s}$		
For determining the thermal conductivity k, with or without units using the slope found above		1 point
$\dfrac{Q}{\Delta t} = \dfrac{kA\Delta T}{L}$ so slope $= kA\Delta T$		
Using slope above: $k = \text{slope}/A\Delta T = 1(\text{J}\bullet\text{m/s})/\left(0.025\ \text{m}^2\right)(100°\ \text{C}) = 0.40\ \text{J/s}\bullet\text{m}°\text{C}$		

Question 3 (continued)

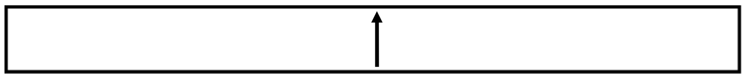
(b) LO 5.B.6.1, SP1.2
2 points

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

(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.		

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

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]

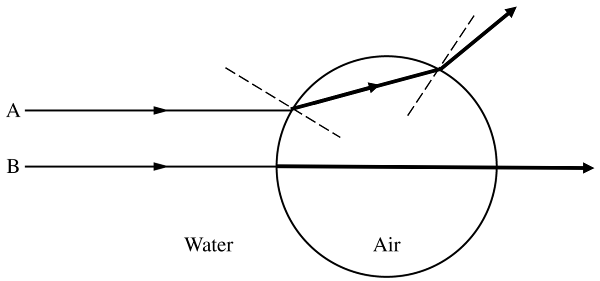
Question 4

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

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.

$P_{4.5\text{m}} = P_{atm} + \rho_w g d$		
$P_{4.5\text{m}} = (1.0 \times 10^5 \text{Pa}) + (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(4.5 \text{ m})$		
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
$P_{4.5\text{m}} V_1 = P_{atm} V_{surface}$		
$V_{surface} = P_{4.5\text{m}} V_1 / P_{atm}$		
For substituting pressures consistent with part (i)		1 point
$V_{surface} = (1.44 \times 10^5 \text{ Pa}) V_1 / (1 \times 10^5 \text{ Pa})$		
$V_{surface} = 1.44 V_1$ (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
Note: The explanation may be qualitative or quantitative. The explanation may also be macroscopic or microscopic.		

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Question 4 (continued)

(c) (continued)
iii. (continued)

Example 1: By the ideal gas law, $P_{4.5\text{m}}V_1/T_1 = P_{atm}V_{surface}/T_{surface}$, so $V_{surface} = P_{4.5\text{m}}V_1T_{surface}/P_{atm}T_1$. The two pressures still have their previous values. $T_{surface} < T_1$, 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: $P_{4.5\text{m}}V_1/T_1 = P_{atm}V_{surface}/T_{surface}$, so $V_{surface} = P_{4.5\text{m}}V_1T_{surface}/P_{atm}T_1$ Example 1 reasoning: The two pressures still have their previous values. $T_{surface} < T_1$, 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]

2018

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*.

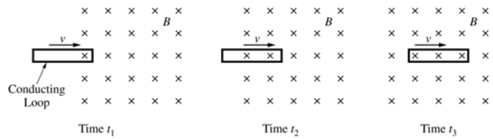
5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 $v = 3.0 \times 10^5 \text{ m/s}$. 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)

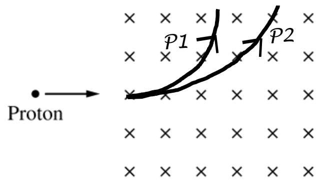
i. LO 2.D.1.1, SP 2.2
1 point

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
$F = qvB$		
$F = \left(1.6 \times 10^{-19}\ \text{C}\right)\left(3.0 \times 10^{5}\ \text{m/s}\right)(0.03\ \text{T})$		
$F = 1.4 \times 10^{-15}\ \text{N}$		

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 not 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

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.)		
$E = vB$		
$E = \left(3.0 \times 10^{5}\ \text{m/s}\right)(0.03\ \text{T})$		
$E = 9000\ \text{N/C}$		

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]

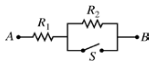
LO 3.C.3.1: The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [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

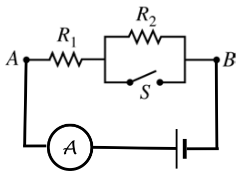
12 points total **Distribution of points**



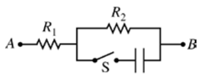
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The 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

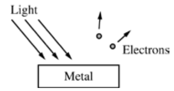
Learning Objectives (LO)

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

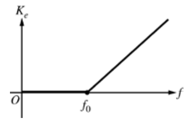
12 points total **Distribution of points**



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

2018 SCORING GUIDELINES

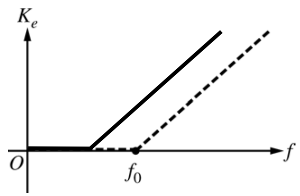
Question 3 (continued)

Distribution of points

(a) (continued)

iii. LO 6.F.3.1, SP 6.4
3 points

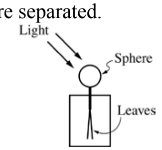
A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



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.		

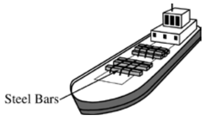
Learning Objectives (LO)

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

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

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]

AP® Physics 2
2015 Scoring Guidelines

2015 SCORING GUIDELINES

Question 1

10 points total | **Distribution of points**

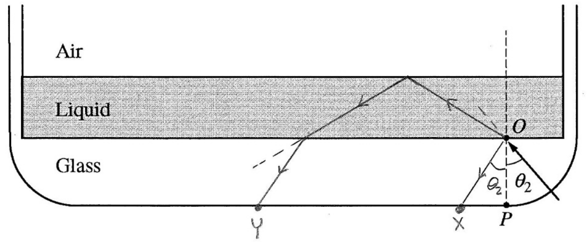
(a) 5 points

For explaining that the light that results in spot *X* reflects at the glass-liquid interface	1 point
For explaining that the light that results in spot *Y* is refracted both as it leaves the glass and reenters the glass (direction of refraction need not be correct)	1 point
For explaining that the light that results in spot *Y* is reflected at the liquid-air interface	1 point
For explaining that *Y* is farther from *P* than *X* in terms of the geometry of the path	1 point
For explaining that at each interface the brightness is affected by reflection, and by transmission and/or refraction as appropriate	1 point

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

(b)

i) 2 points



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

ii) 1 point

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

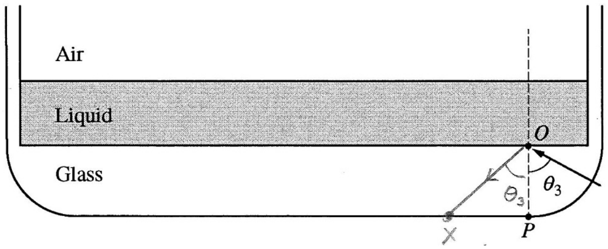
2015 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(c)

i) 1 point



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

ii) 1 point

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

2015 SCORING GUIDELINES

Question 2

12 points total

Distribution of points

(a)

i) 3 points

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

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

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

ii) 3 points

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

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

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

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

iii) 1 point

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

(b)

i) 1 point

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

ii) 1 point

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

2015 SCORING GUIDELINES

Question 2 (continued)

	Distribution of points
(c) 3 points	
For indicating in either part (c)i or part (c)ii that brightness is dependent on potential difference across the bulb OR on current through the bulb	1 point
i)	
For a reasonable explanation for why bulb 1 is brighter than bulb 2	1 point
Example: Immediately after the switch is closed, the potential difference across the capacitor will be zero (like a short in the circuit), so the current through bulb 2 would be zero, which is less than the current through bulb 1.	
Note: No points will be awarded for indicating that bulb1 is brighter than bulb 2 with no justification.	
ii)	
For a reasonable explanation for why bulb 1 is the same brightness as bulb 2	1 point
Example: The current through bulb 2 increases as the potential difference across the capacitor increases (becomes like an open circuit), so a long time after the switch is closed, the current through bulb 2 will be equal to the full current through bulb 1.	
Note: No points will be awarded for indicating that bulb 1 is the same brightness as bulb 2 without a justification.	

2015 SCORING GUIDELINES

Question 3

12 points total	Distribution of points
(a) 2 points	
For indicating that the ideal gas law ($PV = nRT$ or $PV = NkT$) gives the relevant relationship between pressure and temperature of a gas and attempting to use it to support some reasoning	1 point
For indicating that the volume and number of moles (or particles) of gas are held constant	1 point
Note: The student will not be penalized for not specifying that pressure and temperature are only directly proportional when the temperature is measured in Kelvin.	
Alternate Solution	*Alternate Points*
For indicating that the density of a sample of gas increases as its temperature decreases (if the pressure and number of moles or molecules of gas are held constant), and a sample of denser gas will sink below samples of gas that are less dense	*1 point*
For indicating that the gas near the North Pole is not a closed system and its pressure will increase as additional sinking gas molecules are added to it	*1 point*
(b) 4 points	
For selecting one of the cylinders and indicating or implying that volume is held constant	1 point
For selecting all the equipment described in the procedure and no extraneous equipment	1 point
For describing a method of measuring the temperature of the enclosed gas	1 point
For describing a method for measuring the pressure at more than just two temperatures	1 point
Example: Insert the thermometer and pressure sensor in the gasket to measure the gas temperature and pressure. Place the cylinder in the bath with hot (cold) water. Take measurements periodically as the bath water cools (heats) over time.	

2015 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

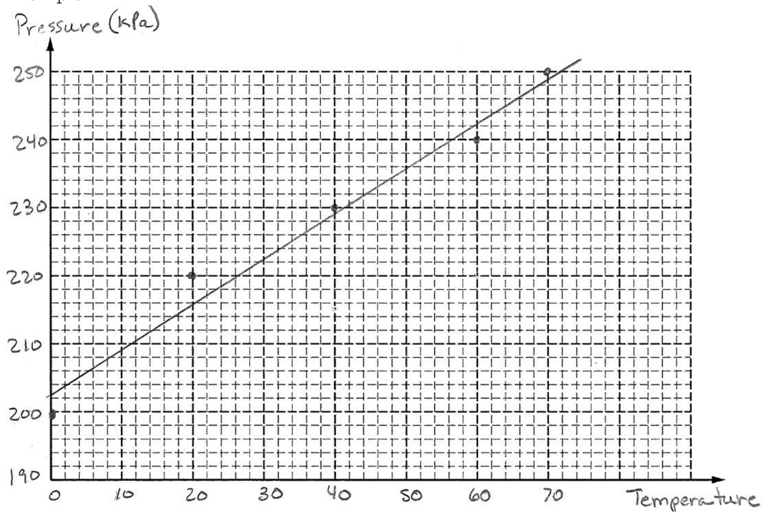
(c) 2 points

For selecting a set of trials in which volume is held constant and explaining that the volume must be held constant to test the relationship between pressure and temperature	1 point
For selecting trials in which volume is $5.0\ \text{cm}^3$, and explaining that there are the most trials for this volume, and the most trials will result in the most reliable test	1 point
Alternate Solution	*Alternate points*
For selecting the full set of trials and explaining that the effect of changing volume on the relationship between pressure and temperature can be taken into account by multiplying pressure by volume (or plotting P/T as a function of $1/V$, etc.)	*1 point*
For explaining that selecting the most trials will result in the most reliable test OR that selecting the widest range of pressure values will result in the most precise determination of the proportionality constant relating pressure and temperature	*1 point*

(d) 3 points

For plotting P as a function of T (or T as a function of $1/P$, etc.) OR plotting PV as a function of T (or P as a function of V/T, etc.) for each trial selected in part (c)	1 point
For appropriate axis labels with units and appropriate scales	1 point
For drawing an appropriate best-fit line or curve	1 point

Example:



2015 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(e) 1 point

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

Examples:

The relationship between P and T is linear.

The relationship between P and V/T is hyperbolic.

2015 SCORING GUIDELINES

Question 4

10 points total | **Distribution of points**

(a) 2 points

The top plate is negative.

For relating the direction of force or acceleration to the direction of the field — 1 point

For relating the direction of the electric field to the sign of the charge on the top plate — 1 point

No points are awarded for identifying that the top plate is negative with no attempt to explain why.

(b) 4 points

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

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

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

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

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

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

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

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

Alternate Solution | *Alternate Points*

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

$\Delta K = \Delta U$

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

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

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

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

$\Delta V = Ed$

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

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

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

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

2015 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(c) 1 point

$E = Q/\varepsilon_0 A$

$Q = \varepsilon_0 AE$

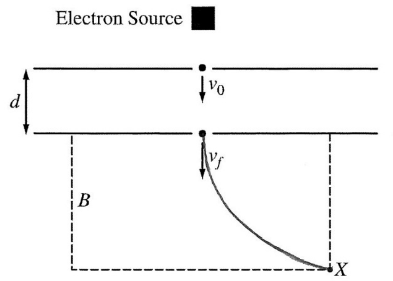
For correct substitution of values into the equation to calculate the magnitude of charge on each parallel plate — 1 point

$Q = \left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(0.25\ \text{m}^2\right)(10{,}000\ \text{N/C})$

$Q = 2.2\times10^{-8}\ \text{C}$

(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.