

Question 2: Translation Between Representations (TBR)

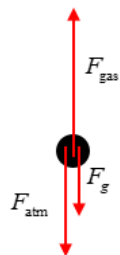
12 points

A For drawing an appropriately labeled arrow downward to represent the direction of the force F_g of gravity that is exerted on the piston **Point A1**

For drawing an appropriately labeled arrow downward to represent the direction of the force F_{atm} of the atmosphere that is exerted on the piston **Point A2**

For drawing an appropriately labeled arrow upward to represent the direction of the force F_{gas} of the gas that is exerted on the piston **Point A3**

Example Response



B For a multistep derivation that includes $U = \frac{3}{2}nRT$, $U = \frac{3}{2}Nk_B T$, $PV = nRT$, **Point B1**

$$PV = Nk_B T, \vec{a}_{\text{sys}} = \frac{\sum \vec{F}}{m_{\text{sys}}} = \frac{\vec{F}_{\text{net}}}{m_{\text{sys}}}, \sum \vec{F} = 0, P = \frac{F_{\perp}}{A}, \text{ an equation that is equivalent}$$

to one of the equations listed, or a relevant equation

Scoring Note: Vector notation is not required for this point to be earned.

For correctly relating the internal energy of the gas to $PV = nRT$ or $PV = Nk_B T$ **Point B2**

$$(\text{e.g., } U = \frac{3}{2}PV)$$

Scoring Note: This point can be earned if the response refers to a generic pressure instead of an absolute pressure.

For an expression for **one** of the following: **Point B3**

- The correct absolute pressure P of the gas (e.g., $PA - P_{\text{atm}}A - Mg = 0$ or $P = P_{\text{atm}} + \frac{Mg}{A}$).
- The absolute pressure of the gas that is consistent with an incorrect diagram provided in part A.

For an expression for the internal energy of the gas that is consistent with the expression **Point B4**

$$\text{for the pressure } P \text{ of the gas that is derived for point B3 (e.g., } U = \frac{3}{2}\left(P_{\text{atm}} + \frac{Mg}{A}\right)V_0)$$

Scoring Note: A correct, isolated, final expression earns points B2, B3, and B4.

Example Response

$$\vec{a}_{\text{sys}} = \frac{\sum \vec{F}}{m_{\text{sys}}} = \frac{\vec{F}_{\text{net}}}{m_{\text{sys}}}$$

$$\Sigma \vec{F} = 0$$

$$P = \frac{F_{\perp}}{A}$$

$$PA - P_{\text{atm}}A - F_g = 0$$

$$PA - P_{\text{atm}}A - Mg = 0$$

$$P - P_{\text{atm}} - \frac{Mg}{A} = 0$$

$$P = P_{\text{atm}} + \frac{Mg}{A}$$

$$U = \frac{3}{2}nRT$$

$$PV = nRT$$

$$U = \frac{3}{2}PV$$

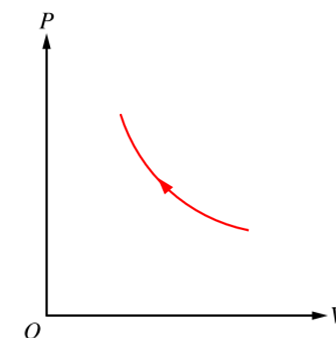
$$U = \frac{3}{2}\left(P_{\text{atm}} + \frac{Mg}{A}\right)V_0$$

C For drawing a line or curve that connects a point in the lower right region of the diagram to the upper left region of the diagram **Point C1**

For drawing a curve that is concave up **Point C2**

For drawing an arrow that points from a greater to a lesser volume or from a lesser to a greater pressure **Point C3**

Example Response



D For indicating $T_{\text{new}} > T_0$ or an indication that is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C **Point D1**

For **one** of the following:

- A correct justification that indicates that the pressure of the gas has increased for the same volume using features of the diagram in part A, the derivation in part B, or features of the graph in part C
- A correct justification that indicates that the volume of the gas has increased for the same pressure using features of the diagram in part A, the derivation in part B, or features of the graph in part C
- A justification that is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C

Point D2

Scoring Notes:

- If the justification is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C, and the justification is consistent with an incorrect selection, points D1 and D2 are earned.
- If the justification is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C, but the justification is not consistent with an incorrect selection, only point D2 is earned.
- If the justification is not consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C, but $T_{\text{new}} > T_0$ is selected, only point D1 is earned.

Example Responses

Using the representation from part A if the response considers the volume of the gas at time t_0 and the final volume of the gas after the process described in part D

- For the piston to remain in equilibrium, the increase in weight from the block would require a greater force, and, therefore, pressure, from the gas on the piston. Because the two volumes are equal, a greater pressure will correspond to a greater temperature. Therefore, $T_{\text{new}} > T_0$.

Using the representation from part B

- According to the derivation in part B, if volume increases while pressure remains constant, the internal energy of the gas increases, and, therefore, the temperature will increase. Therefore, $T_{\text{new}} > T_0$.
- According to the derivation in part B, the added mass on the piston when the volume is back to the original volume increases the internal energy of the gas. Thus, the temperature increases. Therefore, $T_{\text{new}} > T_0$.

Using the representation from part C if the response considers the volume of the gas at time t_f and the final volume of the gas after the process described in part D

- Looking at the graph, if the volume is increased at constant pressure, from the end of the curve that I drew, the product of pressure and volume, and therefore, temperature, will be greater at the end of this process than at the beginning. Therefore, $T_{\text{new}} > T_0$.

Using the representation from part C if the response considers the volume of the gas at time t_0 and the final volume of the gas after the process described in part D

- According to the graph in part C, the pressure of the gas at the end of the process in part C is greater than that at the beginning of the process. For the gas to occupy the original volume (at time t_0), the final gas pressure must be greater than the original gas pressure. Therefore, $T_{\text{new}} > T_0$.
- According to the graph in part C, if the pressure is increased by the added block, and the volume is the same from the beginning of the curve that I drew, the product of pressure and volume, and, therefore, temperature, will be greater at the end of this process than at the beginning. Therefore, $T_{\text{new}} > T_0$.

Question 2: Experimental Design

12 points

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

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

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

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

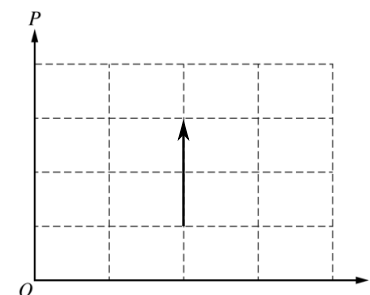
Example Response

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

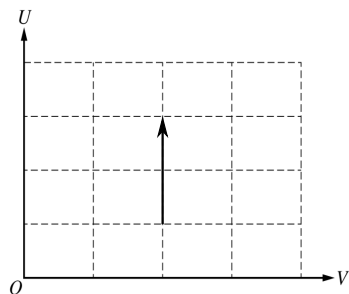
Total for part (a) 3 points

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

Example Response



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

Example Response

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

Example Responses

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

OR

The gas has a constant volume.

Total for part (b) 3 points

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

Example Response

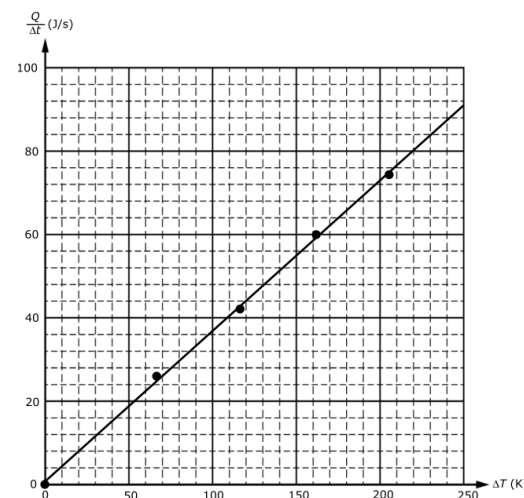
Vertical Axis: $\frac{Q}{\Delta t}$

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

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

For plotting the data points correctly **1 point**

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

Example Response

Total for part (c) 4 points

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

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

Example Response

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

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

Example Response

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

Example Solution

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

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

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

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

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

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

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

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

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

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

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

Total for part (d) 2 points

Total for question 2 12 points

Question 1: Short Answer**10 points**

(a) For indicating that $\Delta U = 0 \text{ J}$ **1 point**

For correctly calculating the net work done during the two processes with correct units **1 point**

$$W = -P\Delta V = -(100 \times 10^3 \text{ Pa})[(4 - 1)(\times 10^3 \text{ m})] = -300 \text{ J}$$

Scoring note: The answer must either have the negative sign or indicate that the work is done by the gas.

For substituting ΔU and W into the first law of thermodynamics to obtain a value for Q OR for applying the first law to show that Q is equal in magnitude to W but opposite in sign **1 point**

Example response for part (a)

The change in internal energy is zero because the initial and final temperatures are the same at points 1 and 3. The work done on the gas is $-P\Delta V = -300 \text{ J}$. Because the work is negative, 300 J of energy must be transferred to the gas by heating in order for the internal energy of the gas to remain constant.

Total for part (a) 3 points

(b) i. For indicating that the work is less than in part (a), with a reference to less area under the curve **1 point**

For indicating that the work is positive or opposite the sign indicated in part (a), with a reference to the sign of the change in volume or the direction of the process as indicated in the graph **1 point**

Example response for part (b)(i)

The magnitude of the work done is less than the work in part (a) because there is less area under the curve. The work is also the opposite sign from part (a) because the volume decreases, as shown by the direction of the arrow.

ii. For stating that there is no change in average kinetic energy/speed of gas molecules **1 point**

For indicating a change that is relevant to the collision rate **1 point**

Scoring note: Acceptable responses include volume, surface area, time to traverse the container.

For indicating that there are more collisions with the walls of the container; thus, more force per area (must refer to the walls) **1 point**

Example response for part (b)(ii)

Temperature does not change, so the speed of the molecules and the force of collisions with the walls of the container stays the same. Volume decreases, so the density of the gas molecules increases, and they collide more frequently. This means more net force due to collisions with the container walls. The smaller volume also means less surface area.

Total for part (b) 5 points

(c) For indicating that the temperature in state 2 is higher than in state 3 **1 point**

For indicating that energy flows from the state indicated as hotter to the state indicated as cooler **1 point**

Example response for part (c)

The temperature of the gas in sample 2 is higher than the temperature of sample 3. Energy goes from hot to cold, so energy will transfer from sample 2 to sample 3.

Total for part (c) 2 points

Total for question 1 10 points

AP[®] Physics 2: Algebra-Based Scoring Guidelines

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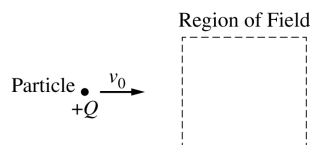
General Notes About 2019 AP Physics Scoring Guidelines

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.

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Question 1

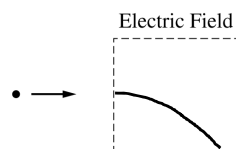
10 points



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

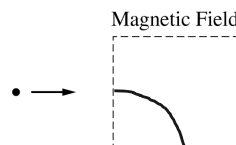
On the figure below, draw a possible path of the particle in the region if the region contains only an electric field directed toward the bottom of the page.



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.



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)

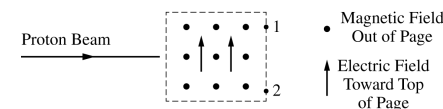
- (a) (continued)

- 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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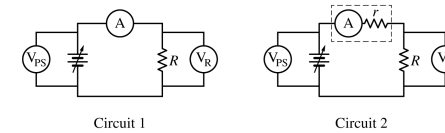
Learning Objectives

- 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

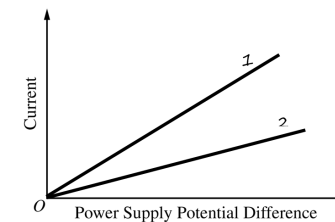


The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R , an ammeter A , and two voltmeters V_{PS} and V_R . In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r . The potential difference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

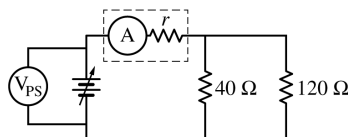
For indicating that the slope is inversely proportional to the resistance	1 point
For explaining that the equations in part (b) show that a larger total resistance corresponds to a smaller slope or smaller current	1 point
Example: Claim: The equations in part (b) account for the differences between graphs 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 $I = \Delta V_R / R = 2.5\text{ V} / 40\ \Omega = 0.0625\text{ A}$	1 point
For using Ohm's law with the calculated current and correct potential difference $r = \Delta V_r / I = (3\text{ V} - 2.5\text{ V}) / 0.0625\text{ A}$	1 point
$r = 8\ \Omega$	

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

- 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 $I_{tot} = 3\text{ V} / 38\ \Omega = 0.079\text{ A}$	1 point
For calculating two currents that are in the correct ratio ($I_{40\ \Omega} = 3I_{120\ \Omega}$) $\Delta V_{parallel} = (3\text{ V}) - (8\ \Omega)(0.079\text{ A}) = 2.36\text{ V}$ $I_{40\ \Omega} = \frac{2.36\text{ V}}{40\ \Omega} = 0.059\text{ A}$ $I_{120\ \Omega} = \frac{2.36\text{ V}}{120\ \Omega} = 0.020\text{ A}$	1 point

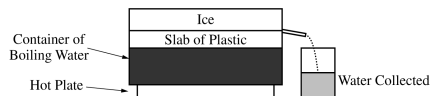
Learning Objectives

- 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.

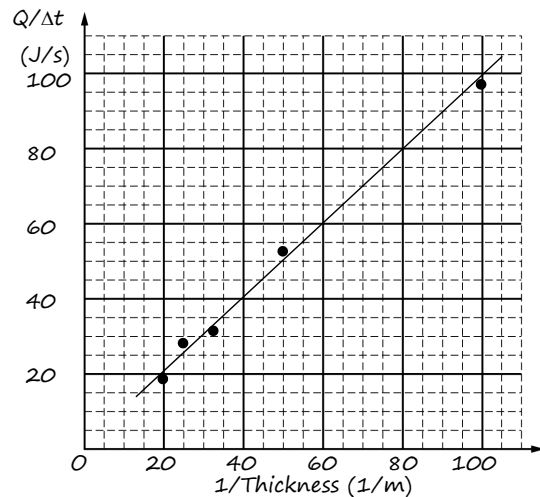
Table with sample entries for part (a)(ii)

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: $k = \text{slope}/A\Delta T = 1(\text{J}\cdot\text{m/s}) / (0.025\text{ m}^2)(100^\circ\text{C}) = 0.40\text{ J/s}\cdot\text{m}^\circ\text{C}$		

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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.	

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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]

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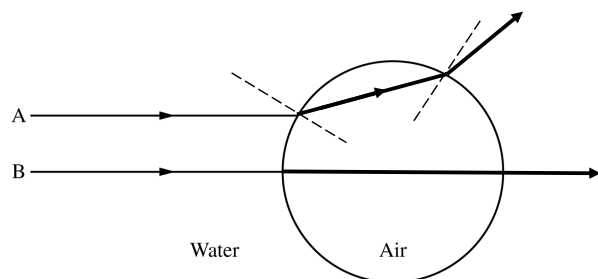
Question 4

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
<u>Note:</u> 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	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 - W_{\text{diss}} $	
$ 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$	

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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.	

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Question 4 (continued)

- (c) (continued)
iii. (continued)

Example 1: By the ideal gas law, $P_{4.5m}V_1/T_1 = P_{atm}V_{surface}/T_{surface}$, so $V_{surface} = P_{4.5m}V_1T_{surface}/P_{atm}T_1$ 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: $P_{4.5m}V_1/T_1 = P_{atm}V_{surface}/T_{surface}$, so $V_{surface} = P_{4.5m}V_1T_{surface}/P_{atm}T_1$ 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]

AP[®] Physics 2

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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
 $PV = nRT$

1 point

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

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

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

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

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

1 point

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

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

(c)

1 point

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

1 point

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

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

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

2016 SCORING GUIDELINES

Question 2

12 points total

Distribution
of points

(a) 3 points

For graphing angles or functions of angles on the axes

1 point

For plotting sines of angles on the axes and indicating or implying that the index of refraction of air is 1

1 point

For indicating a method to determine the index of refraction of the glass that is consistent with the graph described

1 point

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

(b) 4 points

For indicating that the light from the lamp needs to be a beam when it enters the glass (either referring to a beam, explicitly describing how to create a beam, or showing a beam in a diagram)

1 point

For describing some method of determining angles with a protractor (or equivalent tool) in both media at an appropriate boundary

1 point

For using angles with respect to the normal (can measure any angles as long as reference is made to converting them to the correct ones)

1 point

For repeating the measurement at three or more different incidence angles to obtain sufficient data

1 point

(c) 2 points

For indicating that when light travels across the boundary from air to glass, the ray bends toward the normal

1 point

For indicating that the speed of light is slower in glass than in air (or an answer consistent with response for bending of the ray)

1 point

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Question 2 (continued)

Distribution
of points

(d) 3 points

For an appropriate energy-level diagram showing absorption from the lowest level and emission

1 point

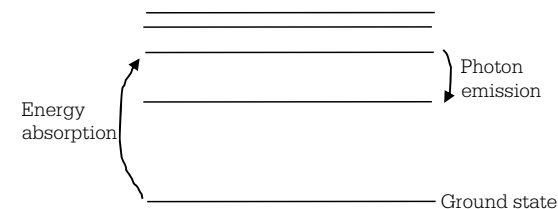
For indicating that a hydrogen atom can be excited from the ground state to a higher energy state by absorbing energy

1 point

For indicating that transitions to lower energy levels cause emission of photons

1 point

Example:



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

2016 SCORING GUIDELINES

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 variables

1 point

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

1 point

ii. 2 points

For using a correct expression for work

1 point

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

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

1 point

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

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

iii. 2 points

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

1 point

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

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

1 point

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

2016 SCORING GUIDELINES

Question 4

10 points total

Distribution
of points

(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

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

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

For correctly calculating the ratio

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

1 point

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.

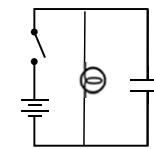
1 point

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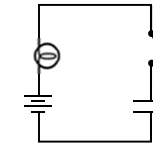
Question 4 (continued)

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