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

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

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

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

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

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

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

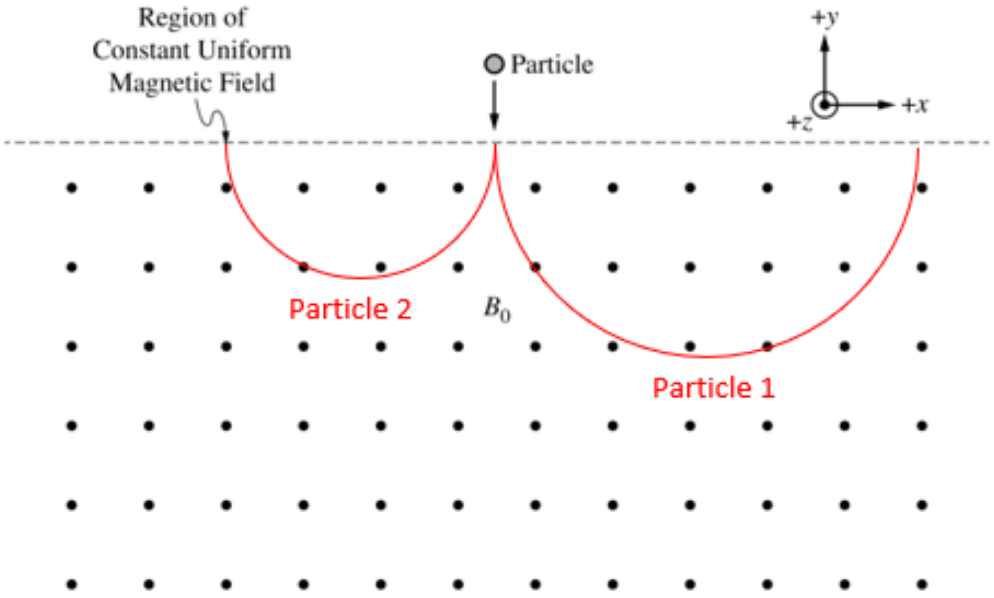
$$\Delta x = 2r$$

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

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 Paragraph Argument — 10 points

(a)

For an evaluation of Student Y 's statement that correctly includes the vector nature of electric field — **1 point**

For indicating that Student Y should have stated that the third particle must have charge $+Q$ for the electric field at Point P to be zero — **1 point**

OR

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

For an evaluation of Student Z 's statement that correctly includes the scalar nature of electric potential — **1 point**

For indicating that zero electric potential at Point P would require the third particle having charge $-2Q$ — **1 point**

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

Example Response

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

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

OR

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

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

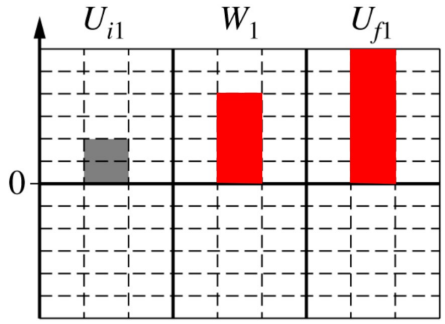
Total for part (a) 5 points

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

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

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

Example Response

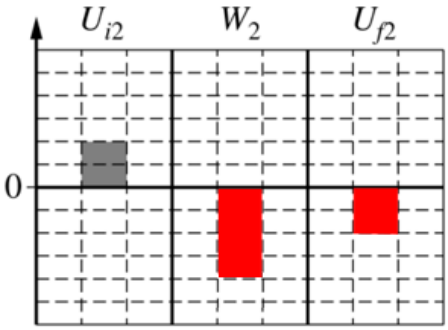


Scenario 1

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

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

Example Response



Scenario 2

Total for part (b) 5 points

Total for question 4 10 points

Question 3: Quantitative/Qualitative Translation — 12 points

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

Example Response

$$\Sigma\vec{F} = m\vec{a}$$
$$F_E = F_C$$
$$\frac{kq^2}{r^2} = \frac{mv^2}{r}$$

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

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

Example Response

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

Scoring Note: q_e and q_p are acceptable.

Total for part (a) — **2 points**

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

Example Response

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

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

Example Response

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

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

Example Response

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

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

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

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

Example Response

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

Total for part (c) **2 points**

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

Example Response

$$E = hf$$
$$E = (6.63 \times 10^{-34}\ \text{J} \cdot \text{s})(3.2 \times 10^{15}\ \text{Hz})$$
$$E = 2.12 \times 10^{-18}\ \text{J}$$

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

Example Response

$$E = mc^2$$
$$E = (9.11 \times 10^{-31}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2$$
$$E = 8.20 \times 10^{-14}\ \text{J}$$

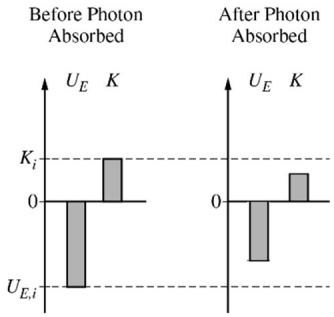
For correctly indicating that the photon energy is negligible compared to the mass energy of the electron (or an answer that is consistent with the energies calculated in part (d)(i) and part (d)(ii)) — **1 point**

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

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

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

Example Response



Total for part (d) 5 points

Total for question 3 12 points

2017

AP CollegeBoard

AP Physics 2: Algebra-Based

Scoring Guidelines

AP® PHYSICS
2017 SCORING GUIDELINES

General Notes About 2017 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 one point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ 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.

2017 SCORING GUIDELINES

Question 1

10 points total **Distribution of points**

(a)

i. 1 point

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

ii. 2 points

Student Y's statement that P_B is greater than P_A is not correct.

For a correct indication of how height affects pressure using the Bernoulli equation (i.e., conservation of energy principles) — 1 point

For correct indication of how the speed affects pressure using the Bernoulli equation (i.e., conservation of energy principles) — 1 point

Example: The pressure at point *B* is not greater. Because the water at *B* is moving faster and is higher than at point *A*, the kinetic energy and the gravitational potential energy terms in Bernoulli's equation are both greater. Because the sum of pressure and these energy terms is a constant, the pressure must be less.

iii. 1 point

For indicating one of the following: — 1 point

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

iv. 1 point

For indicating that student Z is incorrect in stating that the speed is less at point *B*, not indicating any other aspect, and using continuity or the Bernoulli equation (i.e., conservation of energy principles) to show that it is greater — 1 point

OR

if third bullet for (iii) applies, indicating that work is done on the water due to the pressure difference, so the energy is not constant

2017 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b)

i. 2 points

For a correct application of the continuity equation including substitutions — 1 point

$A_A v_A = A_B v_B$

$v_B = A_A v_A / A_B = r_A^2 v_A / r_B^2 = (2.5\text{ cm})^2 (0.5\text{ m/s}) / (1.5\text{ cm})^2$

For a correct answer with units — 1 point

$v_B = 1.4\text{ m/s}$

ii. 1 point

For an application of Bernoulli's equation to this situation and substitutions consistent with (b)(i) — 1 point

$$P_A + \rho g y_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g y_B + \frac{1}{2}\rho v_B^2$$

$$P_B = P_A + \rho g (y_A - y_B) + \frac{1}{2}\rho \left(v_A^2 - v_B^2\right)$$

$$P_B = 2 \times 10^5 + (1000)(10)(-5) + \frac{1}{2}(1000)\left(0.5^2 - 1.4^2\right) = 2 \times 10^5 - 50000 - 855$$

$$P_B = 1.5 \times 10^5\text{ Pa}$$

(c)

i. 1 point

For substituting correctly in an appropriate equation for determining the pressure — 1 point

$P = P_0 + \rho g h_A = 1 \times 10^5\text{ Pa} + \left(1000\text{ kg/m}^3\right)\left(10\text{ m/s}^2\right)(6\text{ m})$

$P = 1.6 \times 10^5\text{ Pa}$

ii. 1 point

For indicating that the buoyant force is toward the top of the page and gravity is toward the bottom of the page, with the buoyant force longer — 1 point

Student can draw lots of pressure forces around the dot instead of one buoyant force, as long as there is no buoyant force labeled and they add up to a net buoyant force that is longer than the gravitational force.

2017 SCORING GUIDELINES

Question 2

12 points total | **Distribution of points**

(a)

i. 5 points

For drawing a circuit with the battery, rod, and ammeter in series (rods can be drawn to look like rods, or schematically as resistors)	1 point
For drawing the voltmeter parallel to the rod, or indicating that the setting on the power supply will be used	1 point
For measuring potential difference and current for a rod	1 point
For measuring the length and diameter of a rod	1 point
For including multiple trials with appropriate controls Examples: 1) Use one rod and apply different potential differences 2) Use different rods	1 point

ii. 2 points

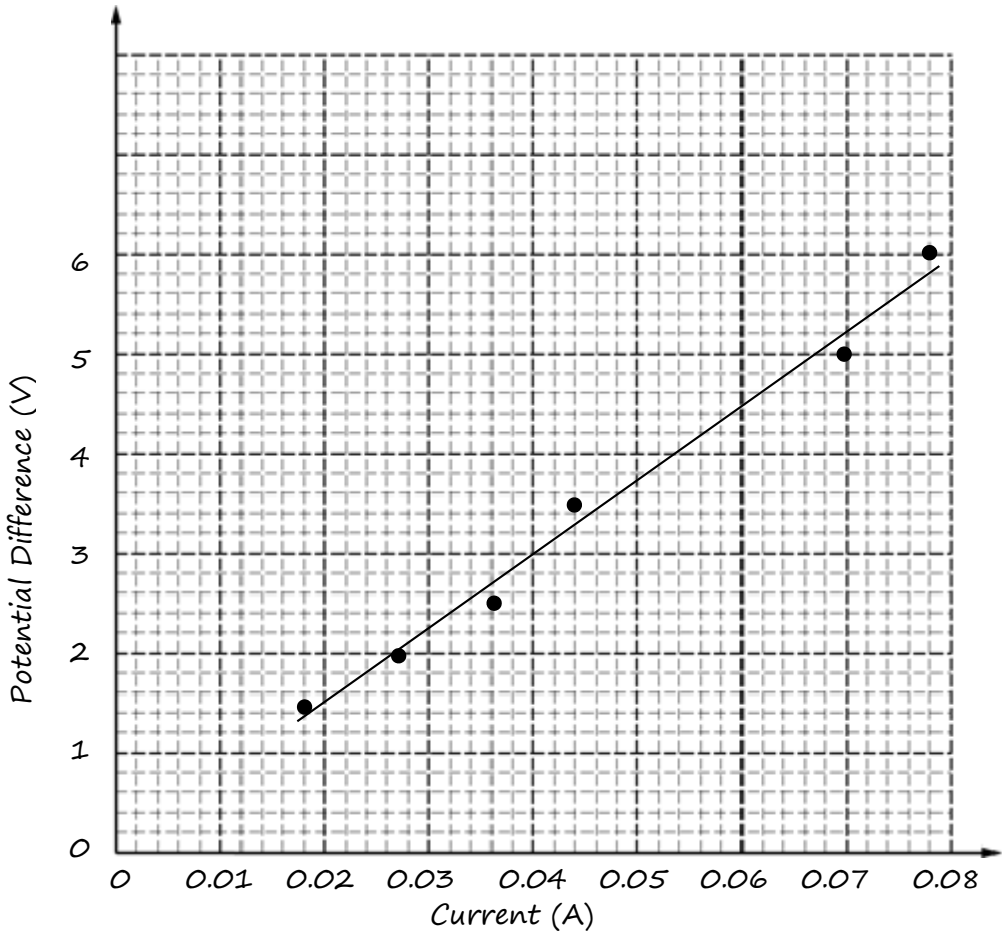
For graphing appropriate quantities whose slope can be used to calculate resistance directly or indirectly	1 point
For correctly stating how the slope relates to the resistivity	1 point

2017 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(b) 3 points



For plotting the data on the graph with potential difference on one axis and current on the other, labeled with units, using a reasonable scale — 1 point

For a clearly shown calculation of slope from a reasonable best-fit line — 1 point

For a correct answer with units — 1 point

Acceptable range is $70 - 79\ \Omega$.

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

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

For the example shown above

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

2017 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(c)

i. 1 point

For indicating that the internal resistance of the power supply will not affect the data acquired, with correct reasoning — 1 point

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

ii. 1 point

For indicating either: — 1 point

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

OR

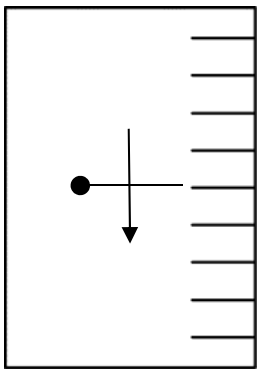
The students should not be concerned because any change in resistivity as the temperature increases is small compared to measurement error.

2017 SCORING GUIDELINES

Question 3

12 points total **Distribution of points**

(a) 2 points



For the arrow drawn upside down relative to the object 1 point
For bar/circle drawn left-to-right reversed relative to the object or consistent with an (incorrect) upright arrow 1 point

(b)

i. 1 point

For correctly showing a calculation of the focal length and a correct answer with units 1 point

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

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

ii. 1 point

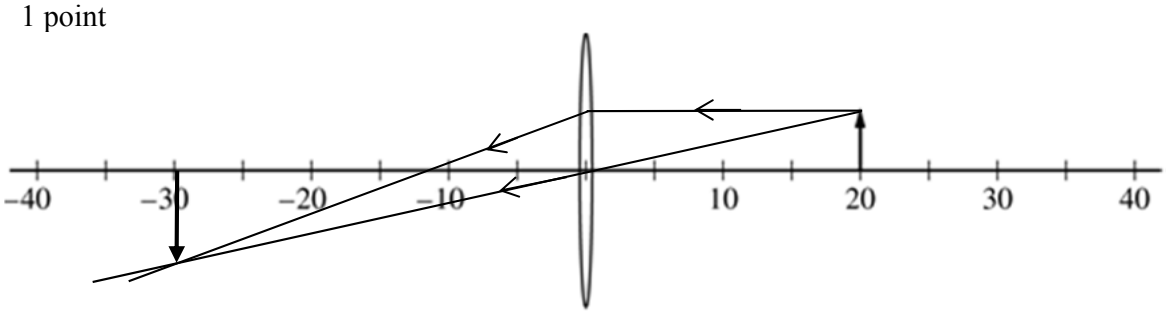
For correctly showing a calculation of the magnitude of the magnification (with or without sign) and a correct answer 1 point

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

$$M = 1.5$$

(c)

i. 1 point



For two reasonably correctly drawn rays consistent with the calculated focal length, and inclusion of an inverted image 1 point

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Question 3 (continued)

Distribution of points

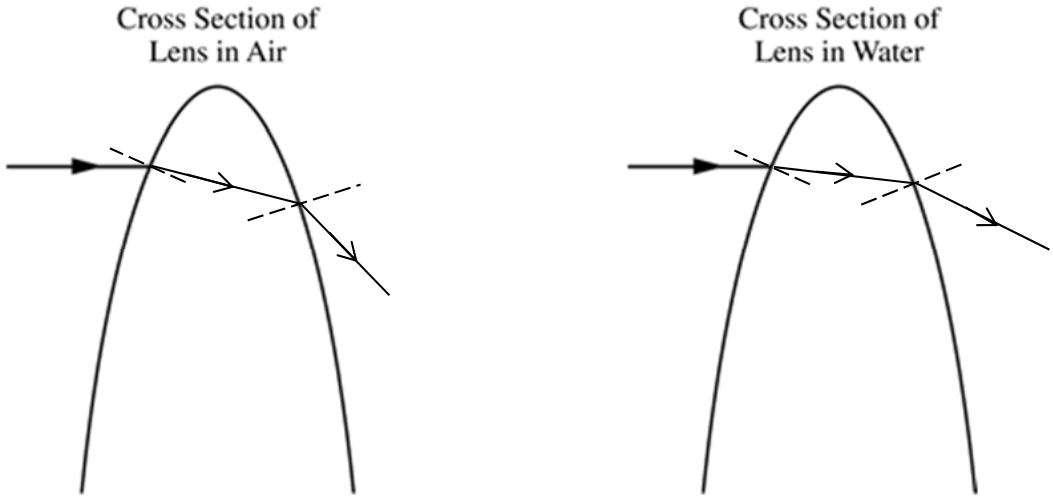
(c) (continued)

ii. 2 points

For a correct explanation of how the rays drawn relate to the focal length — 1 point
For a correct explanation of how the image relates to the magnification — 1 point
Example: The horizontal ray from the object bends to cross the axis at 12 cm from the middle of the lens, which is the focal length. The image arrow is about 1.5 times the height of the object, which is the magnification.

(d)

i. 2 points



For showing the downward refraction of the rays at each surface of the lens in air (i.e., toward the normal entering the lens and away from the normal leaving the lens) — 1 point
For the rays refracted by the lens in water at greater angles to the normal than the corresponding angles for the lens in air — i.e., less bending (can be earned even if first point was not, scoring is relative to whatever is drawn for the lens in air) — 1 point

ii. 3 points

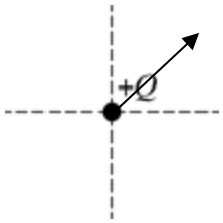
For describing a greater focal length when the lens is in water or a comparison consistent with part (d)(i) — 1 point
For describing a larger image distance and image size or a comparison consistent with part (d)(i) — 1 point
For describing how the rays drawn in (d)(i) support the descriptions — 1 point
Example: The rays do not bend as much as they pass from water to glass as when they pass from air to glass (and vice versa). This means parallel rays coming into the lens will converge at a farther distance, so the focal length is longer. Rays from an object also will converge farther from the lens, so the new image is farther and larger.

2017 SCORING GUIDELINES

Question 4

10 points total **Distribution of points**

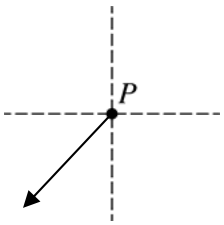
(a) 1 point



For an arrow pointing outward from the object, along a diagonal of the square and away from the object with charge $-2Q$, with no other arrows — 1 point

(b)

i. 3 points



For correctly determining magnitudes of the field from individual objects — 1 point
The fields from the $+2Q$ objects cancel. This can be implicit or explicit in the calculations.

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

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

For correctly adding the individual fields — 1 point
$E = 3kQ/d^2$

For showing the correct direction on the diagram, along a diagonal of the square and toward the object with charge $-2Q$ — 1 point

ii. 1 point

For showing a correct scalar potential summation — 1 point
A final answer is not required; however, no credit is given if an incorrect final answer is included.
$V = (k/d)(+2Q + Q + 2Q - 2Q) = 3kQ/d$

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Question 4 (continued)

Distribution of points

(c) 5 points

For indicating that electric potential energy is the energy stored in a configuration of charged objects	1 point
For indicating that the change in potential energy is equal to the work done by an external force to create a particular configuration	1 point
For indicating that moving the object with $+2Q$ charge results in an increase in energy and indicating that moving the object with $+Q$ charge results in a decrease in energy (i.e., for showing understanding that moving charges of the same sign closer together increases the energy and/or moving charges of opposite sign closer together decreases the energy, with some support such as $U = kqQ/r$ or a description of doing work against forces)	1 point
For indicating that the net result is an increase in the energy with some explanation	1 point
For a logical, relevant, and internally consistent response that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response	1 point

AP® Physics 2
2016 Scoring Guidelines

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

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

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

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

ii. 2 points

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

$PV = nRT$

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

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

(b)

i. 2 points

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

For relating temperature change with internal energy change — 1 point

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

ii. 3 points

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

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

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

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

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

$\Delta U = \Delta K_{\text{per molecule}}\, nN_0 = (3/2) k_B \Delta T n N_0$

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

2016 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b)

ii. (continued)

Alternately, ΔU can be calculated directly from the given data

$$\Delta U = (3/2)nR\Delta T = (3/2)(P_C V_C - P_A V_A)$$
$$= (3/2)\left(\left(0.5 \times 10^5 \text{ Pa}\right)\left(0.10 \text{ m}^3\right) - \left(1.0 \times 10^5 \text{ Pa}\right)\left(0.04 \text{ m}^3\right)\right) = 1500 \text{ J}$$

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

$$Q = \Delta U - W = 1500 \text{ J} - (-6000 \text{ J})$$
$$Q = 7500 \text{ J}$$

(c) 1 point

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

$$\Delta K_{\text{total}} = (3/2)k_B \Delta T\, nN_0 \quad \text{or} \quad \Delta K_{\text{total}} = (3/2)nR\,\Delta T$$
$$\Delta K_{\text{total}} = (3/2)\left(1.38 \times 10^{-23} \text{ J/K}\right)(241 \text{ K} - 301 \text{ K})(2 \text{ mol})\left(6.02 \times 10^{23} \text{ mol}^{-1}\right)$$
$$\Delta K_{\text{total}} = -1500 \text{ J}$$

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Question 2

12 points total | **Distribution of points**

(a) 3 points

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

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

(b) 4 points

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

(c) 2 points

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

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Question 2 (continued)

Distribution of points

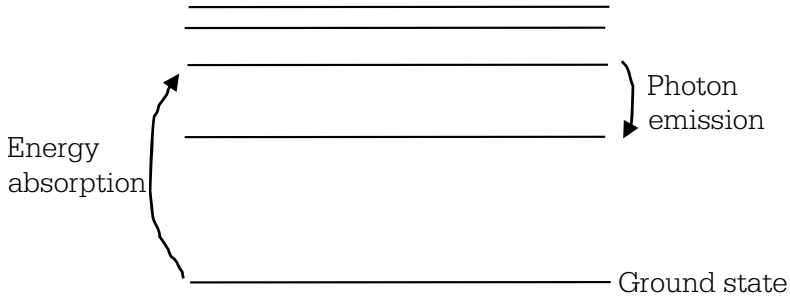
(d) 3 points

For an appropriate energy-level diagram showing absorption from the lowest level and emission — 1 point

For indicating that a hydrogen atom can be excited from the ground state to a higher energy state by absorbing energy — 1 point

For indicating that transitions to lower energy levels cause emission of photons — 1 point

Example:



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

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Question 3

12 points total **Distribution of points**

(a) 1 point

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

(b)

i. 2 points

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

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

Examples:

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

ii. 1 point

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

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

(c) 2 points

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

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

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

Examples:

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

The forces are different in magnitude.

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Question 3 (continued)

Distribution of points

(d)

i. 2 points

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

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

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

ii. 2 points

For using a correct expression for work — 1 point

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

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

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

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

iii. 2 points

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

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

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

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

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Question 4

10 points total **Distribution of points**

(a)

i. 1 point

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

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

ii. 1 point

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

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

(b)

i. 2 points

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

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

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

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

For correctly calculating the ratio 1 point

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

ii. 1 point

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

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

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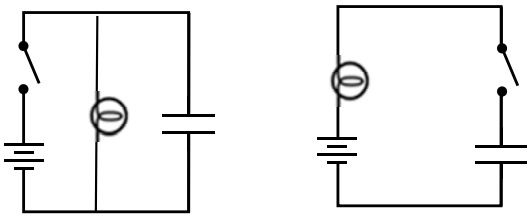
Question 4 (continued)

Distribution of points

(c) 5 points



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

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