

Question 3: Experimental Design and Analysis (LAB)**10 points**

- A** For a procedure that includes **both** of the following measurements: **Point A1**
- The dimensions of the capacitor
 - A current

For a procedure that indicates an appropriate method of reducing experimental uncertainty (e.g., Repeat the procedure multiple times.) **Point A2**

Example Responses

Measure the length of one side of a capacitor plate. Measure the separation distance between the plates. Construct a circuit that includes the battery and the resistor. Measure the current in the resistor. Repeat measurements of current in the resistor for the described closed circuit.

Measure the length of one side of a capacitor plate. Measure the separation distance between the plates. Construct a circuit that includes the battery, resistor, and capacitor. Measure the initial current in the resistor after the closed circuit is constructed. Disconnect the capacitor from the circuit, discharge the capacitor, and repeat the procedure.

- B** For indicating that $\tau = R_{\text{eq}} C_{\text{eq}}$ can be used to calculate τ **Point B1**

For **both** of the following: **Point B2**

- A correct relationship between resistance, the emf of the battery, and current (e.g., $R_{\text{eq}} = \frac{\mathcal{E}}{I}$)
- A correct relationship between capacitance, the area of a capacitor plate, and the distance between the capacitor plates (e.g., $C_{\text{eq}} = \epsilon_0 \frac{A}{d}$)

Example Responses

$\tau = R_{\text{eq}} C_{\text{eq}}$ can be used to determine τ . R_{eq} can be determined by using $R_{\text{eq}} = \frac{\mathcal{E}}{I}$, where I is the current in the resistor when the resistor is connected to the battery.

C_{eq} can be determined by using $C_{\text{eq}} = \epsilon_0 \frac{A}{d}$, where d is the distance between the capacitor plates and A is the square of the length of a capacitor plate.

$\tau = R_{\text{eq}} C_{\text{eq}}$ can be used to determine τ . R_{eq} can be determined by using $R_{\text{eq}} = \frac{\mathcal{E}}{I}$, where I is the initial current in the resistor when the resistor is connected in series with the battery and the capacitor. C_{eq} can be determined by using $C_{\text{eq}} = \epsilon_0 \frac{A}{d}$, where d is the distance between the capacitor plates and A is the square of the length of a capacitor plate.

- C (i)** For indicating appropriate quantities that can be plotted to produce a linear graph to determine C **Point C1**

Scoring Note: Any response that correctly identifies the functional dependence between varied quantities earns this point, regardless of any coefficients that contain numbers or physical/fundamental constants, or which axis is chosen to graph each of those quantities.

Example Responses

q as a function of $|\Delta V|$

$|\Delta V|$ as a function of q

$\frac{1}{q}$ as a function of $\frac{1}{|\Delta V|}$

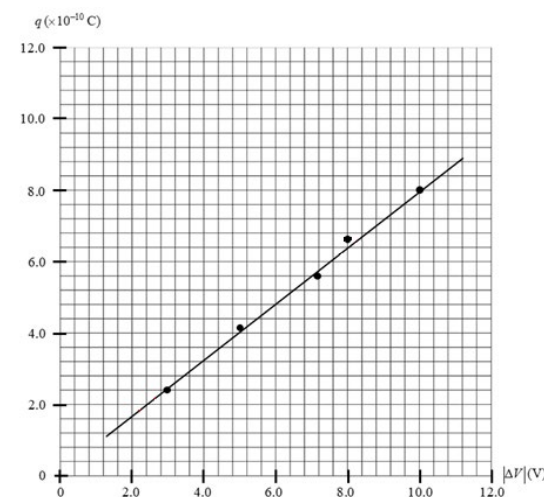
$\frac{1}{|\Delta V|}$ as a function of $\frac{1}{q}$

- (ii)** For labeling the axes (including units) with a linear scale **Point C2**

For correctly plotting the data points, consistent with **one** of the following: **Point C3**

- The quantities indicated in part C (i)
- The quantities provided in the table
- The axes indicated in point C2

- (iii)** For drawing a line or curve that approximates the trend of the plotted data **Point C4**

Example Response

- D** For correctly relating the slope of the straight line graph to $q = C|\Delta V|$ or a correct equation that is consistent with an appropriate graph that can be used to determine C (e.g., $\frac{\Delta q}{\Delta|\Delta V|} = \text{slope} = C$) **Point D1**

Example Responses

The slope of q as a function of $|\Delta V|$ is C .

The slope of $|\Delta V|$ as a function of q is $\frac{1}{C}$.

The slope of $\frac{1}{q}$ as a function of $\frac{1}{|\Delta V|}$ is $\frac{1}{C}$.

The slope of $\frac{1}{|\Delta V|}$ as a function of $\frac{1}{q}$ is C .

For a value for C that is approximately equal to $8 \times 10^{-11} \text{ F}$, within the range

$$7 \times 10^{-11} \text{ F} \leq C \leq 9 \times 10^{-11} \text{ F}$$

Point D2**Scoring Notes:**

- If the slope of the plotted data points is equal to the quantity that is supposed to be determined, a correct, isolated final value earns points D1 and D2.
- If the slope of the plotted data points is not equal to the quantity that is supposed to be determined, a correct, isolated final value earns point D2 only.

Example Response

$$\text{slope} = \frac{\Delta q}{\Delta|\Delta V|}$$

$$\frac{\Delta q}{\Delta|\Delta V|} = \frac{(6.4 \times 10^{-10} \text{ C}) - (2.0 \times 10^{-10} \text{ C})}{8.0 \text{ V} - 2.4 \text{ V}}$$

$$\frac{\Delta q}{\Delta|\Delta V|} = 7.9 \times 10^{-11} \frac{\text{C}}{\text{V}}$$

$$C = \frac{Q}{\Delta V}$$

$$q = C|\Delta V|$$

$$\text{slope} = C$$

$$C \approx 8 \times 10^{-11} \text{ F}$$

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

$$|q\Delta V| = K$$

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

1 point**Example Solution**

$$E_0 = E_f$$

$$\Delta U + \Delta K = 0$$

$$-\Delta U_E = \Delta K$$

$$|q\Delta V| = K$$

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

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

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

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

Total for part (a) 2 point

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

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

Example Response

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

Example Solution

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

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

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

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

Example Response

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

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

Example Response

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

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

Example Solution

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

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

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

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

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

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

$$\Delta x = 2r$$

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

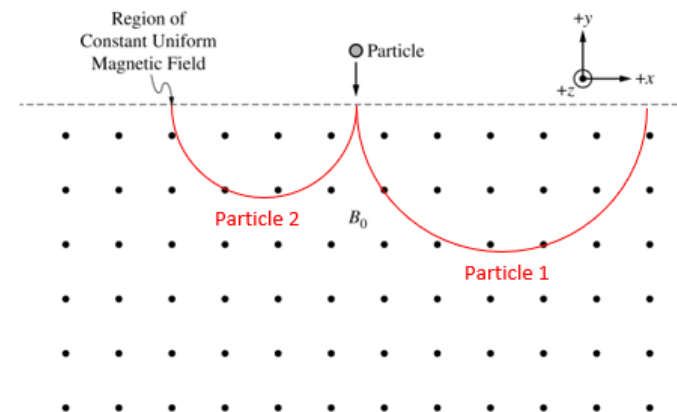
Total for part (b) 4 points

- (c) For drawing a path for Particle 1 that is concave up and to the right **1 point**

For drawing a path for Particle 2 that is concave up and in the opposite direction of Particle 1 **1 point**

For drawing the path for Particle 1 with a larger radius of curvature than the path for Particle 2 **1 point**

Example Response



Total for part (c) 3 points

- (d) For indicating **one** of the following: **1 point**

- That the electric field is directed in the $+x$ -direction
- A direction of the electric field that is consistent with the path of Particle 1 drawn in part (c)

Example Response

$+x$ -direction

Total for part (d) 1 point

Total for question 4 10 points

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 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:

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

1 point

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

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

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

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

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

(c)

i. 1 point

For substituting correctly in an appropriate equation for determining the pressure

1 point

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

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

ii. 1 point

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

1 point

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

2017 SCORING GUIDELINES

Question 2

Distribution
of points

12 points total

(a)

i. 5 points

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

ii. 2 points

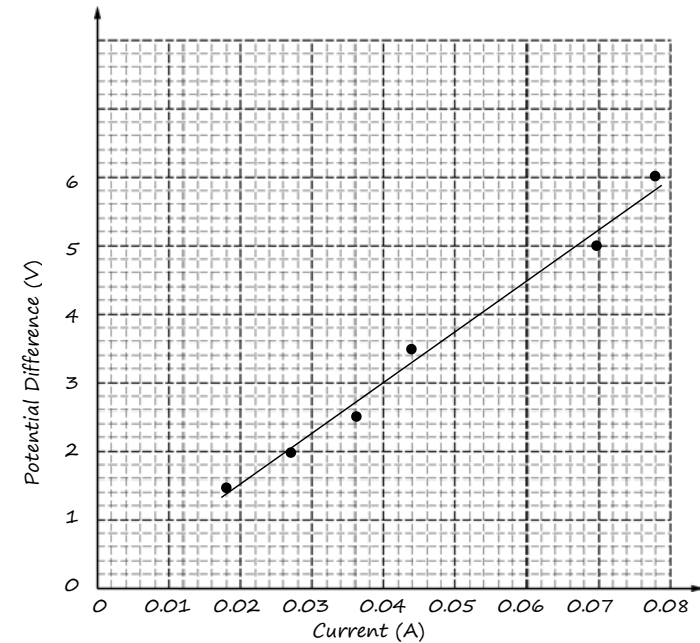
- | | |
|--|---------|
| For graphing appropriate quantities whose slope can be used to calculate resistance directly or indirectly | 1 point |
| For correctly stating how the slope relates to the resistivity | 1 point |

2017 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

(b) 3 points



- | | |
|---|---------|
| For plotting the data on the graph with potential difference on one axis and current on the other, labeled with units, using a reasonable scale | 1 point |
| For a clearly shown calculation of slope from a reasonable best-fit line | 1 point |
| For a correct answer with units
Acceptable range is $70 - 79 \, \Omega$. | 1 point |

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:

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

1 point

OR

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

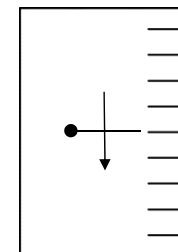
2017 SCORING GUIDELINES

Question 3

Distribution
of points

12 points total

(a) 2 points



For the arrow drawn upside down relative to the object

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

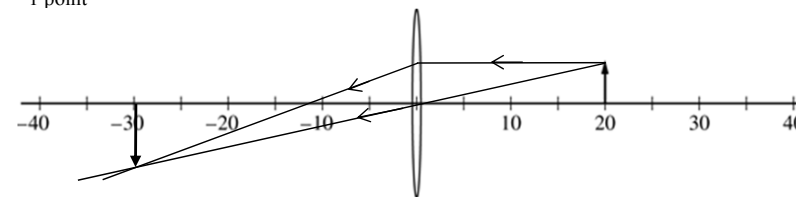
1 point

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

$$M = 1.5$$

(c)

i. 1 point



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

1 point

2017 SCORING GUIDELINES

Question 3 (continued)

Distribution
of points

(c) (continued)

ii. 2 points

For a correct explanation of how the rays drawn relate to the focal length

1 point

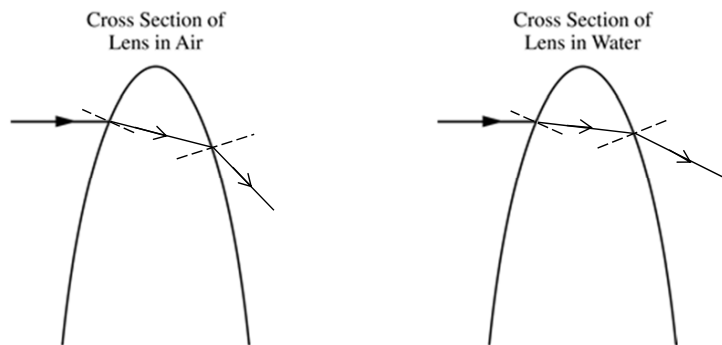
For a correct explanation of how the image relates to the magnification

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.

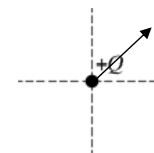
2017 SCORING GUIDELINES

Question 4

Distribution
of points

10 points total

(a) 1 point

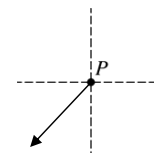


For an arrow pointing outward from the object, along a diagonal of the square and away from the object with charge $-2Q$, with no other arrows

1 point

(b)

i. 3 points



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

1 point

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

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

For correctly adding the individual fields

1 point

$E = 3kQ/d^2$

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

1 point

ii. 1 point

For showing a correct scalar potential summation

1 point

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

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

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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