2023

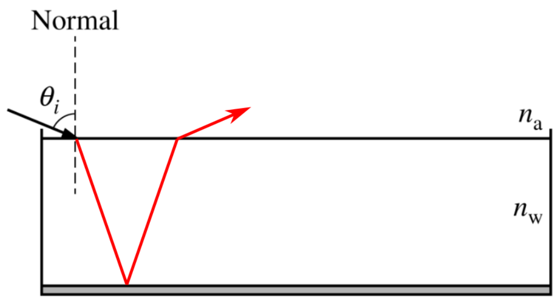
AP® Physics 2: Algebra-Based

Scoring Guidelines

Question 1: Short Answer — 10 points

(a)	For drawing a straight-line path from the entry point to the bottom of the tank with an angle from the normal that is less than θ_i	**1 point**
	For drawing a continuous path that is symmetric about a vertical axis that intersects the mirror at the location where the beam of light is incident upon the mirror	**1 point**

Example Response



Total for part (a) — **2 points**

(b)	For indicating that the wavelength of light decreases without any incorrect statements	**1 point**

Example Response

As light travels from one medium to a medium that has a higher index of refraction, the speed of light decreases and the frequency of the light remains the same. Therefore, the wavelength of the light decreases, as described by the equation $\lambda = \dfrac{v}{f}$.

Total for part (b) — **1 point**

(c)(i)	For a correct application of Snell's law for two media boundaries	**1 point**

Scoring Note: If a test taker correctly applies Snell's law for air and the bottom layer, this point can be earned.

Example Response

$$\theta_4 = \sin^{-1}\left(\frac{n_a}{n_b}\sin\theta_i\right) \text{ OR } \sin\theta_4 = \frac{n_a}{n_b}\sin\theta_i$$

Example Solution

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$n_a \sin\theta_i = n_w \sin\theta_2 = n_m \sin\theta_3 = n_b \sin\theta_4$$

$$n_a \sin\theta_i = n_b \sin\theta_4$$
$$\sin\theta_4 = \frac{n_a}{n_b}\sin\theta_i$$
$$\theta_4 = \sin^{-1}\left(\frac{n_a}{n_b}\sin\theta_i\right)$$

(c)(ii)	For indicating that θ_4 alone is the smallest angle	**1 point**
	For indicating that θ_2 alone is the largest angle	**1 point**
	For indicating that $\theta_1 = \theta_3$	**1 point**
	For an explanation that correctly relates the index of refraction to an angle	**1 point**

Example Response

__2__ θ_1 __1__ θ_2 __2__ θ_3 __3__ θ_4

θ_2 has the greatest value because water has the lowest index of refraction. θ_1 and θ_3 are equal because each is in the same layer with the same index of refraction, but the angles are smaller than θ_2 because the index of refraction is larger in this layer. θ_4 has the smallest value because the bottom layer has the highest index of refraction.

Total for part (c) 5 points

(d)	For indicating that both d_A and d_B are less than d_w, with an attempt at a relevant explanation	**1 point**
	For correctly indicating that the horizontal distance traveled decreases with increasing refraction toward the normal	**1 point**

Example Response

Horizontal distances d_A and d_B are less than d_w. The light rays for all scenarios are entering from air. However, in models A and B, the light rays enter a medium with an index of refraction that is greater than that of water. Therefore, the light rays bend more toward the normal in models A and B than in the original tank. Bending more toward the normal results in a shorter horizontal distance traveled.

Total for part (d) 2 points

Total for question 1 10 points

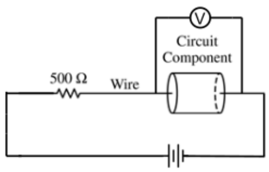
Question 2: Experimental Design — 12 points

(a)(i) For a diagram including a source of potential difference (e.g., battery, power supply) that is in a complete circuit that results in a current in the unknown circuit component — **1 point**

For a diagram including a measurement device that is appropriately connected in the circuit (e.g., voltmeter, ammeter) — **1 point**

Scoring Note: A lightbulb that is connected in series with the circuit component is an acceptable alternative for an ammeter.

Example Responses



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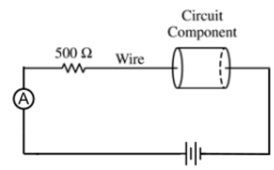

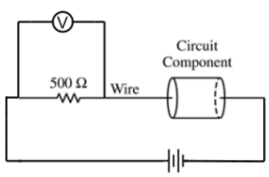

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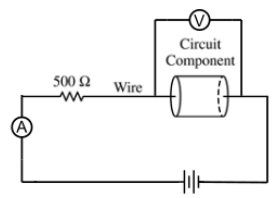

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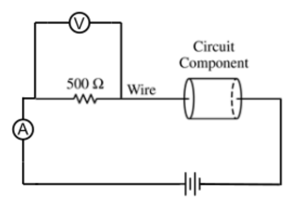


(a)(ii) For describing a procedure that includes a measurement of **one** of the following: — **1 point**

- The potential difference across the circuit component
- The current in the circuit
- The potential difference across the known resistor

For taking measurements at two different times after the circuit is closed or taking one measurement a long time after the circuit is closed, consistent with the procedure described — **1 point**

Example Responses

Measure the current in the ammeter immediately after the circuit is closed and a long time after the circuit is closed.

OR

Measure the potential difference across the circuit component immediately after the circuit is closed and a long time after the circuit is closed.

OR

Measure the potential difference across the circuit component a long time after the circuit is closed.

OR

Measure the potential difference across the $500\,\Omega$ *resistor immediately after the circuit is closed and a long time after the circuit is closed.*

(a)(iii)	For describing a correct result of the experiment that indicates the current in the circuit decreases to zero over time or that the charge of the plates of the capacitor increases over time	**1 point**
	For describing a correct result of the experiment that indicates that the electric potential difference across the capacitor increases from zero over time	**1 point**

Example Response

Immediately after the circuit has been closed, a current should be measured. A long time after the circuit has been closed, a current of zero should be measured. This is because the initially uncharged capacitor becomes fully charged. This results in a potential difference across the capacitor that is equal to the potential difference across the battery a long time after the circuit has been closed. Therefore, according to Kirchhoff's loop rule, a potential difference will not be measured across any other circuit components.

Total for part (a) 6 points

(b)(i)	For an equation that correctly applies the loop rule	**1 point**

Example Response

$0 = +\varepsilon - Ir - IR_{\text{var}}$

(b)(ii)	For indicating appropriate quantities that, when graphed, result in a linear graph that allow students to determine emf ε	**1 point**

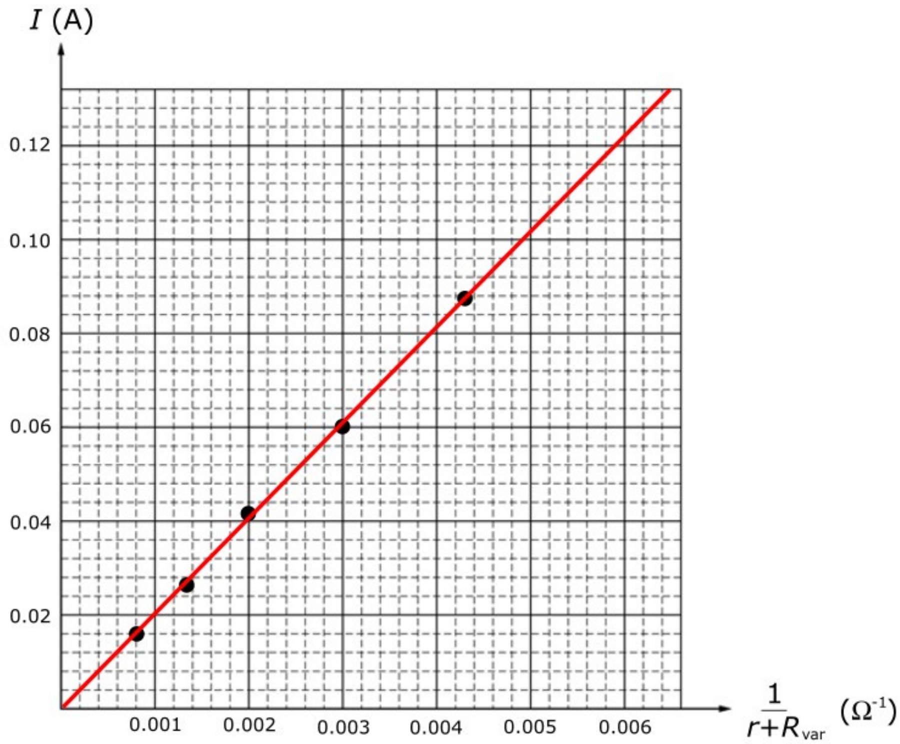
Example Responses

- $\dfrac{1}{r + R_{\text{var}}}$ *vs.* I
- I *vs.* IR_{var}
- R_{var} *vs.* $\dfrac{1}{I}$

(b)(iii)	For including numerical values on both axes with a linear scale and labeling the axes with appropriate labels and units	**1 point**
	For a graph in which data are plotted within at least half of the grid area	**1 point**

For drawing a best-fit line that approximates the trend of the data **1 point**

Example Responses



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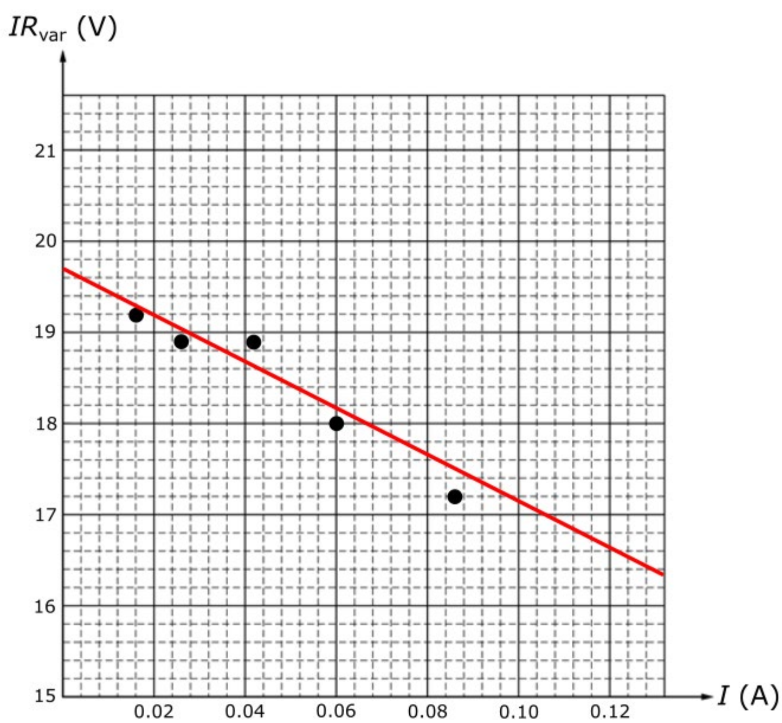


(b)(iv) For correctly using the graph to determine an experimental value for emf ε, including correct units, between $18.0\ \text{V}$ and $22.0\ \text{V}$ — **1 point**

Example Solutions

I as a function of $\dfrac{1}{r + R_{\text{var}}}$

$$\varepsilon - Ir - IR_{\text{var}} = 0$$
$$\varepsilon - I\left(r + R_{\text{var}}\right) = 0$$
$$I\left(r + R_{\text{var}}\right) = \varepsilon$$
$$I = \varepsilon\left(\frac{1}{r + R_{\text{var}}}\right)$$
$$I = \varepsilon\left(\frac{1}{30\ \Omega + R_{\text{var}}}\right)$$
$$\text{Slope} = \varepsilon$$
$$\frac{\Delta y}{\Delta x} = \varepsilon$$
$$\frac{\left(0.08\ \text{A} - 0.04\ \text{A}\right)}{\left(0.004\ \Omega^{-1} - 0.002\ \Omega^{-1}\right)} \approx \varepsilon$$
$$\varepsilon \approx 20\ \text{V}$$

OR

IR_{var} as a function of I

$$\varepsilon - Ir - IR_{\text{var}} = 0$$
$$\varepsilon - Ir = IR_{\text{var}}$$
$$IR_{\text{var}} = -Ir + \varepsilon$$
$$y\text{-intercept} = \varepsilon$$
$$\varepsilon \approx 20\ \text{V}$$

Total for part (b) 6 points

Total for question 2 12 points

Question 3: Quantitative/Qualitative Translation — 12 points

(a)(i)	For a statement that collisions from the water particles exert upward forces on the block and collisions from the air particles exert downward forces on the block	**1 point**
	For a statement indicating that the force from the water is greater than the force from the air	**1 point**

Example Response

The air particles collide with the top of the block and exert downward forces on the block. The water particles collide with the bottom of the block and exert upward forces on the block. The force exerted by the water particles is greater than the force exerted by the air particles. Therefore, the result of these forces is an upward buoyant force from the particles.

(a)(ii)	For indicating that Block A has a greater density than Block B because Block A displaces a larger volume of water, thus the buoyant force on Block A is greater than the buoyant force on Block B	**1 point**

Example Response

Because Block A *displaces a greater volume of fluid, the buoyant force on Block* A *is greater than the buoyant force on Block* B. *Because the buoyant force and gravitational force are balanced for both blocks, Block* A *must weigh more than Block* B. *Because the blocks have the same volume, Block* A *is more dense than Block* B.

Total for part (a) — 3 points

(b)(i)	For using Bernoulli's equation to derive the relationship between v_p and h	**1 point**
	For indicating that $P_2 = P_1$	**1 point**
	For correct substitutions of the heights and speeds	**1 point**

Example Solution

$$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

$$\frac{1}{2}\rho v_s^2 + \rho g h = \rho g(0) + \frac{1}{2}\rho v_p^2$$

$$v_p^2 = v_s^2 + 2gh$$

$$v_p = \sqrt{v_s^2 + 2gh}$$

(b)(ii)	For using the continuity equation to derive the relationship between v_p and R	**1 point**
	For correct substitutions for the expressions of areas and speeds	**1 point**

Example Solution

$A_1 v_1 = A_2 v_2$

$\pi R^2 v_s = \pi r^2 v_p$

$v_p = \dfrac{R^2}{r^2} v_s$

(b)(iii)	For using conservation principles to justify that when $R \gg r$, then $v_s \ll v_p$	**1 point**
	For indicating a very small value of v_s will have a negligible effect on v_p	**1 point**

Example Response

When the cross sectional area of the tank is very large compared to the cross sectional area of the pipe, the speed v_s of the surface of the water is much less than the speed of the water v_p exiting the pipe due to the constant volume flow rate. As a result, the speed of the surface of the water can be approximated as zero, so the speed of the water exiting the pipe can be approximated as $v_p = \sqrt{2gh}$.

Total for part (b) 7 points

(c)	For correctly relating the decrease in v_p to the decrease in the height of the surface of the water h	**1 point**
	For correctly relating the decrease in v_s to the increase in radius R	**1 point**

Example Response

According to the equation in part (b)(i), $v_p = \sqrt{v_s^2 + 2gh}$. As h decreases, v_p decreases. When solving the equation in part (b)(ii) for v_s, it can be shown that $v_s = \dfrac{r^2}{R^2} v_p$. Therefore, an increase in R results in a decrease in v_s. Because v_p decreases with decreasing h, by using the same expression from part (b)(ii) in the case in which v_p decreases and R increases, it can be shown that the speed v_s of the water at the surface decreases.

OR

If the two equations from parts (b)(i) and (b)(ii) are solved simultaneously for v_s as a function of h and R, it can be shown that $v_s = \sqrt{\dfrac{2gh}{\dfrac{R^4}{r^4} - 1}}$. Therefore, as h decreases and R increases, v_s decreases.

Total for part (c) 2 points

Total for question 3 12 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 **OR** For a statement indicating what the resultant magnitude of the electric field at Point P would be for a particle with charge $+2Q$	**1 point**
	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

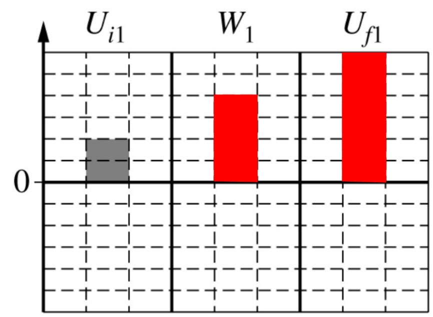
Student Y is incorrect that a particle with charge $+2Q$ placed at the bottom-right vertex will result in no electric field at Point P. The horizontal component of the electric field from Particle A is less than the horizontal component of the electric field from the particle with charge $+2Q$. The sum 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**

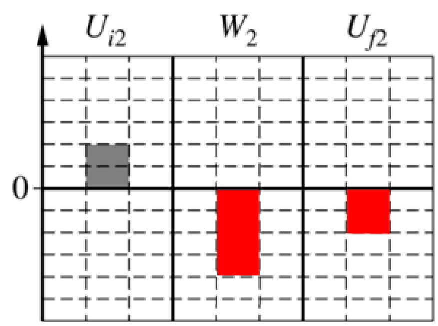
Example Response



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