Sample Responses from the

AP Physics 2: Algebra-Based Practice Exam

Sample Questions

Scoring Guidelines

Student Responses

Commentaries on the Responses

Effective Fall 2014

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Preface

This publication is designed to help teachers and students understand and prepare for the revised AP® Physics 2: Algebra-Based Exam. The publication includes sample free-response questions, scoring guidelines, student responses at various levels of achievement, and reader commentaries. Collectively, these materials accurately reflect the design, composition, and rigor of the revised exam.

The sample questions are those that appear on the AP Physics 2: Algebra-Based Practice Exam, and the student responses were collected from actual AP students during a field test of the exam. The students gave permission to have their work reproduced at the time of the field test, and the responses were read and scored by AP Physics Readers in 2013.

Following each free-response question, its scoring guideline, and three student responses, you will find a commentary about each sample. Commentaries include the score that each response would have earned, as well as a brief rationale to support the score.

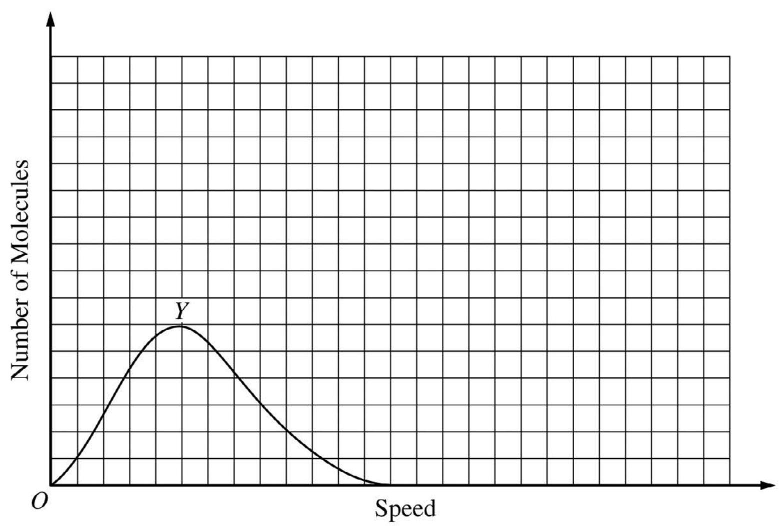
Free-Response Question 1

PHYSICS 2
Section II
4 Questions
Time—90 minutes

Directions: Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Show your work for each part in the space provided after that part.

1. (10 points, suggested time 20 minutes)
Three samples of a gas, X, Y, and Z, are prepared. Each sample contains the same number of molecules, but the samples are at different temperatures. The temperature of sample X is T_X, the temperature of sample Y is lower than that of sample X, and the temperature of sample Z is lower than that of sample Y $(T_X > T_Y > T_Z)$.

(a) The graph below shows the distribution of the speeds of the molecules in sample Y. On the graph, sketch and label possible distributions for sample X and sample Z.



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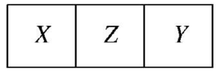
The three samples with initial temperatures $T_X > T_Y > T_Z$ are placed in thermal contact, with sample Z in the middle, as shown below, and the samples are insulated from their surroundings. The samples can exchange thermal energy but not gas molecules. The samples eventually reach equilibrium, with a final temperature greater than T_Y.



(b) In a few sentences, describe the change over time in the average kinetic energy of the molecules of each sample, from initial contact until they reach equilibrium. Explain how these changes relate to the energy flow between the pairs of samples that are in contact.

Sample X

Sample Y

Sample Z

(c) Indicate whether the net entropy of sample X increases, decreases, or remains the same as a result of the process of reaching equilibrium.

____ Increases ____ Decreases ____ Remains the same

Justify your answer at the microscopic level.

(d) For the three-sample system, indicate whether the entropy of the system increases, decreases, or remains the same.

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

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Free-Response Section

Section II is the free-response part of the exam. This section contains four free-response questions, and the student will have a total of 90 minutes to complete them all.

Information for Free-Response Question 1

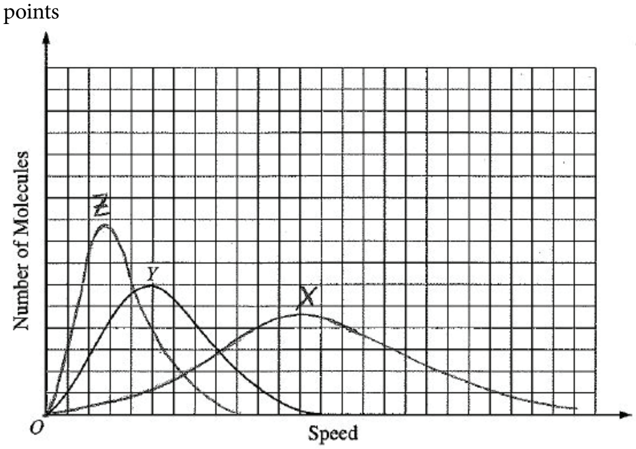
Timing	The student should spend approximately 20 minutes on this question.
Essential Knowledge	4.C.3 Energy is transferred spontaneously from a higher temperature system to a lower temperature system. The process of transferring energy is called heating. The amount of energy transferred is called heat. 5.B.7 The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams isovolumetric processes, isothermal processes, isobaric processes, and adiabatic processes. No calculations of internal energy change from temperature change are required; in this course, examples of these relationships are qualitative and/or semi-quantitative. 7.A.2 The temperature of a system characterizes the average kinetic energy of its molecules. 7.B.2 The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objectives	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. 5.B.7.1 The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles. 7.A.2.2 The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. 7.B.2.1 The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes.

Scoring Guidelines for Free-Response Question 1

Question 1

10 points total	**Distribution of points**

(a) 2 points



For the peak of the curve for *Z* at a smaller speed than *Y*, and *X* at a greater speed than *Y*	1 point
For the curve for *Z* having a higher peak and less spread than *Y*, and *X* with a lower peak and greater spread	1 point
One earned point was deducted for correct curves that are not labeled	

(b) 5 points

The kinetic energy of *X* decreases. It has the highest temperature and so to reach the same equilibrium temperature as the other samples it must lose energy, which flows into *Z*.

The kinetic energy of *Y* decreases and then increases. It has a higher temperature than *Z*, and so initially loses energy which flows into *Z*. But it eventually must end up at a higher temperature than it initially had, so the net energy flow must be into *Y*. That can only happen if the direction of energy flow reverses.

The kinetic energy of *Z* could always increase, or it can increase and then decrease. Initially energy flows into it, since it has the lowest temperature. At some point energy begins to flow from *Z* to *Y*. Whether the temperature and thus the kinetic energy of *Z* continually increases or not depends on how much energy keeps flowing to it from *X*.

For exhibiting understanding that energy flows from systems at higher temperature to systems at lower temperature	1 point
For exhibiting understanding that higher temperature corresponds to higher kinetic energy	1 point
For exhibiting understanding that the energy flow stops	1 point
For exhibiting understanding that the energy flow for a sample can change direction	1 point
For using the above understanding to indicate that the average kinetic energy of all three samples are the same when equilibrium is reached	1 point

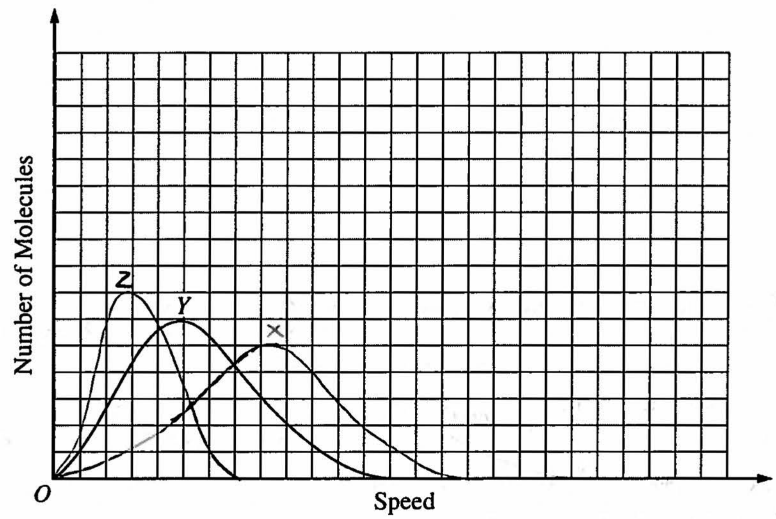
Question 1 (continued)

		Distribution of points
(c)	2 points	
	For checking either the correct response or one consistent with the answer to part (b), with a reasonable attempt at justification	1 point
	For a correct or consistent justification that relates the spread of the molecular distribution to entropy	1 point
	For example: The entropy decreases. When the temperature goes down, the spread of the speeds and thus the kinetic energies of the individual molecules is less. This means less disorder and thus less entropy.	
(d)	1 point	
	For correctly indicating that the entropy of the system increases, and explaining that the entropy of a closed system increases for an irreversible process.	1 point

Sample 1A*

2. (10 points, suggested time 20 minutes)
Three samples of a gas, X, Y, and Z, are prepared. Each sample contains the same number of molecules, but the samples are at different temperatures. The temperature of sample X is T_X, the temperature of sample Y is lower than that of sample X, and the temperature of sample Z is lower than that of sample Y $(T_X > T_Y > T_Z)$.

(a) The graph below shows the distribution of the speeds of the molecules in sample Y. On the graph, sketch and label possible distributions for sample X and sample Z.



PV=NRT

PV=nT

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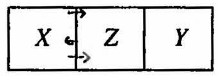
* Due to a question ordering change after the piloting of this exam, some item numbers may appear differently. All item numbers correspond with the AP Physics 2: Algebra-Based Practice Exam.

The three samples with initial temperatures $T_X > T_Y > T_Z$ are placed in thermal contact, with sample Z in the middle, as shown below, and the samples are insulated from their surroundings. The samples can exchange thermal energy but not gas molecules. The samples eventually reach equilibrium, with a final temperature greater than T_Y.



(b) In a few sentences, describe the change over time in the average kinetic energy of the molecules of each sample, from initial contact until they reach equilibrium. Explain how these changes relate to the energy flow between the pairs of samples that are in contact.

Sample X When X is in thermal contact with Z, the average kinetic energy of the molecules in X start to decline. This decline is due to the thermal transfer from X to Z. Although Z also loses some of its energy, X is losing more at a faster rate and this net loss of kinetic energy is conserved with the net gain of energy by Z.

Sample Y When Y is in thermal contact with Z, the average kinetic energy of the molecules in Y is increased. This is because the energy from Z is transferred over to Y. However, at first, Y loses kinetic energy because $T_Z < T_Y$, but shortly afterwards, $T_Z > T_Y$, which is why Y experiences a net gain.

Sample Z Sample Z experiences a net gain of energy overall. This is because $T_Z < T_X$ and $T_Z < T_Y$. As a result, Z gains the energy from X and Y until it reaches thermal equilibrium. However, Z still loses some energy to X and Y, but not as much.

(c) Indicate whether the net entropy of sample X increases, decreases, or remains the same as a result of the process of reaching equilibrium.

____ Increases   _✓_ Decreases   ____ Remains the same

Justify your answer at the microscopic level.

Since the temperature at which these 3 sample reach thermal equilibrium is below the initial temperature of Sample X, the temperature of X drops. And since the temperature drops, so does the average kinetic energy of the molecules in X drops as well, producing a lower entropy because of the decrease in avg. velocity

(d) For the three-sample system, indicate whether the entropy of the system increases, decreases, or remains the same.

____ Increases   ____ Decreases   _✓_ Remains the same

Justify your answer.

No energy is lost in the system, only transferred between the 3 samples. As a result the net entropy of the system stays the same.

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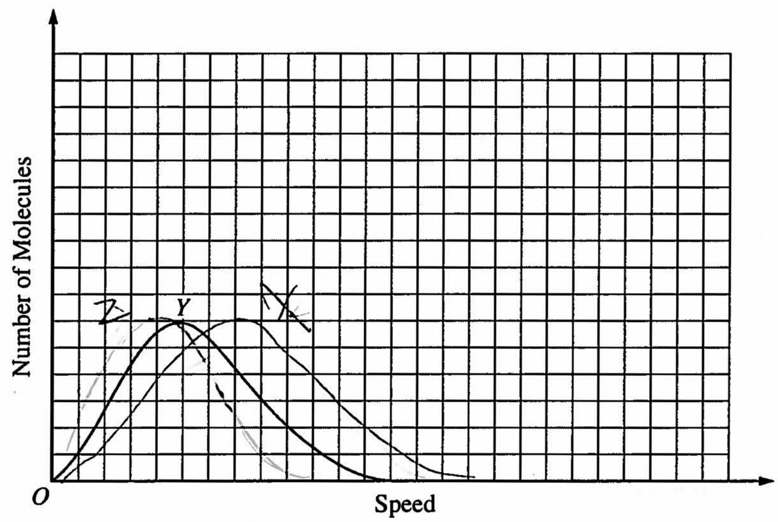
Sample 1B

2. (10 points, suggested time 20 minutes)
Three samples of a gas, *X*, *Y*, and *Z*, are prepared. Each sample contains the same number of molecules, but the samples are at different temperatures. The temperature of sample *X* is T_X, the temperature of sample *Y* is lower than that of sample *X*, and the temperature of sample *Z* is lower than that of sample *Y* $(T_X > T_Y > T_Z)$.

(a) The graph below shows the distribution of the speeds of the molecules in sample *Y*. On the graph, sketch and label possible distributions for sample *X* and sample *Z*.



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The three samples with initial temperatures $T_X > T_Y > T_Z$ are placed in thermal contact, with sample *Z* in the middle, as shown below, and the samples are insulated from their surroundings. The samples can exchange thermal energy but not gas molecules. The samples eventually reach equilibrium, with a final temperature greater than T_Y.

X	*Z*	*Y*

(b) In a few sentences, describe the change over time in the average kinetic energy of the molecules of each sample, from initial contact until they reach equilibrium. Explain how these changes relate to the energy flow between the pairs of samples that are in contact.

Sample *X* Sample X's molecules' average kinetic energy decreases as it transfers thermal energy to sample Z.

Sample *Y* Sample Y's molecules' average kinetic energy decreases as it transfers thermal energy to sample Z.

Sample *Z* Sample Z's molecules' average kinetic energy increases as it gains thermal energy from sample X and sample Y.

(c) Indicate whether the net entropy of sample *X* increases, decreases, or remains the same as a result of the process of reaching equilibrium.

____ Increases __X__ Decreases ____ Remains the same

Justify your answer at the microscopic level.

Entropy is the qualitative measurement of the deviance from equilibrium. On the microscopic level, the molecules are losing KE and thus reducing entropy.

(d) For the three-sample system, indicate whether the entropy of the system increases, decreases, or remains the same.

____ Increases __X__ Decreases ____ Remains the same

Justify your answer.

The entropy of the system decreases due to the fact that it is now at equilibrium.

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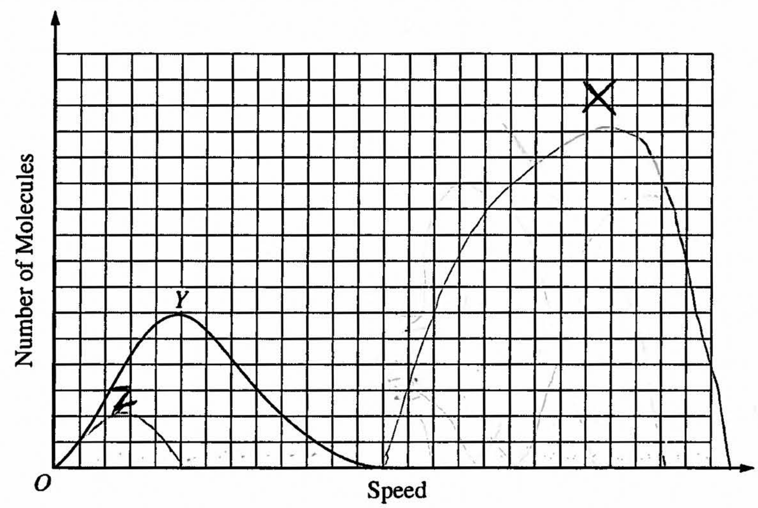
Sample 1C

2. (10 points, suggested time 20 minutes)
Three samples of a gas, X, Y, and Z, are prepared. Each sample contains the same number of molecules, but the samples are at different temperatures. The temperature of sample X is T_X, the temperature of sample Y is lower than that of sample X, and the temperature of sample Z is lower than that of sample Y $(T_X > T_Y > T_Z)$.

(a) The graph below shows the distribution of the speeds of the molecules in sample Y. On the graph, sketch and label possible distributions for sample X and sample Z.



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The three samples with initial temperatures $T_X > T_Y > T_Z$ are placed in thermal contact, with sample *Z* in the middle, as shown below, and the samples are insulated from their surroundings. The samples can exchange thermal energy but not gas molecules. The samples eventually reach equilibrium, with a final temperature greater than T_Y.

highest lowest middle

(b) In a few sentences, describe the change over time in the average kinetic energy of the molecules of each sample, from initial contact until they reach equilibrium. Explain how these changes relate to the energy flow between the pairs of samples that are in contact.

Sample *X* – exchanges some thermal w/ Z, the flow is mostly from X→Z

Sample *Y* Exchanges thermal energy w/ Z, the flow makes Z hotter + Y a little cooler.

Sample *Z* – Z exchanges thermal energy w/: X + Y. Mostly gets thermal energy flow from X.

(c) Indicate whether the net entropy of sample *X* increases, decreases, or remains the same as a result of the process of reaching equilibrium. ? what!

____ Increases _✓_ Decreases ____ Remains the same

Justify your answer at the microscopic level.

The net entropy of X decreases b/c it's molecules are being flowed to Z. And Z's cooler molecules are being transferred to X. So X ends up with less kinetic energy because it's losing heat

(d) For the three-sample system, indicate whether the entropy of the system increases, decreases, or remains the same.

____ Increases _✓_ Decreases ____ Remains the same

Justify your answer.

X + Y's entropy decreases b/c the average kinetic energy of X + Y's molecules is lowered. However, Z's entropy is increased b/c there is more KE b/c of more heat. This is a ratio of 2:1, so overall, the system's entropy decreases

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2014 Practice Exam Scoring Commentary

Note: Student samples are quoted verbatim and may contain grammatical errors.

Free-Response Question 1 Commentary

Overview

This question provided the opportunity for students to demonstrate their understanding of thermal energy. Part (a) provided the opportunity for students to demonstrate their knowledge of the Maxwell speed distribution for a gas; knowing how temperature relates to the most probable speed of the molecules and the height and width of the distribution. Students demonstrated this understanding through graphing the relative speeds and number of molecules of three samples of a gas at different temperatures. Part (b) allowed students to explain their understanding of energy flow as it relates to average kinetic energy and how to determine when equilibrium is reached, specifically explaining the flow of energy for each sample based on the situation described. Part (c) allowed students to demonstrate an understanding of entropy in order to justify an increase or decrease in entropy for the sample X and be able to explain what is actually happening to the molecules of sample X to cause this change. Part (d) allowed students to demonstrate an understanding of entropy in a closed system for an irreversible process.

Sample: 1A
Score: 7

In part (a), the response earned 2 points. The relative most probable speeds of each sample were in the correct order ($Z < Y < X$). The peaks of the normal distribution curves and their relative widths were also correct.

In part (b), the response earned 4 points. The response exhibited an understanding that energy flows from the system of higher temperature to systems of lower temperature. The response exhibited an understanding that higher temperature corresponds to higher kinetic energy and that the energy will continue until thermal equilibrium is reached. The fifth point listed in the scoring guide was not awarded because the student did not arrive at the correct conclusion about the energy flow for each of the three samples.

In part (c), the response earned 1 point. The response correctly indicated that the entropy decreased. However, the response did not justify that at the microscopic level when the temperature decreases the spread of the speeds is less because the kinetic energies of the individual molecules is less.

In part (d), the response earned 0 points. The response incorrectly indicated that the entropy remains the same.

Sample: 1B
Score: 4

In part (a), the response earned 1 point for correctly indicating the correct relative most probable speeds ($Z < Y < X$).

In part (b), the response earned 2 points for exhibiting an understanding that energy flows from systems of higher temperature to systems of lower temperatures and that higher temperature corresponds to higher kinetic energy.

In part (c), the response earned 1 point for indicating that the entropy of sample X decreases including a reasonable attempt at a justification.

In part (d), the response earned 0 points. The student incorrectly indicated that the entropy decreases.

Sample: 1C
Score: 2

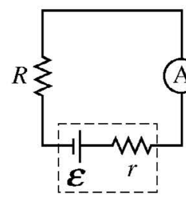
In part (a), the student earned 1 point for correctly indicating the correct relative most probable speeds ($Z < Y < X$).

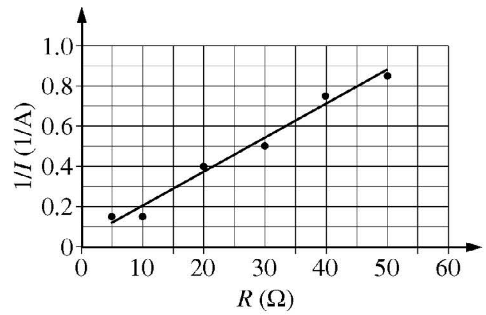
In part (b), the response earned 1 point for exhibiting an understanding that energy flows from systems of higher temperature to systems of lower temperatures.

In part (c), the response earned 0 points. The student correctly checks that the entropy decreases; however, there is not a reasonable attempt at a justification.

In part (d), the response earned 0 points. The student incorrectly indicated that the entropy decreases.

Free-Response Question 2





2. (12 points, suggested time 25 minutes)
Students are given some resistors with various resistances, a battery with internal resistance, and an ammeter. They are asked to determine the emf $\mathcal{E}$ and internal resistance r of the battery using just this equipment. Working with the circuit shown above, they insert each resistor into the circuit and measure the current I in the circuit each time they insert a resistor. From their data, the students generate a graph of $1/I$ as a function of the resistance R of each resistor, as shown above.

(a)

i. Write an algebraic equation describing the circuit that includes $\mathcal{E}$, R, r, and I.

ii. Use your equation and the graph to calculate the emf of the battery and the internal resistance of the battery.

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The students are now given a voltmeter and a new resistor *X* to use with the resistors, battery, and ammeter they already have. They are asked to determine whether resistor *X* is ohmic.

(b)

i. Using standard symbols for circuit elements, as in the previously shown circuit, draw a diagram of a circuit that the students could use to determine whether resistor *X* is ohmic, including the appropriate placement of the meters. Clearly label your diagram.

ii. Describe the procedure you would use with your circuit to get enough data to determine whether resistor *X* is ohmic.

iii. What would you graph using your data, and what would you look for on your graph to determine whether resistor *X* is ohmic?

(c) Would your procedure or data analysis in part (b) need to be different if the internal resistance of the battery was nonohmic? Justify your answer.

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Information for Free-Response Question 2

Timing	The student should spend approximately 25 minutes on this question.
Essential Knowledge	4.E.5 The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors. 5.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.
Science Practices	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.
Learning Objectives	4.E.5.2 The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. 4.E.5.3 The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. 5.B.9.6 The student is able to mathematically express the changes in electric potential energy of a loop in a multi-loop electrical circuit and justify this expression using the principle of the conservation of energy. 5.B.9.7 The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. 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.

Scoring Guidelines for Free-Response Question 2

Question 2

12 points total	**Distribution of points**
(a)	
(i) 1 point	
For a correct equation for the circuit containing all the required variables	1 point
$\mathcal{E} = (r + R)I$	
(ii) 3 points	
Slope-intercept method	
The above equation can be re-arranged to express $1/I$ as a function of R	
$\frac{1}{I} = \frac{R}{\mathcal{E}} + \frac{r}{\mathcal{E}}$	
The emf is the inverse of the slope of the graph.	
For using the slope of the line to determine the emf.	1 point
For using data from the best-fit line	1 point
For example:	
$\text{Slope} = \frac{1}{\mathcal{E}} = \frac{(0.8 - 0.2)(1/\text{A})}{(45 - 10)\Omega} = \frac{0.6}{35}\frac{1}{\text{V}}$	
$\mathcal{E} = \frac{35}{0.6}\ \text{V} = 58.3\ \text{V}$	
For using the intercept of the line to determine the battery resistance	1 point
$\text{Intercept} = r/\mathcal{E}$	
For example, reading an intercept of $0.03(1/\text{A})$	
$r = (\text{Intercept})\mathcal{E} = (0.03(1/\text{A}))(58.3\ \text{V}) = 1.75\ \Omega$	
Alternate Solution:	*Alternate Points*
Simultaneous equation method	
Data is substituted into the equation $\mathcal{E} = (r + R)I$	
For using two points to set up two equations	*1 point*
For using data from the best-fit line	*1 point*
For example	
$\mathcal{E} = (r + 45\ \Omega)(1/0.8(1/\text{A}))$	
$\mathcal{E} = (r + 10\ \Omega)(1/0.2(1/\text{A}))$	
For solving for r and $\mathcal{E}$	*1 point*
$(r + 10\ \Omega)(1/0.2(1/\text{A})) = (r + 45\ \Omega)(1/0.8(1/\text{A}))$	
$(r + 10\ \Omega)(0.8\ 1/\text{A}) = (r + 45\ \Omega)(0.2\ 1/\text{A})$	

Question 2 (continued)

Distribution of points

$r(0.8\ 1/\text{A}) - r(0.2\ 1/\text{A}) = (45\ \Omega)(0.2\ 1/\text{A}) - (10\ \Omega)(0.8\ 1/\text{A})$

$r(0.6\ 1/\text{A}) = (9 - 8)\Omega/\text{A}$

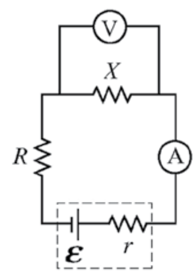
$r = 1/0.6\ \Omega = 1.7\ \Omega$

Using the first simultaneous equation and substituting for r

$\mathcal{E} = (1.7\ \Omega + 45\ \Omega)(1/0.8(1/\text{A})) = 58.3\ \text{V}$

(b)

(i) 2 points



For a design that allows the potential difference across resistor *X* to be varied — 1 point

For an ammeter and a voltmeter connected correctly to measure current and potential difference for resistor *X* — 1 point

(ii) 2 points

For a correct method for varying the potential difference across resistor *X*. — 1 point

For the example circuit shown above, use each of the resistors in turn as resistor *R*.

For indicating appropriate measurements for each trial — 1 point

For example, for each value of resistor *R*, measure the potential difference and current for resistor *X*.

(iii) 2 points

For indicating appropriate quantities to graph — 1 point

For the example described above, graph current as a function of potential difference.

For indicating an appropriate property of the graph — 1 point

For the example described above, the graph would be linear if resistor *X* was ohmic.

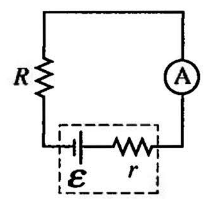
Question 2 (continued)

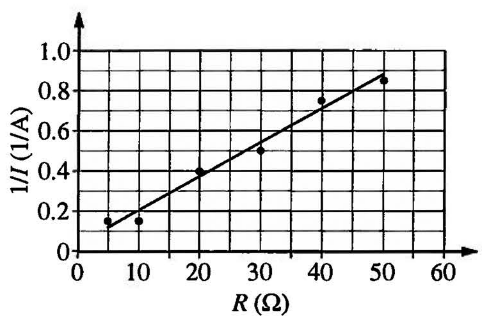
	Distribution of points
(c) 2 points	
For correctly indicating 'yes' or 'no' consistent with circuit drawn, and some reasonable attempt at a correct justification	1 point
For the example described above, the correct response is 'no'.	
For a correct justification	1 point
For the example described above, the measured values are those for only resistor *X*. Since the point is to change the resistance external to *X*, it does not matter how or why it changes. As long as the measurements are the quantities for *X* by itself the data is legitimate.	

Sample 2A

PHYSICS 2
SECTION II
Time—90 minutes
4 Questions

Directions: Answer all four questions, which are weighted according to the points indicated in each question. The suggested time for each question is also indicated. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.





1. (12 points, suggested time 25 minutes)
Students are given some resistors with various resistances, a battery with internal resistance, and an ammeter. They are asked to determine the emf $\mathcal{E}$ and internal resistance r of the battery using just this equipment. Working with the circuit shown above, they insert each resistor into the circuit and measure the current I in the circuit each time they insert a resistor. From their data, the students generate a graph of $1/I$ as a function of the resistance R of each resistor, as shown above.

(a)
i. Write an algebraic equation describing the circuit that includes $\mathcal{E}$, R, r, and I.

$\mathcal{E} - RI - rI = 0$

ii. Use your equation and the graph to calculate the emf of the battery and the internal resistance of the battery.

$\mathcal{E} = RI + rI$

$\mathcal{E} = (R + r)I = \frac{R+r}{\frac{1}{I}}$

$\frac{1}{I} = \frac{0.8\frac{1}{A} - 0.2\frac{1}{A}}{45\Omega - 10\Omega} R + C$

$\frac{1}{I} = \frac{0.6\frac{1}{A}}{35\Omega} R + C$

$C = \frac{1}{I} - \frac{0.6\frac{1}{A}}{35\Omega} R = 0.2\frac{1}{A} - \frac{0.6\frac{1}{A}}{35\Omega}(10\Omega) = 0.0286\ \frac{1}{A}$

$\mathcal{E} = \frac{10\Omega}{0.2} = 50\text{ V}$

$\mathcal{E} = \Delta R\, \Delta I = \frac{(45\Omega - 10\Omega)}{(0.8A^{-1} - 0.2A^{-1})}$

$\boxed{\mathcal{E} = 58.3\text{ V}}$

$\mathcal{E} = RI + rI$

$\frac{\mathcal{E}}{I} - R = r$

$58.3\text{V} \cdot 0.2A^{-1} - 10\Omega = 1.66\Omega$

$\boxed{r = 1.66\Omega}$

GO ON TO THE NEXT PAGE.

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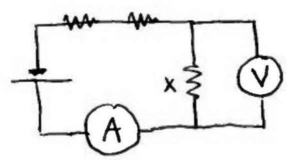
* Due to a question ordering change after the piloting of this exam, some item numbers may appear differently. All item numbers correspond with the AP Physics 2: Algebra-Based Practice Exam.

The students are now given a voltmeter and a new resistor X to use with the resistors, battery, and ammeter they already have. They are asked to determine whether resistor X is ohmic.

(b)

i. Using standard symbols for circuit elements, as in the previously shown circuit, draw a diagram of a circuit that the students could use to determine whether resistor X is ohmic, including the appropriate placement of the meters. Clearly label your diagram.



ii. Describe the procedure you would use with your circuit to get enough data to determine whether resistor X is ohmic.

The non-X resistors will be changed to change the voltage and the current read by the voltmeter and the ammeter.

iii. What would you graph using your data, and what would you look for on your graph to determine whether resistor X is ohmic?

I would graph a voltage vs. current graph where voltage will be on y-axis and current will be on the x-axis. If resistor X is ohmic then the best fit line for the graph will be straight.

(c) Would your procedure or data analysis in part (b) need to be different if the internal resistance of the battery was nonohmic? Justify your answer.

the Internal resistance of the battery will not affect the data because ~~the changing resistance of the resistor~~ if the resistor X is ohmic it will still yeild correct data is the voltage has changed

Time at which I finished the question above (hh:mm): 12 : 41

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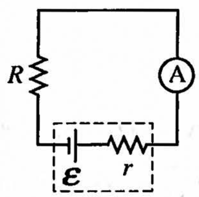
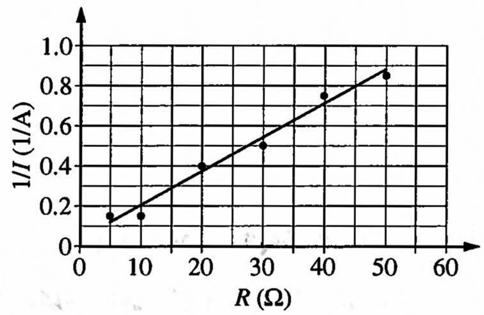
Sample 2B

PHYSICS 2
SECTION II
Time—90 minutes
4 Questions

Directions: Answer all four questions, which are weighted according to the points indicated in each question. The suggested time for each question is also indicated. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.





1. (12 points, suggested time 25 minutes)
Students are given some resistors with various resistances, a battery with internal resistance, and an ammeter. They are asked to determine the emf $\mathcal{E}$ and internal resistance r of the battery using just this equipment. Working with the circuit shown above, they insert each resistor into the circuit and measure the current I in the circuit each time they insert a resistor. From their data, the students generate a graph of $1/I$ as a function of the resistance R of each resistor, as shown above.

(a)
i. Write an algebraic equation describing the circuit that includes $\mathcal{E}$, R, r, and I.

$\frac{1}{\mathcal{E}} = \frac{1}{R_{eq}I} = \frac{1}{\mathcal{E}} = \frac{1}{(R+r)I} = \boxed{\frac{1}{\mathcal{E}} = \frac{1}{RI+rI}}$ $\quad y = mx \quad \frac{1}{I} = \frac{1}{\mathcal{E}} \cdot R_{eq} = \frac{R_{eq}}{\mathcal{E}} = \frac{1}{I}$

$\frac{\frac{1}{I}}{R} = \frac{1}{IR} = m = \frac{1}{\mathcal{E}}$

$R_{eq} = R + r$

$\frac{\mathcal{E}}{r} =$

ii. Use your equation and the graph to calculate the emf of the battery and the internal resistance of the battery.

$m = \frac{(0.8 - 0.3)}{(45 - 15)} = \left(\frac{0.5}{30}\right)^{-1} = \left(\frac{r}{\mathcal{E}}\right)^{-1} \Rightarrow \mathcal{E} = \frac{30}{0.5} = 60\text{V}$

$f(R) = \frac{1}{I} = \frac{R_{eq}}{\mathcal{E}} = \frac{1}{0.7} = \frac{(40+r)}{60\text{ V}} = \frac{1}{0.7} = \frac{2}{3} + \frac{r}{60}$
$\quad -\frac{2}{3} \quad -\frac{2}{3}$

$0.761904686 \cdot 60 = r$

$\boxed{r = 45.71428611}$

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GO ON TO THE NEXT PAGE.

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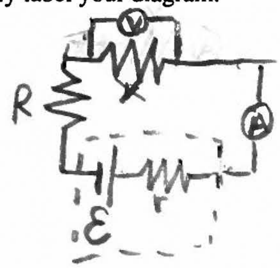
The students are now given a voltmeter and a new resistor X to use with the resistors, battery, and ammeter they already have. They are asked to determine whether resistor X is ohmic.

(b)

i. Using standard symbols for circuit elements, as in the previously shown circuit, draw a diagram of a circuit that the students could use to determine whether resistor X is ohmic, including the appropriate placement of the meters. Clearly label your diagram.



ii. Describe the procedure you would use with your circuit to get enough data to determine whether resistor X is ohmic.

I would calculate the ~~total~~ resistance to find the total current, keeping in mind internal resistance. Then I would examine the voltage drop across resistor X. If the resistor is ohmic, I should be able to derive the same value of current at Resistor X as the total current because it's in a series current.

iii. What would you graph using your data, and what would you look for on your graph to determine whether resistor X is ohmic?

I would graph the inverse current and resistance of X. The slope of the resistor X, the inverse emf, should be equal to the inverse of the voltage I found in my data.

(c) Would your procedure or data analysis in part (b) need to be different if the internal resistance of the battery was nonohmic? Justify your answer.

The procedure would be different because then the internal resistance wouldn't stay constant, so I would have to calibrate the procedure to deal w/ a constant state of flux.

Time at which I finished the question above (hh:mm): 1 2 : 4 1

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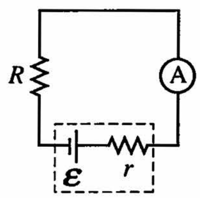
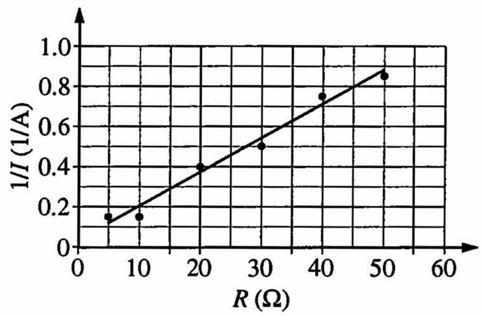
Sample 2C

PHYSICS 2
SECTION II
Time—90 minutes
4 Questions

Directions: Answer all four questions, which are weighted according to the points indicated in each question. The suggested time for each question is also indicated. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.





1. (12 points, suggested time 25 minutes)
Students are given some resistors with various resistances, a battery with internal resistance, and an ammeter. They are asked to determine the emf $\mathcal{E}$ and internal resistance r of the battery using just this equipment. Working with the circuit shown above, they insert each resistor into the circuit and measure the current I in the circuit each time they insert a resistor. From their data, the students generate a graph of $1/I$ as a function of the resistance R of each resistor, as shown above.

(a)
i. Write an algebraic equation describing the circuit that includes $\mathcal{E}$, R, r, and I.

$\mathcal{E} = IR + Ir$

ii. Use your equation and the graph to calculate the emf of the battery and the internal resistance of the battery.

$\mathcal{E} = \frac{1}{.2}(10 + r)$

$\mathcal{E} = 50 + 5r$

GO ON TO THE NEXT PAGE.

The students are now given a voltmeter and a new resistor *X* to use with the resistors, battery, and ammeter they already have. They are asked to determine whether resistor *X* is ohmic.

(b)

i. Using standard symbols for circuit elements, as in the previously shown circuit, draw a diagram of a circuit that the students could use to determine whether resistor *X* is ohmic, including the appropriate placement of the meters. Clearly label your diagram.

ii. Describe the procedure you would use with your circuit to get enough data to determine whether resistor *X* is ohmic.

what is ohmic?

iii. What would you graph using your data, and what would you look for on your graph to determine whether resistor *X* is ohmic?

Voltage and resistance. I would look for the slope

(c) Would your procedure or data analysis in part (b) need to be different if the internal resistance of the battery was nonohmic? Justify your answer.

Time at which I finished the question above (hh:mm): 1 2 : 3 8

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Free-Response Question 2 Commentary

Overview

This question provided an opportunity for students to demonstrate their understanding of emf, resistance, internal resistance, and current. Part (a)(i) allowed students to use data collected from different resistors in a circuit to determine the relationship between the emf E, the resistance R of the various resistors, the internal resistance r of the battery, and the current I in the circuit. Part (a)(ii) allowed students to use the equation from part (a)(i) and the graph to calculate the emf of the battery and internal resistance, understanding the meaning of the slope and y-intercept of the graph. Part (b)(i) allowed students to demonstrate their understanding of circuit construction by deciding whether to place an additional resistor X into the circuit in series or parallel and determining the correct placement of the voltmeter and ammeter. Part (b)(ii) allowed students to apply their knowledge of resistors to design a procedure that would yield the correct data to determine whether or not resistor X was ohmic. Part (b)(iii) allowed students to demonstrate how to analyze the data collected in part (b)(ii) and know what kind of the graph is necessary to make an accurate conclusion about whether or not resistor X was ohmic. Part (c) allowed students to demonstrate their understanding that the internal resistance of the battery was external to resistor X and whether or not resistor X was ohmic did not matter in terms of the data collected about resistor X.

Sample: 2A
Score: 11

In part (a)(i), the response earned 1 point for the algebraic equation describing the circuit including E, R, r, and I. Based on the work in (a)(ii), the symbol after the E is clearly meant to be a minus sign.

In part (a)(ii), the response earned 3 points for using data points from the graph to calculate the slope to determine the emf and then determining the internal resistance using the equation from part (a)(i), emf, and a data point.

In part (b)(i), the response earned 2 points for having a circuit that would allow the potential difference across resistor X to be varied, and having the voltmeter and ammeter connected correctly to allow for the current and potential difference for resistor X to be measured.

In part (b)(ii), the response earned 2 points for a procedure that indicated that more than one resistor would be changed causing the voltage and current across resistor X to change and that the voltmeter and ammeter would measure these values.

In part (b)(iii), the response earned 2 points for graphing voltage and current and indicating that if resistor X was ohmic, then the graph would be linear.

In part (c), the response earned 1 point for indicating that the internal resistance of the battery would not affect the data.

Sample: 2B
Score: 5

In part (a)(i), the response earned 1 point for the algebraic equation describing the circuit including E, R, r, and I.

In part (a)(ii), the response earned 3 points for using two data points from the graph to calculate the slope to determine the emf and using the equation, emf, and a data point to determine the internal resistance.

In part (b)(i), the response earned 2 points for having a circuit that would allow the potential difference across resistor X to be varied, and having the voltmeter and ammeter connected correctly to allow for the current and potential difference for resistor X to be measured.

In part (b)(ii), the response earned 0 points because the procedure given did not indicate how to vary the current and voltage of resistor X.

In part (b)(iii), the response earned 0 points because the response did not indicate the correct quantities to graph and how the graph would look if resistor X was ohmic.

In part (c), the response earned 0 points because the answer was not consistent with the circuit drawn.

Sample: 2C
Score: 3

In part (a)(i), the response earned 1 point for the algebraic equation describing the circuit including E, R, r, and I.

In part (a)(ii), the response earned 0 points. The response used only one data point and did not solve for emf or r.

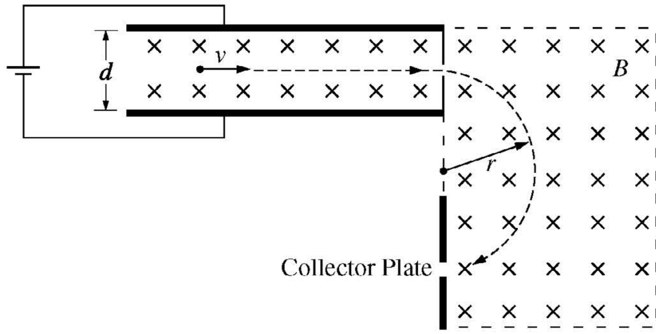
In part (b)(i), the response earned 2 points for having a circuit that would allow the potential difference across resistor X to be varied, and having the voltmeter and ammeter connected correctly to allow for the current and potential difference for resistor X to be measured.

In part (b)(ii), the response earned 0 points. The student did not indicate a correct method for varying the potential difference across resistor X nor did they indicate the appropriate measurements for each trial.

In part (b)(ii), the response earned 0 points. The quantities being graphed were incorrect.

In part (c), the response earned 0 points. The response was not consistent with the circuit drawn nor was there a reasonable attempt at a justification.

Free-Response Question 3



3. (12 points, suggested time 25 minutes)

A particle with unknown mass and charge is projected into the apparatus shown above. The particle moves with constant speed v as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude B directed into the page exists both in the region between the plates and in the region to the right of the plates that is enclosed by the dashed lines. In the region to the right of the plates, the particle's path is circular with radius r. Assume the effects of gravity are negligible compared to other forces.

(a) Explain why the particle moves through the parallel plates undeflected in terms of the forces exerted on the particle.

(b) What is the sign of the charge on the particle? Justify your answer.

GO ON TO THE NEXT PAGE.

A magnetic field of 0.30 T is applied with the plate separation at 5.0×10^{-3} m. Singly ionized particles with various speeds enter the region between the plates, and only those with speed 2.0×10^{6} m/s are undeflected as they pass between the plates. These particles then reach the collector plate a distance of 0.42 m below the point at which they left the region between the parallel plates.

(c) Based on your explanation in part (a), derive an algebraic expression for the potential difference that must be applied to produce the motion of the undeflected particles. Use that expression to calculate the numerical value of the potential difference.

(d) By analyzing the circular part of the motion, derive an algebraic expression for the mass of the particles. Use that expression to calculate a numerical value for the mass.

(e) A scientist wants to use the apparatus to separate singly ionized atoms of ^{12}C and ^{14}C in order to use the ^{14}C in radiocarbon dating. Describe how the motion of the two isotopes of carbon in both regions of the apparatus leads to their separation, appropriately relating your description to the algebraic equations you wrote in parts (c) and (d).

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Information for Free-Response Question 3

Timing	The student should spend approximately 25 minutes on this question.
Essential Knowledge	2.C.1 The magnitude of the electric force F exerted on an object with electric charge q by an electric field E is $F = qE$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates. 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. Treatment is quantitative for angles of $0°$, $90°$, or $180°$ and qualitative for other angles. 3.B.1 If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
Science Practices	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objectives	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: $F = qE$; a vector relation. 2.C.1.2 The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. 2.D.1.1 The student is able to apply mathematical routines to express the force on a moving charged object due to a magnetic field. 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.

Scoring Guidelines for Free-Response Question 3

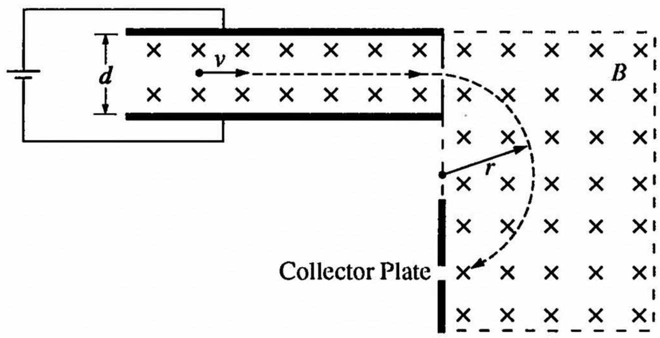
Question 3

12 points total	**Distribution of points**
(a) 2 points	
For any indication that both an electric and a magnetic force are exerted on the particle	1 point
For any indication that these forces are equal in magnitude and opposite in direction	1 point
For example: The plates create a vertical electric field that exerts a vertical force on the particle. The cross-product of the velocity and the magnetic field also results in a vertical force. No matter what the charge of the particle, these forces are in opposite directions. Since the charge moves in a straight line they must be equal in magnitude.	
(b) 1 point	
For indicating that the charge is negative and a correct justification	1 point
Examples:	
The cross-product of the velocity and the magnetic field is directed upward. The particle curves downward as it leaves the plates, so it must be negative.	
With the battery connection shown, the top plate is positive and the bottom one is negative. So the electric field is down. The particle would move down without the electric field, as it initially does when it leaves the plates, so the force from the field must be upward. That means the particle is negative.	
(c) 3 points	
$F_B = qvB$	
For equating the magnitudes of the electric and magnetic forces	1 point
$qE = qvB$ so $E = vB$	
For using the relationship between the field and potential for parallel plates, $E = V/d$	1 point
$V/d = vB$	
$V = vBd$	
For correct substitutions	1 point
$V = \left(2.0 \times 10^{6}\ \text{m/s}\right)(0.30\ \text{T})\left(5.0 \times 10^{-3}\ \text{m}\right)$	
$V = 3000\ \text{V}$	

Question 3 (continued)

		Distribution of points
(d)	3 points	
	For equating the magnitudes of the centripetal and magnetic forces	1 point
	$mv^2/r = qvB$	
	$m = qBr/v$	
	For realizing that the given distance to the collector plate is the diameter and using $r = 2D$	1 point
	For correct substitutions	1 point
	$m = \left(1.6 \times 10^{-19}\ \text{C}\right)(0.30\ \text{T})(0.21\ \text{m})/\left(2.0 \times 10^{6}\ \text{m/s}\right)$	
	$m = \left(5.04 \times 10^{-27}\ \text{kg}\right)$	
(e)	3 points	
	For any indication that the straight-line motion means that all the particles leaving the plates have the same speed regardless of charge and mass, referencing part (c)	1 point
	For any indication that the radius of the circular motion depends on the charge and mass, as indicated by the equation $m = qBr/v$ from part (d)	1 point
	For any indication that radius depends only on the mass	1 point

Sample 3A*



4. (12 points, suggested time 25 minutes)

A particle with unknown mass and charge is projected into the apparatus shown above. The particle moves with constant speed v as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude B directed into the page exists both in the region between the plates and in the region to the right of the plates that is enclosed by the dashed lines. In the region to the right of the plates, the particle's path is circular with radius r. Assume the effects of gravity are negligible compared to other forces.

(a) Explain why the particle moves through the parallel plates undeflected in terms of the forces exerted on the particle.

The particle is undeflected because the electric force caused by the parallel plates is negated by the magnetic force caused by the magnetic field.

(b) What is the sign of the charge on the particle? Justify your answer.

The sign is negative because from the part of the apparatus with only magnetic field affecting the particle. the force acts ↓ direction when v is → direction and B is × direction. Thus particle acts in the opposite force direction as suggested by the right hand rule, so the particle has negative charge.

GO ON TO THE NEXT PAGE.

* Due to a question ordering change after the piloting of this exam, some item numbers may appear differently. All item numbers correspond with the AP Physics 2: Algebra-Based Practice Exam.

A magnetic field of 0.30 T is applied with the plate separation at 5.0×10^{-3} m. Singly ionized particles with various speeds enter the region between the plates, and only those with speed 2.0×10^{6} m/s are undeflected as they pass between the plates. These particles then reach the collector plate a distance of 0.42 m below the point at which they left the region between the parallel plates.

(c) Based on your explanation in part (a), derive an algebraic expression for the potential difference that must be applied to produce the motion of the undeflected particles. Use that expression to calculate the numerical value of the potential difference.

given: $B = .30\,T$, $\Delta x = 5.0 \times 10^{-3}\,m$, $v = 2.0 \times 10^{6}\,m/s$

$F_E = F_B$

$\frac{q\Delta V}{\Delta x} = qvB$

$\Leftrightarrow \Delta V = vB\Delta x = (2.0 \times 10^{6}\,m/s)(.30\,T)(5.0 \times 10^{-3}\,m) = \boxed{3.0 \times 10^{3}\,V}$

(d) By analyzing the circular part of the motion, derive an algebraic expression for the mass of the particles. Use that expression to calculate a numerical value for the mass.

given: $B = .30\,T$, $r = \frac{.42\,m}{2}$, $v = 2.0 \times 10^{6}\,m/s$, $q = 1.60 \times 10^{-19}\,C$

$F_c = F_B$

$\frac{mv^2}{r} = qvB$

$\Leftrightarrow m = \frac{qBr}{v} = \frac{(1.60 \times 10^{-19}\,C)(.30\,T)(\frac{.42\,m}{2})}{2.0 \times 10^{6}\,m/s} = \boxed{5.04 \times 10^{-27}\,kg}$

(e) A scientist wants to use the apparatus to separate singly ionized atoms of ^{12}C and ^{14}C in order to use the ^{14}C in radiocarbon dating. Describe how the motion of the two isotopes of carbon in both regions of the apparatus leads to their separation, appropriately relating your description to the algebraic equations you wrote in parts (c) and (d).

Though ^{12}C and ^{14}C have the same velocity and same F_B acting on them, they differ in mass in that ^{14}C is heavier than ^{12}C. $\frac{mv^2}{r} = qvB$ so to keep qvB ($= F_B$) and v constant with differing mass, r must differ. If m is larger, r must be larger as well. Thus, ^{14}C would travel a larger radius than ^{12}C, separating the two molecules.

(I'm going back to check now). done checking at 12:00)

Time at which I finished the question above (hh:mm): 11 : 49

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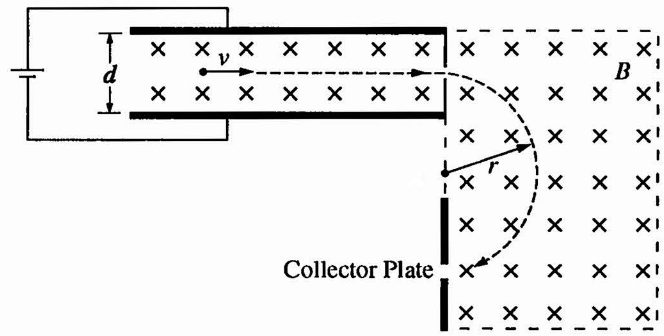
Sample 3B



4. (12 points, suggested time 25 minutes)

A particle with unknown mass and charge is projected into the apparatus shown above. The particle moves with constant speed v as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude B directed into the page exists both in the region between the plates and in the region to the right of the plates that is enclosed by the dashed lines. In the region to the right of the plates, the particle's path is circular with radius r. Assume the effects of gravity are negligible compared to other forces.

(a) Explain why the particle moves through the parallel plates undeflected in terms of the forces exerted on the particle.

because the magnetic field force and electric field force oppose each other and have equal magnitude therefore the particle travels through undeflected.

(b) What is the sign of the charge on the particle? Justify your answer.

The sign of the particle is negative because the velocity is to the right and the magnetic field is into the page. Therefore the force on a negative particle would cause it to travel towards the bottom of the page.

GO ON TO THE NEXT PAGE.

A magnetic field of 0.30 T is applied with the plate separation at 5.0×10^{-3} m. Singly ionized particles with various speeds enter the region between the plates, and only those with speed 2.0×10^{6} m/s are undeflected as they pass between the plates. These particles then reach the collector plate a distance of 0.42 m below the point at which they left the region between the parallel plates.

(c) Based on your explanation in part (a), derive an algebraic expression for the potential difference that must be applied to produce the motion of the undeflected particles. Use that expression to calculate the numerical value of the potential difference.

$F_E = qvB$

$Eq = qvB$

$\frac{Vq}{r} = qvB$

$V = rvB$

$V = (5.0\times10^{-3}\,m)(2.0\times10^{6}\,m/s)(.3T)$

$V = 3000V$

(d) By analyzing the circular part of the motion, derive an algebraic expression for the mass of the particles. Use that expression to calculate a numerical value for the mass.

$F_B = ma_c$

$F_B = \frac{mv^2}{r}$

$qvB = \frac{mv^2}{r}$

$m = \frac{qB}{vr}$

$m = \frac{(1.6\times10^{-19}C)(.3T)}{(2.0\times10^{6}m/s)(.42m)}$

$m = 5.7\times10^{-26}\,g$

(e) A scientist wants to use the apparatus to separate singly ionized atoms of ^{12}C and ^{14}C in order to use the ^{14}C in radiocarbon dating. Describe how the motion of the two isotopes of carbon in both regions of the apparatus leads to their separation, appropriately relating your description to the algebraic equations you wrote in parts (c) and (d).

Only the ^{14}C atom will make it to the collector plate if velocity, forces, and mass are the appropriate magnitude.

Time at which I finished the question above (hh:mm): 8 : 08

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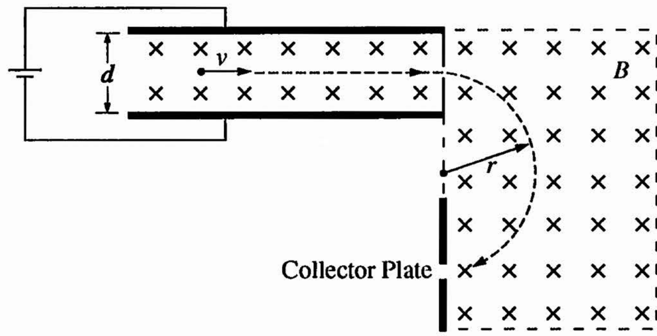
Sample 3C



4. (12 points, suggested time 25 minutes)

A particle with unknown mass and charge is projected into the apparatus shown above. The particle moves with constant speed v as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude B directed into the page exists both in the region between the plates and in the region to the right of the plates that is enclosed by the dashed lines. In the region to the right of the plates, the particle's path is circular with radius r. Assume the effects of gravity are negligible compared to other forces.

(a) Explain why the particle moves through the parallel plates undeflected in terms of the forces exerted on the particle.

The magnetic force that is exerted on the particle is equal and opposite to the electric force that is acting on the particle due to the particle's charge.

(b) What is the sign of the charge on the particle? Justify your answer.

The sign on the particle is positive because it is repelled by the top parallel plate, which is positively charged by the voltage source, and is attracted to the negative plate as demonstrated by its path after exiting the parallel plate region.

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A magnetic field of 0.30 T is applied with the plate separation at 5.0×10^{-3} m . Singly ionized particles with various speeds enter the region between the plates, and only those with speed 2.0×10^{6} m/s are undeflected as they pass between the plates. These particles then reach the collector plate a distance of 0.42 m below the point at which they left the region between the parallel plates.

(c) Based on your explanation in part (a), derive an algebraic expression for the potential difference that must be applied to produce the motion of the undeflected particles. Use that expression to calculate the numerical value of the potential difference.

$F_B = KE$

$q V B = \frac{1}{2} m v^2$

$V = \frac{m v^2}{2 q B}$

$V = \frac{(9.11 \times 10^{-31} kg)(2.0 \times 10^6 m/s)}{2(-1)(0.30 T)}$

$V = -3.04 \times 10^{-24} V$

(d) By analyzing the circular part of the motion, derive an algebraic expression for the mass of the particles. Use that expression to calculate a numerical value for the mass.

$\frac{m v^2}{r} = q V B$

?

(e) A scientist wants to use the apparatus to separate singly ionized atoms of ^{12}C and ^{14}C in order to use the ^{14}C in radiocarbon dating. Describe how the motion of the two isotopes of carbon in both regions of the apparatus leads to their separation, appropriately relating your description to the algebraic equations you wrote in parts (c) and (d).

?

Time at which I finished the question above (hh:mm): ___ ___ : ___ ___

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Free-Response Question 3 Commentary

Overview

This question provided an opportunity for students to demonstrate their knowledge of both electrical and magnetic forces. Part (a) provided the opportunity for students to indicate that if a charge moves undeflected through parallel plates that both an electric force and a magnetic force are exerted on the particle that are equal in magnitude and opposite direction. Part (b) provided an opportunity for students to explain how they determined that the particle was negative. Part (c) provided students with the opportunity to equate the magnitudes of electric and magnetic force and use the relationship between the field and potential for parallel plates to determine the numerical value of the potential difference. Part (d) provided the opportunity to demonstrate that since the particle moves in a circular path that the centripetal force and magnetic force are equal in order to solve for the mass of the particle. Part (e) provided the opportunity for students to apply their understanding of what it means to leave both regions in a straight line. Students were to demonstrate that all particles leave the plates having the same speed regardless of charge and mass. However, the radii of the path of each particle will be different because it depends on the charge and the mass based on the equation from part (d).

Sample: 3A
Score: 12

In part (a), the response earned 2 points for indicating that an electric force and magnetic force were exerted on the particle and that these two forces were equal in magnitude and opposite in direction.

In part (b), the response earned 1 point for indicating that the sign of the particle was negative and for including a correct justification.

In part (c), the response earned 3 points for equating the magnitudes of electric and magnetic forces and using the relationship between field and potential for parallel plates to determine the potential difference.

In part (d), the response earned 3 points for equating centripetal force and magnetic force, realizing the given distance was the diameter not the radius and substituting into the equation to determine the mass of the particle.

In part (e), the response earned 3 points for indicating that the isotopes will have the same velocity and using the equation from part (d) to explain that the radii will differ because the masses of the isotopes are different.

Sample: 3B
Score: 7

In part (a), the response earned 2 points for indicating that both an electric and a magnetic force are exerted on the particle and that the two forces are equal in magnitude and opposite in direction.

In part (b), the response earned 1 point for indicating that the sign of the particle was negative and for including a correct justification.

In part (c),the response earned 3 points for equating the magnitudes of electric and magnetic forces and using the relationship between field and potential for parallel plates to determine the potential difference.

In part (d), the response earned 1 point for equating the magnitudes of centripetal and magnetic forces. The other two points were not earned because the response did not state that the radius was half the given diameter and the substitution was incorrect into the equation.

In part (e), the response earned 0 points. The response did not indicate that all particles leaving the plates have the same speed regardless of charge and mass nor was there an indication that the radius of the circular motion depends on charge and mass.

Sample: 3C
Score: 3

In part (a), the response earned 2 points for indicating that both an electric and magnetic force are exerted on the particle and that the two forces are equal in magnitude and opposite in direction.

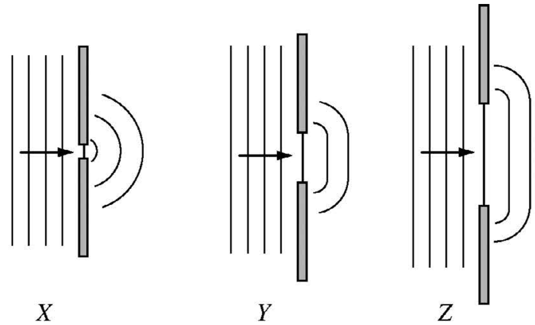
In part (b), the response earned 0 points. The response indicated that the charge was positive.

In part (c), the response earned 0 points. The response did not equate the magnitudes of the electric and magnetic forces.

In part (d), the response earned 1 point for equating the magnitudes of the centripetal and magnetic forces.

In part (e), the response earned 0 points. The response was blank.

Free-Response Question 4



4. (10 points, suggested time 20 minutes)
The figures above labeled *X*, *Y*, and *Z* represent plane waves of the same wavelength incident on barriers that have openings of different sizes. Also shown are the shapes of the wave fronts beyond the barriers.

(a) One model of waves treats every point on a wave front as a point source. Give a clear, coherent, paragraph-length description of how this model can be used to explain the shape of the wave fronts beyond the barriers.

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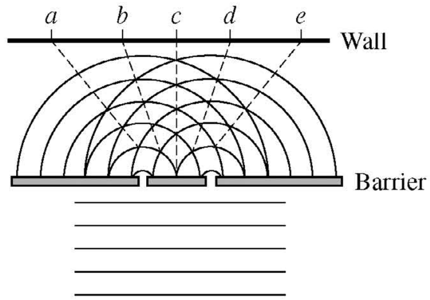
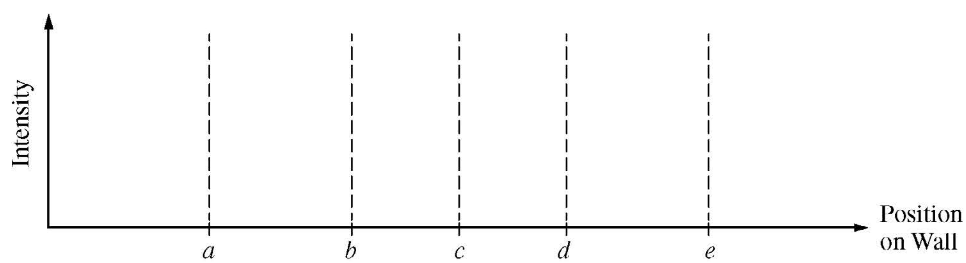


The figure above represents another plane wave incident on a barrier with two identical openings, creating an interference pattern on the wall. Some positions in the pattern on the wall are labeled.

(b) In a few sentences, describe how the point-source model described in part (a) and the figure above can be used to explain the formation of the interference pattern on the wall.

(c) On the axes below, sketch the intensity of the waves that are incident on the wall. The labels correspond to the positions noted in the figure above.



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Information for Free-Response Question 4

Timing	The student should spend approximately 20 minutes on this question.
Essential Knowledge	6.C.1 When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition. 6.C.2 When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed. 6.C.3 When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.
Science Practices	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objectives	6.C.1.1 The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. 6.C.1.2 The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. 6.C.2.1 The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening, and to qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. 6.C.3.1 The student is able to qualitatively apply the wave model to quantities that describe the generation of interference pattern to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small, but larger than the wavelength.

Scoring Guidelines for Free-Response Question 4

Question 4

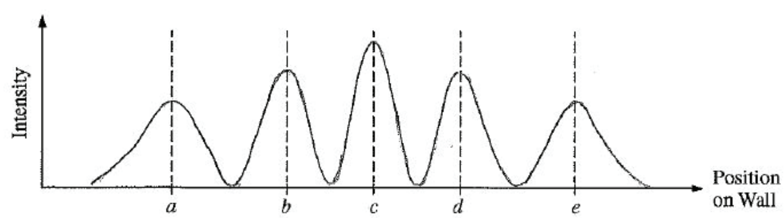
10 points total	**Distribution of points**
(a) 5 points	
For a correct description of *X* as essentially a point source	1 point
For demonstrating understanding that wider openings can be treated as multiple point sources	1 point
For demonstrating understanding that interference of wave fronts creates the pattern on the far side of the opening	1 point
For demonstrating understanding of the lack of interference at the edges	1 point
For coherently connecting the above ideas in a logical explanation	1 point

For example: In *X*, the size of the slit is comparable to the wavelength of the plane waves, so it acts most like a single point source and produces essentially spherical wave fronts. As the slit gets wider in *Y* and *Z*, it acts like an increasing number of point sources. Away from the edges, the spherical wave fronts interfere and the points of constructive interference result in the planar sections that reproduce the incident plane waves. Near the edges, there are no waves on one side to interfere, so the spherical fronts propagate.

(b) 3 points	
For demonstrating understanding that the figure shows a set of wave fronts for each opening	1 point
For demonstrating understanding that maxima in the resulting interference pattern occur where the fronts intersect	1 point
For demonstrating understanding that the dashed lines lead to points of maxima in the resulting interference pattern on the wall	1 point

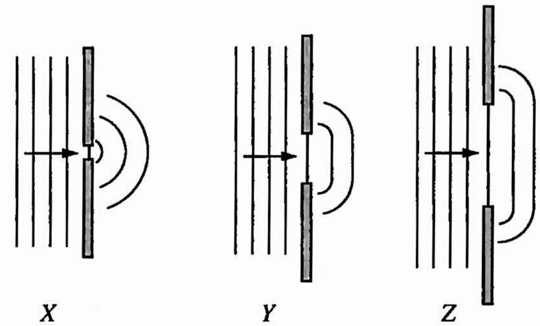
For example: Each opening creates a set of spherical wave fronts as shown. Assuming the wave fronts denote maximum amplitude, where they cross are points of maximum constructive interference. The dashed lines connect these points, and indicate where the maxima of the pattern on the wall are located.

(c) 2 points



For maxima at the labeled positions on the wall and minima in between	1 point
For showing a decrease in the height of the maxima as position moves away from the central point *c*	1 point

Sample 4A*



3. (10 points, suggested time 20 minutes)
The figures above labeled *X*, *Y*, and *Z* represent plane waves of the same wavelength incident on barriers that have openings of different sizes. Also shown are the shapes of the wave fronts beyond the barriers.

(a) One model of waves treats every point on a wave front as a point source. Give a clear, coherent, paragraph-length description of how this model can be used to explain the shape of the wave fronts beyond the barriers.

For wave X, the point source model predicts a wavefront with an almost circular shape beyond the barrier because the opening is small enough to be considered a point. For the other two openings, the points near the edges of the openings cause the circular curvature on the sides of each wave, while in the middle interference occurs between each point source. Due to the interference, only the straight sections of the wavefront are preserved.

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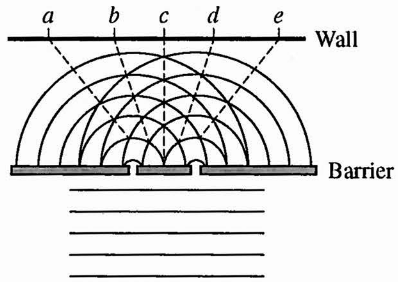
* Due to a question ordering change after the piloting of this exam, some item numbers may appear differently. All item numbers correspond with the AP Physics 2: Algebra-Based Practice Exam.

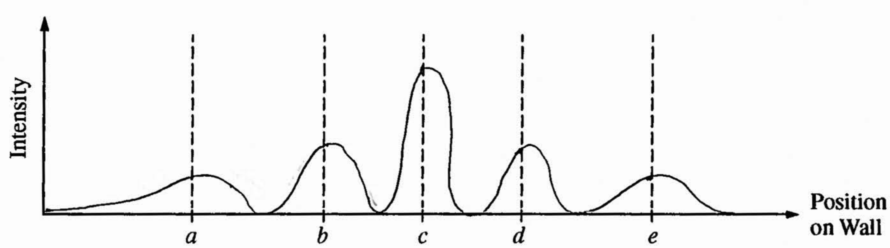


The figure above represents another plane wave incident on a barrier with two identical openings, creating an interference pattern on the wall. Some positions in the pattern on the wall are labeled.

(b) In a few sentences, describe how the point-source model described in part (a) and the figure above can be used to explain the formation of the interference pattern on the wall.

The wave fronts coming from each of the slits are circular due to the point-source model. Furthermore, the figure above shows the points of interference between the waves, corresponding to the locations on the wall where the fringes are found.

(c) On the axes below, sketch the intensity of the waves that are incident on the wall. The labels correspond to the positions noted in the figure above.



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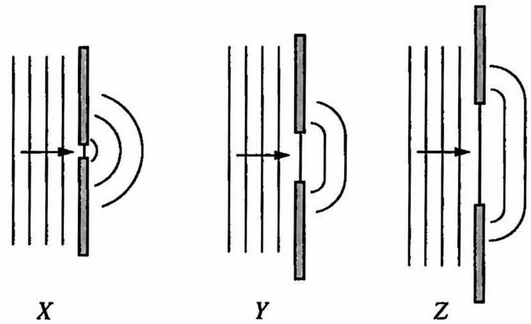
Sample 4B



3. (10 points, suggested time 20 minutes)
The figures above labeled *X*, *Y*, and *Z* represent plane waves of the same wavelength incident on barriers that have openings of different sizes. Also shown are the shapes of the wave fronts beyond the barriers.

(a) One model of waves treats every point on a wave front as a point source. Give a clear, coherent, paragraph-length description of how this model can be used to explain the shape of the wave fronts beyond the barriers.

If each point on a wave is a point source, then the shape would depend on the constructive interference of each wave. In the middle of the slit, there is equal construcitve interference on either side resulting no change in the direction of the wave. On a side of a slit, only the waves on the other side add up constructively, creating a wave the moves towords the side of the slit. The closer the point is to the side of a slit, the more it would bend towords it resulting in the image depicted above

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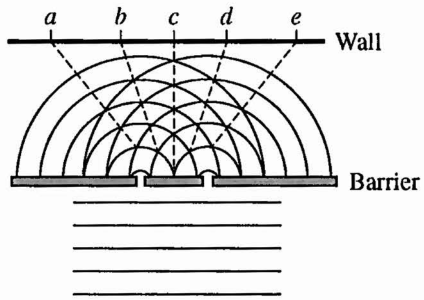
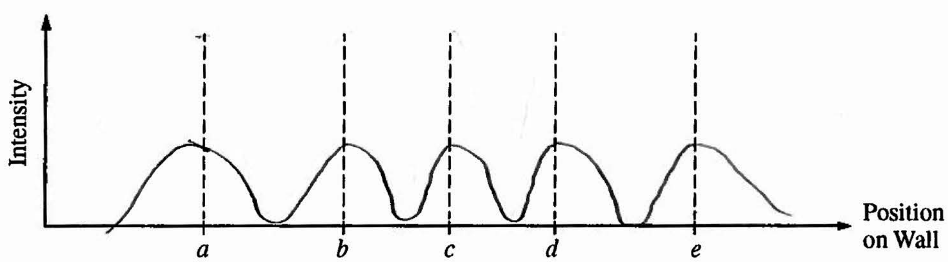


The figure above represents another plane wave incident on a barrier with two identical openings, creating an interference pattern on the wall. Some positions in the pattern on the wall are labeled.

(b) In a few sentences, describe how the point-source model described in part (a) and the figure above can be used to explain the formation of the interference pattern on the wall.

On those points, the surrounding waves add up constructively and thus creates bright bands

(c) On the axes below, sketch the intensity of the waves that are incident on the wall. The labels correspond to the positions noted in the figure above.



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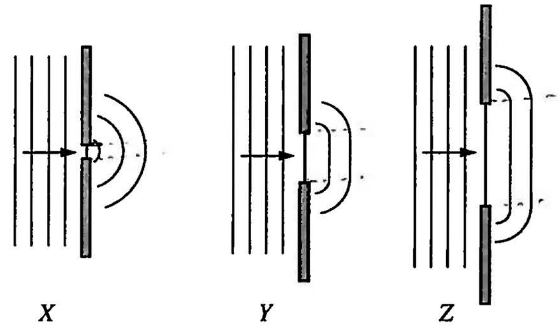
Sample 4C



3. (10 points, suggested time 20 minutes)
The figures above labeled *X*, *Y*, and *Z* represent plane waves of the same wavelength incident on barriers that have openings of different sizes. Also shown are the shapes of the wave fronts beyond the barriers.

(a) One model of waves treats every point on a wave front as a point source. Give a clear, coherent, paragraph-length description of how this model can be used to explain the shape of the wave fronts beyond the barriers.

The particles that freely passed through the opening will produce and unchaged wave. The particles that passed the opening ~~next~~ at the edge ~~will~~ have room to diffract and spread and will do thus. ~~So as shown~~ In X there is the most diffraction because almost no particles can get through the opening freely. Y shows a smaller effect because the opening is larger so ~~more~~ a larger waves ~~to~~ section can pass unchanged. Z shows smallest effect because it has largest opening.

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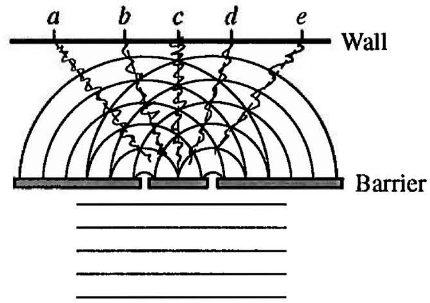
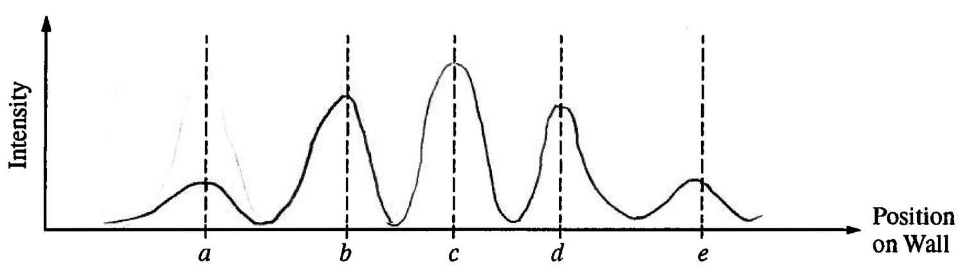


The figure above represents another plane wave incident on a barrier with two identical openings, creating an interference pattern on the wall. Some positions in the pattern on the wall are labeled.

(b) In a few sentences, describe how the point-source model described in part (a) and the figure above can be used to explain the formation of the interference pattern on the wall.

Because the openings are so small the waves are diffracted. The waves intersect because of the phenomenon. At points of intersection that hit the wall the phenomenon of interference is seen because the waves ~~cancel each other out~~. intensify each other.

(c) On the axes below, sketch the intensity of the waves that are incident on the wall. The labels correspond to the positions noted in the figure above.



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Free-Response Question 4 Commentary

Overview

This question provided an opportunity for students to demonstrate their understanding of diffraction. Part (a) allowed students to clearly and coherently explain Huygens principle. Students were to identify *X* as the point source and demonstrate an understanding that wider openings can be treated as multiple point sources. Also, students were given the opportunity to demonstrate an understanding that interference patterns are created on the far side of the opening. In part (b) students demonstrated their knowledge that the figure represented a set of wave fronts for each opening and that the maxima resulted where the fronts intersected. The student was to communicate that the dashed lines lead to points of maxima in the resulting interference pattern produced on the wall. In part (c) students were to graphically represent the interference pattern produced on the wall. The dashed line represented points of maxima so the crests of the wave were located on *a, b, c, d*, and *e*, and the height of the maxima decreased as the position moved away from *c*.

Sample: 4A
Score: 10

In part (a), the response earned 5 points. The response correctly describes *X* as the point source and shows an understanding that the wider openings can be treated as multiple point sources. There is an understanding that interference is created on the far side of the opening and that at the edges no interference is occurring. The explanation was coherent and logical.

In part (b), the response earned 3 points. The response demonstrated an understanding that the figure shows a set of wave fronts and that there are points of interference where the waves intersect resulting in the interference pattern on the wall.

In part (c), the response earned 2 points. The graph had the maxima at the labeled positions (*a, b, c, d, e*) and the minima in between. The graph had the greatest maxima at *c* and decreasing away on each side.

Sample: 4B
Score: 5

In part (a), the response earned 3 points. The response describes how each point on a wave is a point source, and the interference of the wave fronts produce a pattern, and at the edges there is a lack of interference.

In part (b), the response earned 1 point. The response demonstrates an understanding that there is interference that creates a pattern.

In part (c), the response earned 1 point. The graph indicated maxima at the labeled positions on the wall and minima in between.

Sample: 4C
Score: 3

In part (a), the response earned 0 points. The response does not describe *X* as the point source, and demonstrated no understanding of the wider openings being multiple point sources or that there are interference patterns.

In part (b), the response earned 1 point. The response demonstrate an understanding that the maxima in the resulting interference pattern occur where the fronts interest.

In part (c), the response earned 2 points. The maxima are at the labeled positions and the minima in between. The height of the maxima at *c* is the largest and as you move away from central point *c* the heights decrease on both sides.