Sample Responses from the

AP Physics 1: 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 1: 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.

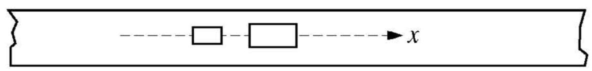
The sample questions are those that appear on the AP Physics 1: Algebra-Based Practice Exam, and the student responses were collected from actual AP students during a field test of the exam. The students gave permission to have their work reproduced at the time of the field test, and the responses were 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 1
Section II
5 Questions
Time—90 minutes

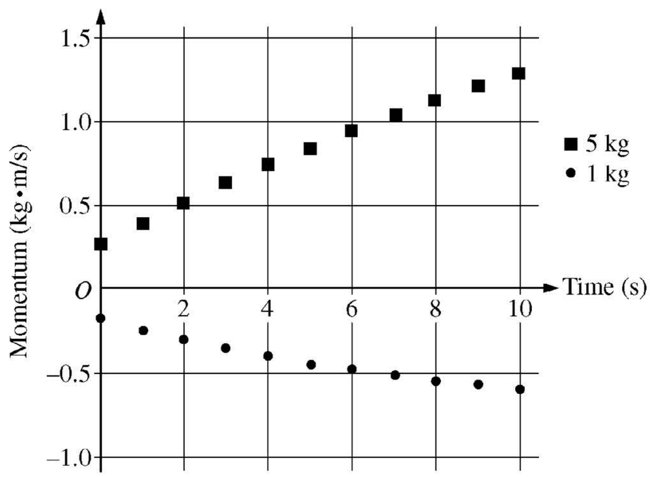
Directions: Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Show your work for each part in the space provided after that part.



Top View

1. (7 points, suggested time about 13 minutes)
The figure above represents two carts, with magnets attached, that make up a system. The mass of one cart and magnet is 1 kg and the mass of the other is 5 kg. The carts are initially at rest on a frictionless track. They are released from rest and exert a repulsive force on each other. The track is not quite horizontal, with the right side slightly lower than the left side.

The speeds of the carts are measured over a 10 s interval. The graph below shows the momentum of the two carts as a function of time for this interval as they move along the x-axis.



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(a) Based on the graph, were the measurements started at the instant the carts were released?

Justify your answer.

(b) Calculate the magnitude of the external force exerted on the system.

(c) Suppose the experiment is repeated with different carts, so that the masses of cart plus magnet are 2 kg and 4 kg. Would your answer to part (b) be different with the new masses?

Justify your answer.

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Information for Free-Response Question 1

Timing	The student should spend approximately 10–13 minutes on this question.
Essential Knowledge/ Big Ideas	3.A.1 An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. 4.A.3 Forces that systems exert on each other are because of interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system. 4.B.1 The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. 4.B.2 The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 5.1 The student can analyze data to identify patterns or relationships.
Learning Objective	3.A.1.3 The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations. 4.A.3.1 The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. 4.B.1.1 The student is able to calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). 4.B.2.1 The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system.

Scoring Guidelines for Free-Response Question 1

Question 1

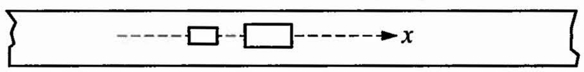
7 points total	**Distribution of points**
(a) 1 point	
For a correct, justified response about the state of motion at time $t = 0$	1 point
For example: No. The carts have a non-zero momentum at $t = 0$, so this cannot be the instant they were released.	
(b) 4 points	
For using the relationship between force and momentum, or Newton's second law and the definitions of acceleration and momentum $F = \Delta p/\Delta t$ or $F = ma$, $a = \Delta v/\Delta t$, and $p = mv$	1 point
For recognizing that the force causes a change in momentum or a change in velocity	1 point
For using reasonable values of momenta from the graph to calculate the momenta of the carts $F_5 = \Delta p/\Delta t = (1.25\ \text{kg}\bullet\text{m/s} - 0.25\ \text{kg}\bullet\text{m/s})/10\ \text{s} = 0.10\ \text{N}$ $F_1 = \Delta p/\Delta t = (-0.6\ \text{kg}\bullet\text{m/s} - -0.2\ \text{kg}\bullet\text{m/s})/10\ \text{s} = -0.04\ \text{N}$	1 point
For recognizing that the external force is the sum of the two forces on the cart $F_{ext} = F_5 + F_1 = 0.10\ \text{N} - 0.04\ \text{N} = 0.06\ \text{N}$	1 point
Calculating only the force on one of the carts earns a maximum of 1 point.	
Alternate Solution:	*Alternate Points*
For recognizing that the momentum of the system is the sum of the momenta of the two carts	*1 point*
For obtaining reasonable values of momenta from the graph and using them to calculate the system momenta $p_{\text{system intial}} = -\frac{0.5\ \text{kg}\bullet\text{m/s}}{3} + 0.25\ \text{kg}\bullet\text{m/s} = 0.08\ \text{kg}\bullet\text{m/s}$ $p_{\text{system final}} = -\left(\frac{6}{5}\right)(0.5\ \text{kg}\bullet\text{m/s}) + 1.25\ \text{kg}\bullet\text{m/s} = 0.65\ \text{kg}\bullet\text{m/s}$	*1 point*
For using the change in the system's momentum (final value minus initial value) $\Delta p_{\text{system}} = 0.65\ \text{kg}\bullet\text{m/s} - 0.08\ \text{kg}\bullet\text{m/s} = 0.57\ \text{kg}\bullet\text{m/s}$	*1 point*
For using the relationship between force and momentum to determine the external force $F = \Delta p/\Delta t = 0.57\ \text{kg}\bullet\text{m/s}/10\ \text{s} = 0.057\ \text{N}$	*1 point*

Question 1 (continued)	**Distribution of points**
(c) 2 points For a correct, justified response about the effect of changing the masses of the carts For example: No. The calculations in part (b) account for the effect of the external force on the motion of the entire system. The changes in individual masses do not change the total mass of the system, so the net effect on the system remains the same. In the absence of other correct reasoning, recognizing that the mass is the same for both situations earned 1 point.	2 points

Sample 1A

PHYSICS 1
SECTION II
Time—90 minutes
5 Questions

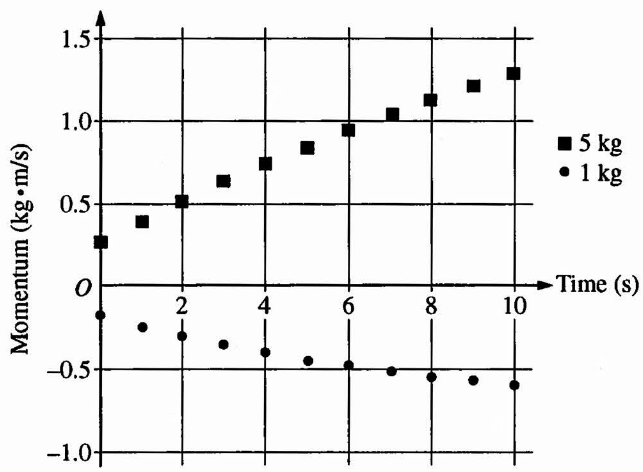
Directions: Answer all five questions, which are weighted according to the points indicated in each question. The suggested time for each question is also indicated. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Top View

1. (7 points, suggested time about 13 minutes)
The figure above represents two carts, with magnets attached, that make up a system. The mass of one cart and magnet is 1 kg and the mass of the other is 5 kg. The carts are initially at rest on a frictionless track. They are released from rest and exert a repulsive force on each other. The track is not quite horizontal, with the right side slightly lower than the left side.

The speeds of the carts are measured over a 10 s interval. The graph below shows the momentum of the two carts as a function of time for this interval as they move along the x-axis.



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(a) Based on the graph, were the measurements started at the instant the carts were released?

Justify your answer.

The measurements were not started at the instance the cart was released because the momentums began at non-zero values.

(b) Calculate the magnitude of the external force exerted on the system.

Cart 1 + magnet = 1 kg Cart 2 + magnet = 5 kg

$\Sigma F = m_1 a_1 + m_2 a_2$

$\Sigma F = \frac{P_1 - P_{0_1}}{t} + \frac{P_2 - P_{0_2}}{t}$

$\Sigma F = \frac{0.6 \text{ kgm/s} - 0.15 \text{ kgm/s}}{10 \text{ s}} + \frac{1.25 \text{ kgm/s} - 0.25 \text{ kgm/s}}{10 \text{ s}}$

$= 0.145 \text{ N}$

(c) Suppose the experiment is repeated with different carts, so that the masses of cart plus magnet are 2 kg and 4 kg. Would your answer to part (b) be different with the new masses?

Justify your answer.

No, because the masses of both objects add up to the same value as the mass of the other two carts which means that the total magnitude exerted would still be the same though their seperate momentums would be different.

Time at which I finished the question above (hh:mm): 0 0 : 1 7

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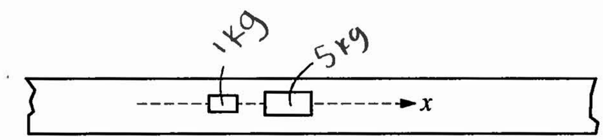
Sample 1B

PHYSICS 1
SECTION II
Time—90 minutes
5 Questions

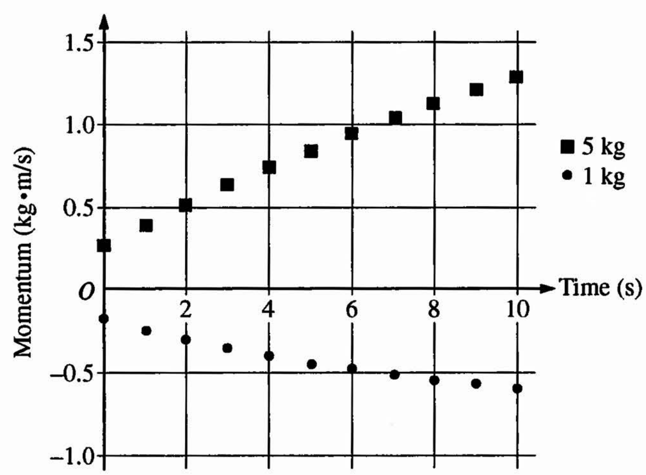
Directions: Answer all five questions, which are weighted according to the points indicated in each question. The suggested time for each question is also indicated. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Top View

1. (7 points, suggested time about 13 minutes)
The figure above represents two carts, with magnets attached, that make up a system. The mass of one cart and magnet is 1 kg and the mass of the other is 5 kg. The carts are initially at rest on a frictionless track. They are released from rest and exert a repulsive force on each other. The track is not quite horizontal, with the right side slightly lower than the left side.

The speeds of the carts are measured over a 10 s interval. The graph below shows the momentum of the two carts as a function of time for this interval as they move along the x-axis.



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(a) Based on the graph, were the measurements started at the instant the carts were released?

Justify your answer.

NO - the carts started from rest, meaning that the momentum of each cart should have been 0 kg·m/s (initial velocity = 0 m/s)

(b) Calculate the magnitude of the external force exerted on the system.

$J = \Delta p = Ft$

5 kg: Δp: $J = m\Delta v = (5\text{kg})(1.25\text{kg}\cdot\text{m/s} - 0.25\text{kg}\cdot\text{m/s}$

$J = 5\text{ J}$

$J = Ft$

$F = \frac{J}{t} = \frac{5\text{J}}{10\text{s}} = \boxed{0.5\text{ N}}$

1 kg: $\Delta p = J = m\Delta v = (1\text{kg})(-0.6\text{ kg}\cdot\text{m/s} - 0.2\text{kg}\cdot\text{m/s})$

$J = -0.7\text{ J}$

$F = \frac{J}{t} = \frac{-0.7\text{J}}{10\text{s}} = \boxed{-0.07\text{ N}}$

$\boxed{0.5 - 0.07\text{N} = 4.93\text{ N}}$

(c) Suppose the experiment is repeated with different carts, so that the masses of cart plus magnet are 2 kg and 4 kg. Would your answer to part (b) be different with the new masses?

Justify your answer.

yes - the magnitude of the external force is determined by the impulse, or the change in momentum. momentum is effected by mass.

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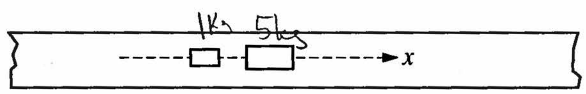
Sample 1C

PHYSICS 1
SECTION II
Time—90 minutes
5 Questions

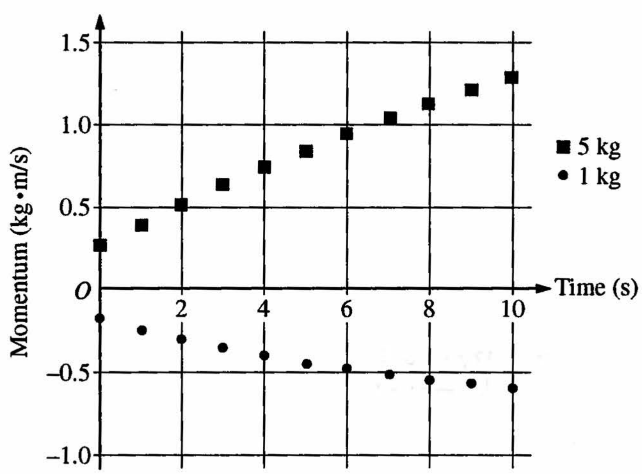
Directions: Answer all five questions, which are weighted according to the points indicated in each question. The suggested time for each question is also indicated. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Top View

1. (7 points, suggested time about 13 minutes)
The figure above represents two carts, with magnets attached, that make up a system. The mass of one cart and magnet is 1 kg and the mass of the other is 5 kg. The carts are initially at rest on a frictionless track. They are released from rest and exert a repulsive force on each other. The track is not quite horizontal, with the right side slightly lower than the left side.

The speeds of the carts are measured over a 10 s interval. The graph below shows the momentum of the two carts as a function of time for this interval as they move along the x-axis.



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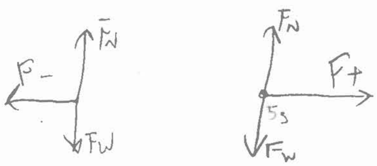
(a) Based on the graph, were the measurements started at the instant the carts were released?

Justify your answer.

No, because if the carts were measure right after releasing, the dots should've started from the zero.

(b) Calculate the magnitude of the external force exerted on the system.



$F_{5kg} = \frac{mv}{t}$

$F = \frac{1.25}{10} = .125\,N$

$\frac{1}{2}mv$

$\Sigma F_{net} = F_{5kg} + F_{1kg} = .125 + -.06 = \boxed{.065\,N}$

$F_{1kg} = \frac{mv}{t} = \frac{-.6}{10} = -.06$

(c) Suppose the experiment is repeated with different carts so that the masses of cart plus magnet are 2 kg and 4 kg. Would your answer to part (b) be different with the new masses?

Justify your answer.

~~Yes, because difference be~~

~~The ration diffe.~~

Yes, because the ratio between new carts' masses and original carts' masses are different. The Force will be different

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2014 Practice Exam Scoring Commentary

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

Free-Response Question 1

Overview

This question provided students an opportunity to describe qualitatively and quantitatively the effect of an external force on a system of particles; in this case, the effect of gravity on a two-cart system on an unleveled kinematics track. Part (a) asked students to use data from a graph and the information given in the question stem to determine if the data started at the instant the carts were released and to justify their answers. Part (b) required that students calculate the magnitude of the external force on the system, using the information from the graph. Part (c) asked students to identify and justify whether their answer to part (b) would be different if the masses of the carts were different (but still totaled the same mass).

Sample: 1A
Score: 6

In part (a), 1 point was earned for correctly stating the measurements were not started at the instant the cart was released, noting that “the momentums began at non-zero values.”

In part (b), 3 points were earned for using appropriate relationships among force, momentum, and Newton’s second law, recognizing that force involves a change in momentum and correctly calculating the force on each cart. The response did not account for force being a vector, which resulted in an incorrect response for the sum of the forces on the system of carts.

In part (c), 2 points were earned for a correct and justified response, noting that since the total mass of both carts hasn’t changed, then “the total magnitude [of external force] exerted would still be the same.”

Sample: 1B
Score: 4

In part (a), 1 point was earned for correctly stating "no," and for justifying the response by stating that the initial momenta on the graph “should have been 0 kg·m/s” since the carts started from rest.

In part (b), 3 points were earned for using appropriate relationships among force, momentum, and Newton’s second law, recognizing that force involves a change in momentum and correctly calculating the sum of the forces on the system of carts. The response incorrectly substitutes values of momenta into the expression for impulse as if they were velocities and miscalculates the force on the 1 kg cart by missing a negative sign on the initial momentum.

In part (c), no points were earned since the justification did not support the answer.

Sample: 1C
Score: 2

In part (a), 1 point was earned for correctly stating "no," and for justifying the response by stating that “if the carts were measured from the beginning, the data should have started from the zero."

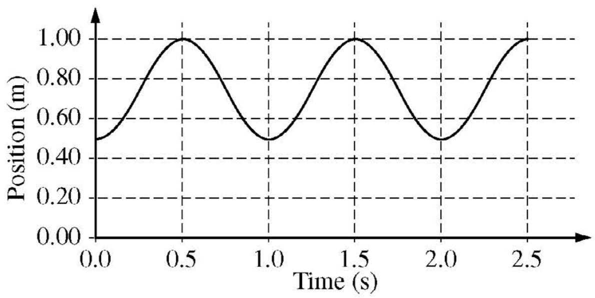
In part (b), 1 point was earned for showing that the external force was the sum of the forces, taking into account that one of the forces must be negative. This is equivalent to the point in the alternate solution for recognizing that the total momentum is the sum of the individual momenta. More points could have been earned if the response stated that force equals mass times a change in velocity over time.

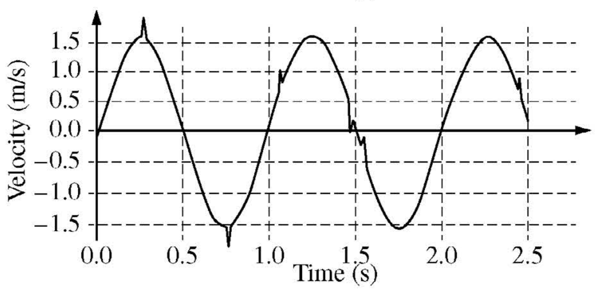
In part (c), no points were earned since the response stated that the external force would be different.

Free-Response Question 2

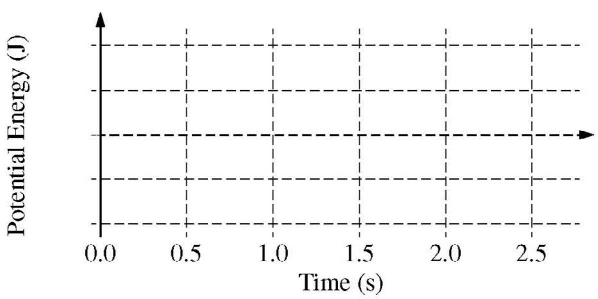
2. (12 points, suggested time 25 minutes)

A student hangs a 0.125 kg object on a spring, sets it into oscillation, and obtains the data for the position and velocity of the object as a function of time shown in the graphs below.

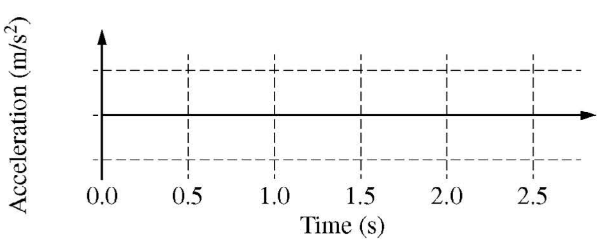




(a) On the grid below, sketch the potential energy of the object-spring-Earth system as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



(b) On the axes below, sketch the acceleration of the object as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



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Next the student is given a rubber band and asked to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring.

(c) Describe an experimental procedure that the student could use to collect the necessary data, including all the equipment the student would need.

(d) How should the student analyze the data to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring? What evidence from the analysis would be used to make the determination?

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Information for Free-Response Question 2

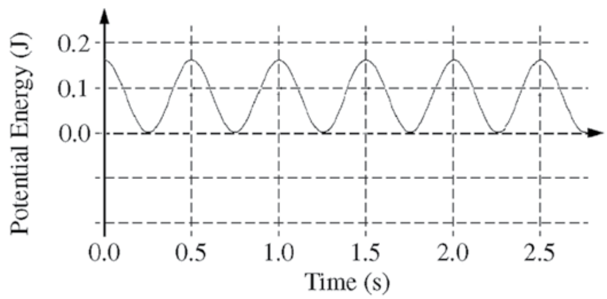
Timing	The student should spend approximately 20–25 minutes on this question.
Essential Knowledge	3.B.3 Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum and mass-spring oscillator. 5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 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.

Scoring Guidelines for Free-Response Question 2

Question 2

12 points total **Distribution of points**

(a) 3 points



Zero potential energy can be defined at any point. For convenience define it to be at the equilibrium point of the hanging object. The graph above uses this definition.

Then $E = U + K = \frac{1}{2}mv_{max}^2$, so

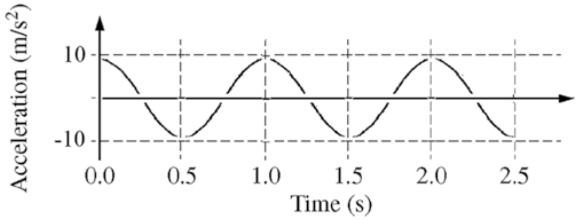
$U = \frac{1}{2}mv_{max}^2 - K = \frac{1}{2}mv_{max}^2 - \frac{1}{2}m[v(t)]^2$.

The amplitude of the velocity graph is approximately 1.6 m/s, and the period is 1 s. So $v(t) = (1.6 \text{ m/s})\sin(2\pi t/1 \text{ s})$.

$U = \frac{1}{2}(0.125 \text{ kg})(1.6 \text{ m/s})^2\left(1 - \sin^2(2\pi t/1 \text{ s})\right) = (0.16 \text{ J})\left(1 - \sin^2(2\pi t/1 \text{ s})\right)$

For a graph with a reasonable sine squared shape	1 point
For having the maxima of the graph at the labeled times	1 point
For having maxima and minima with a potential energy difference of about 0.16 J	1 point

(b) 3 points



For a graph that is either a sine or cosine curve	1 point
For a graph that has the appropriate phase relationship to the given position and velocity graphs	1 point

$a_{max} = F_{max}/m = kx_{max}/m$

The spring constant k can be determined using the period.

$T = 2\pi\sqrt{m/k}$, so $k = 4\pi^2 m/T^2 = 4\pi^2(0.125 \text{ kg})/(1 \text{ s})^2 = 0.5\pi^2 \text{ kg/s}^2$

$a = (0.5\pi^2 \text{ kg/s}^2)(0.25 \text{ m})/0.125 \text{ kg} = 9.87 \text{ m/s}^2$

For an amplitude of approximately 10 m/s^2	1 point

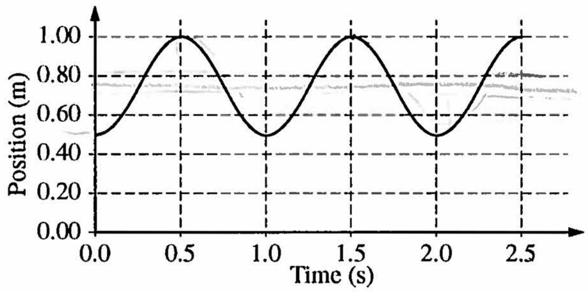
Question 2 (continued)

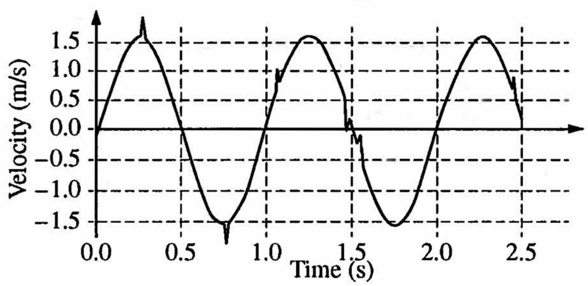
		Distribution of points
(c)	3 points	
	For a reasonable experimental setup that would allow useful measurements	1 point
	For indicating all measurements needed and no extraneous ones	1 point
	For evidence that multiple trials are performed	1 point
	For example: Hook the rubber band over a horizontal rod, and measure its length. Hang an object of known mass from it and measure the new length. Repeat for a number of different objects.	
(d)	3 points	
	For an appropriate analysis that would check for a linear relationship between force and rubber band stretch	1 point
	For indicating an appropriate characteristic from the analysis that signifies a linear relationship	1 point
	For indicating that a linear graph means that the rubber band exhibits $F \propto x$ like an ideal spring	1 point
	For example: Plot the rubber band stretch as a function of the mass of the objects. A linear graph would show that the stretch and the force exerted on the rubber band (i.e. the weight of the object) are directly proportional, as they are for a spring.	

Sample 2A

2. (12 points, suggested time 25 minutes)

A student hangs a 0.125 kg object on a spring, sets it into oscillation, and obtains the data for the position and velocity of the object as a function of time shown in the graphs below.





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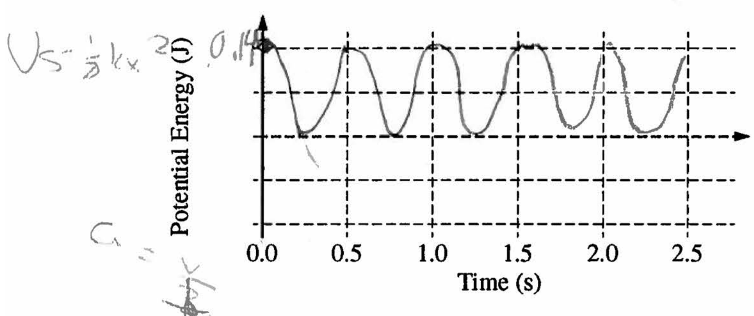
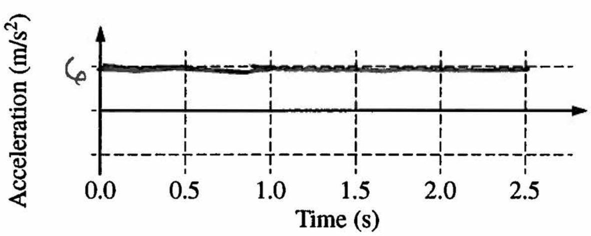


(b) On the axes below, sketch the acceleration of the object as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



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Next the student is given a rubber band and asked to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring.

(c) Describe an experimental procedure that the student could use to collect the necessary data, including all the equipment the student would need.

$F_s = k|x|$

Use a scale reader and hang ~~two~~ different masses (0.25kg, 0.5kg, 1kg, 5kg) from the band using scale. For each masses, measure the length of the band and find displacement by finding the difference of length by the length of band when it is at equilibrium. Measure the force by reading scale. Record and repeat for different amounts of masses.

(d) How should the student analyze the data to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring? What evidence from the analysis would be used to make the determination?

~~For each set of data~~

$\frac{F_s}{x}$ Fs/

Plot the data on a x vs. Fs graph. X axis is the displacement and y axis is the force of spring. Connect the line. Find the slope of the line. That is the "Spring constant." If the graph ~~is~~ has positive ~~and~~ correlation linear.

Time at which I finished the question above (hh:mm): 1 2 : 3 6

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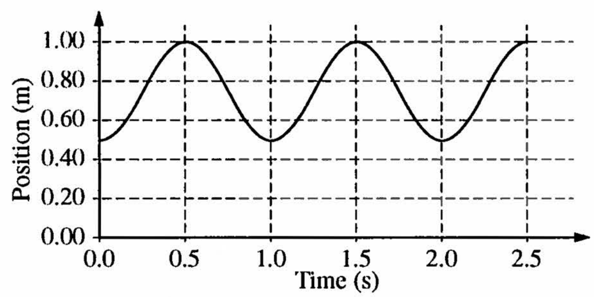
Sample 2B

2. (12 points, suggested time 25 minutes)

A student hangs a 0.125 kg object on a spring, sets it into oscillation, and obtains the data for the position and velocity of the object as a function of time shown in the graphs below.



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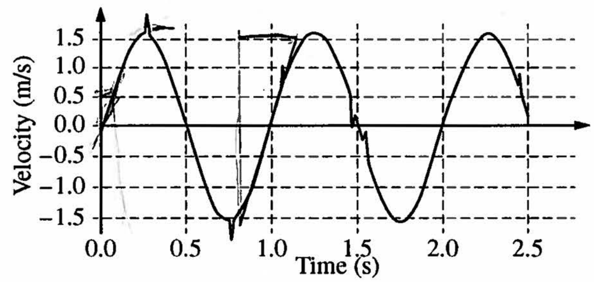
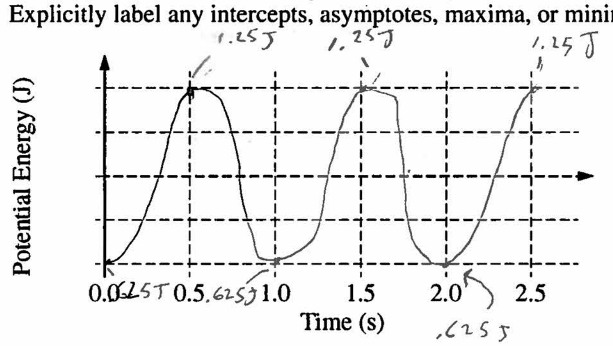


(a) On the grid below, sketch the potential energy of the object-spring-Earth system as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



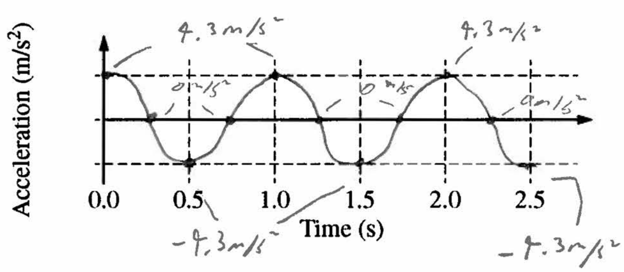
constant

$E_g = mgh$

$(.125 kg)(10 m/s^2)(1 m)$

$= 1.25 J$

(b) On the axes below, sketch the acceleration of the object as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



$\frac{3 m/s}{.69 s} \approx 4.3 m/s^2$

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Next the student is given a rubber band and asked to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring.

(c) Describe an experimental procedure that the student could use to collect the necessary data, including all the equipment the student would need.

$F=-kx$

The student would need the rubber band, a ruler to measure the displacement of the rubber band and perhaps a sensor connected to a graphing program to record the peak force applied to the sensor. The student would calculate and graph the forces applied to the sensor with different displacements initialized on the band.

(d) How should the student analyze the data to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring? What evidence from the analysis would be used to make the determination?

The Student would look for a linear relationship between the rubber band's displacement and the restoring force it exerts. A graph of restoring force v. displacement would be enough to determine the relationship

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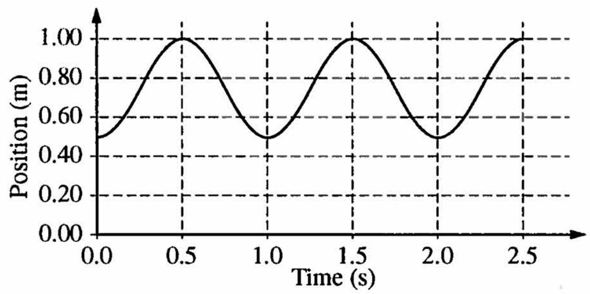
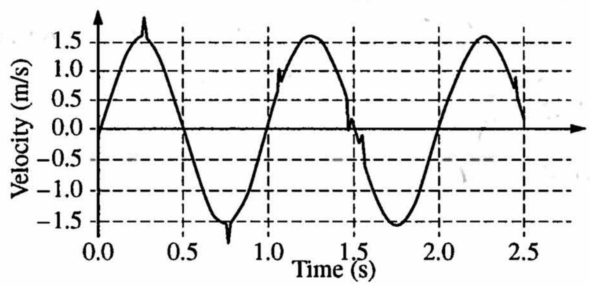
Sample 2C

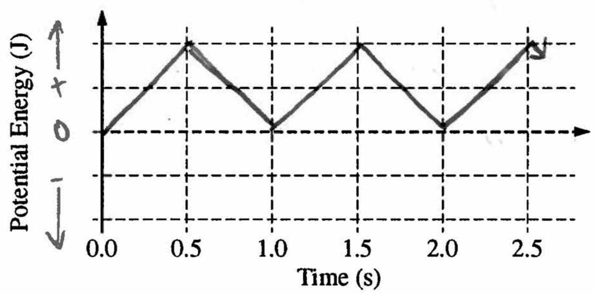
2. (12 points, suggested time 25 minutes)

A student hangs a 0.125 kg object on a spring, sets it into oscillation, and obtains the data for the position and velocity of the object as a function of time shown in the graphs below.

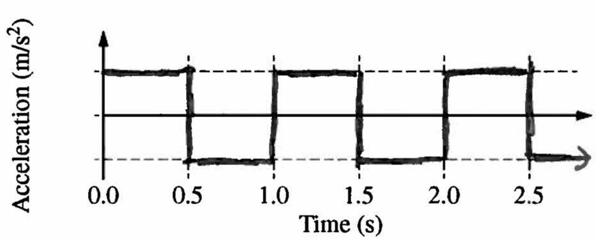




(a) On the grid below, sketch the potential energy of the object-spring-Earth system as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



(b) On the axes below, sketch the acceleration of the object as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



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Next the student is given a rubber band and asked to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring.

(c) Describe an experimental procedure that the student could use to collect the necessary data, including all the equipment the student would need.

Equipment: 2 spring scales, rubber band, Ideal spring, Solid surface, Ruler, data sheet.

Procedure: Set the two spring scales up on a solid surface and put the rubber on one scale hook and an Ideal spring on the other hook. Use the ruler to set specific target distances such as 0 cm, 5 cm, 10 cm, 15 cm, 20 cm, and 25 cm pulling distance. Record the force on the scale for each medium (rubber, spring) at each distance.

(d) How should the student analyze the data to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring? What evidence from the analysis would be used to make the determination?

They can read it straight from the spring scale. If the readings are ~~[illegible]~~ the same at each distance, the force is the same on the spring & the rubber band.

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Free-Response Question 2

Overview

This question provided students the opportunity to demonstrate their understanding of the energy transformation and kinematics of simple harmonic motion, as well as experimental design and analysis. Part (a) asked students to use the given position-time and velocity-time graphs to construct a graph of the potential energy as a function of time. Part (b) asked students to use the given graphs to construct a graph of acceleration as a function of time. Part (c) required students to describe an experimental procedure to determine whether a given rubber band behaves like an ideal spring, including needed equipment and what data is to be collected. Part (d) asked students how they would use their data to determine if the rubber band behaves like an ideal spring.

Sample: 2A
Score: 7

In part (a), 3 points were earned for drawing a reasonable sine squared graph with maxima occurring at half-second intervals starting with zero, and for identifying the maximum potential energy as 0.14 J.

In part (b), no points were earned.

In part (c), 3 points were earned for describing an experimental setup that would yield useful measurements, identifying the measurements needed, and stating "repeat for different amounts of masses."

In part (d), 1 point was earned for an analysis that would check for a linear relationship between "x vs. F_s." By saying, "Connect the line. Find the slope of the line," the response assumes linearity.

Sample: 2B
Score: 7

In part (a), 1 point was earned for a reasonable sine squared graph, but the response had maxima at one-second intervals and a difference between maximum and minimum potential energy of 0.625 J.

In part (b), 2 points were earned for a cosine curve with a correct phase relationship to the given graphs. The response missed the third point by calculating a maximum acceleration of 4.3 m/s^2 instead of approximately 10 m/s^2.

In part (c), 2 points were earned for an experiment that indicates which measurements are needed and includes multiple trials: "calculate and graph the forces applied … with different displacements …" The description of the setup was incomplete in that there was no mention of what would apply the force.

In part (d), 2 points were earned for indicating a correct method of analysis and not assuming but checking for a linear relationship. A statement that force is directly proportional to stretch for a spring would have earned the 3rd point.

Sample: 2C
Score: 3

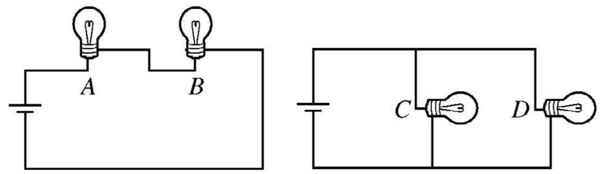
In part (a), no points were earned.

In part (b), no points were earned.

In part (c), 3 points were earned for a reasonable setup with useful measurements and an indication of all measurements needed, as well as multiple trials ("Record the force on the scale for each medium … at each distance").

In part (d), no points were earned.

Free-Response Question 3



3. (12 points, suggested time 25 minutes)
In a physics lab, students will compare the two circuits shown above. In one circuit, lightbulbs *A* and *B* will be connected to a battery in series. In the other circuit, lightbulbs *C* and *D* will be connected to an identical battery in parallel. All four lightbulbs are identical.

Student 1 predicts that the bulbs will be brighter in the series arrangement, while Student 2 disagrees and predicts that the bulbs will be brighter in the parallel arrangement. Their arguments are as follows.

Student 1: "Bulbs *A* and *B* will be brighter than *C* and *D* because in the series circuit, each bulb gets all the current coming out of the battery. But in the parallel circuit each bulb gets only half the current."

Student 2: "But you're not taking into account that bulb *A* uses up some of the current before it reaches bulb *B*, making the bulbs dimmer in the series circuit. And in the parallel circuit, the full voltage of the battery is across each bulb, so it's as if the other bulb weren't even there. So bulbs *C* and *D* will be brighter."

(a) For part (a), ignore whether the students' predictions are correct or incorrect. Do not simply repeat the students' arguments as your answers.

i. Which aspects of Student 1's reasoning, if any, are correct? Explain your answer.

ii. Which aspects of Student 1's reasoning, if any, are incorrect? Explain your answer.

iii. Which aspects of Student 2's reasoning, if any, are correct? Explain your answer.

iv. Which aspects of Student 2's reasoning, if any, are incorrect? Explain your answer.

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Together the students write the following equations to describe the two circuits.

Series Arrangement
Equation 1: $I_S = I_A = I_B$
Equation 2: $\Delta V - I_A R_A - I_B R_B = 0$

Parallel Arrangement
Equation 3: $I_P = I_C + I_D$
Equation 4: $\Delta V - I_C R_C = \Delta V - I_D R_D = 0$

(b)

i. Indicate all of the equations above that support Student 1's reasoning, and explain how each equation provides support.

ii. Indicate all of the equations above that support Student 2's reasoning, and explain how each equation provides support.

(c) Resolve the two lines of reasoning about the two circuits to conclude which arrangement will have brighter bulbs. Use the equations above and any other equations that you need, and explain how the equations support your conclusion.

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Information for Free-Response Question 3

Timing	The student should spend approximately 20–25 minutes on this question.
Essential Knowledge	1.B.1 Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system. 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. 5.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Because charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only.]
Science Practices	2.2 The student can make claims and predictions about natural phenomena based on scientific theories and models. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

Scoring Guidelines for Free-Response Question 3

Question 3

12 points total	**Distribution of points**
(a) 5 points	
(i)	
For indicating that Student 1 is correct that bulbs *A* and *B* "get all the current coming out of the battery", and explaining that it is because there is only one loop in the circuit	1 point
For indicating that bulbs *C* and *D* each get half the current, and explaining that it is because of the junction rule	1 point
(ii)	
For indicating that while bulbs *C* and *D* do get half the current in their circuit, Student 1 is incorrect in assuming that this means they must have less current than *A* and *B*, and explaining that it is because the total current is not the same in both circuits	1 point
(iii)	
For indicating that Student 2 is correct that the potential difference across bulbs *C* and *D* is the same and equal to the battery voltage, and explaining that for each bulb you can trace a loop that only goes through the bulb and the battery	1 point
(iv)	
For indicating that Student 2 is incorrect in saying that current is "used up" by bulb *A* before it reaches bulb *B*, and explaining that a current moves an equal amount of charge through all the circuit elements carrying it	1 point
(b) 3 points	
(i)	
Equations 1 and 3 support Student 1's reasoning.	
For indicating that equation 1 shows that series bulbs *A* and *B* each carry the total current in the circuit	1 point
For indicating that equation 3 shows that parallel bulbs *C* and *D* share the total current in the circuit	1 point
(ii)	
Equation 4 directly supports Student 2's reasoning. Equation 2 can also be considered as providing support for the implied contrast between circuits.	
For indicating that equation 4 shows that the potential difference across bulbs *C* and *D* is the same	1 point
No penalty for also indicating that equation 2 shows that the voltage is shared in the series circuit.	

Question 3 (continued)

	Distribution of points
(c) 4 points	
For indicating a valid quantity that can be used to compare bulb brightness across circuits (power, current, or voltage)	1 point
For correctly manipulating equations in an attempt to determine some quantity for the circuits with a valid assumption	1 point
For stating a conclusion that follows from the work for the two points above (even if that work is incorrect)	1 point
For explaining how the calculations support the conclusion (connecting ideas by using the chosen valid quantity to determine how it affects power which determines brightness)	1 point

For example, calculating currents and comparing power:

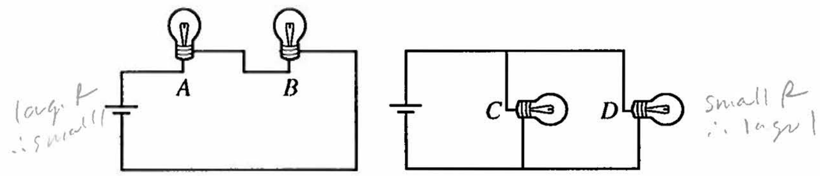
Substituting I_S into equation 2 and solving gives $I_S = \Delta V/(R_A + R_B)$

Solving each part of equation 4 gives $I_C = \Delta V/R_C$ and $I_D = \Delta V/R_D$

Since the resistors are identical, $I_S = I_C/2 = I_D/2$

Power is given by $P = I^2R$, and for identical resistors depends on the current. Therefore the power and thus the brightness of bulbs *A* and *B* is less.

Sample 3A*



5. (12 points, suggested time 25 minutes)
In a physics lab, students will compare the two circuits shown above. In one circuit, lightbulbs *A* and *B* will be connected to a battery in series. In the other circuit, lightbulbs *C* and *D* will be connected to an identical battery in parallel. All four lightbulbs are identical.

Student 1 predicts that the bulbs will be brighter in the series arrangement, while Student 2 disagrees and predicts that the bulbs will be brighter in the parallel arrangement. Their arguments are as follows.

Student 1: "Bulbs *A* and *B* will be brighter than *C* and *D* because in the series circuit, each bulb gets all the current coming out of the battery. But in the parallel circuit each bulb gets only half the current."

Student 2: "But you're not taking into account that bulb *A* uses up some of the current before it reaches bulb *B*, making the bulbs dimmer in the series circuit. And in the parallel circuit, the full voltage of the battery is across each bulb, so it's as if the other bulb weren't even there. So bulbs *C* and *D* will be brighter."

(a) For part (a), ignore whether the students' predictions are correct or incorrect. Do not simply repeat the students' arguments as your answers.

i. Which aspects of Student 1's reasoning, if any, are correct? Explain your answer.

- $I_A = I_B = I_T$ since series circuits' resistors have same current (electrons flow same path)
- I_C and I_D both $= \frac{1}{2} I_T$ since bulbs are same resistance and voltage in each same b/c of parallel circuit, and as $I = \frac{V}{R}$, both will be $\frac{1}{2}$ the total current

ii. Which aspects of Student 1's reasoning, if any, are incorrect? Explain your answer.

- Series is dimmer than parallel since total resistance in series is larger than that of parallel; while V is the same in both b/c of same battery, $I_T = \frac{V_T}{R_T}$ so I_T is smaller in series; $P_T = I_T V_T$ so series has less power and is less bright

iii. Which aspects of Student 2's reasoning, if any, are correct? Explain your answer.

- Bulbs C/D brighter since total resistance is smaller, therefore total current is larger ($I_T = \frac{V_T}{R_T}$; V constant, b/c same battery); P=IV so power is larger in parallel ∴ parallel is brighter
- Voltage is equal in both bulbs in parallel because V=IR; I is split between 2 branches but are same since bulbs C/D have same R ∴ V_C, V_D equal

iv. Which aspects of Student 2's reasoning, if any, are incorrect? Explain your answer.

- Bulb A does not use up some of the current b/f bulb B does as the current of A and B are equal because it's a series circuit

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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 1: Algebra-Based Practice Exam.

Together the students write the following equations to describe the two circuits.

Series Arrangement
Equation 1: $I_S = I_A = I_B$
Equation 2: $\Delta V - I_A R_A - I_B R_B = 0$
or $V_T = V_A + V_B$

Parallel Arrangement
Equation 3: $I_P = I_C + I_D$
Equation 4: $\Delta V - I_C R_C = \Delta V - I_D R_D = 0$
or $V_T = V_C = V_D$

(b)

i. Indicate all of the equations above that support Student 1's reasoning, and explain how each equation provides support.

- $I_S = I_A = I_B$ since it confirms that in series, bulb A and bulb B get the current from the battery
- $I_P = I_C + I_D$ since it confirms that in parallel, bulb C and bulb D together form the full current

ii. Indicate all of the equations above that support Student 2's reasoning, and explain how each equation provides support.

- $\Delta V - I_C R_C = \Delta V - I_D R_D = 0$ since it confirms that bulbs C and D get the same voltage
- $\Delta V - I_A R_A - I_B R_B = 0$ since it confirms that bulb A must use up some of the current before the current goes to bulb B

(c) Resolve the two lines of reasoning about the two circuits to conclude which arrangement will have brighter bulbs. Use the equations above and any other equations that you need, and explain how the equations support your conclusion.

$R_A = R_B = R_C = R_D = R$

$\frac{1}{R_{\parallel}} = \frac{1}{R_C} + \frac{1}{R_D}$ $\therefore R_{\parallel} = \frac{R}{2}$ where $R_S = R_A + R_B$ $\therefore R_S = 2R$ $\therefore \Sigma R$ in $\parallel < \Sigma R$ in series

$V = IR$ or $I_T = \frac{V_T}{R_T}$; $I_{T_{\parallel}} = \frac{2V}{R}$ and $I_{T_S} = \frac{V}{2R}$ $\therefore I_T$ in $\parallel > I_T$ in S

$P_T = I_T V_T$; $P_{T_{\parallel}} = \frac{2V^2}{R}$ and $P_{T_S} = \frac{V^2}{2R}$ $\therefore P_{\parallel} > P_S$ $\therefore$ $\parallel$ brighter

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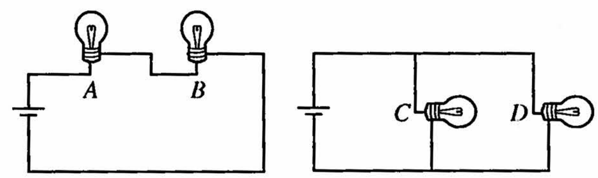
Sample 3B



5. (12 points, suggested time 25 minutes)
In a physics lab, students will compare the two circuits shown above. In one circuit, lightbulbs *A* and *B* will be connected to a battery in series. In the other circuit, lightbulbs *C* and *D* will be connected to an identical battery in parallel. All four lightbulbs are identical.

Student 1 predicts that the bulbs will be brighter in the series arrangement, while Student 2 disagrees and predicts that the bulbs will be brighter in the parallel arrangement. Their arguments are as follows.

Student 1: "Bulbs *A* and *B* will be brighter than *C* and *D* because in the series circuit, each bulb gets all the current coming out of the battery. But in the parallel circuit each bulb gets only half the current."

Student 2: "But you're not taking into account that bulb *A* uses up some of the current before it reaches bulb *B*, making the bulbs dimmer in the series circuit. And in the parallel circuit, the full voltage of the battery is across each bulb, so it's as if the other bulb weren't even there. So bulbs *C* and *D* will be brighter."

(a) For part (a), ignore whether the students' predictions are correct or incorrect. Do not simply repeat the students' arguments as your answers.

i. Which aspects of Student 1's reasoning, if any, are correct? Explain your answer.

Each bulb gets all current coming from the battery because in a series circuit there are no junction points to split the current. Also, student 1 is correct about each bulb in a parallel circuit only gets half the current from the battery because the voltage is equal and R is equal so V = IR shows they get equal current.

ii. Which aspects of Student 1's reasoning, if any, are incorrect? Explain your answer.

None

iii. Which aspects of Student 2's reasoning, if any, are correct? Explain your answer.

The full voltage of the battery is across each bulb in a parallel circuit because the loop rule states this exact principle.

iv. Which aspects of Student 2's reasoning, if any, are incorrect? Explain your answer.

Bulb A uses up some of the current before it reaches Bulb B because in a series circuit the current is equal throughout the entire circuit so none is used up.

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Together the students write the following equations to describe the two circuits.

<u>Series Arrangement</u>
Equation 1: $I_S = I_A = I_B$
Equation 2: $\Delta V - I_A R_A - I_B R_B = 0$

<u>Parallel Arrangement</u>
Equation 3: $I_P = I_C + I_D$
Equation 4: $\Delta V - I_C R_C = \Delta V - I_D R_D = 0$

(b)

i. Indicate all of the equations above that support Student 1's reasoning, and explain how each equation provides support.

Equation 1, Equation 3

(Equation 3) This demonstrates the junction rule that is described when student 2 states each bulb gets half the current

(Equation 1) This supports student 1's reasoning that each bulb get all the current coming from the battery.

ii. Indicate all of the equations above that support Student 2's reasoning, and explain how each equation provides support.

Equation 2, Equation 4

(Equation 4) This demonstrates the loop rule described when student 2 states that all bulbs get the full voltage in parallel.

(Equation 2) This demonstrates the false statement that each bulb uses up some current in a series circuit when not combined with the equation 1.

(c) Resolve the two lines of reasoning about the two circuits to conclude which arrangement will have brighter bulbs. Use the equations above and any other equations that you need, and explain how the equations support your conclusion.

The second circuit will have brighter bulbs because the current coming from the battery will be greater and the current in the bulbs will be greater, despite the junction point. For example, Req of circuit 1 = $R_A + R_B$ and all the R values are equal so $R_{eq} = 2R$. Thus, the current to each bulb will be $\frac{V_B}{2R}$. In contrary, the Req for the second circuit $= \left(\frac{1}{R_C} + \frac{1}{R_D}\right)^{-1} = \left(\frac{2}{R}\right)^{-1} = \frac{R}{2}$. Therefore the current from the battery equals $\frac{2V_B}{R}$. Since the current splits at the junction point, the current into each bulb in parallel equals $\frac{V_B}{R}$. $\frac{V_B}{R} > \frac{V_B}{2R}$ so the parallel circuit has brighter bulbs.

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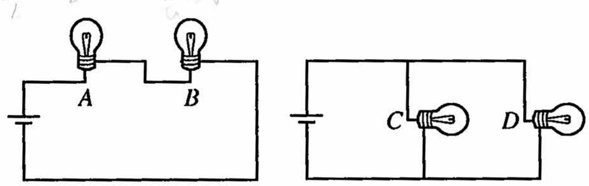
Sample 3C



5. (12 points, suggested time 25 minutes)
In a physics lab, students will compare the two circuits shown above. In one circuit, lightbulbs *A* and *B* will be connected to a battery in series. In the other circuit, lightbulbs *C* and *D* will be connected to an identical battery in parallel. All four lightbulbs are identical.

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(a) For part (a), ignore whether the students' predictions are correct or incorrect. Do not simply repeat the students' arguments as your answers.

i. Which aspects of Student 1's reasoning, if any, are correct? Explain your answer.

In the series circuit each bulb gets all the current coming out of the ~~volta~~ battery because

ii. Which aspects of Student 1's reasoning, if any, are incorrect? Explain your answer.

~~Bulb C and D do not get only have the current, the current spreads equally across~~

all correct

iii. Which aspects of Student 2's reasoning, if any, are correct? Explain your answer.

full voltage does spread equally across each Bulb

iv. Which aspects of Student 2's reasoning, if any, are incorrect? Explain your answer.

~~The~~ A does not use up some current the current is equally distributed also ~~volt~~ full voltage does not go across

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Together the students write the following equations to describe the two circuits.

???

Series Arrangement
Equation 1: $I_S = I_A = I_B$
Equation 2: $\Delta V - I_A R_A - I_B R_B = 0$

Parallel Arrangement
Equation 3: $I_P = I_C + I_D$
Equation 4: $\Delta V - I_C R_C = \Delta V - I_D R_D = 0$

(b)

i. Indicate all of the equations above that support Student 1's reasoning, and explain how each equation provides support.

Is = IA = IB - states that each bulb gets the same current

ii. Indicate all of the equations above that support Student 2's reasoning, and explain how each equation provides support.

equation 4 - ΔV = IcRc
ΔV = IDRD
IcRc = IDRD
V = V
-states that voltage is the same at both bulbs

(c) Resolve the two lines of reasoning about the two circuits to conclude which arrangement will have brighter bulbs. Use the equations above and any other equations that you need, and explain how the equations support your conclusion.

bulbs A and B will be brighter because they get the same current (Is = IA = IB) and C and D won't be bright because the full current is distributed among them

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

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Free-Response Question 3

Overview

This question asked students to demonstrate an understanding of the difference between the brightness of two light bulbs wired in series or wired in parallel to the same battery. Specifically, students were asked to compare and contrast two predictions and lines of reasoning about the brightness of the bulbs. Part (a) requested that students ignore the predictions about the brightness but address the correctness and incorrectness of the reasoning behind the predictions. Part (b) asked students to identify any of the given equations describing the circuits as support for the reasoning in part (a) and to explain how each equation provides support. Part (c) asked that students resolve the two lines of reasoning to generate their own conclusion about which arrangement is brighter, and to support their conclusion.

Sample: 3A
Score: 10

In part (a)(i), 2 points were earned for stating that the currents in A and B are the same because "electrons flow along the same path," and for stating and explaining why the currents in C and D are half of the total current.

In part (a)(ii), 1 point was earned for stating and explaining why the total current is smaller in series than in parallel.

In part (a)(iii), no point was earned. The point could have been earned if the response explained that potential difference is the same in parallel because a loop can be traced that goes through only one bulb and the battery.

In part (a)(iv), no point was earned for a statement that says current is the same in A and B "because it's a series circuit."

In part (b)(i), 2 points were earned for correctly indicating and explaining how Equations 1 and 3 support Student 1's reasoning.

In part (b)(ii), 1 point was earned for correctly indicating and explaining how Equation 4 supports Student 2's reasoning.

In part (c), 4 points were earned for indicating that power can be used to compare bulb brightness, and for using equations correctly and logically to arrive at the correct conclusion.

Sample: 3B
Score: 7

In part (a)(i), 1 point was earned for stating "each bulb gets all current from the battery because in a series circuit there are no junction points to split the current." The student restates the second prediction and says it is because "the voltage is equal and R is equal so V = IR shows they get equal current." That same line of reasoning could be used to explain why two identical light bulbs in series get the same current. Nothing is said about the total current being split equally, so the second point is not earned.

In part (a)(ii), no point was earned.

In part (a)(iii), no point was earned. Merely citing the name of a rule (in this case, the loop rule) instead of explaining how it is used to explain the observation is not enough to earn the point.

In part (a)(iv), no point was earned. Stating that the current in a series circuit is the same throughout the circuit with no explanation why was insufficient to earn the point.

In part (b)(i), 2 points were earned for correctly indicating and explaining how Equations 1 and 3 support Student 1's reasoning.

In part (b)(ii), 1 point was earned for correctly indicating and explaining how Equation 4 supports Student 2's reasoning.

In part (c), 4 points were earned for indicating that current can be used to compare bulb brightness, and for using equations correctly and logically to arrive at the correct conclusion.

Sample: 3C
Score: 3

In part (a)(i), no points were earned. Only one correct prediction was identified but with no explanation.

In part (a)(ii), no point was earned. No incorrect predictions were identified.

In part (a)(iii), no point was earned. The correct prediction was identified but with no explanation.

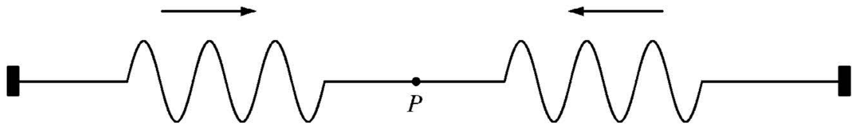
In part (a)(iv), no point was earned. The correct prediction was identified, but stating that "the current is equally distributed" with no explanation why was insufficient to earn the point.

In part (b)(i), 1 point was earned for correctly indicating and explaining how Equation 1 supports Student 1's reasoning.

In part (b)(ii), 1 point was earned for correctly indicating and explaining how Equation 4 supports Student 2's reasoning.

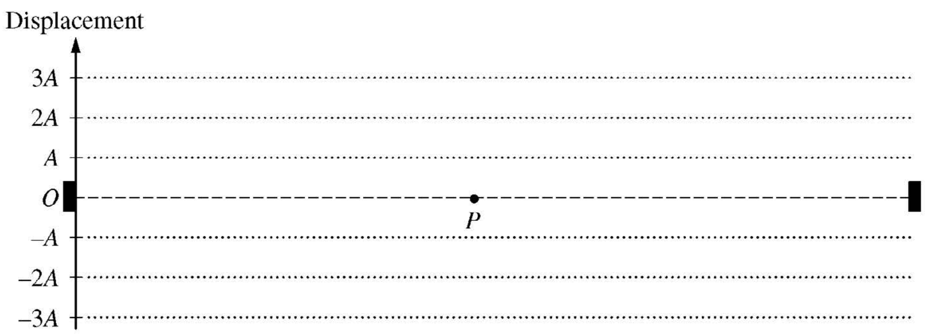
In part (c), 1 point was earned for indicating that current can be used to compare bulb brightness.

Free-Resposne Question 4



4. (7 points, suggested time about 13 minutes)
A string is held taut, with each of its ends fixed to an oscillator that creates wave pulses on the string. The figure above shows identical pulses at a particular instant when they are traveling toward each other on the string. The pulses have wavelength λ and amplitude A, and are equidistant from point P.

(a) On the figure below, the dashed line at zero displacement represents the string with no pulses. On the figure, draw the shape of the string at the instant when the pulses overlap by $1/3$ of the length of each pulse.



(b) On the axes below, sketch a graph of displacement as a function of time for point P, from time $t = 0$ when the pulses just begin to overlap until $t = t_1$ when they once again do not overlap.

(c) Next the oscillators are adjusted to create continuous waves of wavelength λ, instead of the wave pulses shown. A standing wave is created on the string. What can be inferred about the length of the string? Justify your answer. Equations may be part of your reasoning, but equations alone are not sufficient justification.

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Information for Free-Response Question 4

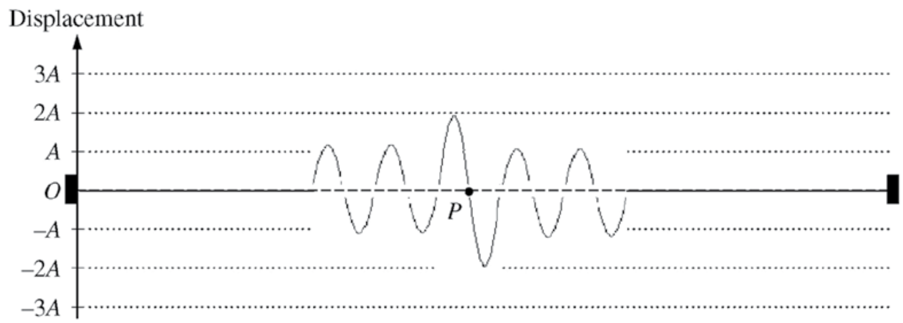
Timing	The student should spend approximately 10–13 minutes on this question.
Essential Knowledge	6.D.1 Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition. 6.D.3 Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes.
Science Practice	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.D.1.1 The student is able to use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses. 6.D.3.2 The student is able to predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes.

Scoring Guidelines for Free-Response Question 4

Question 4

7 points total	**Distribution of points**

(a) 3 points



For overlap of one wavelength showing something other than amplitude *A*	1 point
For showing amplitude 2*A* in the overlapping segment	1 point
For showing two wavelengths of amplitude *A* on both sides	1 point

(b) 2 points

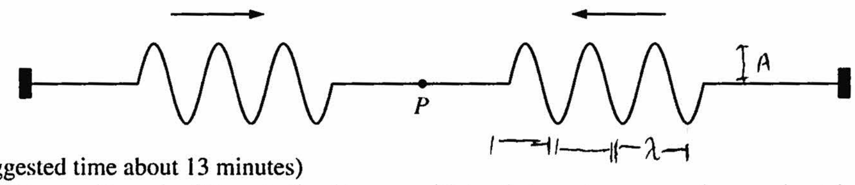
For a straight line at zero displacement	2 points

(c) 2 points

For a complete, correct response with justification	2 points

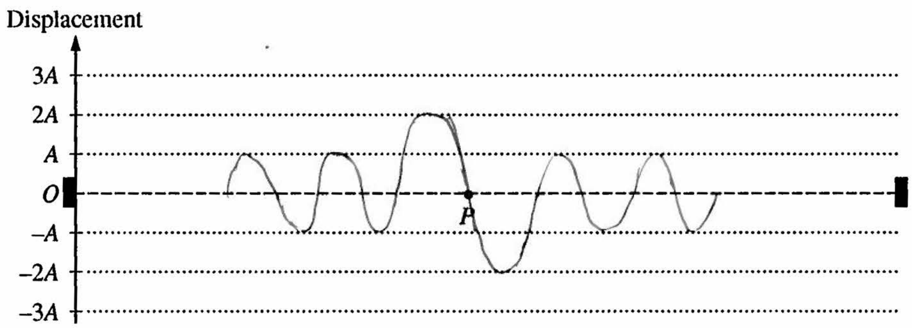
For example: The length is either a multiple of λ or $\lambda/2$. The ends are nodes, so the pattern has zero amplitude at the ends. That can only happen if the 'middle' or 'end' of a wavelength is at each end.

Sample 4A

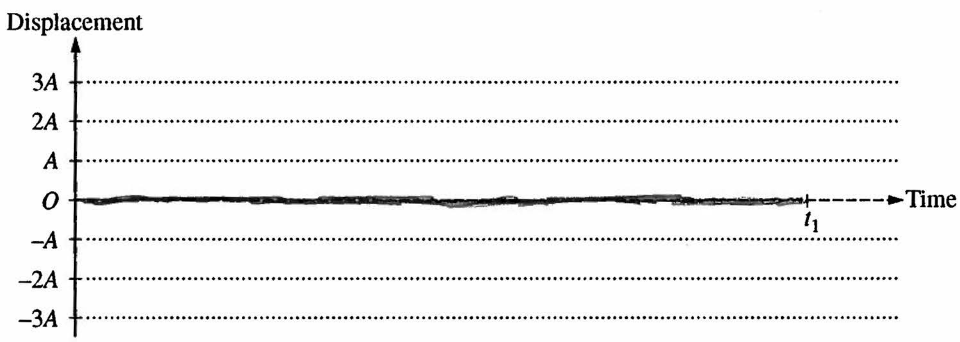


4. (7 points, suggested time about 13 minutes)
A string is held taut, with each of its ends fixed to an oscillator that creates wave pulses on the string. The figure above shows identical pulses at a particular instant when they are traveling toward each other on the string. The pulses have wavelength λ and amplitude A, and are equidistant from point P.

(a) On the figure below, the dashed line at zero displacement represents the string with no pulses. On the figure, draw the shape of the string at the instant when the pulses overlap by $1/3$ of the length of each pulse.



(b) On the axes below, sketch a graph of displacement as a function of time for point P, from time $t = 0$ when the pulses just begin to overlap until $t = t_1$ when they once again do not overlap.



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(c) Next the oscillators are adjusted to create continuous waves of wavelength λ, instead of the wave pulses shown. A standing wave is created on the string. What can be inferred about the length of the string? Justify your answer. Equations may be part of your reasoning, but equations alone are not sufficient justification.

The length of the strength can be inferred to be n times the half-wavelength, where n is a positive integer. This is because in order for a standing wave to be created in a string, there has to be a node at the ends of the string. Since a string has a node at every half-wavelength, a standing wave can be created whenever there is an integer multiple of the half-wavelength, $n(\frac{\lambda}{2})$ where n is an integer.

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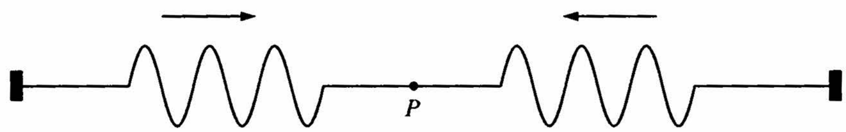
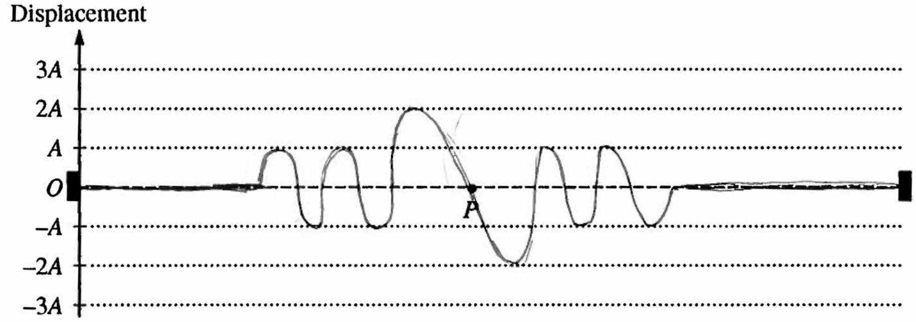
Sample 4B

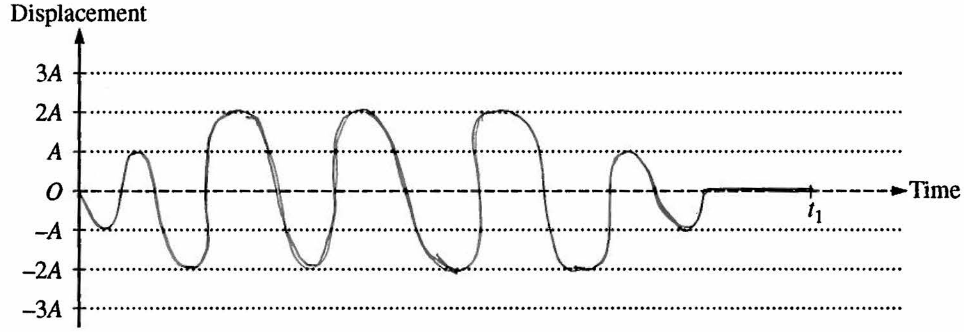


4. (7 points, suggested time about 13 minutes)
A string is held taut, with each of its ends fixed to an oscillator that creates wave pulses on the string. The figure above shows identical pulses at a particular instant when they are traveling toward each other on the string. The pulses have wavelength λ and amplitude A, and are equidistant from point P.

(a) On the figure below, the dashed line at zero displacement represents the string with no pulses. On the figure, draw the shape of the string at the instant when the pulses overlap by $1/3$ of the length of each pulse.



(b) On the axes below, sketch a graph of displacement as a function of time for point P, from time $t = 0$ when the pulses just begin to overlap until $t = t_1$ when they once again do not overlap.



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(c) Next the oscillators are adjusted to create continuous waves of wavelength λ, instead of the wave pulses shown. A standing wave is created on the string. What can be inferred about the length of the string? Justify your answer. Equations may be part of your reasoning, but equations alone are not sufficient justification.

The length of the string is half of the wavelength. This is because in the 1st harmonic waves, $\lambda = 2L$ therefore $\frac{1}{2}\lambda = L$.

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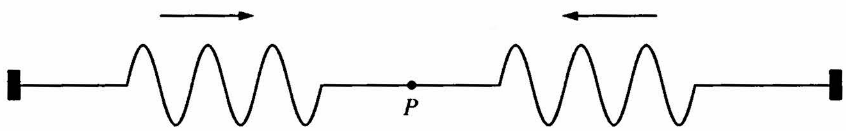
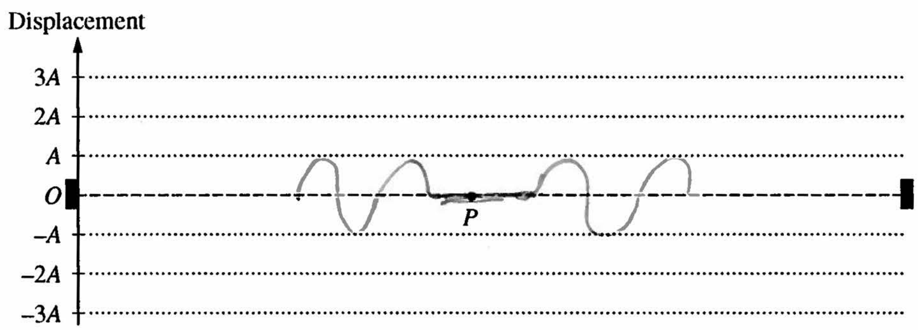
Sample 4C

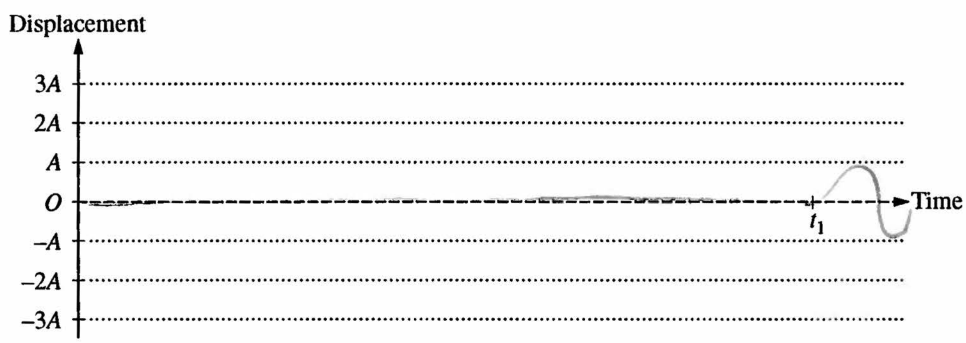


4. (7 points, suggested time about 13 minutes)
A string is held taut, with each of its ends fixed to an oscillator that creates wave pulses on the string. The figure above shows identical pulses at a particular instant when they are traveling toward each other on the string. The pulses have wavelength λ and amplitude A, and are equidistant from point P.

(a) On the figure below, the dashed line at zero displacement represents the string with no pulses. On the figure, draw the shape of the string at the instant when the pulses overlap by $1/3$ of the length of each pulse.



(b) On the axes below, sketch a graph of displacement as a function of time for point P, from time $t = 0$ when the pulses just begin to overlap until $t = t_1$ when they once again do not overlap.



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(c) Next the oscillators are adjusted to create continuous waves of wavelength λ, instead of the wave pulses shown. A standing wave is created on the string. What can be inferred about the length of the string? Justify your answer. Equations may be part of your reasoning, but equations alone are not sufficient justification.

The length of the string is 4x the length of one wave.

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Free-Response Question 4

Overview

This question provided students an opportunity to illustrate their knowledge of the nature of wave interaction and standing waves. In Part (a), students were asked to draw a picture of the shape of a string as two identical wave pulses traveling towards each other just begin to overlap. Part (b) required students to construct a graph of the position of a point in the middle of the string as a function of time for the duration of time the two waves are interacting. Part (c) asked students to infer the length of the string if a continuous standing wave is set up on the string.

Sample: 4A
Score: 7

In part (a), 3 points were earned for drawing a string shape with constructive interference in the overlapping segment with an amplitude of 2A and for showing two wavelengths of amplitude A on both sides of the overlapping segment.

In part (b), 2 points were earned for drawing a straight line on the time axis between $t = 0$ and $t = t_1$.

In part (c), 2 points were earned for a correct justification of the length of the string being "n times the half wavelength." The points were awarded for describing the locations of nodes at the ends of the string, stating that "a string has a node at every half-wavelength," and stating that "a standing wave can be created whenever there is an integer multiple of the half-wavelength."

Sample: 4B
Score: 4

In part (a), 3 points were earned for drawing a string shape with constructive interference in the overlapping segment with an amplitude of 2A and for showing two wavelengths of amplitude A on both sides of the overlapping segment.

In part (b), no points were earned.

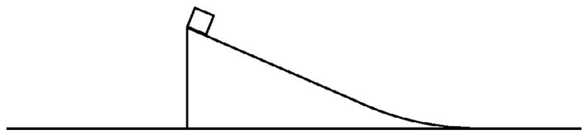
In part (c), 1 point was earned for correctly identifying the condition for the first harmonic or fundamental frequency ("The length of the string is half of the wavelength … because in the 1st harmonic, $\lambda = 2L$ …").

Sample: 4C
Score: 2

In part (a), no points were earned. The middle segment shows complete destructive interference, and the waves on either side are 1.5 wavelengths instead of 2.

In part (b), 2 points were earned for drawing a straight line on the time axis between $t = 0$ and $t = t_1$. The drawing after t_1 was disregarded.

In part (c), no points were earned because no part of the student response was correct.



5. (7 points, suggested time about 13 minutes)
The figure above shows part of a system consisting of a block at the top of an inclined plane that rests on a table, which is located on Earth. The block and plane are at rest when the block is released. In trial 1 there is no friction between the block and the plane or between the plane and the table. In trial 2 the plane is fixed to the table so it cannot move, but there is still no friction between the block and the plane.

Indicate whether the speed of the block relative to the table when the block reaches the bottom of the plane is greater in trial 1 or trial 2. Justify your answer in a clear, coherent, paragraph-length explanation.

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Information for Free-Response Question 5

Timing	The student should spend approximately 10–13 minutes on this question.
Essential Knowledge/ Big Idea	3.A.3 A force exerted on an object is always due to the interaction of that object with another object. 3.A.4 If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction. 3.E.1 The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted. 4.C.1 The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. 5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. 5.D.1 In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. 5.D.3 The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]
Science Practice	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.

Learning Objective	3.A.3.1 The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. 3.A.4.1 The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. 3.E.1.1 The student is able to make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. 4.C.1.2 The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. 5.B.3.1 The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. 5.D.1.1 The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. 5.D.3.1 The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force).

Scoring Guidelines for Question 5

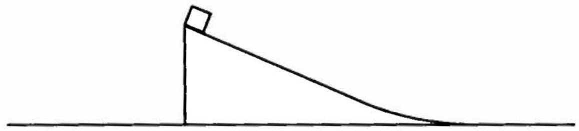
Question 5

7 points total	**Distribution of points**
For any mention of energy conversion	1 point
For indicating that the same amount of potential energy is converted to kinetic energy in each trial	1 point
For indicating that the kinetic energy is shared between the block and plane in trial 1	1 point
For indicating that the block has all the kinetic energy in trial 2	1 point
For a description of the motion of the plane in each trial	1 point
For using momentum or forces to explain the motion in each trial	1 point
For a coherent argument that leads to a correct conclusion	1 point

For example:

The speed of the block is greater in trial 2. Since gravity is the only force doing work in both trials, energy is conserved. The potential energy of the block at the top of the plane is converted into kinetic energy. In trial 1 the plane is free to move, so if the block ends up going to the right, the plane has to move to the left to conserve momentum. *[Alternate: In trial 1 the plane is free to move, so if the plane pushes the block to the right, the block pushes the plane to the left.]* Since the plane moves, the original potential energy of the block must be divided between the plane and the block. In trial 2 the plane doesn't move, so the block gets all of the available energy. More kinetic energy means a greater speed.

Sample 5A



3. (7 points, suggested time about 13 minutes)
The figure above shows part of a system consisting of a block at the top of an inclined plane that rests on a table, which is located on Earth. The block and plane are at rest when the block is released. In trial 1 there is no friction between the block and the plane or between the plane and the table. In trial 2 the plane is fixed to the table so it cannot move, but there is still no friction between the block and the plane.

Indicate whether the speed of the block relative to the table when the block reaches the bottom of the plane is greater in trial 1 or trial 2. Justify your answer in a clear, coherent, paragraph-length explanation.

trial 2, because in trial one the plane can slide backwards due to momentum and PE of the block. When the plane moves it takes some energy out of the system and therefore out of the block. This decreases its speed. In trial 2 with the plane fixed to the table all the energy at the start goes into the block instead of splitting it with the plane.

Time at which I finished the question above (hh:mm): ___ 7 : 5 6

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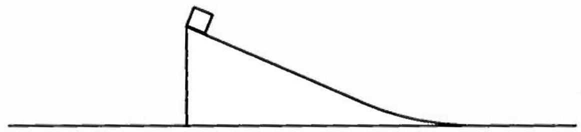
* Due to a question ordering change after the piloting of this exam, some item numbers may appear differently. All item numbers correspond with the AP Physics 1: Algebra-Based Practice Exam.

Sample 5B



3. (7 points, suggested time about 13 minutes)
The figure above shows part of a system consisting of a block at the top of an inclined plane that rests on a table, which is located on Earth. The block and plane are at rest when the block is released. In trial 1 there is no friction between the block and the plane or between the plane and the table. In trial 2 the plane is fixed to the table so it cannot move, but there is still no friction between the block and the plane.

Indicate whether the speed of the block relative to the table when the block reaches the bottom of the plane is greater in trial 1 or trial 2. Justify your answer in a clear, coherent, paragraph-length explanation.

Greater for trial 2 because the force downward increases the speed. In trial 1, the force downward was used to push the plane to the left. I have concluded this using Newton's 3rd law, equal & opposite forces... The kinetic energy, while converted to work, while moving the incline in trial 1, remains kinetic energy in Trial 2

Time at which I finished the question above (hh:mm): 0 1 : 0 7

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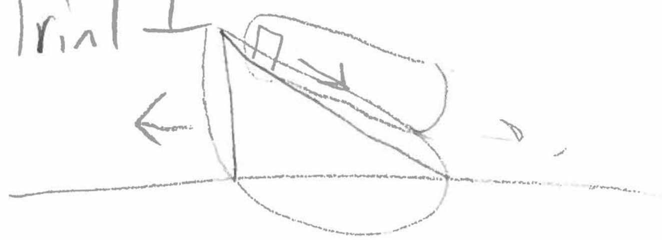
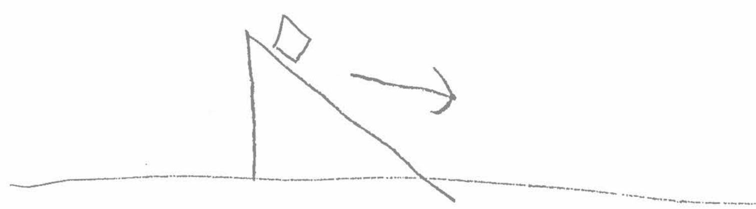
Trial 1



Trial 2



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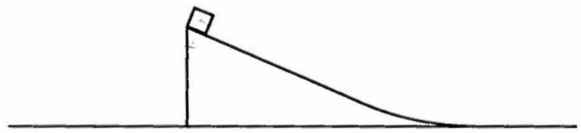
Sample 5C



3. (7 points, suggested time about 13 minutes)
The figure above shows part of a system consisting of a block at the top of an inclined plane that rests on a table, which is located on Earth. The block and plane are at rest when the block is released. In trial 1 there is no friction between the block and the plane or between the plane and the table. In trial 2 the plane is fixed to the table so it cannot move, but there is still no friction between the block and the plane.

Indicate whether the speed of the block relative to the table when the block reaches the bottom of the plane is greater in trial 1 or trial 2. Justify your answer in a clear, coherent, paragraph-length explanation.

The speed of the block relative to the table is faster in trial 2 than in trial 1. In trial 1, the incline is not fixed to the table so that means the block exerts a force on the incline, pushing it to the left as the block travels to the right. This means it'll take the block less time to reach the surface of the table, giving it less time to accelerate. Since in both trials, the surface between the block and the incline is frictionless, the one with the longer time will have more time to accelerate, resulting in a greater velocity; in this case, trial 2

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

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Free-Response Question 5

Overview

This question asked students to compare the energy transformation from potential energy to kinetic energy for two trials. The first trial is a block sliding from rest down an inclined plane that is free to move on a horizontal surface. The second trial is the same block sliding from rest down the same inclined plane, except that the plane is fixed so it cannot move. In both scenarios, there is no friction among any of the surfaces.

Sample: 5A
Score: 6

The response earned a total of 6 points. The statement "When the plane moves it takes some of the energy out of the system and therefore out of the block" is incorrect. The total energy of the system is the same in both trials.

Sample: 5B
Score: 4

The response earned a total of 4 points. An inaccurate statement of energy conversion ("the kinetic energy, while converted to work, while moving the incline in Trial 1 …") earns one point, but there is no mention of the initial potential energy. The same statement indicates that the kinetic energy is shared between the block and plane in Trial 1, earning a 2nd point. Additionally, the response indicates that the block will retain all available kinetic energy in Trial 2, earning a 3rd point. The statement, "the force downward was used to push the plane to the left" is technically incorrect; however, it's clear that the student can demonstrate how forces can be used to explain motion. Due to this underlying understanding, the 4th point was awarded.

Sample: 5C
Score: 2

The response earned a total of 2 points. One point was earned for an explanation using forces to describe why the plane moves to the left in Trial 1. The argument is coherent, albeit off the mark; but it leads to a correct conclusion, resulting in the 2nd point.