Question 2: Experimental Design — 12 points

(a)(i) For indicating two quantities that, when graphed together, produce a straight line whose slope can be used to determine the acceleration a — **1 point**

Example Response

Vertical Axis : *Position*   Horizontal Axis : *Time squared*

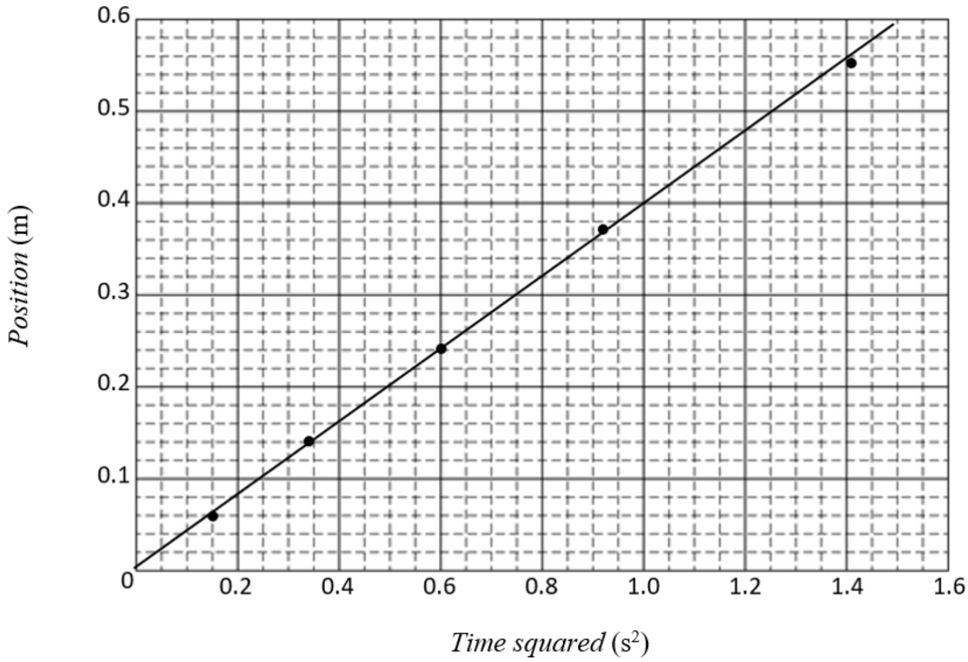
Position x (m)	Time t (s)	Time squared t^2 (s^2)
0.06	0.39	0.15
0.14	0.59	0.35
0.24	0.77	0.59
0.37	0.96	0.92
0.55	1.20	1.44

(a)(ii) The axes have a linear scale and are identified (labels **OR** units) so that when graphed correctly, the data will span more than half of the horizontal and vertical axes — **1 point**

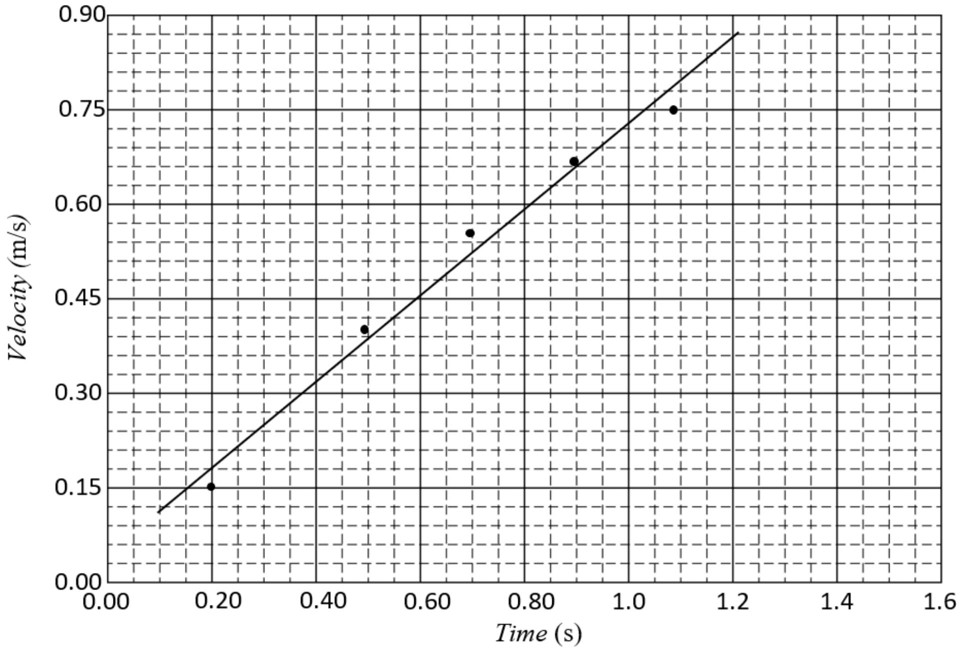
For plotting at least 4 of the data points correctly — **1 point**

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

Example Response



Alternate Example Response



Scoring Note: The following tables represent the most common linearized graphs with the data that were used to determine the acceleration.

Graph: v vs. t	
$v\ \left(\frac{\text{m}}{\text{s}}\right)$	t (s)
0.15	0.20
0.40	0.49
0.56	0.68
0.68	0.87
0.75	1.08

Graph: $2x$ vs. t^2	
$2x$ (m)	t^2 (s^2)
0.12	0.15
0.28	0.35
0.48	0.59
0.74	0.92
1.10	1.44

Graph: $2v_{\text{avg}}$ vs. t	
$2v_{\text{avg}}\ \left(\frac{\text{m}}{\text{s}}\right)$	t (s)
0.31	0.39
0.47	0.59
0.62	0.77
0.77	0.96
0.92	1.20

Graph: x vs. $\frac{1}{2}t^2$	
x (m)	$\frac{1}{2}t^2$ (s^2)
0.06	0.08
0.14	0.17
0.24	0.30
0.37	0.46
0.55	0.72

Graph: ${v_{\text{avg}}}^2$ vs. x	
${v_{\text{avg}}}^2\ \left(\frac{\text{m}^2}{\text{s}^2}\right)$	x (m)
0.02	0.06
0.06	0.14
0.10	0.24
0.15	0.37
0.21	0.55

Graph: $\sqrt{x}$ vs. t	
$\sqrt{x}$ ($\sqrt{\text{m}}$)	t (s)
0.24	0.39
0.37	0.59
0.49	0.77
0.61	0.96
0.74	1.20

(a)(iii)	For attempting to find the slope, $\left(\dfrac{\text{rise}}{\text{run}}\right)$ or $\left(\dfrac{\Delta y}{\Delta x}\right)$, of the best-fit line drawn in part (a)(ii) **Scoring Note:** An indication that a calculator was used for linear regression to determine the value of the slope may earn this point.	**1 point**
	For using the slope in a valid kinematic equation to calculate the acceleration **Scoring Note:** This point can be earned if evidence of a kinematic equation exists in graphed quantities (e.g., a graph of position as a function of $\frac{1}{2}t^2$).	**1 point**

Example Response

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta\ \text{position}}{\Delta\ \text{time}^2} = \frac{0.48\ \text{m} - 0.18\ \text{m}}{1.2\ \text{s}^2 - 0.4\ \text{s}^2} = 0.375\ \frac{\text{m}}{\text{s}^2}$$

$$\Delta x = v_0 t + \frac{1}{2}at^2$$

$$\frac{\Delta x}{t^2} = \frac{1}{2}a$$

$$\text{slope} \times 2 = a$$

$$a = 0.75\ \frac{\text{m}}{\text{s}^2}$$

Total for part (a) 6 points

(b)(i)	For indicating a quantity to be measured Accept **one** of the following: • The angle θ with the horizontal • The height h and length L of the ramp **Scoring Note:** Stating only the height needs to be measured can earn this point if an energy approach is used.	**1 point**
(b)(ii)	For providing a correct expression relating the acceleration of gravity to the acceleration measured **Scoring Note**: If $\cos\theta$ is used, the response must specify that θ was measured from the vertical.	**1 point**

Example Response

$mg_{\text{exp}} \sin\theta = ma$

$g_{\text{exp}} = \dfrac{a}{\sin\theta}$

OR

$\sin\theta = \dfrac{h}{L}$

$g_{\text{exp}} = \left(\dfrac{L}{h}\right)a$

OR

$mg_{\text{exp}}h = \dfrac{1}{2}mv^2$

$g_{\text{exp}}h = \dfrac{1}{2}v^2$

$v = \sqrt{2g_{\text{exp}}h}$

$v = at$

$at = \sqrt{2g_{\text{exp}}h}$

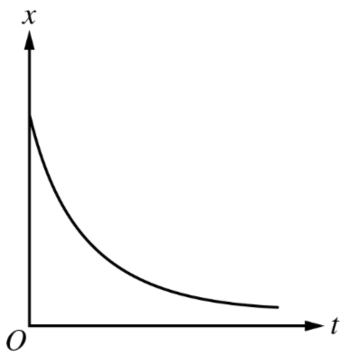
$g_{\text{exp}} = \dfrac{a^2t^2}{2h}$

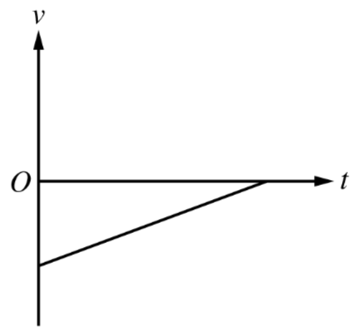
Total for part (b) 2 points

(c)(i)	For identifying a physical factor that could have affected the result Accept **one** of the following: • A physical factor in the materials used (e.g., the wheels have nonnegligible rotational inertia, the ramp was bumpy, the wheels were wobbly or not perfectly round, the base of the ramp was not level, the floor was not level.) • A physical factor in the environment (e.g., the room was being accelerated, elevator, the experiment was performed at high elevation or on a different planet.) • A physical error in measurement collection (e.g., time, position, or angle was measured incorrectly.) **Scoring Note:** A statement of "Human error" does not earn this point.	**1 point**
(c)(ii)	For correctly indicating the functional dependence between the reason listed in part (c)(i) and g_{exp} Accept **one** of the following: • Correctly indicating the functional dependence between the physical factor in the materials used and g_{exp} (e.g., if the rotational inertia of the rotating wheels is nonnegligible, the cart will have a smaller acceleration and g_{exp} will be smaller.) • Correctly indicating the functional dependence between the physical factor in the environment and g_{exp} (e.g., if the experiment was performed at a high elevation, the acceleration will be smaller and g_{exp} will be smaller.) • Correctly indicating the functional dependence between the physical error in the measurement collection and g_{exp} (e.g., if the angle of the ramp is smaller than the measured value, the cart will have a smaller acceleration and g_{exp} will be smaller.)	**1 point**
	Example Response *The expression I derived for the value for g_{exp} did not take into consideration that the wheels had any rotational inertia. If the wheels have rotational inertia and are rotating, the acceleration of the cart would be less than $g\sin\theta$, so the value of g_{exp} would be less than* $9.8\ \frac{\text{m}}{\text{s}^2}$.	
	Total for part (c)	**2 points**

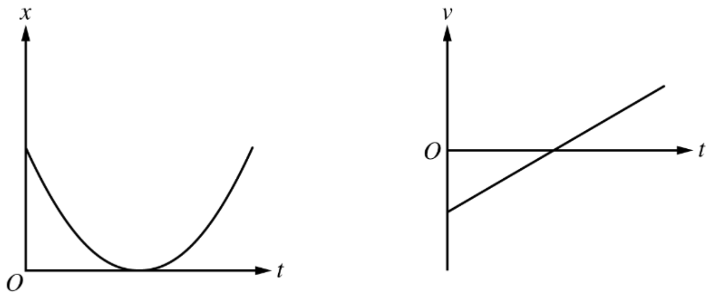
(d)	For sketching a concave up curve with an initially negative slope for the graph of position as a function of time	**1 point**
	For **one** of the following: • Drawing a line with a positive slope and a negative vertical intercept for the v vs. t graph • Drawing a v vs. t graph that is consistent with the x vs. t graph that shows acceleration	**1 point**

Example Response

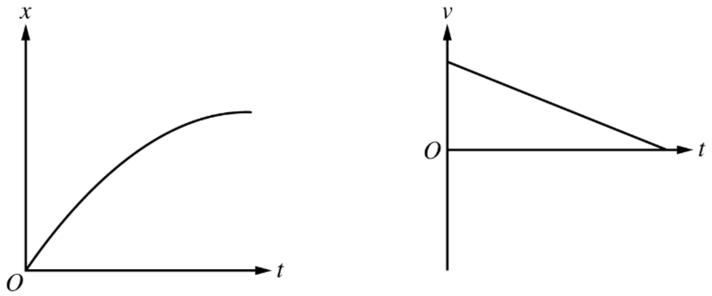




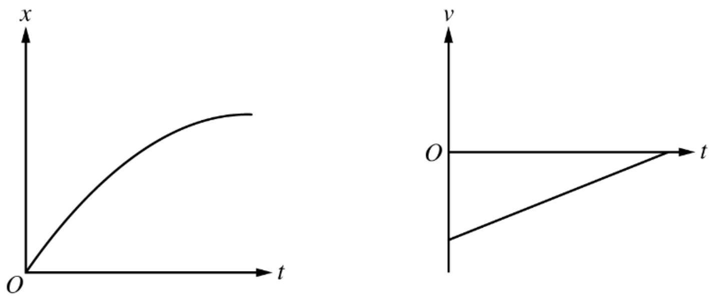
Scoring Note: The following are alternate example graphs with the points the response would earn.



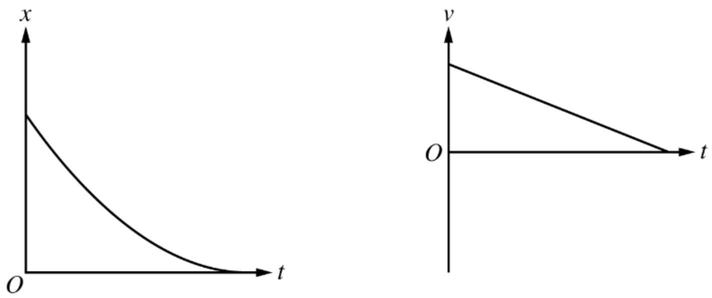
Earns 2 points



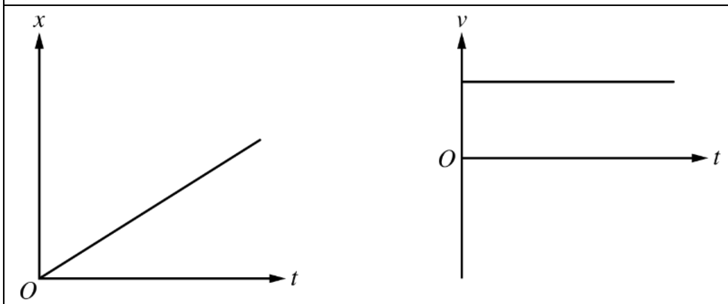
Earns 1 point



Earns 1 point



Earns 1 point



Earns 0 points

Total for part (d) 2 points

Total for question 2 12 points

Question 1: Short Answer — 7 points

(a)	For using conservation of energy to find the speed v of the bicycle as it leaves the ramp	**1 point**
	For using kinematics, vertical components, attempting to find the time the bicycle is in the air	**1 point**
	For a correct expression for X_0 in terms of given quantities	**1 point**

Example response for part (a)

$$E_{top} = E_{bottom}$$
$$m_0 g H_0 = \tfrac{1}{2} m_0 v^2$$
$$v = \sqrt{2gH_0}$$
$$v_{fy} = v_{iy} + at$$
$$-v\sin\theta = v\sin\theta - gt$$
$$-2v\sin\theta = -gt$$
$$2\sin\theta_0\sqrt{2gH_0} = gt$$
$$t = \frac{2\sin\theta_0\sqrt{2gH_0}}{g}$$
$$X_0 = v_x t$$
$$X_0 = \cos\theta_0\sqrt{2gH_0}\,\frac{2\sin\theta_0\sqrt{2gH_0}}{g}$$
$$X_0 = 4H_0\cos\theta_0\sin\theta_0$$

Scoring Note:

Using the range equation to get $X_0 = 2H_0\sin 2\theta_0$ is sufficient to earn the second and third points.

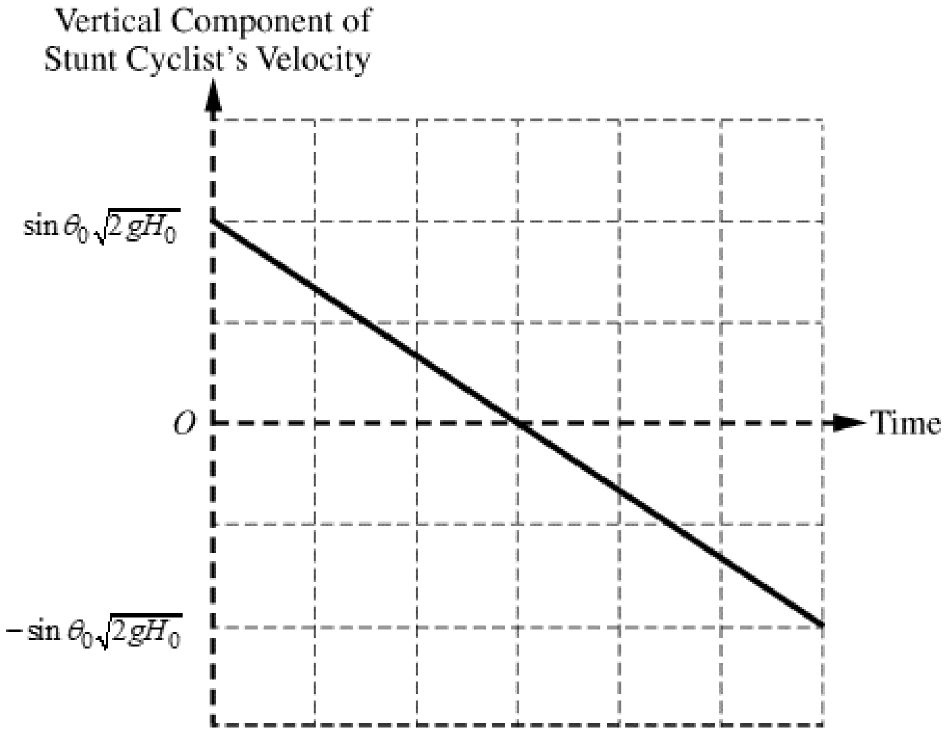
Total for part (a) 3 points

(b)	Correct answer: 12 cars	
	For an answer and justification that attempts to use the functional dependence of the horizontal distance on the initial height	**1 point**
	For an answer consistent with the expression derived in part (a)	**1 point**

Total for part (b) 2 points

(c)	For a linear graph with a constant negative slope	**1 point**
	For a graph that starts at v_y and ends at $-v_y$, using only allowed variables	**1 point**

Example response for part (c)



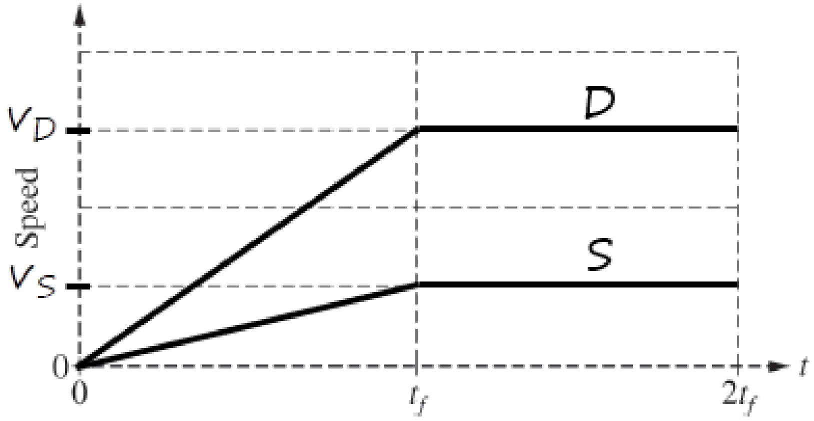
Total for part (c) 2 points

Total for Question 1 7 points

Question 3: Qualitative/Quantitative Translation — 12 points

(a)	**i.**	For a correct answer $v_D = \dfrac{F_H t_f}{M_D}$	**1 point**
	ii.	For indicating the total momentum of the system is the same before and after the collision **Scoring Note**: If the response only includes a correct final answer of $\dfrac{M_S}{M_D}$, the response earns this point but not the next point.	**1 point**
		For correctly substituting the appropriate variables into a conservation of momentum equation **AND** an answer in the form $\dfrac{v_D}{v_S} = \ldots$ **Scoring Notes:** This point can be earned only if the first point is earned. The answer need not be correct to earn this point.	**1 point**
		Example response for part (a)(ii) $p_i = p_f$ $0 = M_S v_S - M_D v_D$ $\dfrac{v_D}{v_S} = \dfrac{M_S}{M_D}$	
		Total for part (a)	**3 points**
(b)		For two functions that are straight segments for $t < t_f$, **AND** begin at the origin, **AND** have two different positive slopes	**1 point**
		For two functions that are horizontal functions for $t > t_f$ **AND** are continuous over the entire time range $0 < t < 2t_f$	**1 point**
		For labeling values on the vertical axis with $v_D > v_S$ **OR** The curve labeled D is greater than the curve labeled S for all t > 0 **Scoring note:** This point can still be earned if the labels are not on the vertical axis but clearly indicate that $v_D > v_S$.	**1 point**

Example response for part (b)



		Total for part (b)	**3 points**
(c)	**i.**	For stating or mathematically representing that if the disk is much more massive, then the block will have little effect on the motion of disk 1 **OR** For stating or mathematically representing that when $M_D >> M_B$, $v_{cm} = v_1$	**1 point**
	ii.	For correct reasoning. Correct answer: When $M_D << M_B$, $v_{cm} = 0$	**1 point**
		Example response for part (c) (ii) *If the block is much more massive, then it will barely move when the disk collides and sticks to it.*	
	iii.	For using conservation of momentum	**1 point**
		For a correct answer $v_{cm} = \dfrac{m_D v_1}{m_D + m_B}$	**1 point**
	iv.	For an attempt to use limiting-case reasoning or functional dependence with the equation in part (c)(iii)	**1 point**
		For recognizing the equation from (c)(iii) reduces to a simpler form and the simplified form is correctly compared to their answer in (c)(i)	**1 point**
		Example 1 response for part (c) (iv) *Yes. If M_B is very small, then the denominator of the equation simplifies to M_D, which then can cancel out of the equation leaving $v_{cm} = v_1$.*	
		Total for part (c)	**6 points**
		Total for question 3	**12 points**

AP® Physics 1
2015 Scoring Guidelines

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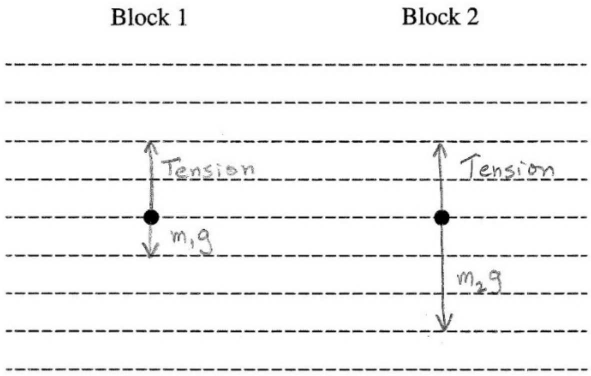
Question 1

7 points total **Distribution of points**

(a) 2 points



For drawing two vectors starting on the dots that point upward, have the same length and are labeled as the tension force — 1 point

For drawing two vectors starting on the dots that point downward, where the vector for block 1 is smaller than the vector for block 2 and both are labeled as the gravitational force — 1 point

One earned point is deducted for drawing any extraneous vectors.

One earned point is deducted for vector lengths that do not allow the system to accelerate in the proper direction.

(b) 3 points

For writing an equation for Newton's second law for block 1 — 1 point

$m_1a = T - m_1g$

For writing an equation for Newton's second law for block 2 — 1 point

$m_2a = m_2g - T$

For eliminating T to obtain an equation that can be solved for the acceleration — 1 point

$T = m_1a + m_1g$

$m_2a = m_2g - m_1a - m_1g$

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

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Question 1 (continued)

Distribution of points

(b) (continued)

Alternate solution — *Alternate points*

The system of two blocks must move as a unit, so the acceleration of the system is the acceleration of block 2.

For writing an equation showing that the net force acting on the system is the difference in masses times the acceleration of gravity — *1 point*

$$F_{net} = (m_2 - m_1)g$$

For writing an equation that relates the net force to the sum of the masses and the acceleration of the system — *1 point*

$$F_{net} = (m_2 + m_1)a$$

For writing an equation that can be solved for the acceleration in terms of the variables used in the summation of forces equations — *1 point*

$$(m_2 + m_1)a = (m_2 - m_1)g$$

$$a = (m_2 - m_1)g/(m_2 + m_1)$$

(c) 2 points

The acceleration of the new system, and thus of block 2, is smaller.

For indicating that the mass of the system is larger — 1 point

For a clear indication that the tension on block 2 is greater — 1 point

Alternate solution — *Alternate points*

For indicating that the mass of the system is larger — *1 point*

For indicating that the net force exerted on the system stays the same — *1 point*

Notes:

No points are earned for a correct prediction without a reasonable attempt at an explanation.

No points are earned for an incorrect prediction, regardless of the explanation.

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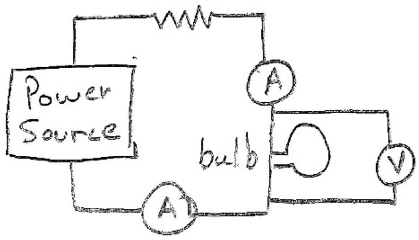
Question 2

12 points total | **Distribution of points**

(a) 5 points



For drawing a circuit in which the power source, resistor, and bulb are wired in series — 1 point

For connecting at least one ammeter in series with the bulb — 1 point

For connecting the voltmeter across the bulb in parallel — 1 point

For describing measurements that can plausibly be used to answer question 1 — 1 point

Example: Measure the current entering and leaving the bulb with ammeters connected in series on either side of the bulb.

For describing measurements that can plausibly be used to answer question 2 — 1 point

Example: Measure the potential difference across the bulb with a voltmeter connected in parallel with the bulb.

The response does not need to mention multiple measurements.

(b)

(i) 1 point

For describing an analytical method of using the data, and explaining how that analytical method can be used to answer question 1 — 1 point

Example: If the current is the same on both sides of the bulb, then the number of electrons per second entering and leaving the bulb is the same.

(ii) 1 point

For describing an analytical method of using the data, and explaining how that analytical approach can be used to answer question 2 — 1 point

Example: If the potential difference across the bulb is not zero, then electrons that leave the bulb have different electric potential energy than electrons that enter it.

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Question 2 (continued)

Distribution of points

(c)

(i) 1 point

For any of the following: — 1 point

Describing any changes to the circuit needed to have a setup that can plausibly be used to determine whether the bulb's resistance is constant as a function of current.

Describing changes to a circuit that are not needed but do not impair the ability to determine whether the bulb's resistance is constant as a function of current.

Correctly indicating that no changes are needed.

Example based on circuit diagram in part (a): Remove one of the ammeters.

(ii) 1 point

For describing any additional measurements needed to determine whether current varies linearly as a function of voltage, or indicating that none are needed if the appropriate multiple measurements are mentioned in part (a) or (c)(i) — 1 point

Example: Measure the current through the bulb and the potential difference across the bulb for multiple settings of the power source.

(d) 3 points

For describing an analytical method in which data are represented or manipulated in some way that can plausibly be used to determine whether current varies linearly as a function of potential difference — 1 point

Examples:

Graphing measurements of current as a function of potential difference

Calculating the ratio of current to potential difference for multiple settings of the power source

For identifying that linearity is the relevant feature for determining whether the bulb is ohmic — 1 point

Examples:

Evaluating whether a plot of current as a function of voltage is linear

Evaluating whether the ratio of current to potential difference is constant

For describing a strategy for evaluating whether the conclusion of linearity is valid for a given data set taking into account the meter uncertainties — 1 point

Examples:

Drawing error boxes that represent the uncertainties of the meters around each point and evaluating whether a straight line can be drawn that goes through all the error boxes.

Indicating that small differences in the ratios could be due to uncertainty in the meters and would not discount the conclusion that the bulb is ohmic

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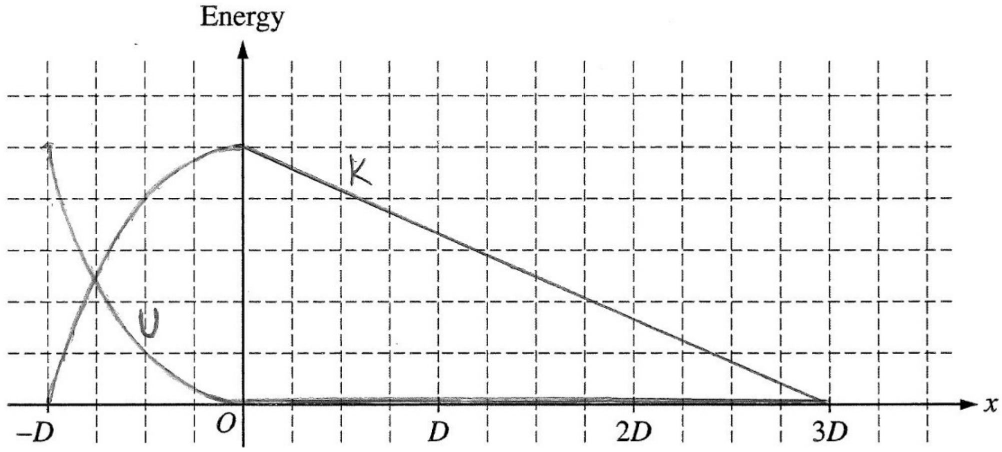
Question 3

12 points total **Distribution of points**

(a) 4 points



For sketching either energy curve with a reasonably correct shape between $x = -D$ and $x = 0$, with zero and maximum values at the correct locations — 1 point

For sketching two curves from $x = -D$ to $x = 0$ with shapes and values such that the total energy is constant (even if the curves are incorrect) — 1 point

For sketching potential energy equal to zero from $x = 0$ to $x = 3D$ — 1 point

For sketching kinetic energy as a linear function from its maximum value at $x = 0$ to zero at $x = 3D$ — 1 point

(b)

(i) 1 point

For identifying that the student is correct that the block will have more energy when it leaves the spring — 1 point

(ii) 1 point

For identifying that the student is incorrect about the new final position of the block because the spring's energy does not scale linearly with its compression — 1 point

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Question 3 (continued)

Distribution of points

(c) 3 points

For indicating that the final energy in the spring (which becomes the mechanical energy of the block as it reaches the rough track) is four times the original energy in the spring — 1 point

For indicating that the frictional force remains the same — 1 point

For equating the initial energy in the spring to an expression that shows that the energy dissipated by friction is proportional to the distance the block slides down the rough track — 1 point

Example:

$U_1 = \frac{1}{2}kD^2$ and $U_2 = \frac{1}{2}k(2D)^2$ so $U_2 = 4U_1$

$W_1 = \mu mg(3D)$ and $W_2 = \mu mg\Delta x_2$

$W_1 = U_1$ and $W_2 = U_2 = 4U_1 = 4W_1$

$\mu mg\Delta x_2 = 4(\mu mg(3D))$

$\Delta x_2 = 4(3D) = 12D$

(d) 3 points

For indicating that the student's correct reasoning that the block has more energy in the second situation is expressed by the calculations comparing the initial energy in the spring — 1 point

For indicating that the student's correct reasoning that the block will slide farther is expressed by an equation that indicates that the work done by friction to stop the block in the second situation is some factor greater than the work done in the first situation — 1 point

For indicating that the student's incorrect reasoning that energy scales linearly with the spring's compression is corrected by the expression for the initial energy of the spring — 1 point

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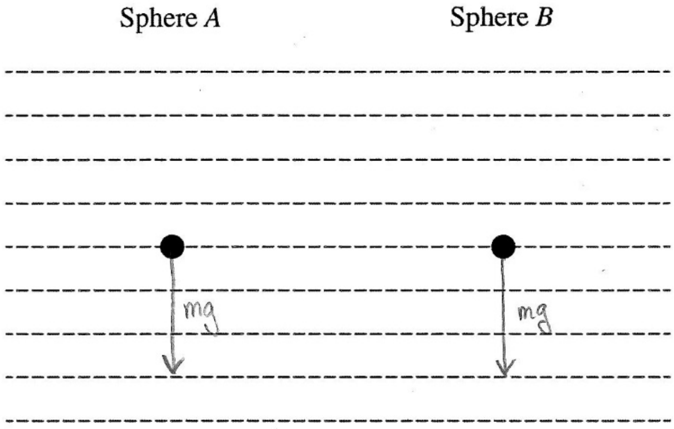
Question 4

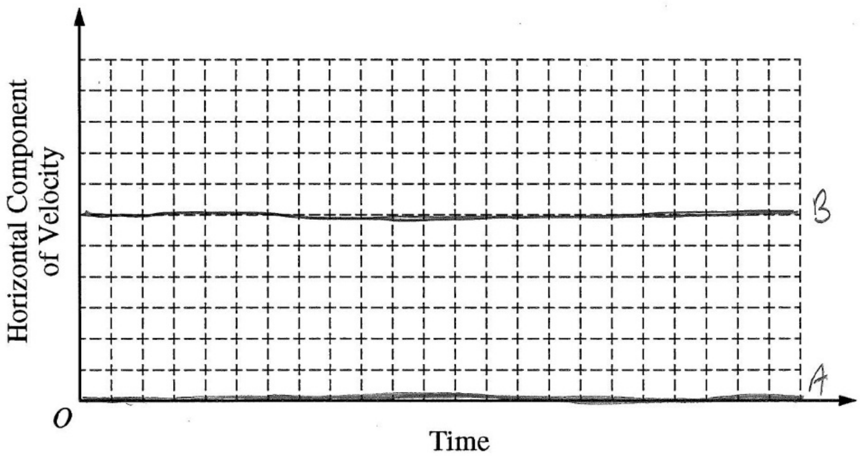
7 points total | **Distribution of points**

(a) 1 point



For sketching only one force pointing straight down from each sphere and indicating that this force represents the force of gravity — 1 point

(b) 1 point



For sketching a horizontal line at zero velocity for sphere *A*, and sketching a horizontal line at some non-zero velocity for sphere *B* — 1 point

(c) 5 points

For indicating that the difference in horizontal motion does not affect the vertical motion of the spheres — 1 point
For indicating that both spheres start with the same vertical velocity — 1 point
For indicating that both spheres have the same vertical acceleration — 1 point
For indicating that falling the same height would take the same time — 1 point
For no incorrect or irrelevant statements — 1 point

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Question 5

7 points total — **Distribution of points**

(a) 3 points

For reasoning that since the strings all have the same length, and since the wavelength of the fundamental depends on the length, all four waves have the same wavelength (e.g., $\lambda_1 = 2L$) — 1 point

For reasoning that since the wavelengths are all the same, different frequencies correspond to different velocities of the waves on the strings — 1 point

For reasoning that all the string tensions are the same due to the same mass M of each block, and therefore the linear mass densities must be different for different velocities since $v = \sqrt{F_T/(m/L)}$ (or since the vertical component of the tension will result in different vertical accelerations for strings with different masses) — 1 point

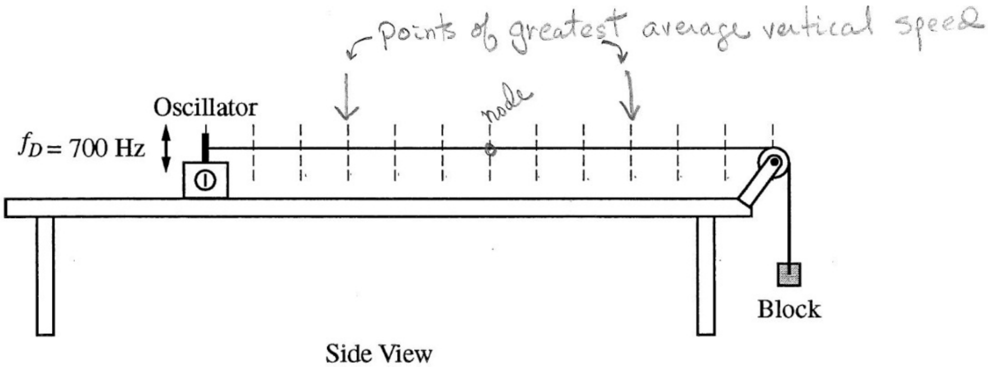
Note: Responses may refer to the physical differences between the strings in a variety of ways, e.g., different linear mass density, different total mass, different thicknesses of the same material

(b) 2 points

For combining $v = f\lambda$ with $v = \sqrt{F_T/(m/L)}$ (or referring to such an equation written in part (a)) — 1 point

For indicating how the equation leads to the conclusion that frequency would not be proportional to the inverse of the linear mass density — 1 point

(c) 2 points



For any indication of the second harmonic on the string, or a wave drawn such that $\lambda_2 = L$. — 1 point

For points which are at the antinodes of the second harmonic, or at the antinodes of any standing wave drawn on the string — 1 point

Notes:

Full credit is earned for having two points that are located one fourth the length of the string and three fourths the length of the string from the oscillator.

One earned point is deducted for each incorrect point marked on the figure