NAME ______________________________ DATE ______________

Scenario

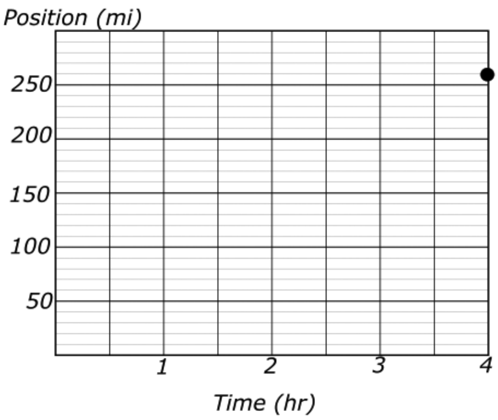
A police officer pulls over a truck driver and says that the driver was speeding. They have the following conversation:

Driver: *The speed limit is 65 miles per hour. I started my shift at noon and it is 4 p.m. now. According to my travel logs, I have only traveled 260 miles.*

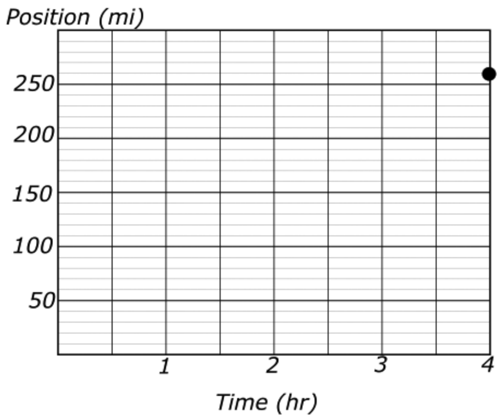
Police officer: *Okay, but you were going faster than the posted speed limit of 65 miles per hour when you passed me.*

PART A: Sketch two graphs representing the truck's distance as a function of the time that has elapsed. Noon is $t = 0$ and 4 p.m. is $t = 4\ \mathrm{hr}$. The dot represents the 260 miles that the truck has traveled when the driver is pulled over. For the first graph, sketch the position of the truck as a function of time assuming that the truck driver is correct in that he obeyed the speed limit the entire time. For the second, sketch a possible graph of the position of the truck as a function of time assuming that the police office is correct, and the truck was speeding at the time the driver passed the police officer.

(i) Case 1: The truck has obeyed the speed limit his entire trip.



(ii) Case 2: The truck was speeding at the time the driver passed the police officer.



PART B: Explain in a clear coherent paragraph-length response how the truck driver and the police officer can both be telling the truth, and the police officer was still correct in pulling the truck driver over for speeding.

NAME ______________________ DATE ____________

Scenario

In a game of football, two players find themselves running towards each other. A wide receiver is running east with velocity v_w. A distance x_c ahead the wide receiver sees a cornerback heading directly towards him at a different velocity, v_c. The wide receiver and cornerback continue running toward each other at constant speeds. The location where the cornerback tackles the wide receiver x_T is measured from the wide receiver's initial position $x = 0$.

PART A: Draw a diagram of the situation described above. Label the given quantities on the diagram.

PART B: If the cornerback runs faster, would the location at which the cornerback tackles the wide receiver (x_T) increase, decrease, or remain the same?

________ Increase ________ Decrease ________ Remain the same

Briefly explain your reasoning, without manipulating equations. Consider using the terms speed, velocity, distance, and time in your reasoning.

PART C: Two students, Angela and Blake, attempt to develop an equation that relates the given variables to predict the location at which the wide receiver and cornerback tackle each other. The equations were developed so that only the magnitude of the velocity of each player gets substituted. Each of their equations is given below.

Angela: $x_T = \dfrac{x_c v_w}{v_w + v_c}$ Blake: $x_T = \dfrac{x_c (v_w - v_c)}{2v_w}$

Regardless of whether the above equations are correct, which student's equation agrees with your qualitative reasoning from Part B?

________ Angela ________ Blake ________ Both ________ Neither

Justify your reasoning.

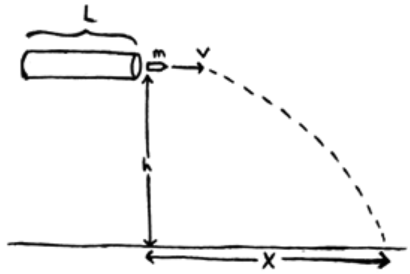
PART D: A third student, Carlos, notices that Blake's equation cannot be correct for reasons not described by the reasoning given in Part B. Without deriving the correct equation, how can you tell if Carlos's claim is correct? In other words, describe why Blake's equation does not make physical sense.

PART E: In terms of the variables given in the scenario, quantitatively demonstrate that Angela's equation is correct. (Substitute the given quantities to derive the equation.)

NAME ____________________ DATE ____________

Scenario

A constant force F is exerted on a dart of mass m in the horizontal direction as it moves through a tube of length L. The tube is situated a height h above the ground. Upon exiting the tube, the dart travels a horizontal distance x before striking the ground, as depicted in the diagram at right.



PART A: Suppose students experiment with the tube and a variety of darts. Some darts have higher masses than others but are the same aerodynamic shape. Assuming air resistance is negligible for the darts. Should the students use a dart with large mass or small mass to launch the dart the farthest distance possible?

______ Large mass ______ Small mass ______ Neither; the mass does not matter.

Briefly explain your reasoning without manipulating equations.

PART B: On the internet, a student finds the following equation used in a similar lab situation: $x = \dfrac{mh^2 g}{FgL^2}$.

Regardless of whether this equation to find the horizontal distance is correct, does it agree with your qualitative reasoning in Part A? In other words, does this equation for x have the expected dependence as reasoned in Part A?

______ Yes ______ No

Briefly explain your reasoning without deriving an equation for x.

PART C: Another student makes a mistake in their derivation and develops the following expression to predict the landing location of the dart: $x = \frac{Fhg}{mL}$. Without deriving the correct equation, how can you tell that this equation is not plausible? In other words, that it does not make physical sense. If there is more than one reason, make sure you discuss each.

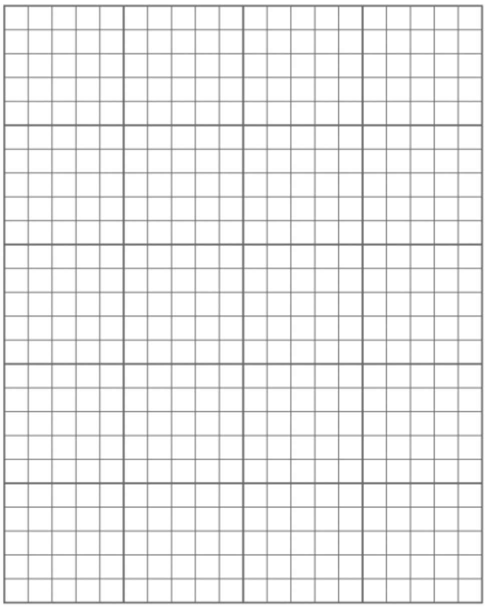
PART D: The group of students is then given a task: Experimentally determine the height of the tube using a linear regression analysis. The students are able to change the magnitude of the constant force exerted on the darts but not the length of the tube or the mass of the dart. In their derivation, the students correctly determine that the height of the table can be expressed as $h = \frac{mgx^2}{4FL}$.

What quantities should be graphed to produce a linear graph from which the vertical height of the tube could be obtained? Justify your answer. Calculations or equations may be used in your answer, but calculations alone are not a sufficient justification.

PART E: An experiment is then performed in which the force exerted on the dart is varied, resulting in the dart traveling various horizontal distances *x*, which are recorded in the table below.

Trial	***1***	***2***	***3***	***4***	***5***	***6***
Force exerted (*N*)	0.2	0.5	0.8	1.2	1.7	2.0
Horizontal Distance *x* (*m*)	3.5	5.5	7.0	8.6	10.2	11.1

Use the grid below to plot a linear graph of x squared as a function of F. Use the empty boxes in the data table, as appropriate, to record the calculated values you are graphing. Label the axes as appropriate (with correct units), and place numbers on both axes.

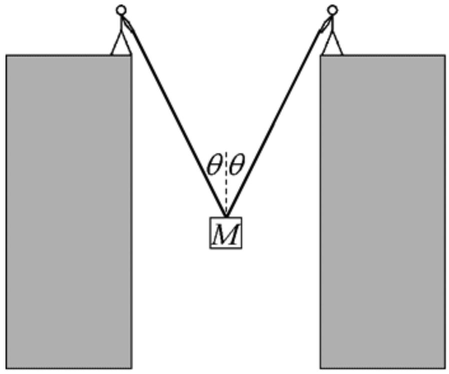


PART F: From the graph, determine the height of the tube given the mass of the dart is 0.020 kg and the length of the tube is 0.35 m.

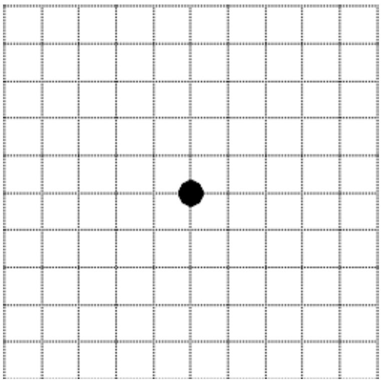
NAME ______________________ **DATE** ______________

Scenario

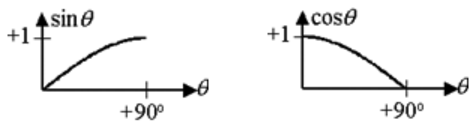
Two people standing on equal-height buildings are lifting a box of mass M between the buildings using two ropes. The people keep the two ropes the same length between their hands and the box so that both ropes make an angle θ with the vertical.



PART A: On the dot below that represents the box, draw and label the forces exerted on the box at one moment in time when the box is at rest.



PART B: Derive an expression for the magnitude of the tension F_T in the two ropes in terms of M, θ, and fundamental constants.

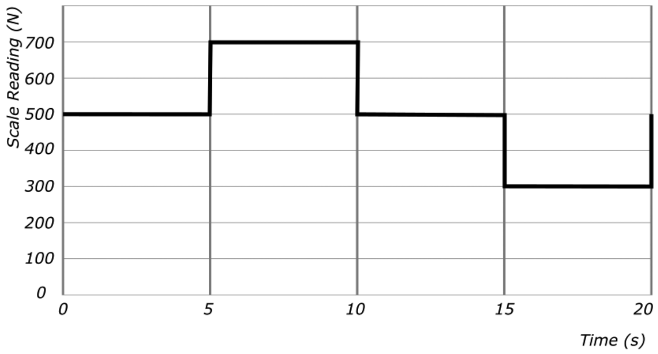


PART C: The graphs above show the values of $\sin\theta$ and $\cos\theta$ for angles between $0°$ and $+90°$. The two people notice that as the box rises at constant velocity, the force they must exert on the ropes becomes greater and greater, and they cannot make the ropes horizontal no matter how much force they exert. Use your equation from Part B and one or both of the graphs above to explain why the people have these experiences.

NAME ______________________ **DATE** ____________

Scenario

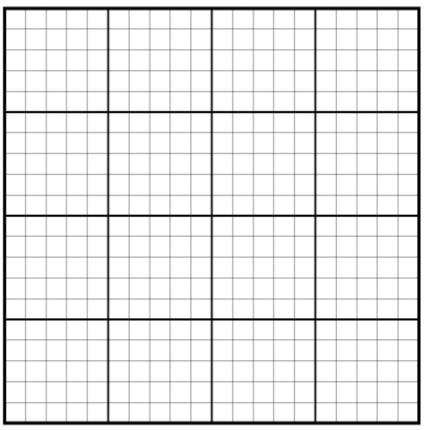
A student whose normal weight is 500 N *stands on a scale in an elevator and records the scale reading as a function of time. The data are shown in the graph below.*



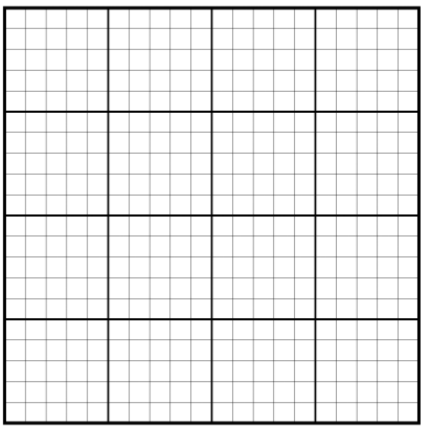
PART A: Describe the motion of the elevator for each of the four segments by filling in the table below to represent the directions of position, velocity, and acceleration. Assume that the upward direction is positive in all cases. The elevator starts from rest at $t = 0$.

Time Segment	*Acceleration (+/–/0)*	*Speeding up/ Slowing Down/ Constant Speed*	*Moving up/ Moving Down/ At Rest*
0–5 seconds			
5–10 seconds			
10–15 seconds			
15–20 seconds			

PART B: On the graph below, sketch a graph of velocity vs. time for the 20 seconds shown in the graph above.



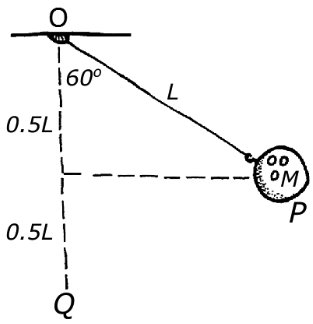
C. On the axis below, sketch a graph of position vs. time for the 20 seconds shown in the graph above.



NAME ______________________ DATE ______________

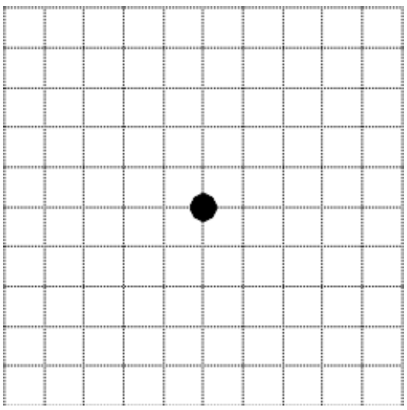
Scenario

A teacher wishes to set up a demonstration that involves connecting a bowling ball of mass M to a fixed-point O on the ceiling by a string. The distance between O and the center of the bowling ball is L. The teacher plans to exert a horizontal force to pull the bowling ball to position P, where the string makes a $60°$ angle to the vertical (holding the ball in place at time T_1). The teacher then plans to release the ball from rest so that the ball swings down to point Q, where the string is vertical (time T_2). However, the teacher is concerned that the tension will be too great at point Q, and the string will break at time T_2 and the bowling ball will become a projectile.

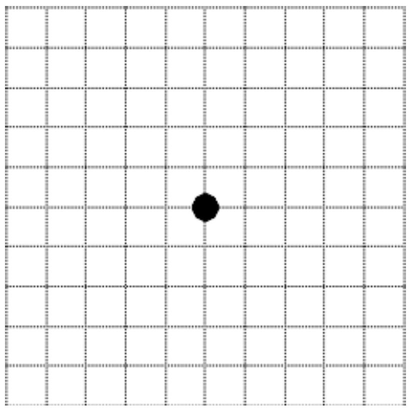


PART A: The dots below represent the bowling ball at the locations and moments indicated. Draw free-body diagrams showing and labeling the forces (not components) exerted on each ball. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.

The ball is at rest at point P as the teacher exerts a horizontal force to keep the ball in place (time T_1).



The ball has been released and at this instant is passing through point Q (time T_2).



PART B: Use conservation of energy to derive an expression for the speed of the ball at point Q in terms of g and L.

PART C: Determine the tension in the rope at the two moments in time indicated in terms of m and g.

i. Time T_1

ii. Time T_2

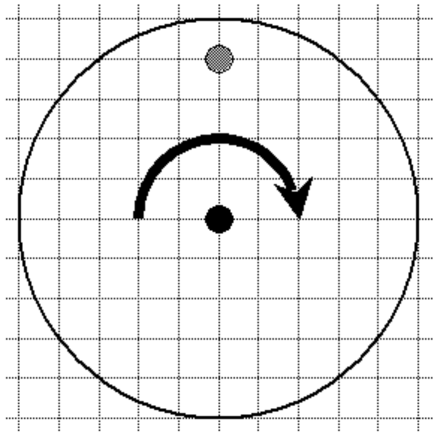
Argumentation

PART D: If the string does not break at time T_1, then the teacher does not need to worry about letting go of the ball. Explain why using your answers to Part C.

NAME ______________________ DATE ______________

Scenario

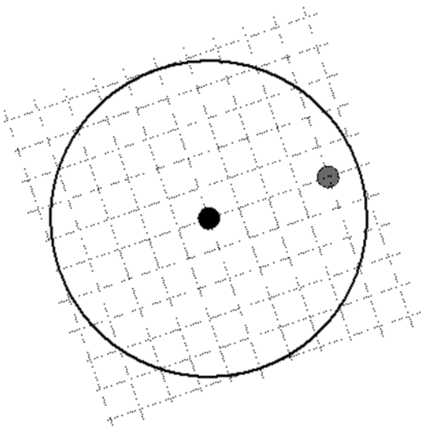
A coin is set on a large turntable a distance of 4 m from the center of the turntable. The turntable is slowing down so that the speed of the coin is given by the equation $v = 6 - 2t$, in units of meters and seconds.



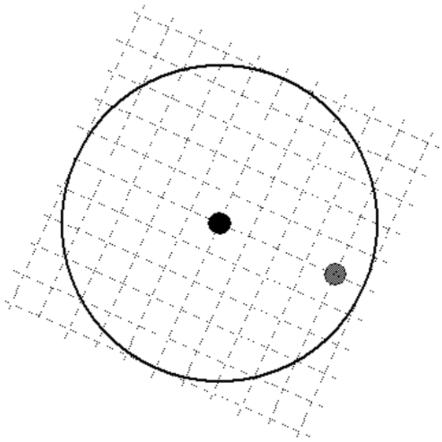
PART A: The coin is in the locations shown in the diagrams below at times $t = 1$ s and $t = 2$ s. On each diagram, draw the following three vectors. Make the vector lengths such that each square on the diagram represents either one m/s or one m/s^2.

- A vector (labeled v) representing the velocity of the coin at this instant
- A vector (labeled a_t) representing the tangential component of acceleration of the coin at this instant
- A vector (labeled a_c) representing the centripetal component of acceleration of the coin at this instant

Time t = 1 second



Time t = 2 seconds

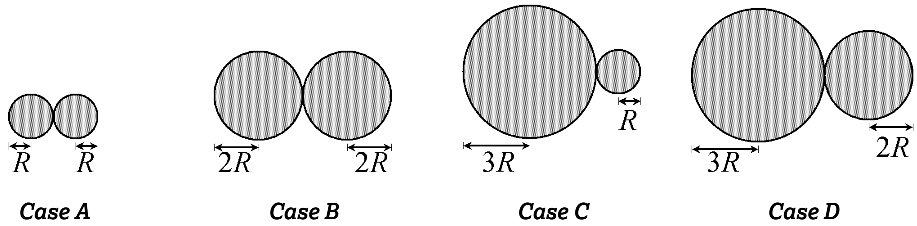


PART B: The experiment is repeated with the coin again set 4 m from the center. This time, two trials are performed with the turntable starting at rest. On Trial 1, the turntable increases its motion very gradually, and the coin slips on the turntable surface when the coin moves any faster than $6\ \text{m/s}$. On Trial 2, the turntable increases its motion so that the coin's speed increases at a rate of $8\ \text{m/s}^2$, and the coin slips when its speed reaches $4\ \text{m/s}$. In a clear, coherent, paragraph-length response that may include equations, figures, and calculations (but these are not necessary), explain why the speed to make the coin slip in Trial 2 was less than in Trial 1.

NAME ______________________ DATE ______________

Scenario

In the four cases shown below, two spheres are in contact with each other somewhere in space far from the influence of other objects. The spheres have radii shown in each diagram. In each case, the two spheres exert a gravitational force on each other.



PART A: i. Consider all given cases and assume all of the spheres have the same mass M. Let the left sphere have a radius R_1 and the right sphere have a radius R_2. Write an equation for the gravitational force F that the two spheres exert on each other that could apply to any scenario above. Your equation should contain M_1, M_2, R_1, R_2, and physical constants as appropriate.

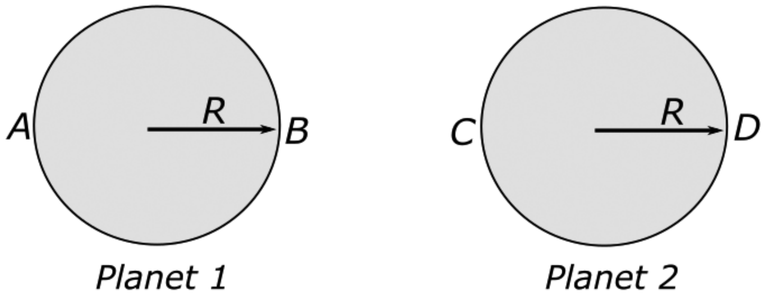
ii. Rank the cases by the gravitational force that the spheres exert on each other, assuming that all the spheres shown have the same mass. Include $<$, $>$, or $=$ to clarify your ranking.

_____ _____ _____ _____

Strongest force Weakest force

Use your equation from Part A (i) to explain how you made your ranking.

PART B: The figure shows two identical planets with radius R. Their centers are separated by a distance of $4R$. They are near each other but are not colliding because they are orbiting each other. An astronaut stands at one of the labeled positions. Rank the magnitudes of net gravitational force on the astronaut at each of the four labeled positions from greatest to least. Include <, >, or = to clarify your ranking.

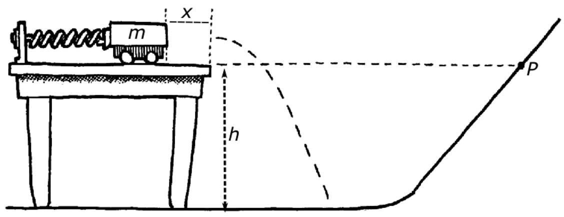


Greatest net force ______________________ Least net force

Justify your ranking:

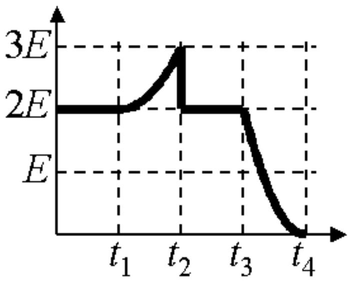
NAME ______________________ **DATE** ______________

Scenario

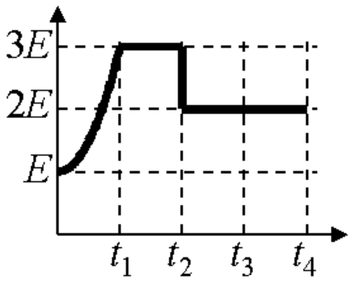


A cart of mass m with frictionless bearings and very light wheels initially compresses a spring (force constant k) a distance x from its equilibrium length. The cart and spring are on a table of height h. Suppose that E represents an amount of energy so that $E = mgh$ and $\frac{1}{2}kx^2 = 2E$.

At time $t = 0$, the cart is released, and the spring begins to expand. At time $t = t_1$, the spring returns to its natural length just as the cart leaves the table. At time $t = t_2$, the cart lands on the floor, losing all its vertical velocity but none of its horizontal velocity. At time $t = t_3$, the cart reaches the bottom of a slope, and at time $t = t_4$ the cart comes momentarily to rest on the slope.



Graph A



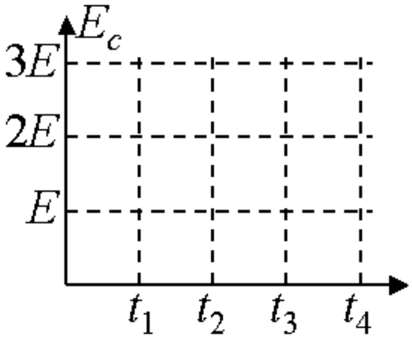
Graph B

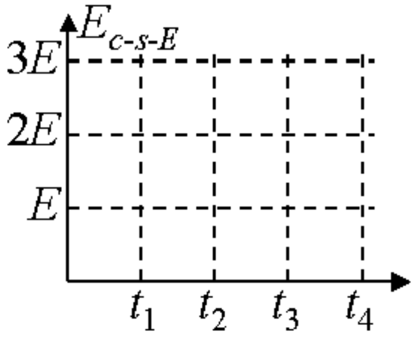
PART A: One of the graphs shown (Graph A or Graph B) represents the mechanical energy of the cart-Earth system as a function of time, and the other represents the mechanical energy of the cart-spring system vs. time. Which graph represents the mechanical energy of the cart-Earth system?

________ Graph A ________ Graph B

Explain how you know, justifying by citing relevant features of the graph.

PART B: Create a graph of E_c, the mechanical energy of the cart system as a function of time, and a graph of $E_{c\text{-}s\text{-}E}$, the mechanical energy of the cart-spring-Earth system as a function of time. Be sure your graphs have straight or curved segments so that they are consistent with the graphs above.



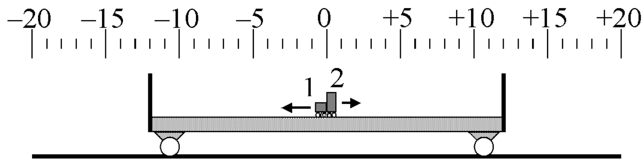


PART C: The ramp is much longer than shown. Does the cart stop below, at, or above point P on the ramp? Explain your reasoning.

NAME ______________________ DATE ______________

Scenario

Two small carts, Cart 1 (mass $m_1 = 5\ kg$) and Cart 2 (mass $m_2 = 10\ kg$), are set in contact with each other at position $x = 0$ on a larger platform. The platform is centered on position $x = 0$ and is 24 meters long. The carts and platform can roll on bearings of negligible friction and are all initially at rest.

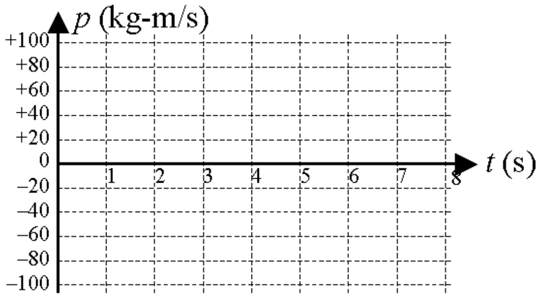


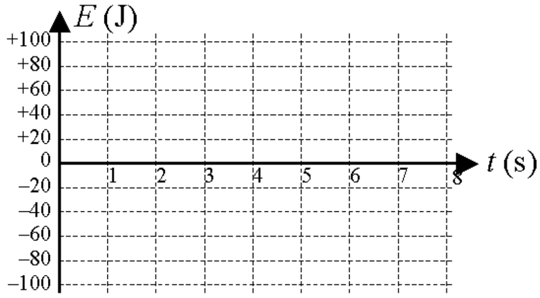
At time $t = 0$, a small spring between the two carts expands, sending Cart 1 to the left with an initial speed of 4 m/s. Both carts collide and bounce off the bumpers at the ends of the platform, which can be assumed to be perfectly elastic. When the carts collide with each other again, they stick together.

PART A: For this part, assume that the brakes on the platform's wheels are set so that the platform cannot move. The carts collide again at time $t = 8$ seconds.

i. Do the carts collide again at, to the left of, or to the right of $x = 0$? After colliding, are the two carts moving left, moving right, or not moving? In a clear, coherent, paragraph-length response that explains the motions of the carts between times $t = 0$ and $t = 8$ s and includes specific calculations as needed, explain your reasoning.

ii. On the axes below, draw graphs of the total momentum p of the two-cart system (where positive momentum is rightward momentum) and the total mechanical energy E of the two-cart system (where the top of the platform is zero gravitational potential energy) as a function of time for the interval between $t = 0$ and $t = 8$ seconds.



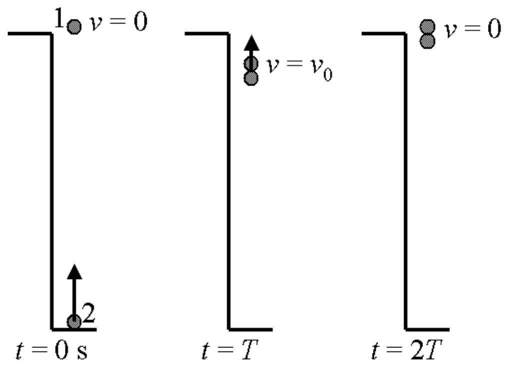


PART B: Suppose that the platform's wheels are free to roll, but the platform has much more mass than the two carts. If the experiment is repeated again exactly as before, will the center of the platform be to the left, to the right, or at $x = 0$ when the carts collide again and stick? Briefly explain your reasoning.

NAME DATE

Scenario

A time $t = 0$, clay ball 1 is dropped from rest at the top of a building. At the same time, identical clay ball 2 is launched upward from ground level. At time $t = T$, the two collide and stick. Just after the collision, the combined object has upward speed v_0. At time $t = 2T$, the combined object is momentarily at rest at the top of the building.

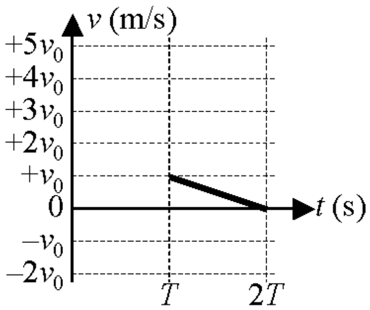


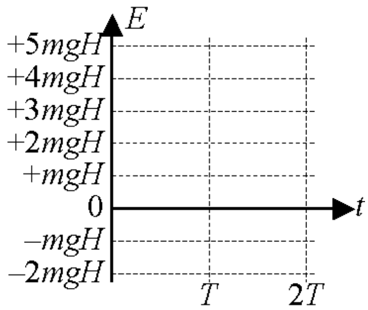
PART A: The graph on the left below shows velocity as a function of time, where up is positive. The velocity of the combined object is already drawn for $T < t < 2T$. Draw and label the following for the interval $0 < t < T$.

i. The velocity of ball 1 and label the graph "1."

ii. The velocity of ball 2 and label the graph "2."

iii. The velocity of the center of mass of the two-ball system and label the graph "C."





PART B: Let E represent the total mechanical energy of the two-balls-and-Earth system, defining gravitational potential energy as zero on the ground. At time $t = 0$, $E = 3mgH$, where m is the mass of one ball and H is the height of the building. At time $t = 2T$, $E = 2mgH$. On the graph above and to the right, draw a graph of E as a function of time for $0 < t < 2T$.

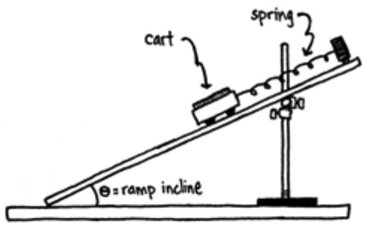
PART C: Use the v vs. t graph above and to the left to calculate the height of the building H in terms of v_0, T, and g. Explain your method.

PART D: If the experiment is repeated but this time ball 2 has the same upward launch speed but greater mass, would the two-ball combination rise higher, the same height, or lower than the top of the building? Explain your reasoning.

NAME ______________________ DATE ______________

Scenario

Blake and Carlos are challenged to find the mass of an unknown cart by attaching it to a spring of known spring constant on an incline as shown at right. Assume the spring is ideal and there are no frictional losses in the cart.



PART A: Describe an experimental procedure the students could use to collect the data needed to determine the mass of the cart.

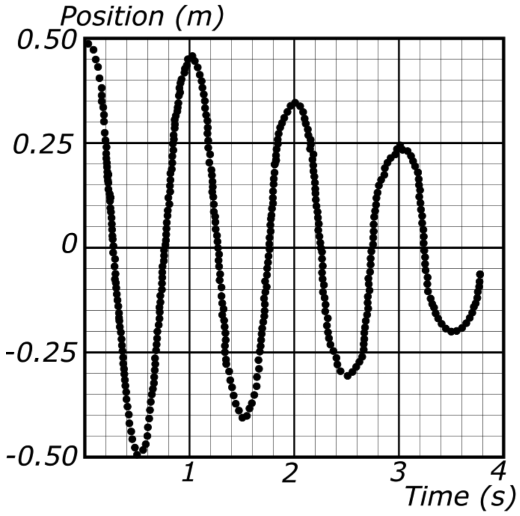
i. What quantities would be measured?

ii. What equipment would be used for the measurements, and how would that equipment be used?

iii. Describe the overall procedure to be used. Give enough detail so that another student could replicate the experiment.

PART B: Describe how the data from the measurements could be analyzed to determine the mass of the cart.

PART C: One group creates a position vs. time graph using a motion sensor as shown below. Explain how the group could use the graph to calculate the mass of the cart.



PART D: The actual mass of the cart is significantly less than the calculated mass in Part C. Give one reasonable physical explanation for the difference.

PART E: The group repeated their experiment from Part C but halved the distance they stretched the spring before releasing the cart. On the graph for Part C, sketch the position vs. time graph that this group can expect to see.

NAME ____________________ DATE ____________

Scenario

Dominique is given a bowling ball and informed that the ball is solid (not hollow) and is made of the same material throughout. Her online research indicates, however, that most bowling balls have materials of different densities in their core. Further research indicates that a solid sphere of mass M and radius R having uniform density has a rotational inertia $I = 0.4MR^2$. Dominique decides to experimentally measure the bowling ball's rotational inertia.

PART A: Dominique has access to a ramp, a meterstick, a stopwatch, an electronic balance, and several textbooks. In the space below, outline a procedure that she could follow to make measurements that can be used to determine the rotational inertia of the bowling ball. Give each measurement a meaningful algebraic symbol and be sure to explain how each piece of equipment is being used.

PART B: Derive an expression that could be used to determine the rotational inertia of the ball in terms of the symbols and measurements chosen above. Once your equation has the accepted symbols and measurements, you may stop.

PART C: Identify one assumption that you made about the system in your derivation above.

PART D: Dominique finds that the mass of the bowling ball is $7.0\ \mathrm{kg}$ and its radius is $0.1\ \mathrm{m}$. Upon being released from the top of a ramp $0.05\ \mathrm{m}$ high, the ball reaches a speed of $0.75\ \mathrm{m/s}$. Can she conclude that the ball is solid and made of uniformly dense material? Explain your reasoning and calculations.

PART E: The surface of the ramp is now changed so that the coefficient of friction is smaller so that the ball both rotates and slips down the incline. Indicate whether the total kinetic energy at the bottom of the ramp is greater than, less than, or equal to the kinetic energy at the bottom of the other ramp.

Greater than ________ Less than ________ The same as ________

Justify your choice.

PART F: Indicate whether the translational speed at the bottom of the incline is greater than, less than, or equal to the translational speed of the ball at the bottom of the other ramp.

Greater than ________ Less than ________ The same as ________