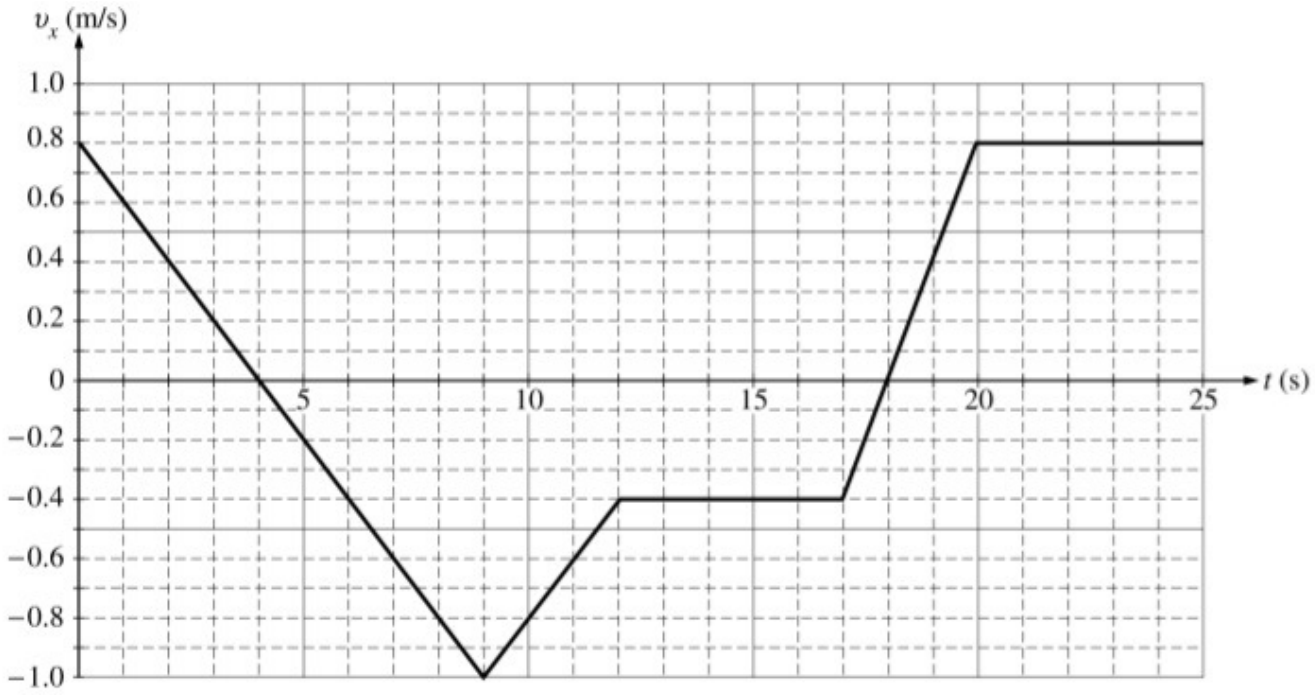
chapter1partd

1. A 0.50 kg cart moves on a straight horizontal track. The graph of velocity v_x versus time t for the cart is given below.



a. Indicate every time t for which the cart is at rest.

b. Indicate every time interval for which the speed (magnitude of velocity) of the cart is increasing.

c. Determine the horizontal position x of the cart at $t = 9.0$ s if the cart is located at $x = 2.0$ m at $t = 0$.

d. On the axes below, sketch the acceleration a *versus* time t graph for the motion of the cart from $t = 0$ to $t = 25$ s.

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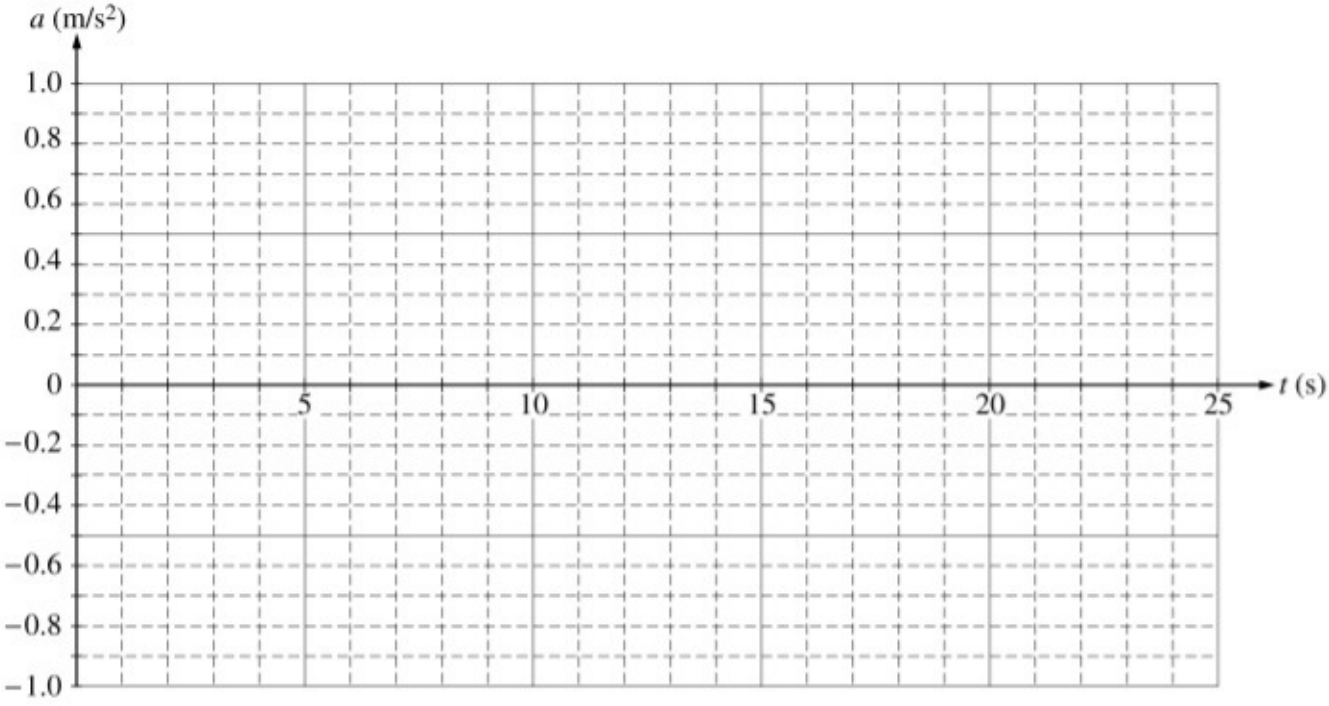

e. From $t = 25$ s until the cart reaches the end of the track, the cart continues with constant horizontal velocity. The cart leaves the end of the track and hits the floor, which is 0.40 m below the track. Neglecting air resistance, determine each of the following.

   i. The time from when the cart leaves the track until it first hits the floor

   ii. The horizontal distance from the end of the track to the point at which the cart first hits the floor

   iii. The kinetic energy of the cart immediately before it hits the floor

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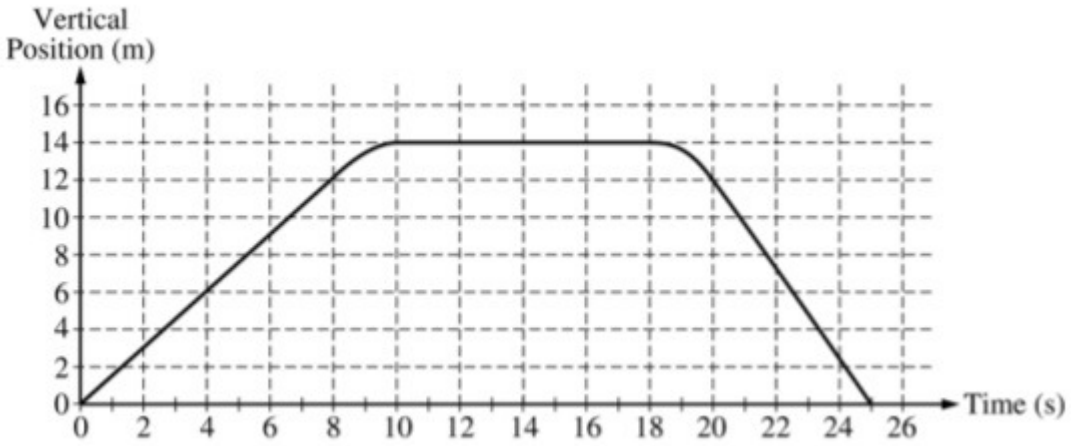
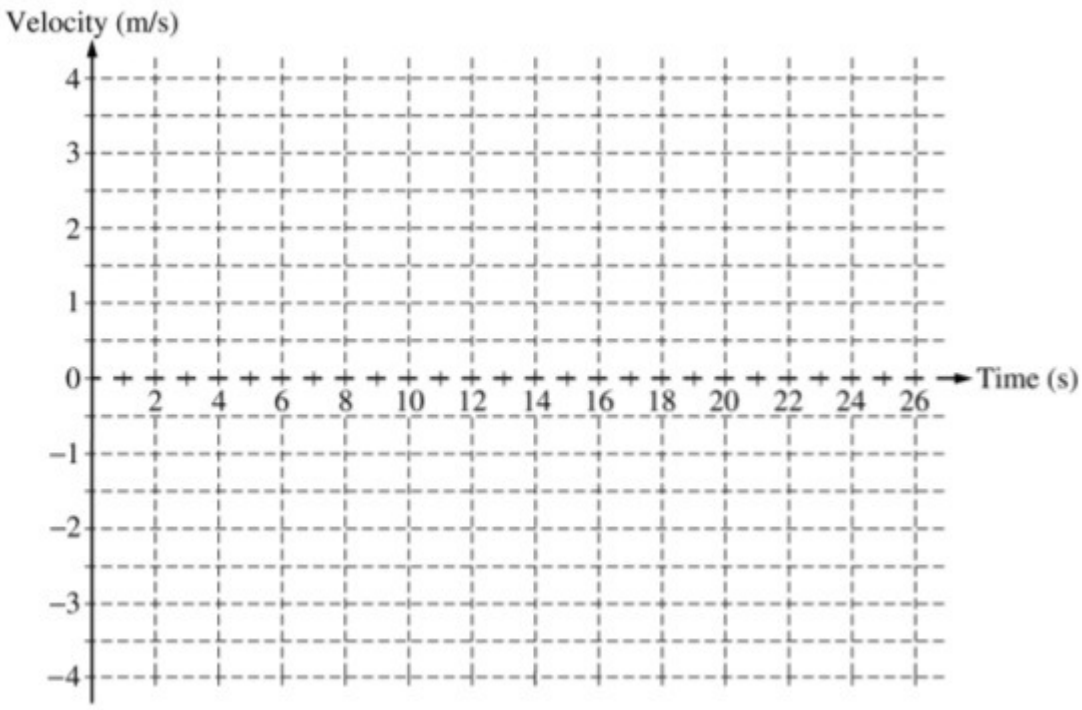
2.



The vertical position of an elevator as a function of time is shown above.

a. On the grid below, graph the velocity of the elevator as a function of time.



b. i. Calculate the average acceleration for the time period $t = 8$ s to $t = 10$ s.

ii. On the box below that represents the elevator, draw a vector to represent the direction of this average acceleration.



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c. Suppose that there is a passenger of mass 70 kg in the elevator. Calculate the apparent weight of the passenger at time $t = 4$ s.

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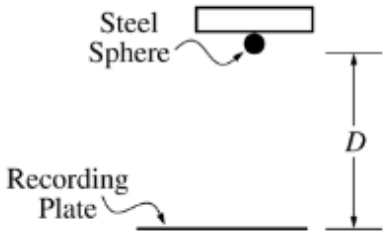
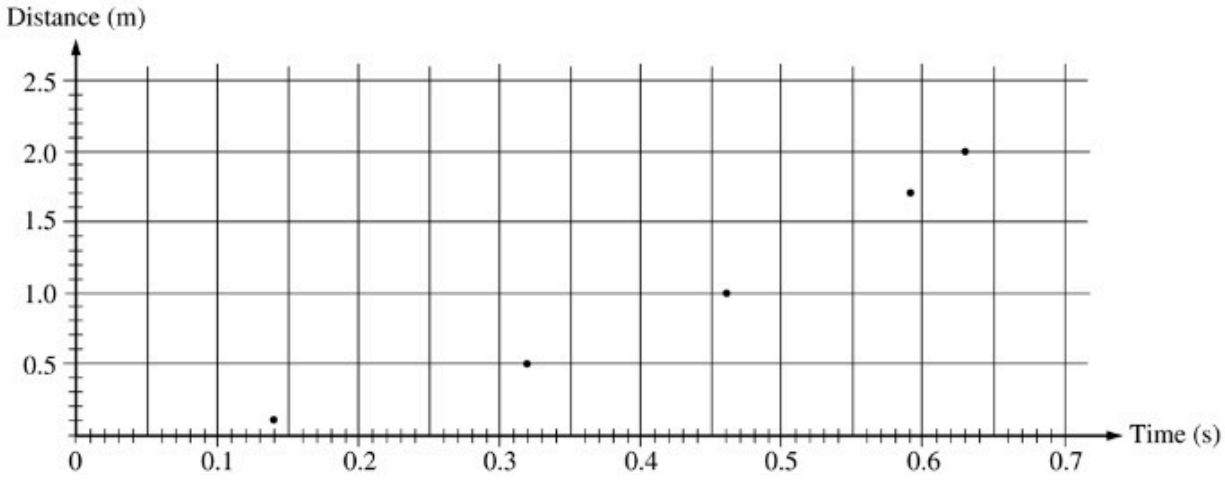
3.



A student wishing to determine experimentally the acceleration *g* due to gravity has an apparatus that holds a small steel sphere above a recording plate, as shown above. When the sphere is released, a timer automatically begins recording the time of fall. The timer automatically stops when the sphere strikes the recording plate. The student measures the time of fall for different values of the distance *D* shown above and records the data in the table below. These data points are also plotted on the graph.

Distance of Fall (m)	0.10	0.50	1.00	1.70	2.00
Time of Fall (s)	0.14	0.32	0.46	0.59	0.63



(a) On the grid above, sketch the smooth curve that best represents the student's data.

The student can use these data for distance *D* and time *t* to produce a second graph from which the acceleration *g* due to gravity can be determined.

(b) If only the variables *D* and *t* are used, what quantities should the student graph in order to produce a linear relationship between the two quantities?

(c) On the grid below, plot the data points for the quantities you have identified in part (b), and sketch the best straight-line fit to the points. Label your axes and show the scale that you have chosen for the graph.

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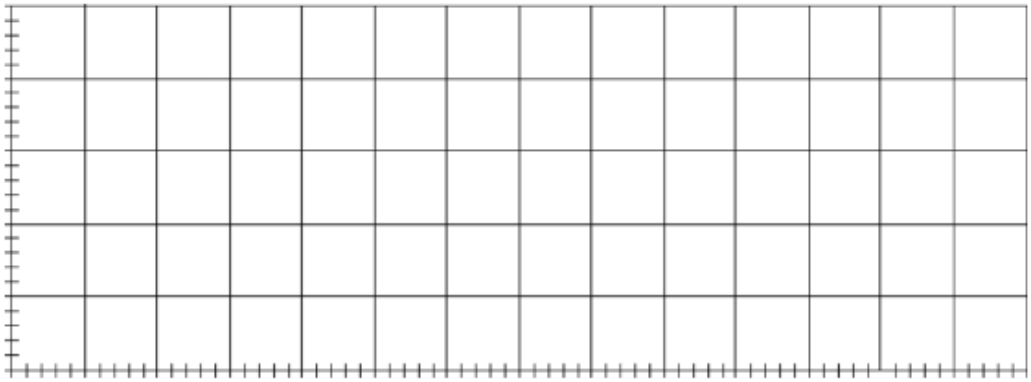

(d) Using the slope of your graph in part (c), calculate the acceleration *g* due to gravity in this experiment.

(e) State one way in which the student could improve the accuracy of the results if the experiment were to be performed again. Explain why this would improve the accuracy.

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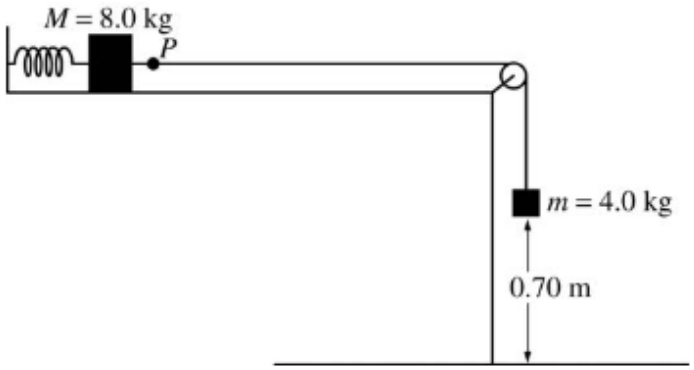
4.



An ideal spring of unstretched length 0.20 m is placed horizontally on a frictionless table as shown above. One end of the spring is fixed and the other end is attached to a block of mass M = 8.0 kg. The 8.0 kg block is also attached to a massless string that passes over a small frictionless pulley. A block of mass m = 4.0 kg hangs from the other end of the string. When this spring-and-blocks system is in equilibrium, the length of the spring is 0.25 m and the 4.0 kg block is 0.70 m above the floor.

(a) On the figures below, draw free-body diagrams showing and labeling the forces on each block when the system is in equilibrium.

M = 8.0 kg

m = 4.0 kg

(b) Calculate the tension in the string.

(c) Calculate the force constant of the spring.

The string is now cut at point P.

(d) Calculate the time taken by the 4.0 kg block to hit the floor.

(e) Calculate the frequency of oscillation of the 8.0 kg block.

(f) Calculate the maximum speed attained by the 8.0 kg block.

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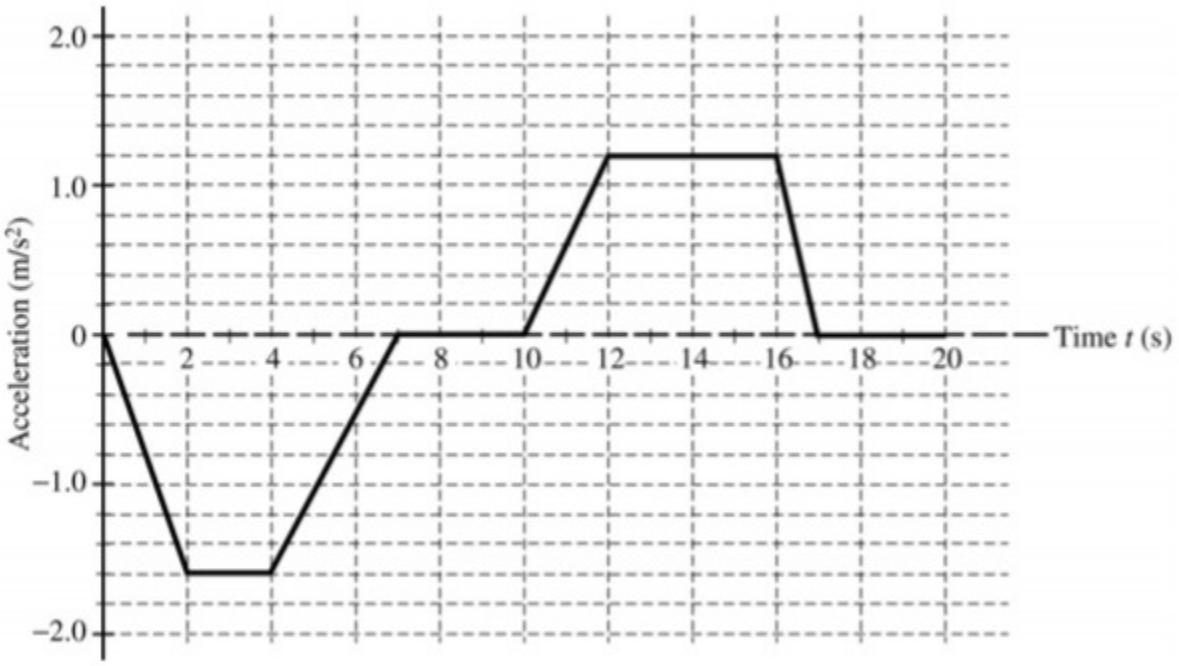
5. A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

a. Draw a free-body diagram showing and labeling all the forces acting on the student, who is represented by the dot below.



b. Derive an expression for the reading on the scale in terms of the acceleration *a* of the elevator, the mass *m* of the student, and fundamental constants.

An inspector provides the student with the following graph showing the acceleration a of the elevator as a function of time *t*.



c. i. During what time interval(s) is the force exerted by the platform scale on the student a maximum value?

ii. Calculate the magnitude of that maximum force for a 45 kg student.

d. During what time interval(s) is the speed of the elevator constant?

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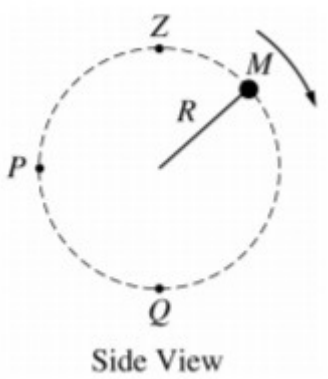
6.



A ball of mass M is attached to a string of length R and negligible mass. The ball moves clockwise in a vertical circle, as shown above. When the ball is at point P, the string is horizontal. Point Q is at the bottom of the circle and point Z is at the top of the circle. Air resistance is negligible. Express all algebraic answers in terms of the given quantities and fundamental constants.

a. On the figures below, draw and label all the forces exerted on the ball when it is at points P and Q, respectively.



b. Derive an expression for v_{min} , the minimum speed the ball can have at point Z without leaving the circular path.

c. The maximum tension the string can have without breaking is T_{max} . Derive an expression for v_{max}, the maximum speed the ball can have at point Q without breaking the string.

d. Suppose that the string breaks at the instant the ball is at point P. Describe the motion of the ball immediately after the string breaks.

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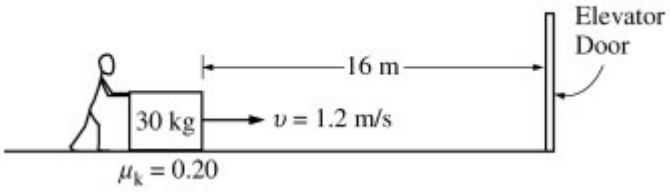
7.



Beginning at time $t = 0$, a student exerts a horizontal force on a box of mass 30 kg, causing it to move at 1.2 m/s toward an elevator door located 16 m away, as shown above. The coefficient of kinetic friction u_k between the box and the floor is 0.20.

(a) On the dot below that represents the box, draw and label the forces (not components) that act on the box as it moves at constant speed.

(b) Calculate the magnitude of the horizontal force the student must exert on the box in order to keep it moving at 1.2 m/s. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

At $t = 4.0$ s, the elevator door opens and remains open for 5.0 s. The student immediately exerts a larger constant force on the box and the front of the box reaches the elevator door just as it starts to close.

(c) Calculate the magnitude of the new force that the student exerts.

(d) On the axes below, sketch graphs of the acceleration a, velocity v, and position x of the box versus time t between $t = 0$ and the time the front of the box reaches the elevator.

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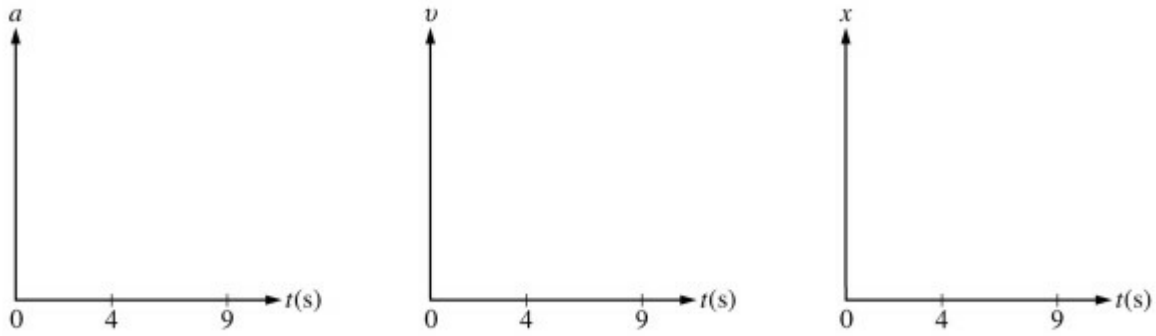

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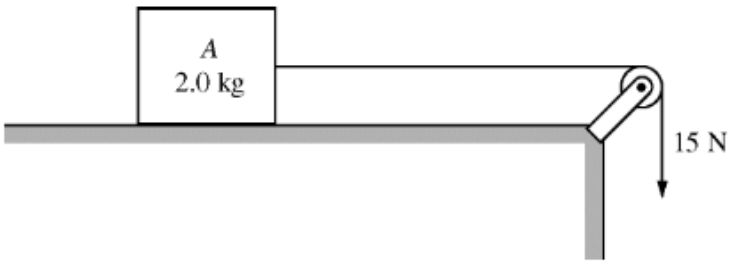
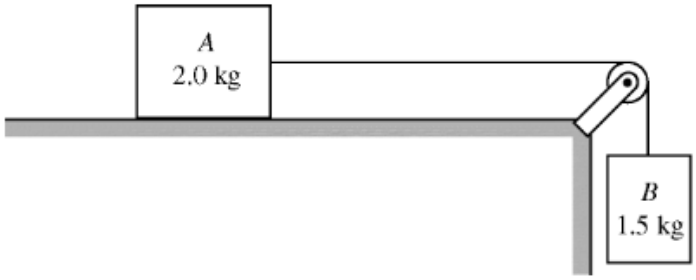
8.



Block *A* of mass 2.0 kg is pulled along a horizontal table by a force of 15 N, which is applied by a light string that passes over a light frictionless pulley, as shown above. The coefficient of kinetic friction between the block and the surface is 0.25.

(a) On the dot below, which represents the block, draw and label the forces (not components) that act on the block as it is pulled across the table.

(b) Calculate the magnitude of the acceleration of the block.



The applied force is removed. Block *B* of mass 1.5 kg is now attached to the string, as shown above. The system is released from rest so that the 1.5 kg box descends and the 2.0 kg block is again pulled across the table.

(c) Calculate the acceleration of the 1.5 kg block as it descends.

(d) Calculate the tension in the string connecting the two blocks.

(e) Calculate the distance that the 1.5 kg block descends in 0.40 s.

(f) If this system is set up in a laboratory and the acceleration of the 1.5 kg block is experimentally determined, the

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experimental value is found to be smaller than the value calculated above. If the given value for the coefficient of friction is correct and air resistance is negligible, explain briefly, but specifically, why the experimental value of the acceleration is smaller.

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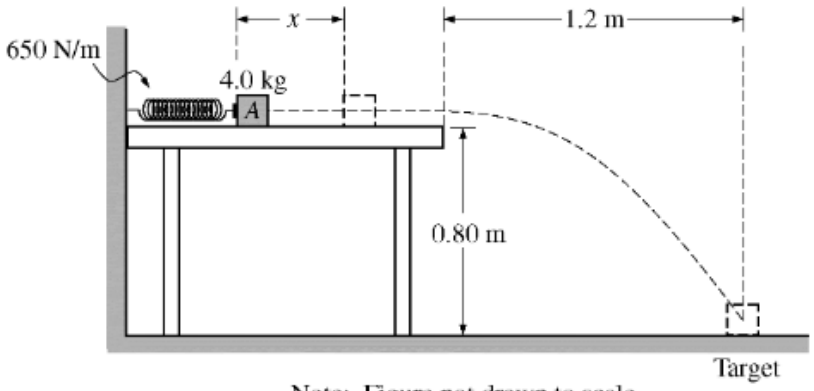
9.



Note: Figure not drawn to scale.

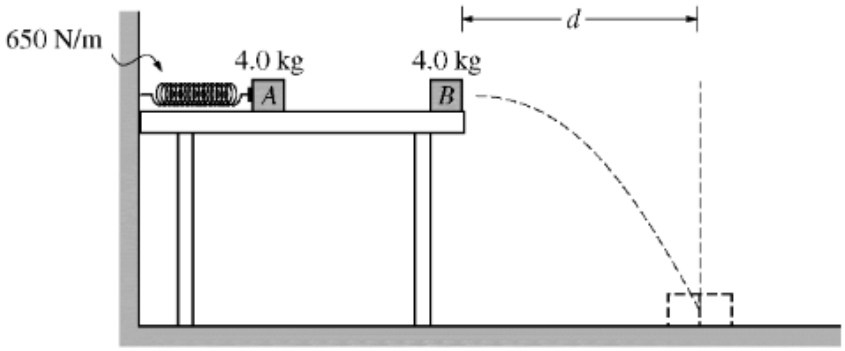
Block A of mass 4.0 kg is on a horizontal, frictionless tabletop and is placed against a spring of negligible mass and spring constant 650 N m. The other end of the spring is attached to a wall. The block is pushed toward the wall until the spring has been compressed a distance x, as shown above. The block is released and follows the trajectory shown, falling 0.80 m vertically and striking a target on the floor that is a horizontal distance of 1.2 m from the edge of the table. Air resistance is negligible.

(a) Calculate the time elapsed from the instant block A leaves the table to the instant it strikes the floor.

(b) Calculate the speed of the block as it leaves the table.

(c) Calculate the distance x the spring was compressed.

Block B, also of mass 4.0 kg, is now placed at the edge of the table. The spring is again compressed a distance x, and block A is released. As it nears the end of the table, it instantaneously collides with and sticks to block B. The blocks follow the trajectory shown in the figure below and strike the floor at a horizontal distance d from the edge of the table.



Note: Figure not drawn to scale.

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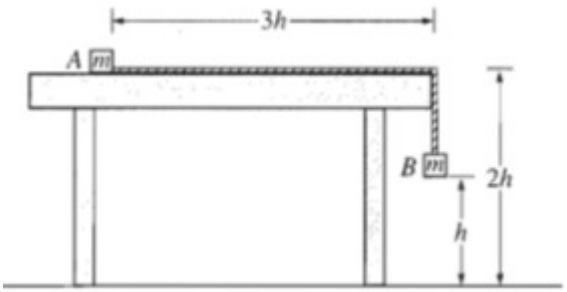
(d) Calculate d if x is equal to the value determined in part (c).

(e) Consider the system consisting of the spring, the blocks, and the table. How does the total mechanical energy E_2 of the system just before the blocks leave the table compare to the total mechanical energy E_1 of the system just before block A is released?

____ $E_1 < E_2$ ____ $E_2 = E_1$ ____ $E_2 > E_1$

Justify your answer.

10.



Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

(e) Determine the distance between the landing points of the two blocks.

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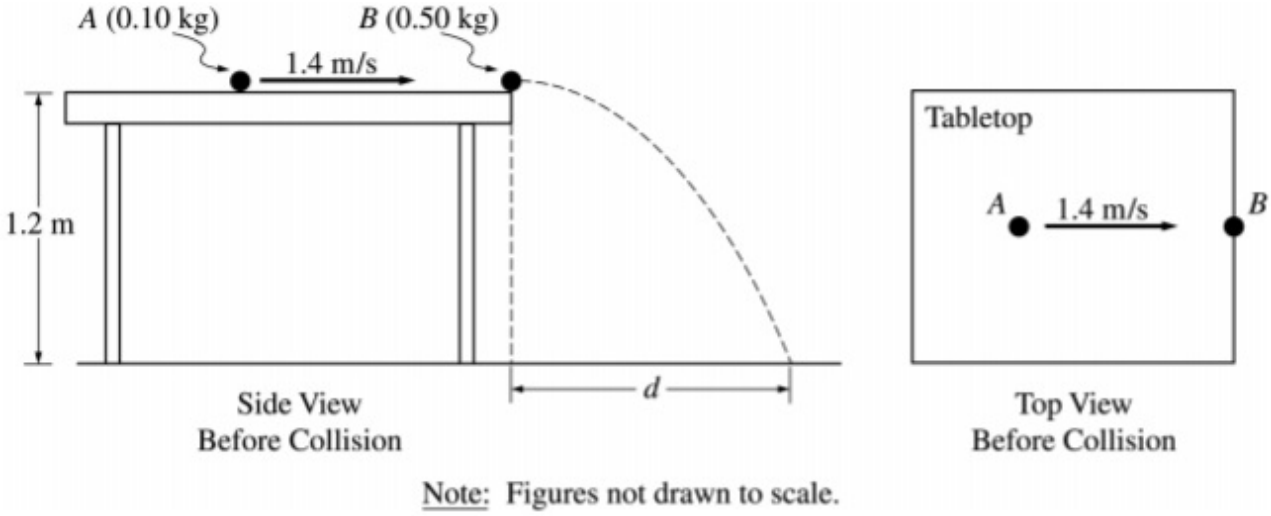
11.

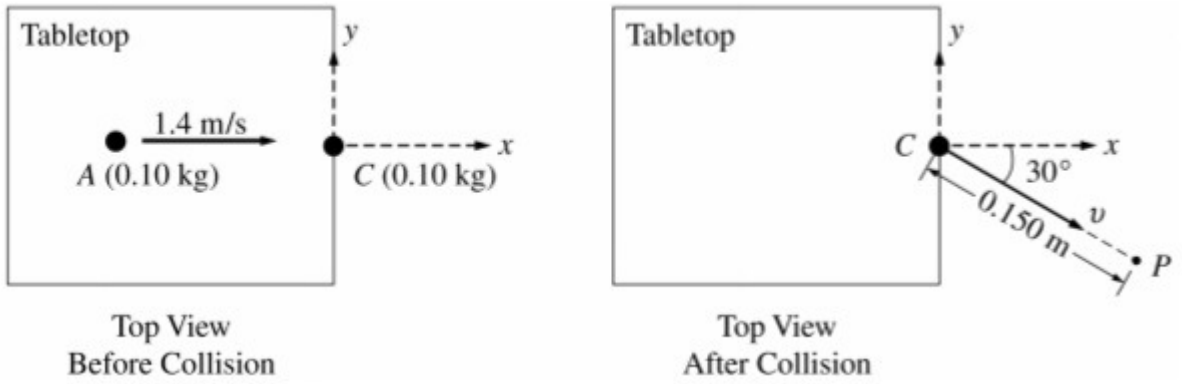


An incident ball *A* of mass 0.10 kg is sliding at 1.4 m/s on the horizontal tabletop of negligible friction shown above. It makes a head-on collision with a target ball *B* of mass 0.50 kg at rest at the edge of the table. As a result of the collision, the incident ball rebounds, sliding backwards at 0.70 m/s immediately after the collision.

a. Calculate the speed of the 0.50 kg target ball immediately after the collision.

The tabletop is 1.20 m above a level, horizontal floor. The target ball is projected horizontally and initially strikes the floor at a horizontal displacement *d* from the point of collision.

b. Calculate the horizontal displacement *d*.



In another experiment on the same table, the target ball *B* is replaced by target ball *C* of mass 0.10 kg. The incident ball *A* again slides at 1.4 m/s, as shown above left, but this time makes a glancing collision with the target ball *C* that is at rest at the edge of the table. The target ball *C* strikes the floor at point *P*, which is at a horizontal displacement of 0.15 m from the point of the collision, and at a horizontal angle of 30° from the +*x*-axis, as shown above right.

c. Calculate the speed *v* of the target ball *C* immediately after the collision.

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d. Calculate the *y*-component of incident ball *A*'s momentum immediately after the collision.

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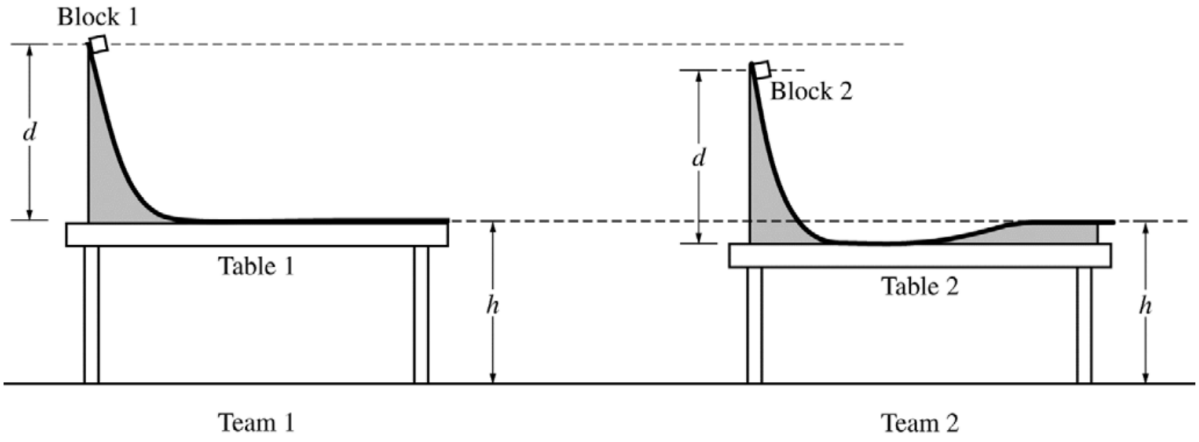
12.



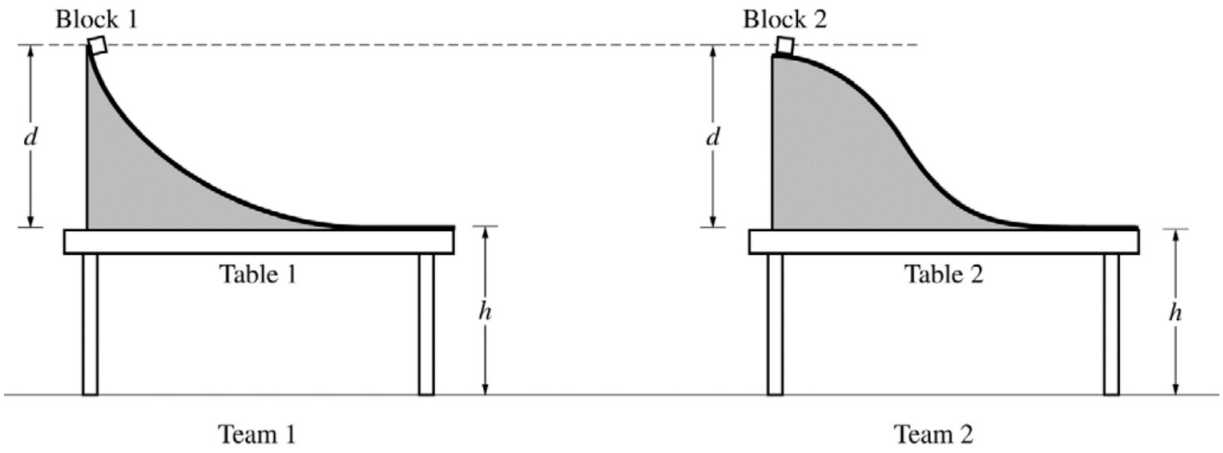
A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

a. Both blocks are released from rest at the top of their respective slides. Do block 1 and block 2 land the same distance from their respective tables?

_____Yes _____No

Justify your answer.

In another experiment, teams 1 and 2 use tables and low-friction slides with the same height. However, the two slides have different shapes, as shown below.



b. Both blocks are released from rest at the top of their respective slides at the same time.

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i. Which block, if either, lands farther from its respective table?

_____Block 1 _____ Block 2 ____ The two blocks land the same distance from their respective tables.

Briefly explain your reasoning without manipulating equations.

ii. Which block, if either, hits the floor first?

_____Block 1 _____ Block 2_____The two blocks hit the floor at the same time.

Briefly explain your reasoning without manipulating equations.

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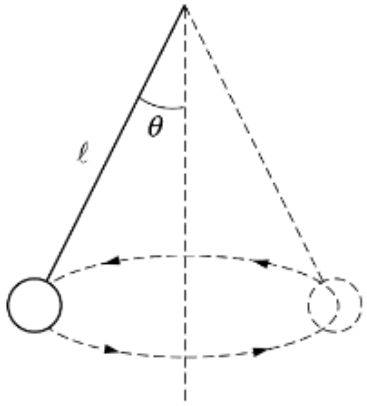
13.



A ball attached to a string of length l swings in a horizontal circle, as shown above, with a constant speed. The string makes an angle θ with the vertical, and T is the magnitude of the tension in the string. Express your answers to the following in terms of the given quantities and fundamental constants.

a. On the figure below, draw and label vectors to represent all the forces acting on the ball when it is at the position shown in the diagram. The lengths of the vectors should be consistent with the relative magnitudes of the forces.



b. Determine the mass of the ball.

c. Determine the speed of the ball.

d. Determine the frequency of revolution of the ball.

e. Suppose that the string breaks as the ball swings in its circular path. Qualitatively describe the trajectory of the ball after the string breaks but before it hits the ground.

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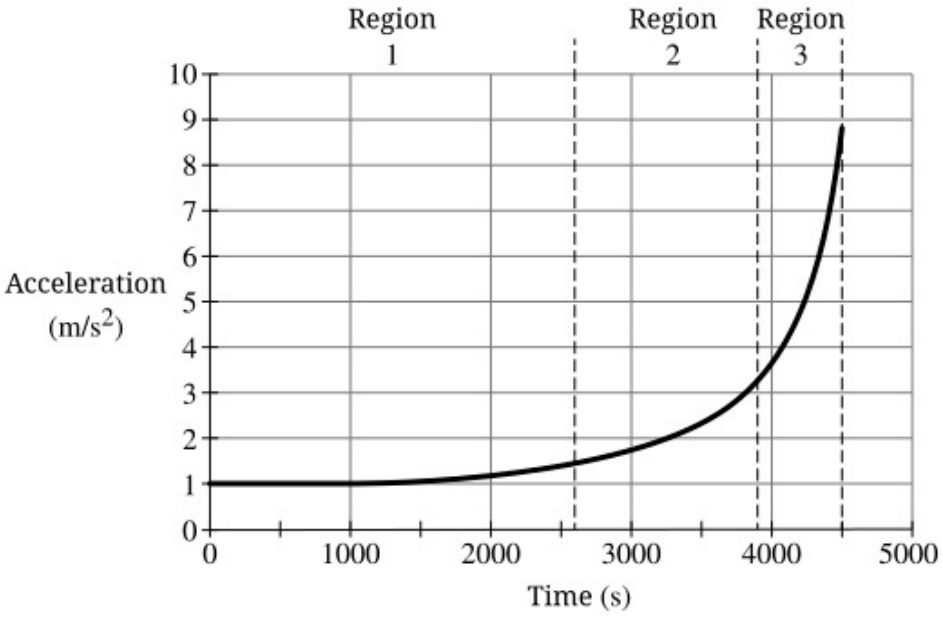
14. This question is a short free-response question. Show your work for each part of the question.



(7 points, suggested time 13 minutes)

An object is released from high above the surface of Planet A, which does not have an atmosphere. The object falls toward the surface of Planet A due to the gravitational field of Planet A only. The graph shows the magnitude of the acceleration of the object as a function of time until the object reaches the surface of the planet. The area bound by the curve and the horizontal axis is the same for regions 1, 2, and 3.

(a) The object is released from rest at time $t = 0\ \mathrm{s}$ and reaches the surface of the planet at time $t = 4500\ \mathrm{s}$.

i. In addition to the information provided by the graph, which one of the following quantities is needed to calculate the magnitude of the net force exerted by the planet on the object?

____ Mass of the planet ____ Radius of the planet

____ Mass of the object ____ Initial height of the object

ii. Determine the ratio of the gravitational force exerted on the object by Planet A at time $t = 4500\ \mathrm{s}$ to the gravitational force exerted on the object by Planet A at time $t = 2600\ \mathrm{s}$.

(b) Determine the ratio of the speed of the object at time $t = 4500\ \mathrm{s}$ to the speed of the object at time $t = 2600\ \mathrm{s}$.
Briefly justify your answer.

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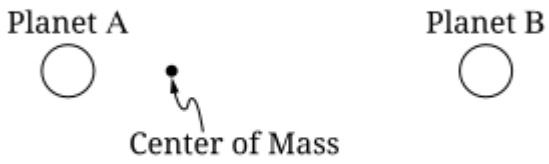
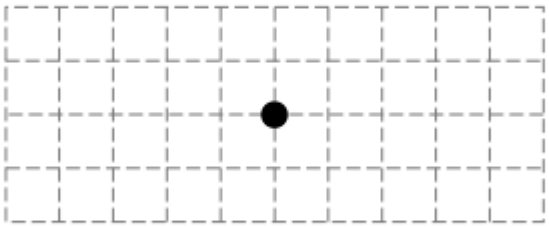


(c) At a later time, the object is launched from the surface of Planet A so that it travels to Planet B. The diagram shows Planet A, Planet B, and the center of mass of the two-planet system. The motion of each planet is negligible.

i. On the following dot, which represents the object, draw and label the gravitational forces F_A and F_B (not components) exerted by Planet A and Planet B, respectively, on the object when the object is at the center of mass of the system. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Relative magnitudes of the forces must be indicated but not necessarily drawn to scale.



ii. As the object passes through the center of mass of the system, is the speed of the object increasing, decreasing, or remaining the same? Justify your answer.

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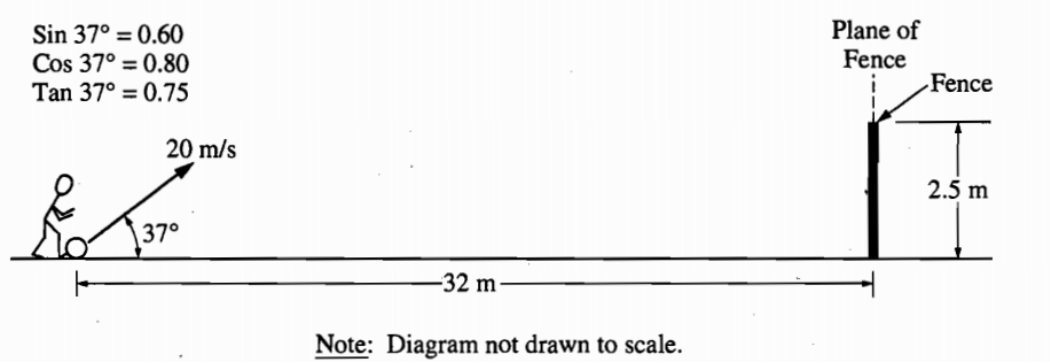
15.



A ball of mass 0.5 kilogram, initially at rest, is kicked directly toward a fence from a point 32 meters away, as shown above. The velocity of the ball as it leaves the kicker's foot is 20 meters per second at a angle of 37° above the horizontal. The top of the fence is 2.5 meters high. The kicker's foot is in contact with the ball for 0.05 second. The ball hits nothing while in flight and air resistance is negligible.

(a) Determine the magnitude of the average net force exerted on the ball during the kick.

(b) Determine the time it takes for the ball to reach the plane of the fence.

(c) Will the ball hit the fence? If so, how far below the top of the fence will it hit? If not, how far above the top of the fence will it pass?

(d) On the axes below, sketch the horizontal and vertical components of the velocity of the ball as functions of time until the ball reaches the plane of the fence.

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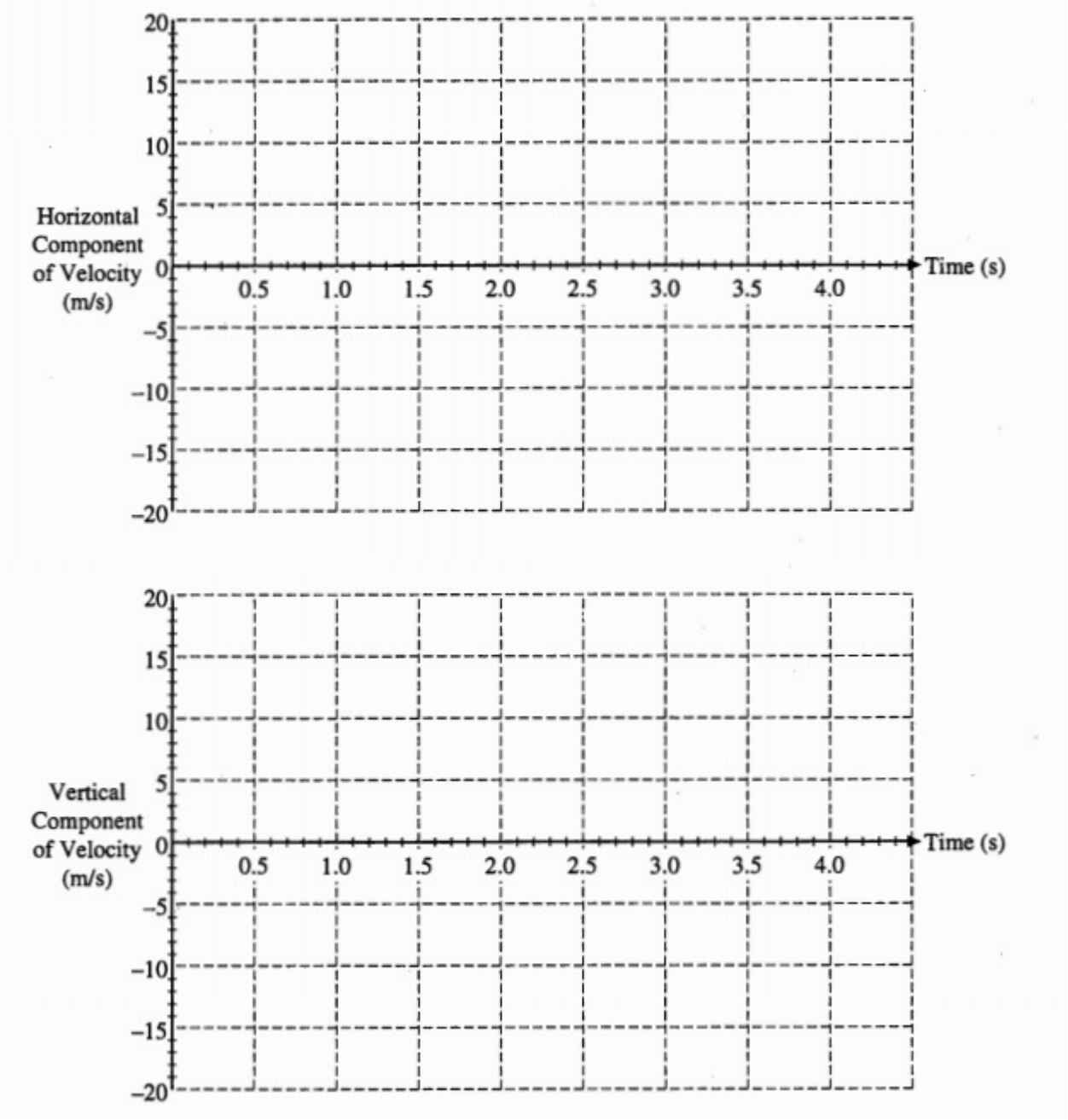

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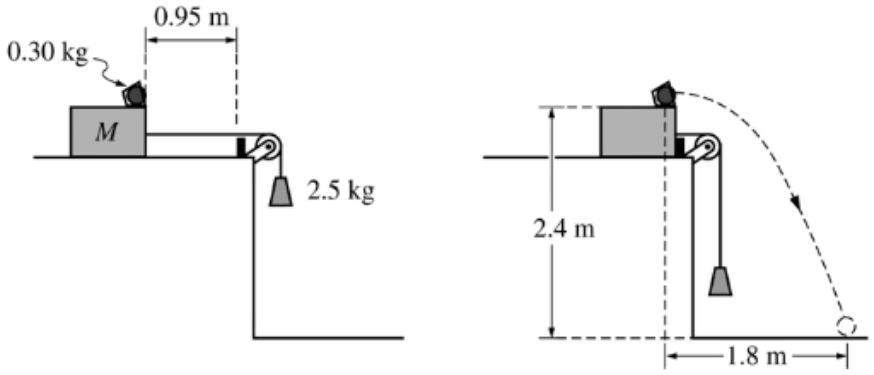
16.



A 0.30 kg ball is in a cup of negligible mass attached to a block of mass M that is on a table. A string passing over a light pulley connects the block to a 2.5 kg object, as shown above. The system is released from rest, the block accelerates to the right, and after moving 0.95 m the block collides with a bumper near the end of the table. The ball continues to move and lands on the floor at a position 2.4 m below and 1.8 m horizontally from where it leaves the cup. Assume all friction is negligible.

(a) Calculate the speed of the ball just after the block hits the bumper and the ball leaves the cup.

(b) Calculate the magnitude of the acceleration of the block as it moves across the table.

(c) Calculate the mass *M* of the block.

(d) If the mass of the ball is increased, the horizontal distance it travels before hitting the floor will decrease. Explain why this will happen.

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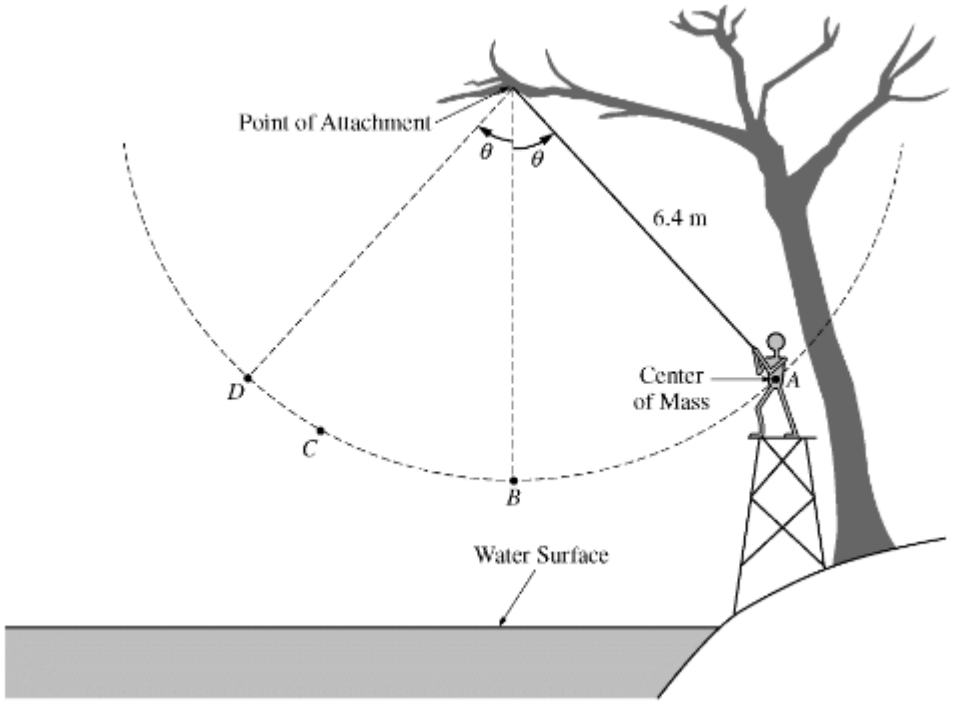
17.



Starting from rest at point A, a 50 kg person swings along a circular arc from a rope attached to a tree branch over a lake, as shown in the figure above. Point D is at the same height as point A. The distance from the point of attachment to the center of mass of the person is 6.4 m. Ignore air resistance and the mass and elasticity of the rope.

(a) The person swings two times, each time letting go of the rope at a different point.

i. On the first swing, the person lets go of the rope when first arriving at point C. Draw a solid line to represent the trajectory of the center of mass after the person releases the rope.

ii. A second time, the person lets go of the rope at point D. Draw a dashed line to represent the trajectory of the center of mass after the person releases the rope.

(b) The center of mass of the person standing on the platform is at point A, 4.1 m above the surface of the water. Calculate the gravitational potential energy when the person is at point A relative to when the person is at the surface of the water.

(c) The center of mass of the person at point B, the lowest point along the arc, is 2.4 m above the surface of the water. Calculate the person's speed at point B.

(d) Suppose that the person swings from the rope a third time, letting go of the rope at point B. Calculate R, the horizontal distance moved from where the person releases the rope at point B to where the person hits the water.

(e) If the person does not let go of the rope, how does the magnitude of the person's momentum p_C at point C compare with the magnitude of the person's momentum p_B at point B ?

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_____ $p_C > p_B$ _____ $p_C < p_B$ _____ $p_C = p_B$

Provide a physical explanation to justify your answer.

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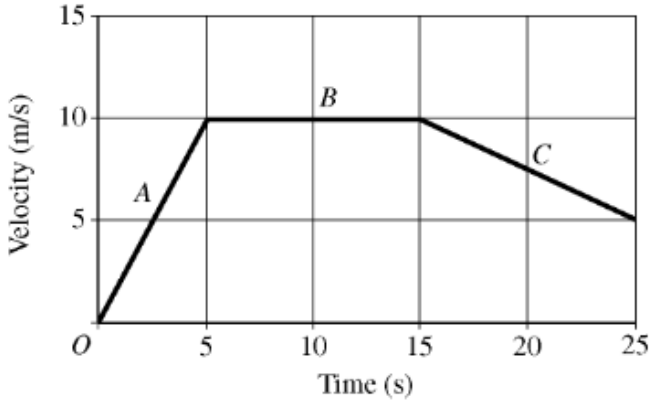
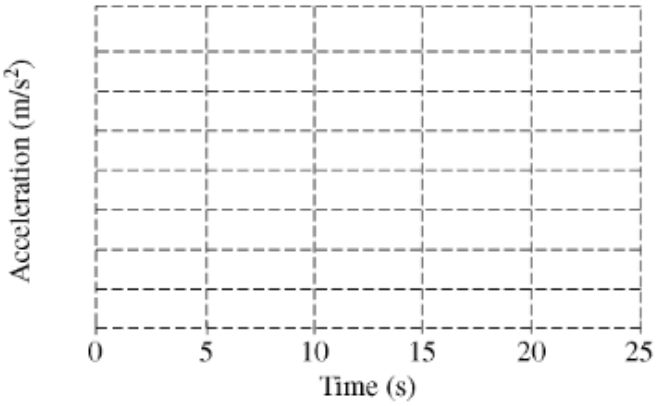
18.



A 0.40 kg object moves in a straight line under the action of a net force. The graph above shows the velocity as a function of time for the object during a 25 s interval. At time $t = 0$, the object is at the position $x = 0$.

(a) On the grid below, sketch a graph of the acceleration as a function of time for the object. Label the scale for the acceleration.



(b) Calculate the position of the object at t = 5.0 s.

(c) On which segment of the graph is the net force acting on the object zero?

____ A ____ B ____ C

Justify your answer.

(d) Calculate the net force on the object during the first 3.0 s of the motion.

(e) Calculate the amount of work done on the object by the net force during the first 15 s of the motion.

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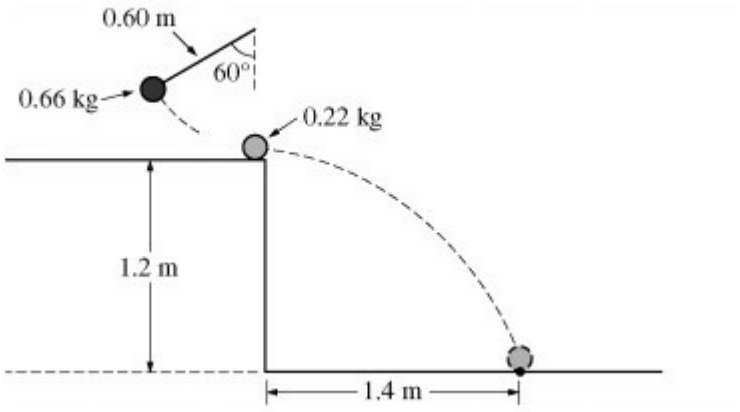
(f) For the interval t = 15 s to t = 25 s, is the work done on the object by the net force positive, negative, or zero?

____ Positive ____ Negative ____ Zero

Justify your answer.

19.



The experimental apparatus shown in the figure above contains a pendulum consisting of a 0.66 kg ball attached to a string of length 0.60 m. The pendulum is released from rest at an angle of 60 degrees and collides with a ball of mass 0.22 kg initially at rest at the edge of a table. The 0.22 kg ball hits the floor a distance of 1.4 m from the edge of the table.

a. Calculate the speed of the 0.66 kg ball just before the collision.

b. Calculate the speed of the 0.22 kg ball immediately after the collision.

c. Calculate the speed of the 0.66 kg ball immediately after the collision.

d. Indicate the direction of motion of the 0.66 kg ball immediately after the collision.

____ To the left ____ To the right

e. Calculate the height to which the 0.66 kg ball rises after the collision.

f. Based on your data, is the collision elastic?

____ Yes ____ No

Justify your answer.

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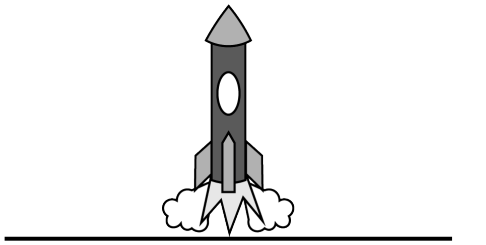
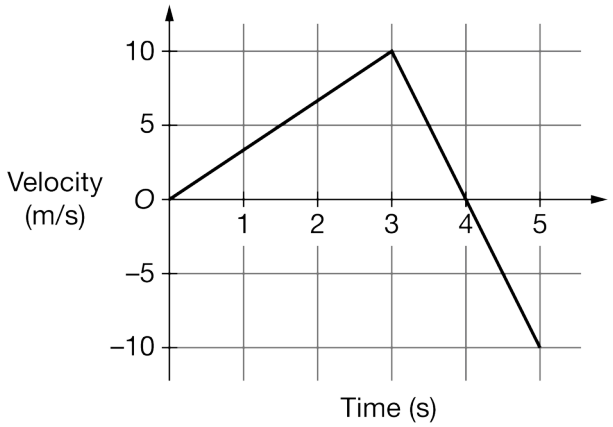
20. This question is a short free-response question. Show your work for each part of the question.



Time $t = 0$: Rocket Engine Ignites

(7 points, suggested time 13 minutes)

A model rocket of constant mass $0.5\ \text{kg}$ is launched vertically at time $t = 0$. The rocket's engine provides a constant force of magnitude F_0 for three seconds and then stops firing. The vertical velocity of the rocket as a function of time for the first 5 seconds of the flight is shown in the graph below.



(a) Calculate F_0.

(b) Calculate the time at which the rocket hits Earth after being launched.

(c) On the axes below, sketch a graph of the vertical position of the rocket as a function of time for the first 5 seconds of the flight.

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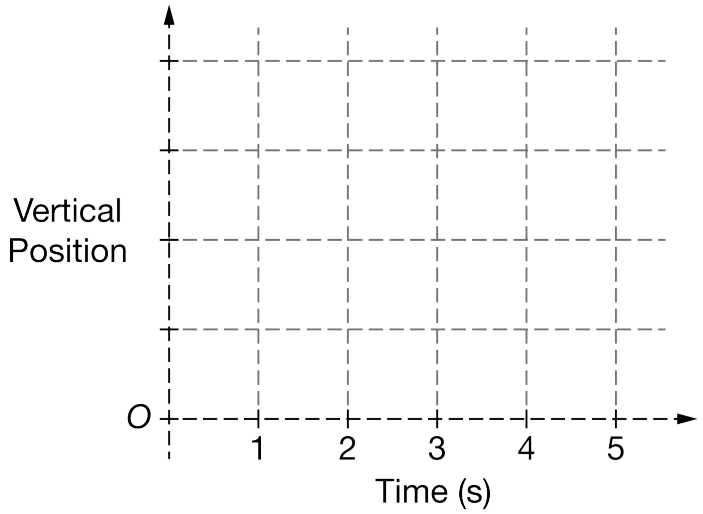

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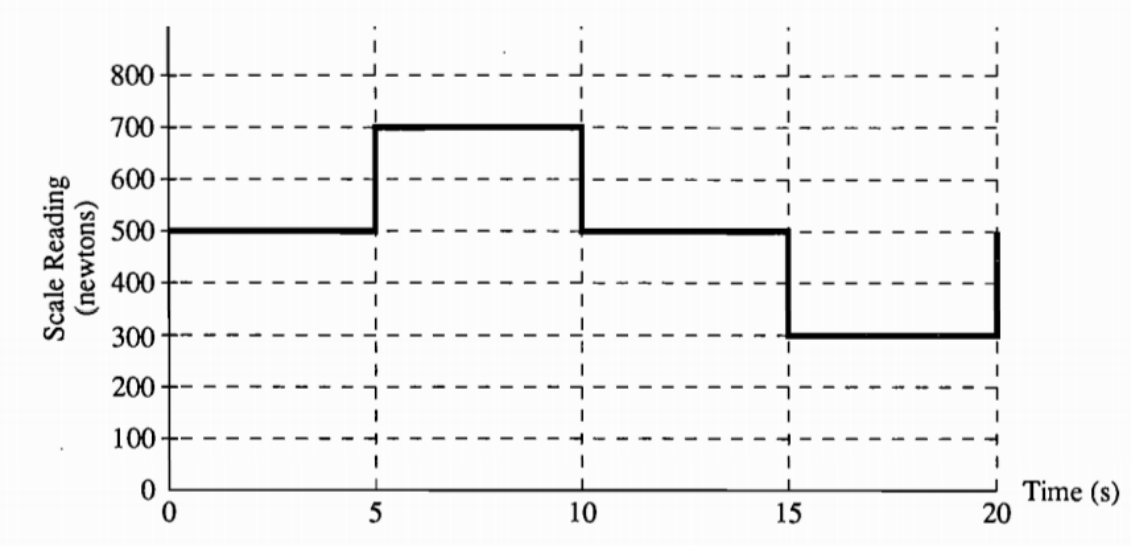
21.



A student whose normal weight is 500 newtons stands on a scale in an elevator and records the scale reading as a function of time. The data are shown in the graph above. At time t = 0, the elevator is at displacement x = 0 with velocity v = 0. Assume that the positive directions for displacement, velocity, and acceleration are upward.

(a) On the diagram to the right,draw and label of the forces on the student at t = 8 seconds.



(b) Calculate the acceleration a of the elevator for each 5-second interval.

i. Indicate your results by completing the following table.

Time interval(s)	0-5	5-10	10-15	15-20
a(m/s^2)	____	____	____	____

ii. Plot the acceleration as a function of time on the following graph

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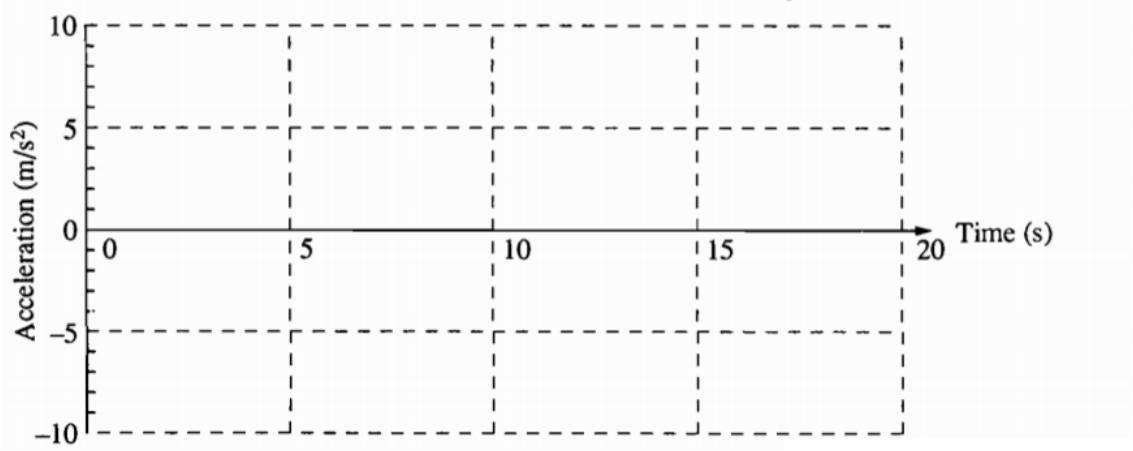
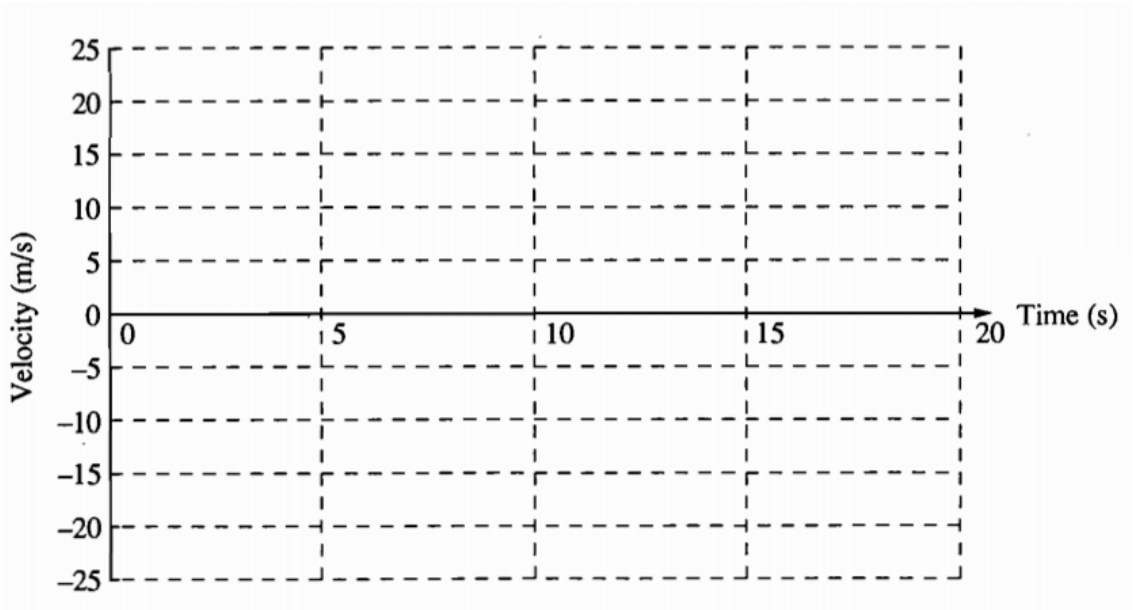


(c) Determine the velocity *v* of the elevator at the end of each 5-second interval.

i. Indicate your results by completing the following table

Time interval(s)	5	10	15	20
v(m/s)	____	____	____	____

ii. Plot the velocity as a function of time on the following graph.



(d) Determine the displacement *x* of the elevator above the starting point at the end of each 5-second interval.

i. Indicate your results by completing the following table

Time interval(s)	5	10	15	20
x(m)	____	____	____	____

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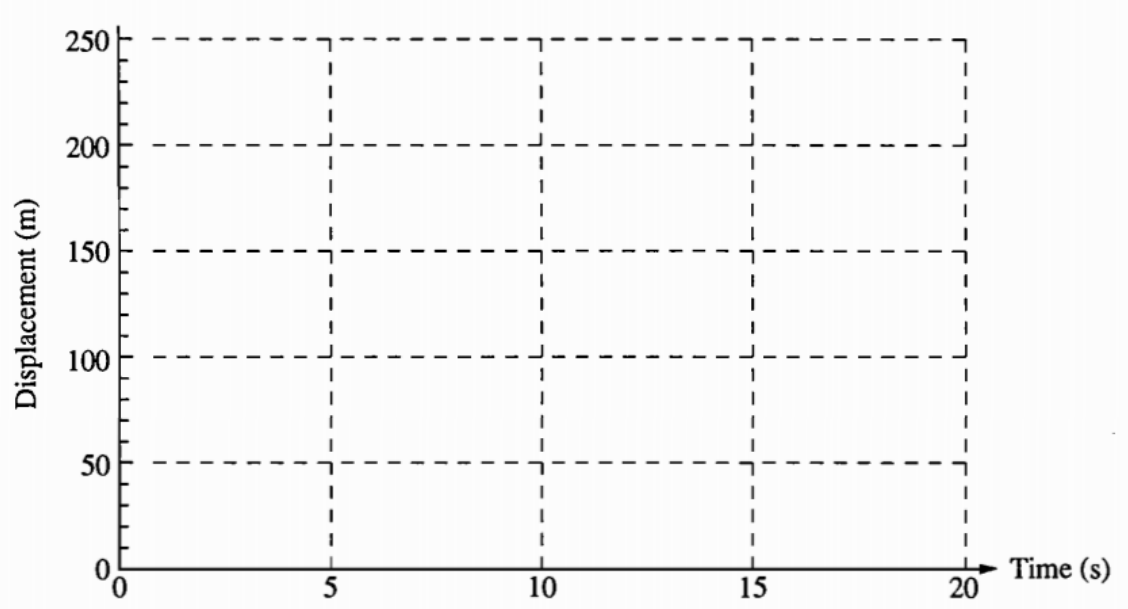
ii. Plot the displacement as a function of time on the following graph.



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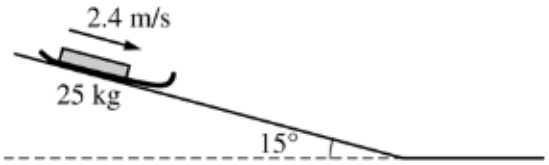
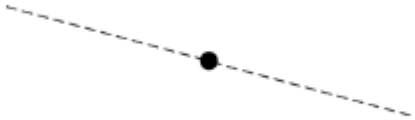
22.



An empty sled of mass 25 kg slides down a muddy hill with a constant speed of 2.4 m/s. The slope of the hill is inclined at an angle of 15° with the horizontal as shown in the figure above.

(a) Calculate the time it takes the sled to go 21 m down the slope.

(b) On the dot below that represents the sled, draw and label a free-body diagram for the sled as it slides down the slope.



(c) Calculate the frictional force on the sled as it slides down the slope.

(d) Calculate the coefficient of friction between the sled and the muddy surface of the slope.

(e) The sled reaches the bottom of the slope and continues on the horizontal ground. Assume the same coefficient of friction.

i. In terms of velocity and acceleration, describe the motion of the sled as it travels on the horizontal ground.

ii. On the axes below, sketch a graph of speed *v* versus time *t* for the sled. Include both the sled's travel down the slope and across the horizontal ground. Clearly indicate with the symbol t_l the time at which the sled leaves the slope.

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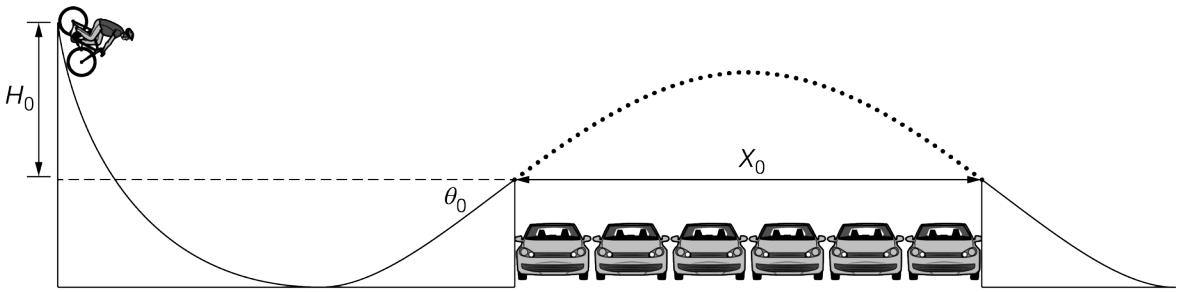
chapter1partd

23. This question is a short free-response question. Show your work for each part of the question.



Note: Figure not drawn to scale.

(7 points, suggested time 13 minutes)

A stunt cyclist builds a ramp that will allow the cyclist to coast down the ramp and jump over several parked cars, as shown above. To test the ramp, the cyclist starts from rest at the top of the ramp, then leaves the ramp, jumps over six cars, and lands on a second ramp.

H_0 is the vertical distance between the top of the first ramp and the launch point.
θ_0 is the angle of the ramp at the launch point from the horizontal.
X_0 is the horizontal distance traveled while the cyclist and bicycle are in the air.
m_0 is the combined mass of the stunt cyclist and bicycle.

(a) Derive an expression for the distance X_0 in terms of H_0, θ_0, m_0, and physical constants, as appropriate.

(b) If the vertical distance between the top of the first ramp and the launch point were $2H_0$ instead of H_0, with no other changes to the first ramp, what is the maximum number of cars that the stunt cyclist could jump over?

Justify your answer, using the expression you derived in part (a).

(c) On the axes below, sketch a graph of the vertical component of the stunt cyclist's velocity as a function of time from immediately after the cyclist leaves the ramp to immediately before the cyclist lands on the second ramp. On the vertical axis, clearly indicate the initial and final vertical velocity components in terms of H_0, θ_0, m_0, and physical constants, as appropriate. Take the positive direction to be upward.

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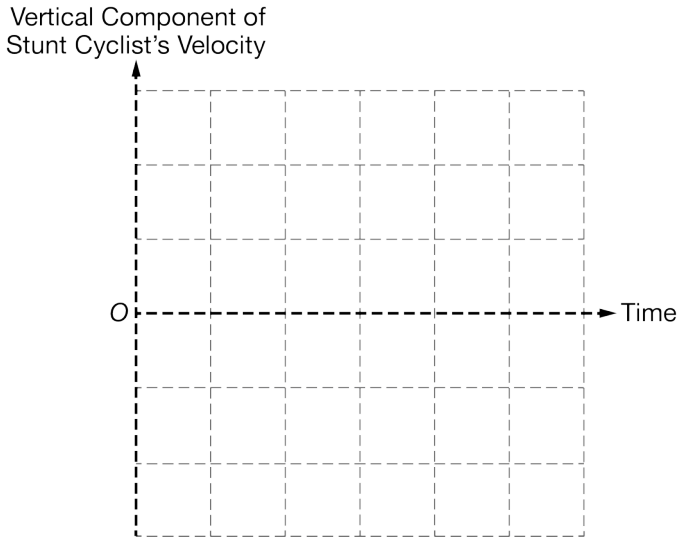
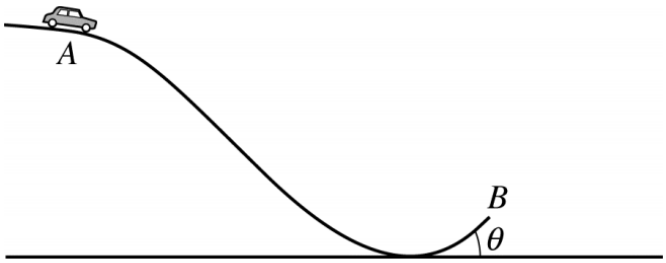


24.



A toy car coasts along the curved track shown above. The car has initial speed v_A when it is at point *A* at the top of the track, and the car leaves the track at point *B* with speed v_B at an angle θ above the horizontal. Assume that the rotational kinetic energy of the car's wheels and energy losses due to friction are both negligible.

a. Suppose the toy car is released from rest at point *A* ($v_A = 0$).

   i. After the car leaves the track and reaches the highest point in its trajectory it will be at a different height than it was at point *A*. Briefly explain why this is so.

   ii. Determine the speed of the car when it is at the highest point in its trajectory after leaving the track, in terms of v_B and θ. Briefly explain how you arrived at your answer.

b. Suppose the toy car is given an initial push so that it has nonzero speed at point *A*. Determine the speed Av of the car at point *A* such that the highest point in its trajectory after leaving the track is the same as its height at point *A*. Express your answer in terms of v_B and θ. Explain how you arrived at your answer.

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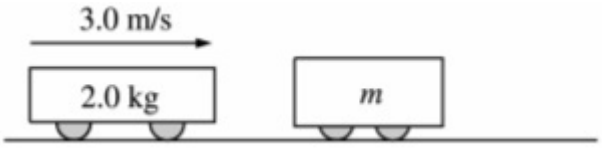
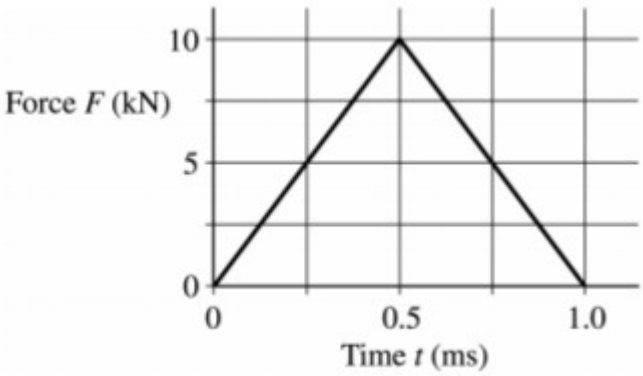
25.



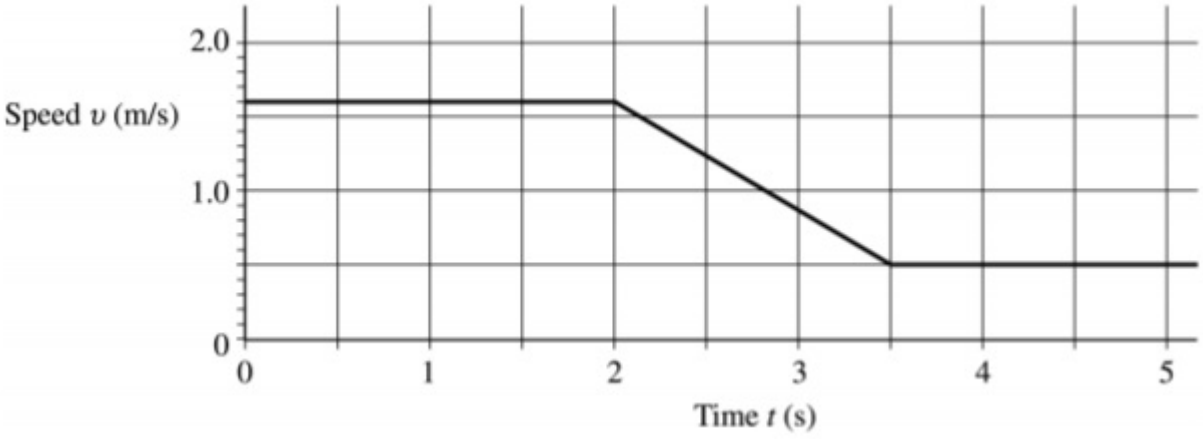
A 2.0 kg frictionless cart is moving at a constant speed of 3.0 m/s to the right on a horizontal surface, as shown above, when it collides with a second cart of undetermined mass m that is initially at rest. The force F of the collision as a function of time t is shown in the graph below, where $t = 0$ is the instant of initial contact. As a result of the collision, the second cart acquires a speed of 1.6 m/s to the right. Assume that friction is negligible before, during, and after the collision.



a. Calculate the magnitude and direction of the velocity of the 2.0 kg cart after the collision.

b. Calculate the mass m of the second cart.

After the collision, the second cart eventually experiences a ramp, which it traverses with no frictional losses. The graph below shows the speed v of the second cart as a function of time t for the next 5.0 s, where $t = 0$ is now the instant at which the carts separate.



c. Calculate the acceleration of the cart at $t = 3.0$ s.

d. Calculate the distance traveled by the second cart during the 5.0 s interval after the collision (0 s < t < 5.0 s).

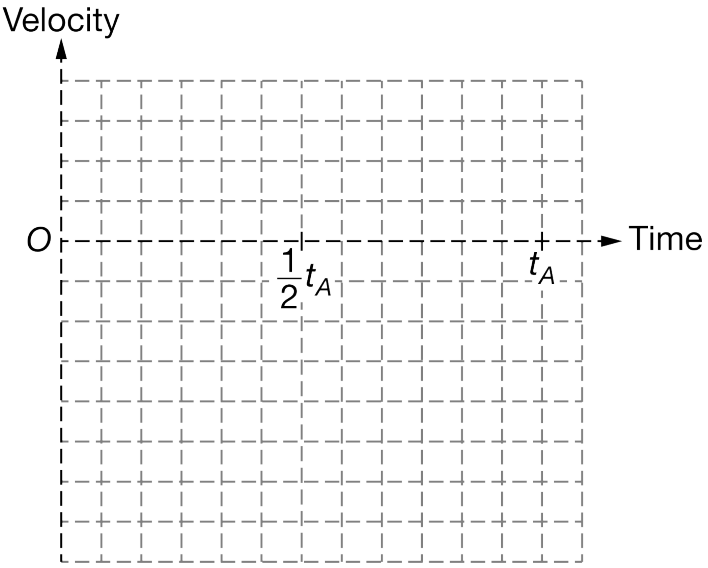
e. State whether the ramp goes up or down and calculate the maximum elevation (above or below the initial height) reached by the second cart on the ramp during the 5.0 s interval after the collision (0 s < t < 5.0 s).

26. This question is a short free-response question. Show your work for each part of the question.

(7 points, suggested time 13 minutes)

In an experiment two identical rocks are simultaneously thrown from the edge of a cliff a distance h_0 above the ground. Rock A is thrown vertically upward with speed v_0 and rock B is thrown vertically downward with speed v_0. Rock A and rock B strike the ground at times t_A and t_B, respectively. Consider the positive vertical direction to be upward.

(a) On the axes given below, sketch and label graphs of the velocity as a function of time for rock A and rock B. Label the time t_B. Times t_A and $\frac{1}{2}t_\mathrm{A}$ are given on the graph.



(b) Rock B hits the ground at time t_B. Derive an equation for the time t_A it takes rock A to hit the ground in terms of v_0, t_B, and physical constants, as appropriate.