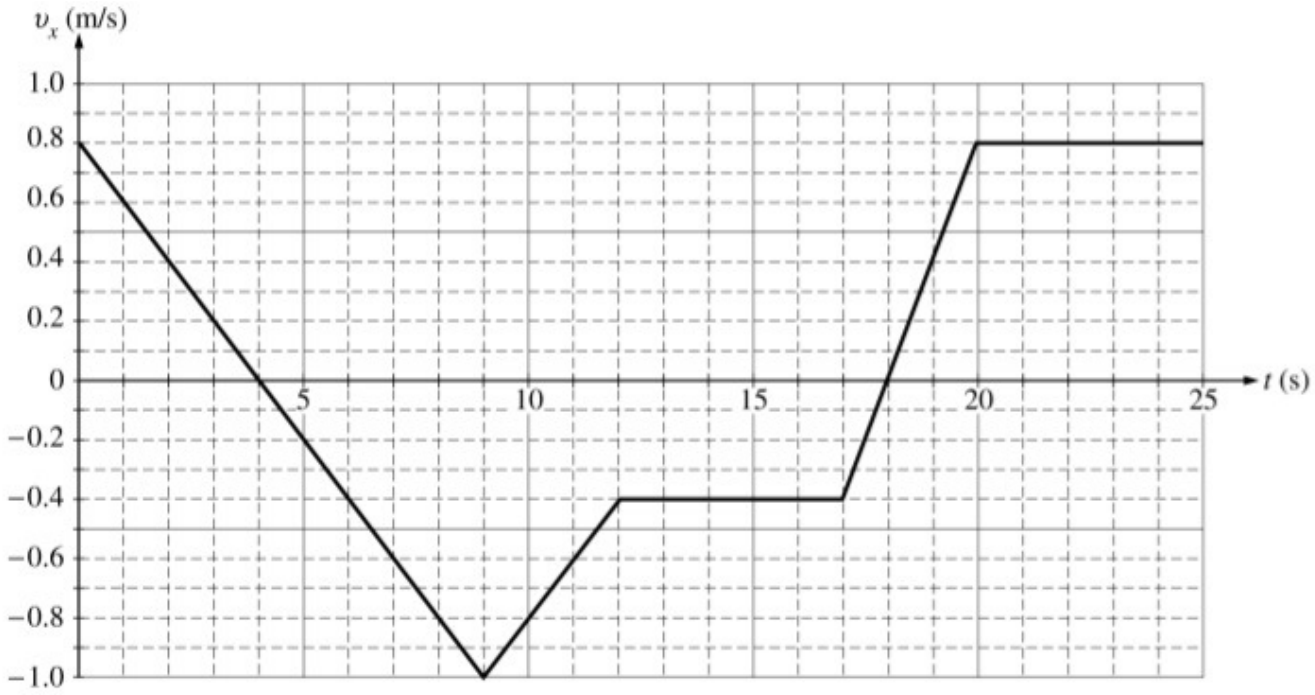
chapter1partd

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.



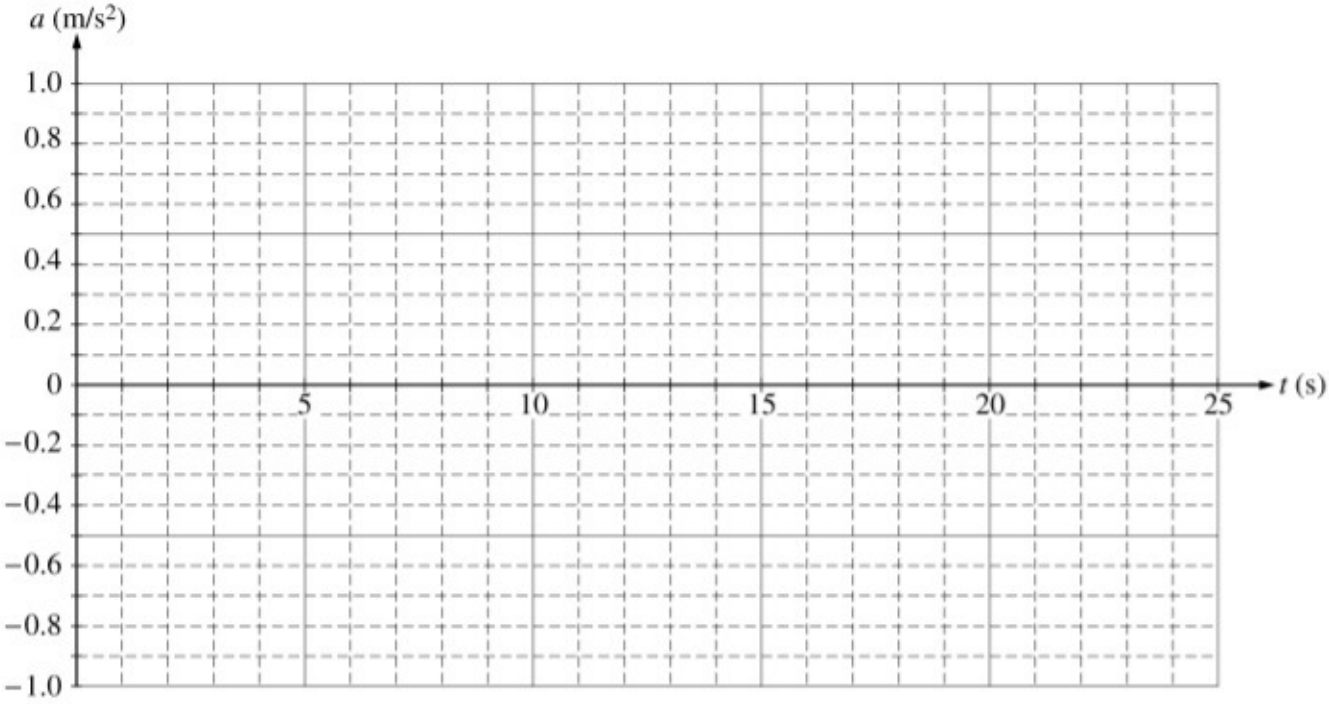
a. Indicate every time t for which the cart is at rest.

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.

chapter1partd



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

Part A

The cart is at rest at $t = 4$ s and 18 s.

1 point is earned: For indicating both times that the car is at rest and not including any incorrect times

0	1 ✓

The student response earns all of the following points:

The cart is at rest at $t = 4$ s and 18 s.

1 point is earned: For indicating both times that the car is at rest and not including any incorrect times

Part B

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The speed of the cart is increasing during the intervals t = 4 to 9 s and 18 to 20 s.

2 points are earned: For each correct time interval one point was awarded.

One point was deducted for each incorrect interval, for a maximum two-point deduction.

0	1	2 ✓

The student response earns all of the following points:

The speed of the cart is increasing during the intervals t = 4 to 9 s and 18 to 20 s.

2 points are earned: For each correct time interval one point was awarded.

One point was deducted for each incorrect interval, for a maximum two-point deduction.

Part C

1 point is earned: For indicating that the change in position is equal to the area under the graph, or for using an appropriate kinematic equation with non-zero initial velocity

Δx = area OR, for example, $\Delta x = v_i t + \frac{1}{2}at^2$

1 point is earned: For correct substitution of values

$\Delta x = \frac{1}{2}(4\text{ s})(0.8\text{ m/s}) + \frac{1}{2}(5\text{ s})(-1\text{ m/s})$

OR $\Delta x = (0.8\text{ m/s})(9\text{ s}) + \frac{1}{2}(-0.2\text{ m/s}^2)(9\text{ s})^2$

Δx = –0.9 m

1 point is earned: For adding the initial position to Δx

$x = x0 + \Delta x$ = 2 m + (–0.9 m)

x = 1.1 m

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For indicating that the change in position is equal to the area under the graph, or for using an appropriate kinematic equation with non-zero initial velocity

Δx = area OR, for example, $\Delta x = v_i t + \frac{1}{2}at^2$

chapter1partd

1 point is earned: For correct substitution of values

$\Delta x = \frac{1}{2}(4\text{ s})(0.8\text{ m/s}) + \frac{1}{2}(5\text{ s})(-1\text{ m/s})$

OR $\Delta x = (0.8\text{ m/s})(9\text{ s}) + \frac{1}{2}(-0.2\text{ m/s}^2)(9\text{ s})^2$

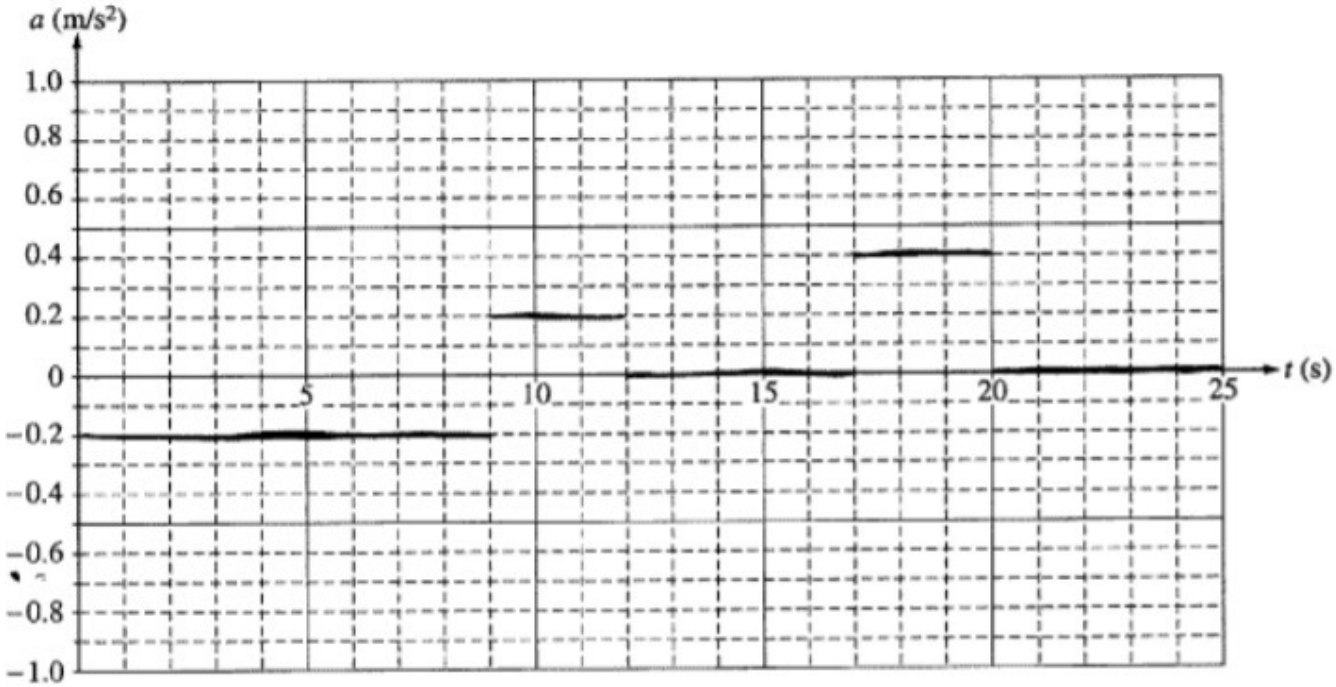
Δx = –0.9 m

1 point is earned: For adding the initial position to Δx

$x = x0 + \Delta x$ = 2 m + (–0.9 m)

x = 1.1 m

Part D



1 point is earned: For indicating that the acceleration is zero during the intervals of constant velocity, 12 to 17 s and 20 to 25 s

1 point is earned: For indicating that the acceleration is negative and constant from zero to 9 s, and positive and constant from 9 to 11 s and 17 to 20 s

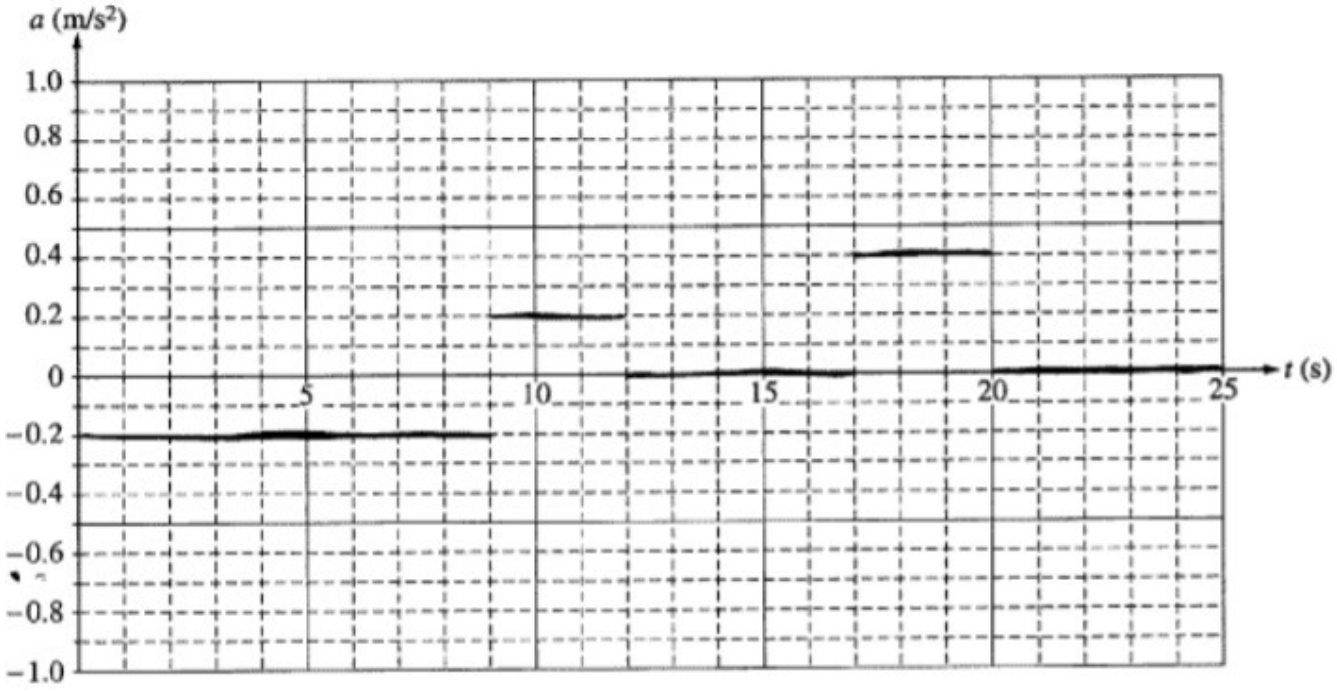
1 point is earned: For having the correct values for two of the three intervals of non-zero accelerations:

–0.20 m/s2, +0.20 m/s2, and +0.40 m/s2

0	1	2	3 ✓

chapter1partd

The student response earns all of the following points:



1 point is earned: For indicating that the acceleration is zero during the intervals of constant velocity, 12 to 17 s and 20 to 25 s

1 point is earned: For indicating that the acceleration is negative and constant from zero to 9 s, and positive and constant from 9 to 11 s and 17 to 20 s

1 point is earned: For having the correct values for two of the three intervals of non-zero accelerations:

–0.20 m/s2, +0.20 m/s2, and +0.40 m/s2

Part E

- **1 point is earned:** For using the correct kinematic equation, with the initial vertical velocity equal to zero

  $y = \frac{1}{2}gt^2$

  Solving for *t*:

  $t = \sqrt{2y/g}$

  $t = \sqrt{2(0.40\ \text{m})/10\ \text{m/s}^2}$

  $t = 0.28\ \text{s} (\text{or } 0.29\ \text{s using } g = 9.8\ \text{m/s}^2)$

- Using the kinematic equation for the horizontal motion:

  x = *vxt*

  1 point is earned: For using the correct value for the horizontal speed

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vx = 0.8 m/s

x = (0.8 m/s)(0.28 s)

1 point is earned: For the correct answer

x = 0.22 m (or 0.23 m using *g* = 9.8 m/s2)

- **2 points are earned:** For correctly applying conservation of energy

Kbottom = *Ktop* + *Utop*

$$K_{bottom} = \frac{1}{2}mv_x{}^2 + mgy$$
$$K_{bottom} = \frac{1}{2}(0.50\text{ kg})(0.8\text{ m/s})^2 + (0.50\text{ kg})(10\text{ m/s}^2)(0.40\text{ m})$$

1 point is earned: For the correct answer

Kbottom = 2.2 J (or 2.1 J using *g* = 9.8 m/s2)

In the absence of any of the above credit, one point was awarded for any recognition that the vertical velocity changes.

(Alternate solution)

1 point is earned: For any recognition that the vertical velocity changes.

Calculating the *y*-component of velocity at the bottom:

vy = vyt – *gt*

vy = 0 + (10 m/s2)(0.28 s) = 2.8 m/s

1 point is earned: For correctly calculating the total speed from the components

*v*2 = *vx*2 + *vy*2

$$v = \sqrt{(0.8\text{ m/s})^2 + (2.8\text{ m/s})^2}$$

v = 2.9 m/s

1 point is earned: For correctly calculating the final kinetic energy

$$K = \frac{1}{2}mv^2$$
$$K = \frac{1}{2}(0.50\text{ kg})(2.9\text{ m/s})^2$$

K = 2.2 J (or 2.1 J depending on the value of *g* used and amount of rounding in intermediate calculations)

chapter1partd

0	1	2	3	4	5	6 ✓

The student response earns all of the following points:

- **1 point is earned:** For using the correct kinematic equation, with the initial vertical velocity equal to zero

  $y = \frac{1}{2}gt^2$

  Solving for *t*:

  $t = \sqrt{2y/g}$

  $t = \sqrt{2(0.40\text{ m})/10\text{ m/s}^2}$

  $t = 0.28\text{ s}(\text{or } 0.29\text{ s using } g = 9.8\text{ m/s}^2)$

- Using the kinematic equation for the horizontal motion:

  x = *vxt*

  1 point is earned: For using the correct value for the horizontal speed

  vx = 0.8 m/s

  x = (0.8 m/s)(0.28 s)

  1 point is earned: For the correct answer

  x = 0.22 m (or 0.23 m using *g* = 9.8 m/s2)

- **2 points are earned:** For correctly applying conservation of energy

  Kbottom = *Ktop* + *Utop*

  $K_{bottom} = \frac{1}{2}mv_x{}^2 + mgy$

  $K_{bottom} = \frac{1}{2}(0.50\text{ kg})(0.8\text{ m/s})^2 + (0.50\text{ kg})(10\text{ m/s}^2)(0.40\text{ m})$

  1 point is earned: For the correct answer

  Kbottom =2.2 J (or 2.1 J using *g* = 9.8 m/s2)

  (Alternate solution)

  1 point is earned: For any recognition that the vertical velocity changes.

  Calculating the *y*-component of velocity at the bottom:

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v_y = vyt – gt

v_y = 0 + (10 m/s2)(0.28 s) = 2.8 m/s

1 point is earned: For correctly calculating the total speed from the components

$v2 = vx2 + vy2$

$$v = \sqrt{(0.8\ \text{m/s})^2 + (2.8\ \text{m/s})^2}$$

v = 2.9 m/s

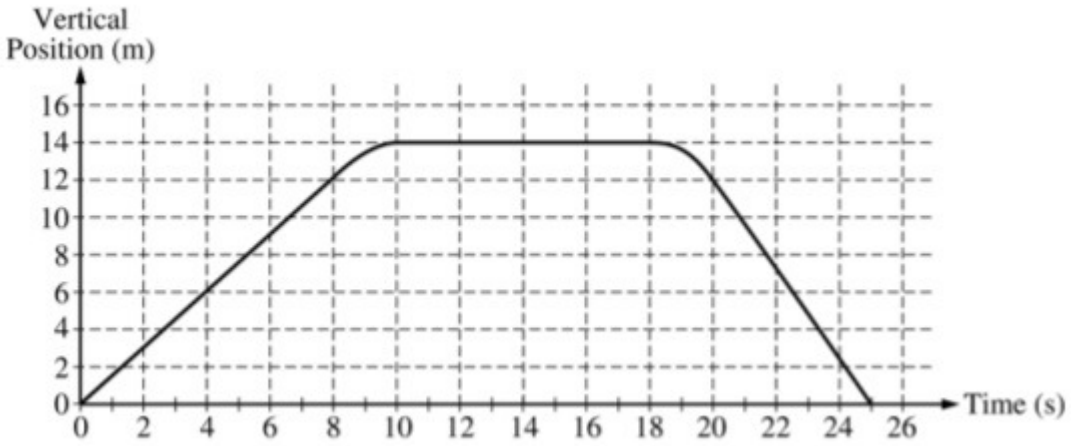
1 point is earned: For correctly calculating the final kinetic energy

$$K = \tfrac{1}{2}mv^2$$
$$K = \tfrac{1}{2}(0.50\ \text{kg})(2.9\ \text{m/s})^2$$

K = 2.2 J (or 2.1 J depending on the value of g used and amount of rounding in intermediate calculations)

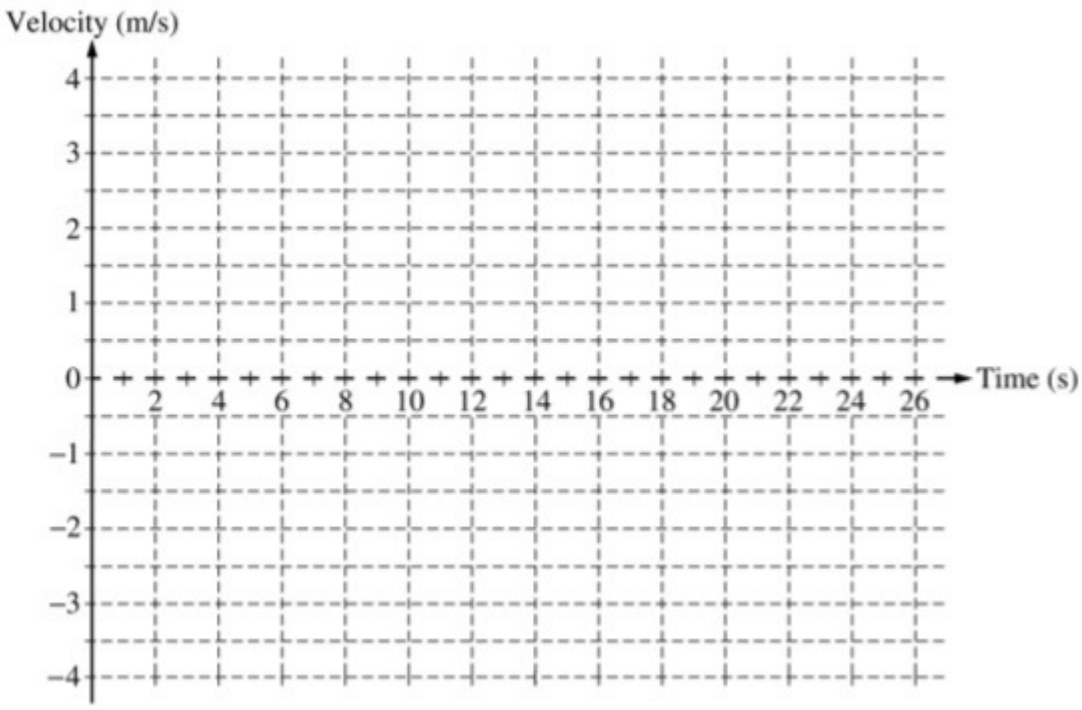
chapter1partd

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.

Part A



The velocities can be found from the slope of the position graph.

1 point is earned: For showing a positive velocity of magnitude 1.5 m/s (i.e., 12 m/8 s) between 0 s and 8 s inclusive

1 point is earned: For showing zero velocity between 10 s and 18 s inclusive

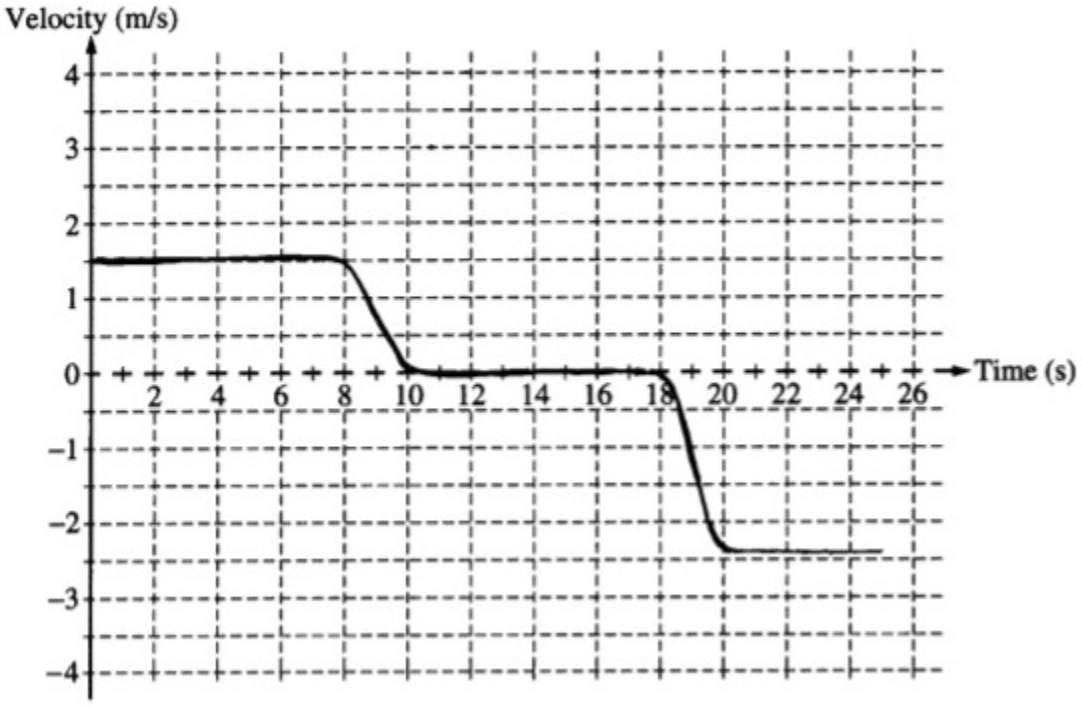
1 point is earned: For showing a negative velocity of magnitude 2.4 m/s (i.e., 12 m/5 s) between 20 s and 25 s inclusive

1 point is earned: For showing two nonvertical transition regions; between $t = 8$ s and 10 s and between $t = 18$ s and 20 s

0	1	2	3	4 ✓

The student response earns four of the following points:

chapter1partd



The velocities can be found from the slope of the position graph.

1 point is earned: For showing a positive velocity of magnitude 1.5 m/s (i.e., 12 m/8 s) between 0 s and 8 s inclusive

1 point is earned: For showing zero velocity between 10 s and 18 s inclusive

1 point is earned: For showing a negative velocity of magnitude 2.4 m/s (i.e., 12 m/5 s) between 20 s and 25 s inclusive

1 point is earned: For showing two nonvertical transition regions; between t = 8 s and 10 s and between t = 18 s and 20 s

Part B

i. **1 point is earned:** For a definition or equation for average acceleration

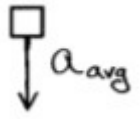
$a_{avg} = \Delta v / \Delta t$ OR $v = v_0 + at$

1 point is earned: For the correct substitution from part (a)

a_{avg} = (0 – 1.5 m/s)/2 s

1 point is earned: For the correct answer including units and sign

$a_{avg} = -0.75$ m/s^2

ii. 

1 point is earned: For a correctly drawn vector, with or without a label

chapter1partd

0	1	2	3	4 ✓

The student response earns four of the following points:

i. **1 point is earned:** For a definition or equation for average acceleration

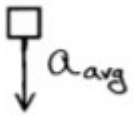
$a_{avg} = \Delta v / \Delta t$ OR $v = v_0 + at$

1 point is earned: For the correct substitution from part (a)

$a_{avg} = (0 – 1.5 \text{ m/s})/2 \text{ s}$

1 point is earned: For the correct answer including units and sign

$a_{avg} = –0.75 \text{ m/s}^2$

ii. 

1 point is earned: For a correctly drawn vector, with or without a label

Part C

The acceleration is zero, so the normal force (apparent weight) is equal to the gravitational force.

1 point is earned: For a correct relationship leading to a calculation of apparent weight

$N = W = mg$ OR $N – W = ma$

$W_{app} = (70 \text{ kg})(9.8 \text{ m/s}^2)$

1 point is earned: For the correct answer with units

$W_{app} = 686$ N (or 700 N using $g = 10 \text{ m/s}^2$)

0	1	2 ✓

The student response earns two of the following points:

The acceleration is zero, so the normal force (apparent weight) is equal to the gravitational force.

chapter1partd

1 point is earned: For a correct relationship leading to a calculation of apparent weight

$N = W = mg$ OR $N - W = ma$

$W_{app} = (70 \text{ kg})(9.8 \text{ m/s}^2)$

1 point is earned: For the correct answer with units

$W_{app} = 686$ N (or 700 N using $g = 10 \text{ m/s}^2$)

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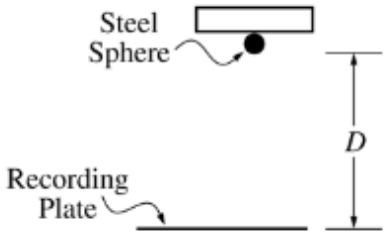
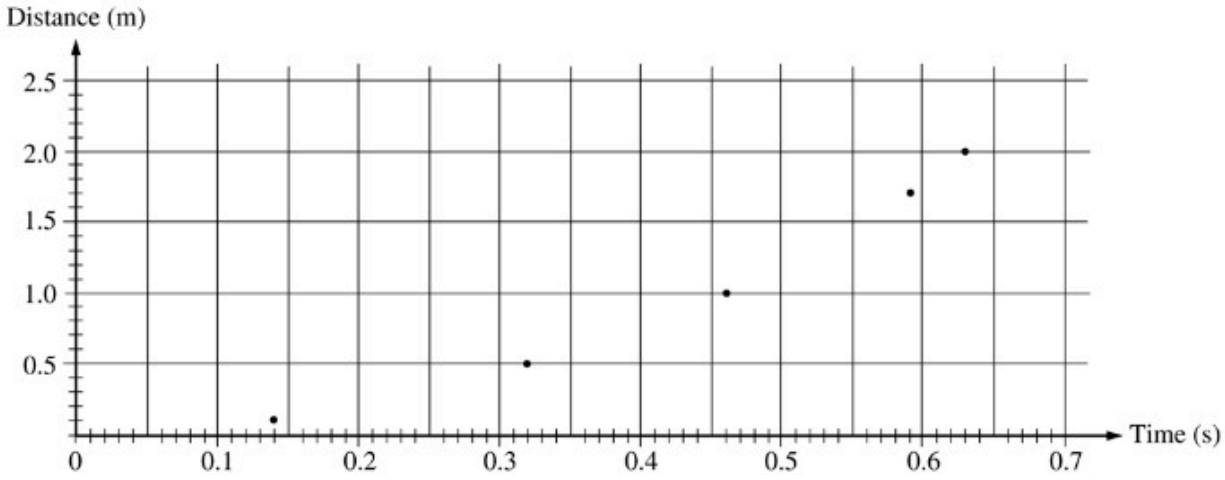
3.



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



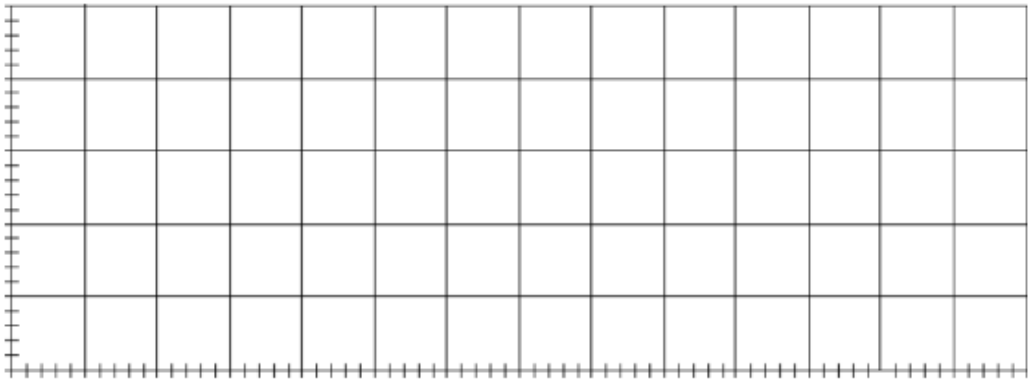
(a) On the grid above, sketch the smooth curve that best represents the student's data.

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.

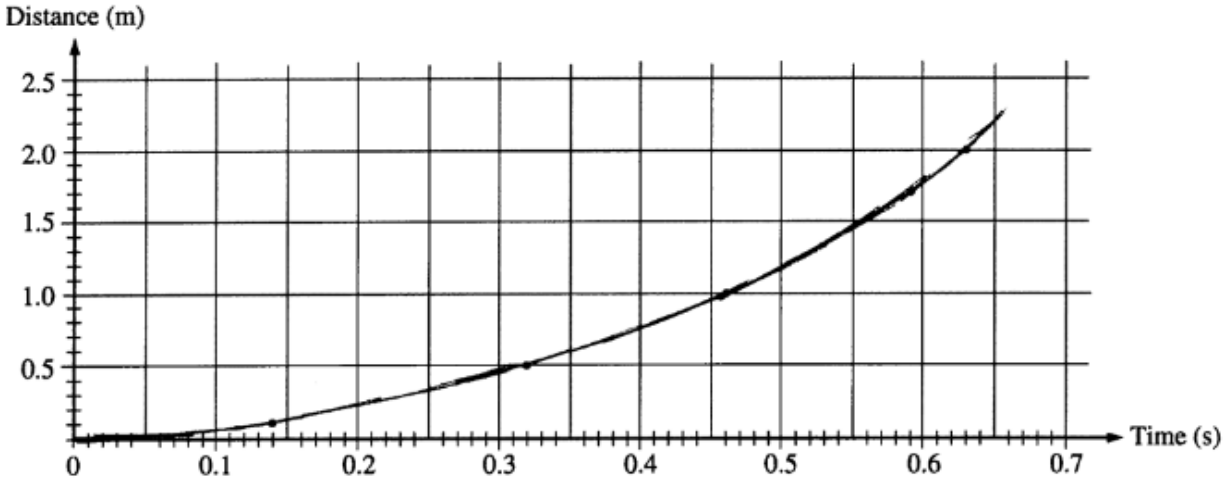
chapter1partd



(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.

Part A



1 point is earned: For a line that is close to all of the data points

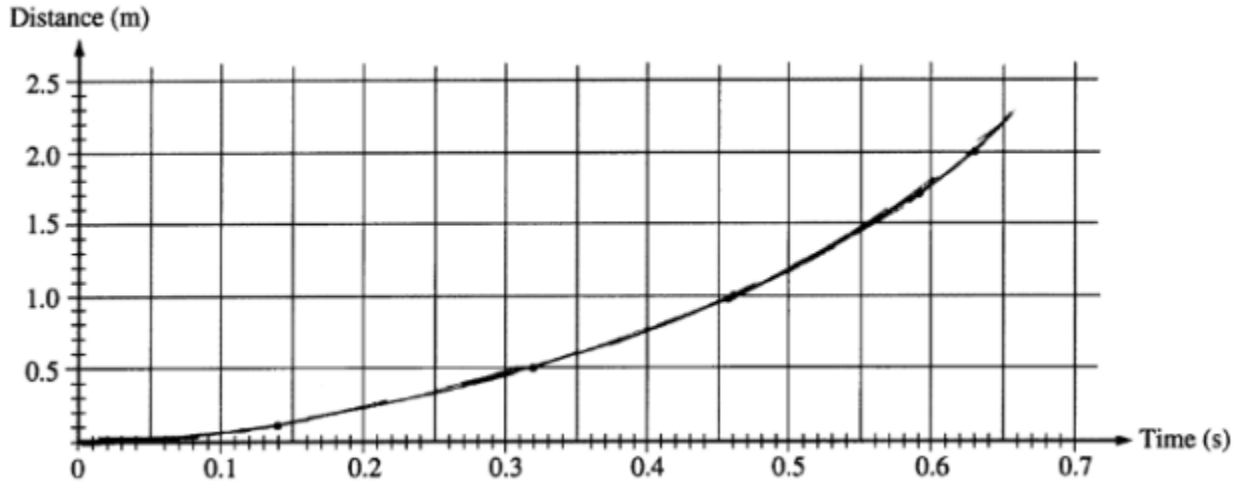
1 point is earned: For a smooth curve

1 point is earned: For a nonlinear curve that is concave up

0	1	2	3 ✓

The student response earns all of the following points:

chapter1partd



1 point is earned: For a line that is close to all of the data points

1 point is earned: For a smooth curve

1 point is earned: For a nonlinear curve that is concave up

Part B

Distance and time are related by the equation $D = \frac{1}{2}gt^2$

2 point are earned: For a correct pair of quantities, expressed in terms of *D* and *t,* that will yield a straight line

Examples: *D* and *t*2 OR $\sqrt{D}$ and *t*

0	1	2 ✓

The student response earns all of the following points:

Distance and time are related by the equation $D = \frac{1}{2}gt^2$

2 point are earned: For a correct pair of quantities, expressed in terms of *D* and *t,* that will yield a straight line

Examples: *D* and *t*2 OR $\sqrt{D}$ and *t*

Part C

1 point is earned: For correctly scaling and labeling the horizontal axis for a quantity cited in part (b)

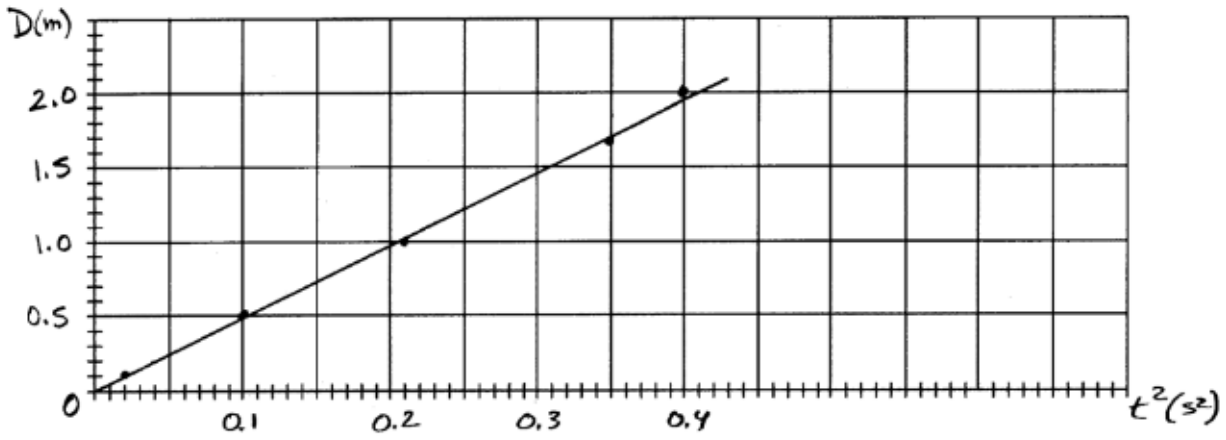
1 point is earned: For correctly scaling and labeling the vertical axis for a quantity cited in part (b)

1 point is earned: For a reasonably correct plotting of the data

chapter1partd

1 point is earned: For a reasonably straight line through the data points

Example graphing *D* versus *t2*:



0	1	2	3	4

The student response earns all of the following points:

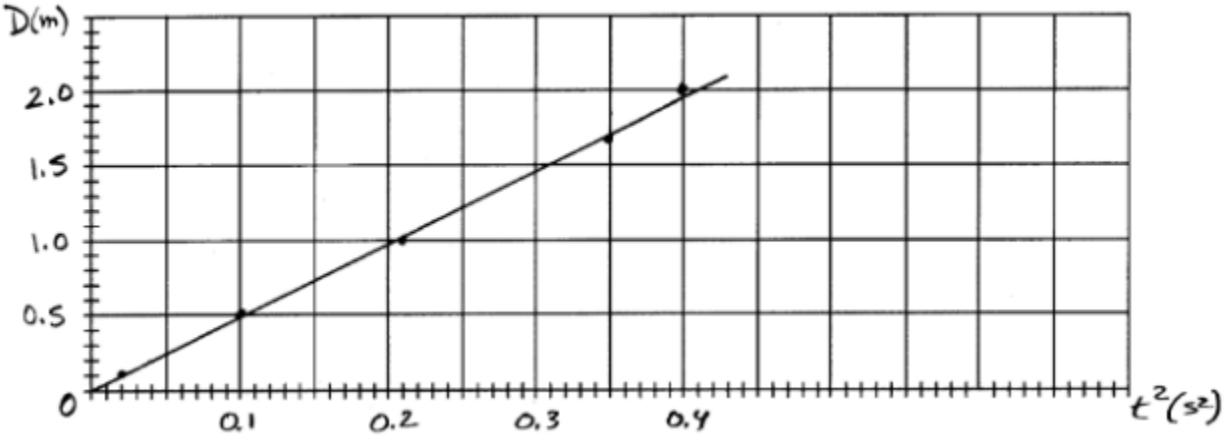
1 point is earned: For correctly scaling and labeling the horizontal axis for a quantity cited in part (b)

1 point is earned: For correctly scaling and labeling the vertical axis for a quantity cited in part (b)

1 point is earned: For a reasonably correct plotting of the data

1 point is earned: For a reasonably straight line through the data points

Example graphing *D* versus *t2*:



Part D

chapter1partd

1 point is earned: For determining the slope of the line drawn on the graph

Using the example graph above, slope = $\frac{(2.0-0.1)m}{(0.41-0.02)s^2} = \frac{1.9m}{0.39^2} = 4.9m/s^2$

1 point is earned: For an expression relating g to the slope

In the example given, $D = \frac{1}{2}gt^2, so \frac{1}{2}g = slope$

1 point is earned: For a value of *g* in the range 9 - 11 m/s2

In the example given, *g* = 2(4.9 m/s2) = 9.8 m/s2

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For determining the slope of the line drawn on the graph

Using the example graph above, slope = $\frac{(2.0-0.1)m}{(0.41-0.02)s^2} = \frac{1.9m}{0.39^2} = 4.9m/s^2$

1 point is earned: For an expression relating g to the slope

In the example given, $D = \frac{1}{2}gt^2, so \frac{1}{2}g = slope$

1 point is earned: For a value of *g* in the range 9 - 11 m/s2

In the example given, *g* = 2(4.9 m/s2) = 9.8 m/s2

Part E

2 points are earned: For a good, specific improvement

1 point is earned: For an explanation of how this would improve accuracy

Example: Do several trials for each value of D and take averages. This reduces personal and random error.

One point could be earned for less appropriate or less specific answers, for example "do trials in a vacuum" or "cut down on air resistance."

0	1	2	3 ✓

The student response earns all of the following points:

2 points are earned: For a good, specific improvement

chapter1partd

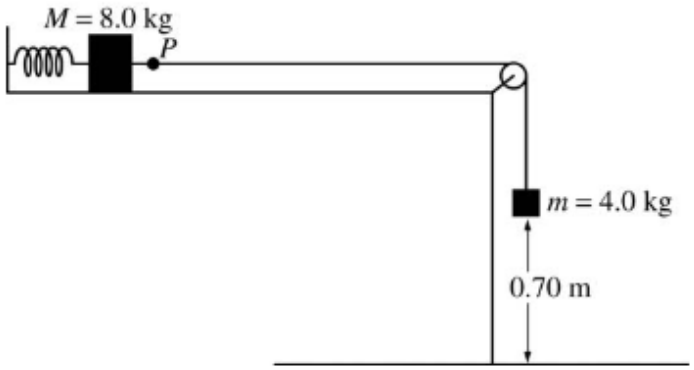
1 point is earned: For an explanation of how this would improve accuracy

Example: Do several trials for each value of D and take averages. This reduces personal and random error.

One point could be earned for less appropriate or less specific answers, for example "do trials in a vacuum" or "cut down on air resistance."

chapter1partd

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.

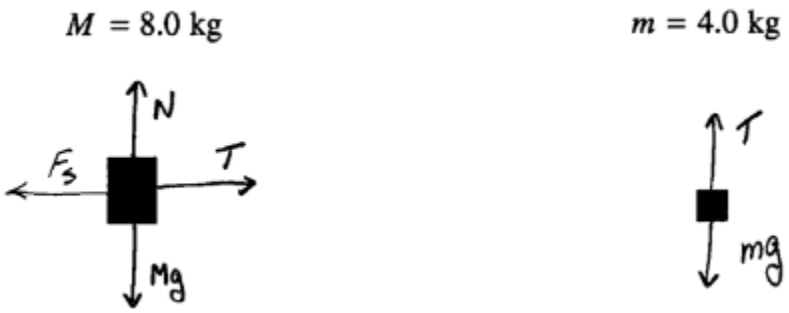
(d) Calculate the time taken by the 4.0 kg block to hit the floor.

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

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

Part A

chapter1partd



For the 4 kg mass:

1 point is earned: For two correctly labeled vertical vectors, one up and one down, and no horizontal vectors

For the 8 kg mass:

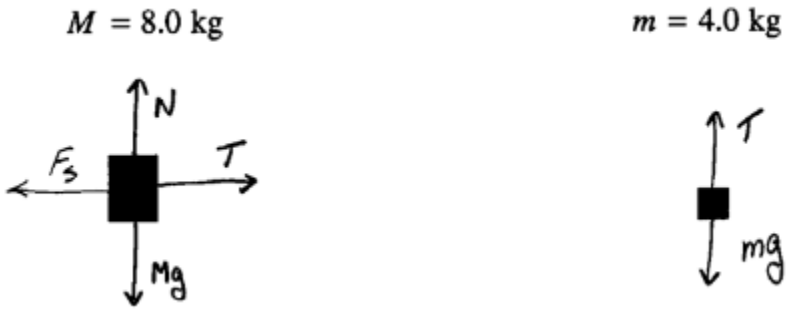
1 point is earned: For two correctly labeled vertical vectors, one up and one down

1 point is earned: For two correctly labeled horizontal vectors, one left and one right

Note: Labels could be in words, symbols, or correct numerical values. The two masses were considered independently. It was not necessary to indicate that the tension forces had the same magnitudes or that the weights were different.

0	1	2	3 ✓

The student response earns all of the following points:



For the 4 kg mass:

1 point is earned: For two correctly labeled vertical vectors, one up and one down, and no horizontal vectors

For the 8 kg mass:

1 point is earned: For two correctly labeled vertical vectors, one up and one down

chapter1partd

1 point is earned: For two correctly labeled horizontal vectors, one left and one right

Note: Labels could be in words, symbols, or correct numerical values. The two masses were considered independently. It was not necessary to indicate that the tension forces had the same magnitudes or that the weights were different.

Part B

1 point is earned: For a correct approach using Newton's 2nd law and the static equilibrium condition for the 4 kg mass that leads to a relationship between tension and weight

$T = mg$

T = (4.0 kg)(9.8 m/s2)

1 point is earned: For the correct answer

T = 39 N (40 N using g = 10m/s2)

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For a correct approach using Newton's 2nd law and the static equilibrium condition for the 4 kg mass that leads to a relationship between tension and weight

$T = mg$

T = (4.0 kg)(9.8 m/s2)

1 point is earned: For the correct answer

T = 39 N (40 N using g = 10m/s2)

Part C

1 point is earned: For a correct application of Newton's 2nd law and the static equilibrium condition for the 8 kg mass leading to a relationship between tension from part (b) and spring force
T = Fs = kΔx
k = T / Δx

1 point is earned: For using the correct displacement of the spring from equilibrium
Δx = 0.25m - 0.20m = 0.05m

1 point is earned: For a correct calculation leading to a positive value of k using the tension from (b)

k = 39 N/0.05 m

k = 780 N/m (800 N/m using 40 N from part (b))

chapter1partd

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For a correct application of Newton's 2nd law and the static equilibrium condition for the 8 kg mass leading to a relationship between tension from part (b) and spring force

T = Fs = kΔx
k = T / Δx

1 point is earned: For using the correct displacement of the spring from equilibrium

Δx = 0.25m - 0.20m = 0.05m

1 point is earned: For a correct calculation leading to a positive value of k using the tension from (b)

k = 39 N/0.05 m

k = 780 N/m (800 N/m using 40 N from part (b))

Part D

1 point is earned: For a correct kinematic approach for an accelerating system applied to the 4 kg mass

$y = \frac{1}{2}gt^2$
$t = \sqrt{2y/g}$
$t = \sqrt{2(0.70m)(9.8m/s^2)}$

1 point is earned: For the correct answer

t = 0.38 s (0.37 s using *g* = 10 m/s2)

Note: An alternate approach using conservation of energy to determine the speed at the bottom and then use of a kinematic equation for time could also earn full credit.

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For a correct kinematic approach for an accelerating system applied to the 4 kg mass

chapter1partd

$y = \frac{1}{2}gt^2$

$t = \sqrt{2y/g}$

$t = \sqrt{2(0.70m)(9.8m/s^2)}$

1 point is earned: For the correct answer

t = 0.38 s (0.37 s using *g* = 10 m/s2)

Note: An alternate approach using conservation of energy to determine the speed at the bottom and then use of a kinematic equation for time could also earn full credit.

Part E

1 point is earned: For a correct approach to calculating the frequency (*f or* ω) of a mass-spring system

$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} OR, \omega = \sqrt{\frac{k}{m}}$

$f = \frac{1}{2\pi}\sqrt{\frac{780N/m}{8.0kg}} OR, \omega = \sqrt{\frac{780N/m}{8.0kg}}$

1 point is earned: For a correct value of frequency *(f or* ω *)* consistent with the value of *k* from part (c)

f = 1.6 Hz OR ω = 10 rad/s

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For a correct approach to calculating the frequency (*f or* ω) of a mass-spring system

$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} OR, \omega = \sqrt{\frac{k}{m}}$

$f = \frac{1}{2\pi}\sqrt{\frac{780N/m}{8.0kg}} OR, \omega = \sqrt{\frac{780N/m}{8.0kg}}$

1 point is earned: For a correct value of frequency *(f or* ω *)* consistent with the value of *k* from part (c)

f = 1.6 Hz OR ω = 10 rad/s

Part F

1 point is earned: For using conservation of energy, setting the spring potential energy equal to the kinetic energy of the block

chapter1partd

$\frac{1}{2}mv^2 = \frac{1}{2}kA^2$

$v = \sqrt{\frac{k}{m}}A$

$v = \sqrt{\frac{780N/m}{8.0kg}}(0.05m)$

1 point is earned: For a correct calculation of speed consistent with the value of *k* from part (c) and the correct displacement from equilibrium

v = 0.49 m/s (0.50 ms using 800 N/m from part (c))

0	1	✓ 2

The student response earns all of the following points:

1 point is earned: For using conservation of energy, setting the spring potential energy equal to the kinetic energy of the block

$\frac{1}{2}mv^2 = \frac{1}{2}kA^2$

$v = \sqrt{\frac{k}{m}}A$

$v = \sqrt{\frac{780N/m}{8.0kg}}(0.05m)$

1 point is earned: For a correct calculation of speed consistent with the value of *k* from part (c) and the correct displacement from equilibrium

v = 0.49 m/s (0.50 ms using 800 N/m from part (c))

(Global)

1 point is earned: For correct units and a reasonable number of digits in all numerical answers obtained (must have at least one final numerical answer to earn this point)

0	✓ 1

The student response earns all of the following points:

1 point is earned: For correct units and a reasonable number of digits in all numerical answers obtained (must have at least one final numerical answer to earn this point)

chapter1partd

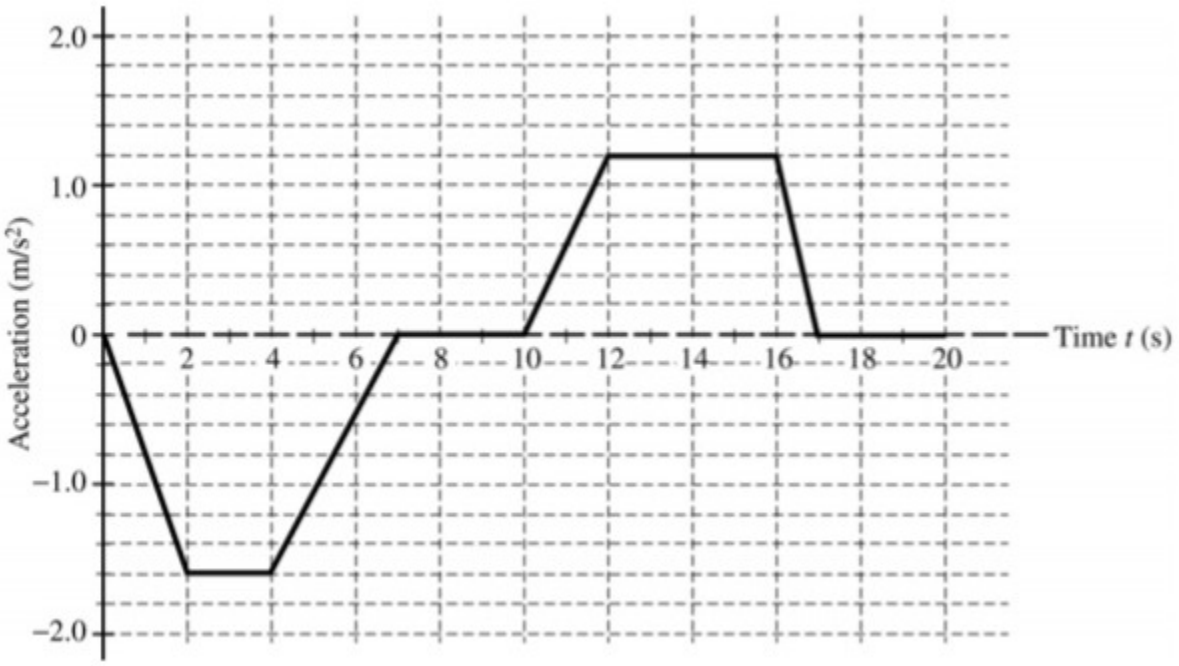
5. A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

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?

Part A

chapter1partd



1 point is earned: For an upward force with a label indicating a normal force or a force from the scale

1 point is earned: For a downward force with a label appropriate for a weight

One point was deducted for each extraneous force until the net score was zero.

0	1	2 ✓

The student response earns two of the following points:



1 point is earned: For an upward force with a label indicating a normal force or a force from the scale

1 point is earned: For a downward force with a label appropriate for a weight

One point was deducted for each extraneous force until the net score was zero.

Part B

The scale reading is the magnitude of the normal force on the student.

1 point is earned: For starting with Newton's second law

$F_{net} = ma$

1 point is earned: For correctly expressing the net force

$N - mg = ma$

1 point is earned: For correctly solving for the normal force

$N = m(g + a)$

chapter1partd

0	1	2	3 ✓

The student response earns three of the following points:

The scale reading is the magnitude of the normal force on the student.

1 point is earned: For starting with Newton's second law

$F_{net} = ma$

1 point is earned: For correctly expressing the net force

$N - mg = ma$

1 point is earned: For correctly solving for the normal force

$N = m(g + a)$

Part C

i. The normal force exerted by the scale is maximum when the acceleration has its maximum positive value.

The force is maximum from 12 to 16 seconds.

1 point is earned: For an interval beginning at 12 seconds

1 point is earned: For an interval ending at 16 seconds

One point was deducted for each interval with no correct endpoints until the net score was zero.

ii. Using the expression for the normal force from part (b)

$N = m(g + a)$

$N = (45 \text{ kg})(9.8 \text{ m/s}^2 + 1.2 \text{ m/s}^2)$

$N = (45 \text{ kg})(11.0 \text{ m/s}^2)$

1 point is earned: For the correct answer with units

$N = 500 \text{ N}$

0	1	2	3 ✓

chapter1partd

The student response earns three of the following points:

i. The normal force exerted by the scale is maximum when the acceleration has its maximum positive value.

The force is maximum from 12 to 16 seconds.

1 point is earned: For an interval beginning at 12 seconds

1 point is earned: For an interval ending at 16 seconds

One point was deducted for each interval with no correct endpoints until the net score was zero.

ii. Using the expression for the normal force from part (b)

$N = m(g + a)$

$N = (45\text{ kg})(9.8\text{ m/s}^2 + 1.2\text{ m/s}^2)$

$N = (45\text{ kg})(11.0\text{ m/s}^2)$

1 point is earned: For the correct answer with units

$N = 500\text{ N}$

Part D

The speed of the elevator is constant when the acceleration is zero.

This occurs from 7 to 10 seconds and from 17 to 20 seconds.

1 point is earned: For each correct interval

One point was deducted for each extraneous interval until the net score was zero.

One point was awarded if the scale was misread for both intervals and the response was given as both 6.5 to 10 and 16.5 to 20.

0	1	2 ✓

The student response earns two of the following points:

The speed of the elevator is constant when the acceleration is zero.

This occurs from 7 to 10 seconds and from 17 to 20 seconds.

1 point is earned: For each correct interval

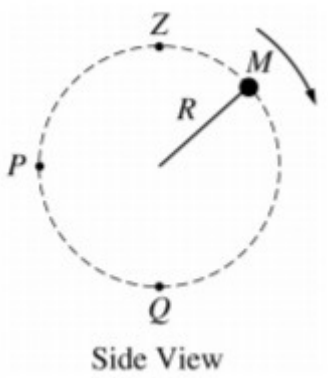
One point was deducted for each extraneous interval until the net score was zero.

One point was awarded if the scale was misread for both intervals and the response was given as both 6.5 to 10 and 16.5

chapter1partd

to 20.

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.

Part A

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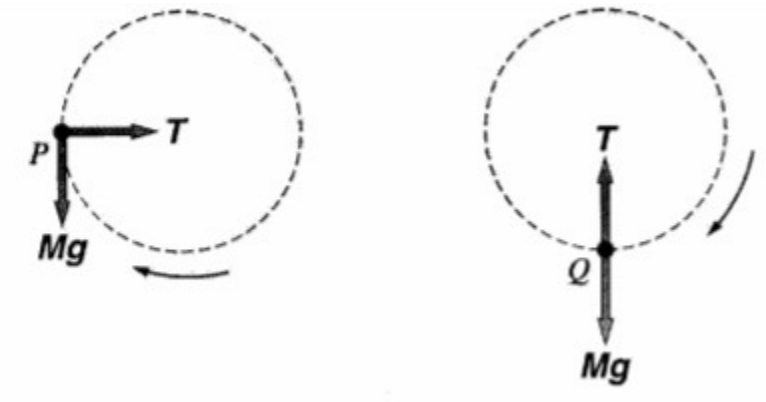


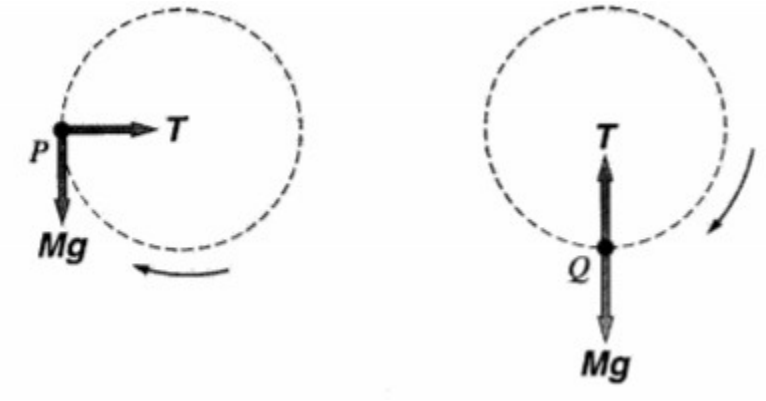
1 point is earned (total 4 points): For each correctly drawn and appropriately labeled force

One point was deducted for each incorrect force, to a maximum of the number of points earned for correct forces (i.e., lowest score awarded is zero).

The upward force in the figure on the right did not receive credit if it was labeled as the centripetal force, since in this case the net centripetal force is the sum of two physical forces (tension and weight).

0	1	2	3	4 ✓

The student response earns all of the following points:



1 point is earned (total 4 points): For each correctly drawn and appropriately labeled force

One point was deducted for each incorrect force, to a maximum of the number of points earned for correct forces (i.e., lowest score awarded is zero).

The upward force in the figure on the right did not receive credit if it was labeled as the centripetal force, since in this case the net centripetal force is the sum of two physical forces (tension and weight).

Part B

1 point is earned: For setting the net force equal to some physical force, such as gravity or a tension

chapter1partd

1 point is earned: For correctly identifying that the only force is that due to gravity

Fnet = Ma = Mg

1 point is earned: For substituting the expression for centripetal acceleration

$\frac{Mv_{\text{min}}^2}{R} = Mg$

1 point is earned: For the correct answer

$v_{\text{min}} = \sqrt{Rg}$

Alternate Solution

1 point is earned: For using the expression for centripetal acceleration

$a = \frac{v^2}{R}$

2 points are earned: For recognizing that the condition for minimum speed at point *Z* is that the centripetal acceleration equals the acceleration due to gravity

$g = \frac{v^2}{R}$

1 point is earned: For the correct answer

$v_{\text{min}} = \sqrt{Rg}$

0	1	2	3	4 ✓

The student response earns all of the following points:

1 point is earned: For setting the net force equal to some physical force, such as gravity or a tension

1 point is earned: For correctly identifying that the only force is that due to gravity

Fnet = Ma = Mg

1 point is earned: For substituting the expression for centripetal acceleration

$\frac{Mv_{\text{min}}^2}{R} = Mg$

1 point is earned: For the correct answer

$v_{\text{min}} = \sqrt{Rg}$

Alternate Solution

chapter1partd

1 point is earned: For using the expression for centripetal acceleration

$a = \frac{v^2}{R}$

2 points are earned: For recognizing that the condition for minimum speed at point *Z* is that the centripetal acceleration equals the acceleration due to gravity

$g = \frac{v^2}{R}$

1 point is earned: For the correct answer

$v_{\text{min}} = \sqrt{Rg}$

Part C

1 point is earned: For setting the net force equal to some physical force, such as gravity or a tension

1 point is earned: For indicating that the net force is the difference between the tension and gravity

1 point is earned: For indicating that the tension is larger than gravity

Ma = T – Mg

1 point is earned: For substituting the expression for centripetal acceleration

$M\frac{v_{\text{max}}^2}{R} = T_{\text{max}} - Mg$

1 point is earned: For the correct answer

$v_{\text{max}} = \sqrt{\frac{R}{M}(T_{\text{max}} - Mg)}$



0	1	2	3	4	5

The student response earns all of the following points:

1 point is earned: For setting the net force equal to some physical force, such as gravity or a tension

1 point is earned: For indicating that the net force is the difference between the tension and gravity

1 point is earned: For indicating that the tension is larger than gravity

Ma = T – Mg

1 point is earned: For substituting the expression for centripetal acceleration

$M\frac{v_{\text{max}}^2}{R} = T_{\text{max}} - Mg$

chapter1partd

1 point is earned: For the correct answer

$v_{\max} = \sqrt{\frac{R}{M}(T_{\max} - Mg)}$

Part D

1 point is earned: For any indication that the velocity of the ball is straight up

1 point is earned: For any indication that the ball would be slowing down

0	1	2 ✓

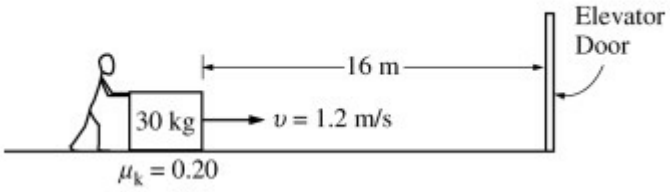
The student response earns all of the following points:

1 point is earned: For any indication that the velocity of the ball is straight up

1 point is earned: For any indication that the ball would be slowing down

chapter1partd

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.

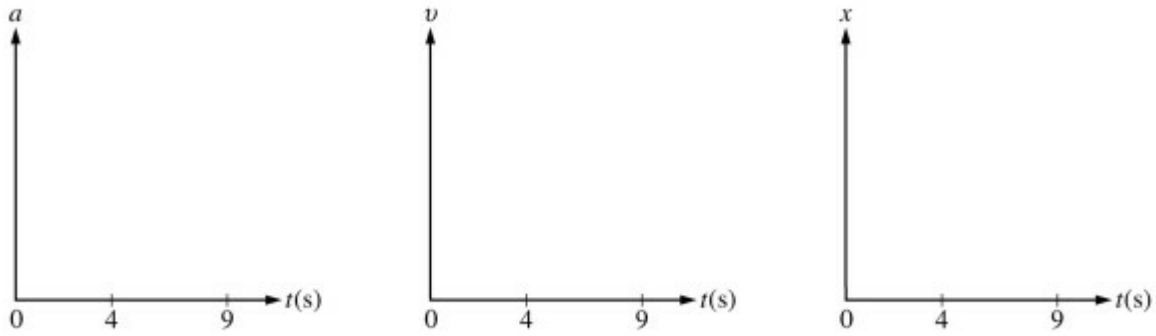
(b) Calculate the magnitude of the horizontal force the student must exert on the box in order to keep it moving at 1.2 m/s. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

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.

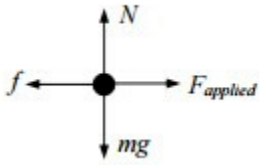
(c) Calculate the magnitude of the new force that the student exerts.

(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.

chapter1partd



Part A

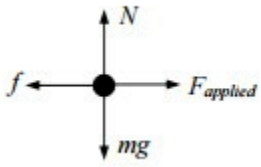


The line of action of each force vector must pass through the dot.

One point is earned for each correctly drawn and labeled force

0	1	2	3	4 ✓

The student earns all of the following points:



The line of action of each force vector must pass through the dot.

One point is earned for each correctly drawn and labeled force

Part B

To move the box at constant speed the applied force must equal the frictional force.

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$\sum F = F_{applied} - f = ma = 0$

$F_{applied} = f$

One point is earned for a correct expression relating the frictional and normal forces

$f = \mu N$

One point is earned for a correct expression for the normal force

$N = mg$
$f = \mu mg$

One point is earned for consistent substitution and evaluation

$$f = (0.20)(30kg)(9.8m/s^2)$$
$$f = 58.8N \ (or \ 60N \text{ using } g = 10m/s^2)$$

0	1	2	3 ✓

The student earns all of the following points:

To move the box at constant speed the applied force must equal the frictional force.

$\sum F = F_{applied} - f = ma = 0$

$F_{applied} = f$

One point is earned for a correct expression relating the frictional and normal forces

$f = \mu N$

One point is earned for a correct expression for the normal force

$N = mg$
$f = \mu mg$

One point is earned for consistent substitution and evaluation

$$f = (0.20)(30kg)(9.8m/s^2)$$
$$f = 58.8N \ (or \ 60N \text{ using } g = 10m/s^2)$$

Part C

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One point is earned for correctly determining the distance between the box and the elevator at $t = 4$ s

$d = 16m - (1.2m/s)(4s) = 11.2m$

One point is earned for consistent substitution into a correct kinematic equation to determine the box's acceleration

$d = v_0t + (1/2)at^2$
$a = 2(d - v_0t)/t^2 = 2((11.2m) - (1.2m/s)(5/s))/(5s)^2 = 0.42m/s^2$

One point is earned for an application of Newton's second law to find the new applied force

$F'_{applied} - f = ma$
$F'_{applied} = ma + f$

One point is earned for consistent substitution of values into Newton's second law

$$F'_{applied} = (30kg)(0.42m/s^2) + 58.8N$$
$$F'_{applied} = 71.4N \ (or\ 72.6N \text{ using } g = 10m/s^2$$

0	1	2	3	4 ✓

The student earns all of the following points:

One point is earned for correctly determining the distance between the box and the elevator at $t = 4$ s

$d = 16m - (1.2m/s)(4s) = 11.2m$

One point is earned for consistent substitution into a correct kinematic equation to determine the box's acceleration

$d = v_0t + (1/2)at^2$
$a = 2(d - v_0t)/t^2 = 2((11.2m) - (1.2m/s)(5/s))/(5s)^2 = 0.42m/s^2$

One point is earned for an application of Newton's second law to find the new applied force

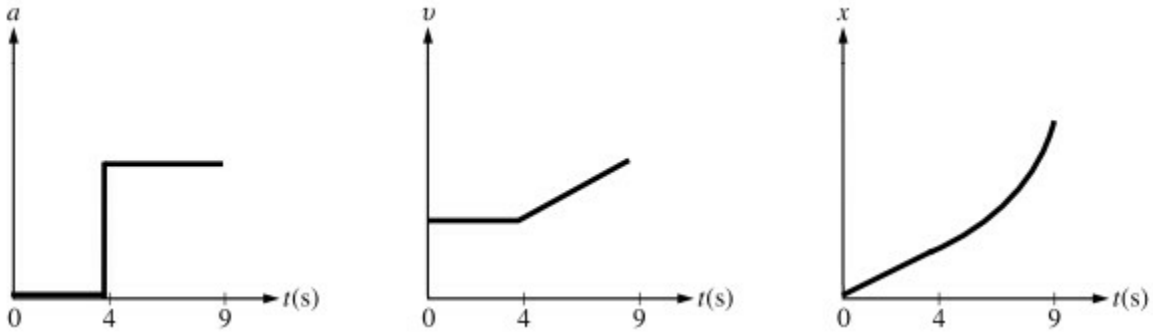
$F'_{applied} - f = ma$
$F'_{applied} = ma + f$

One point is earned for consistent substitution of values into Newton's second law

$$F'_{applied} = (30kg)(0.42m/s^2) + 58.8N$$
$$F'_{applied} = 71.4N \ (or\ 72.6N \text{ using } g = 10m/s^2$$

Part D

chapter1partd



One point is earned for indicating a zero initial acceleration

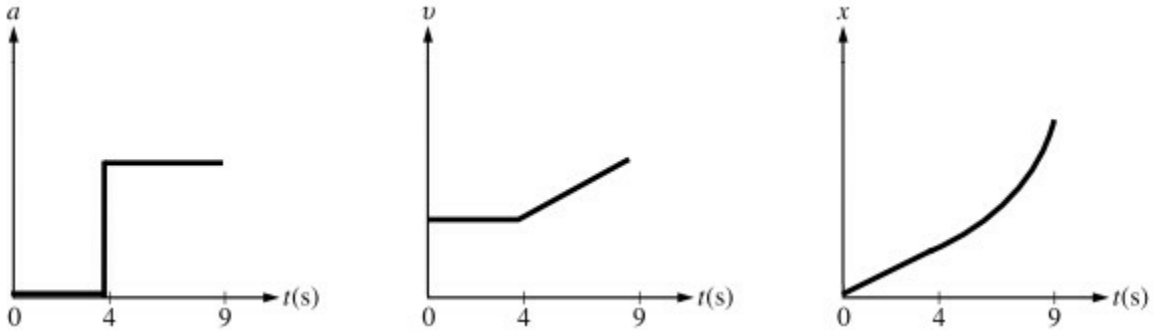
One point is earned for showing zero acceleration until 4 s, then a change to a non-zero, positive constant until 9 s

One point is earned for a velocity graph that is a non-zero, positive constant until 4 s, then linearly increasing until 9 s

One point is earned for a distance graph that is linearly increasing until 4 s, then appropriately curved until 9 s

0	1	2	3	4 ✓

The student earns all of the following points:



One point is earned for indicating a zero initial acceleration

One point is earned for showing zero acceleration until 4 s, then a change to a non-zero, positive constant until 9 s

One point is earned for a velocity graph that is a non-zero, positive constant until 4 s, then linearly increasing until 9 s

One point is earned for a distance graph that is linearly increasing until 4 s, then appropriately curved until 9 s

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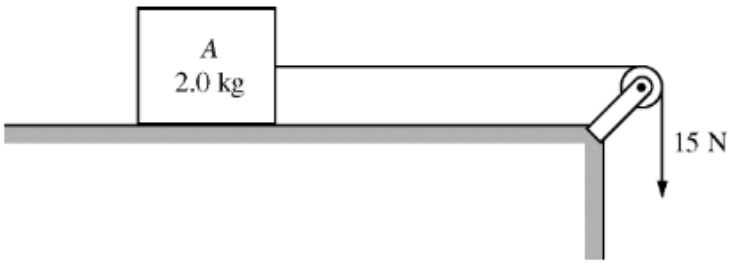
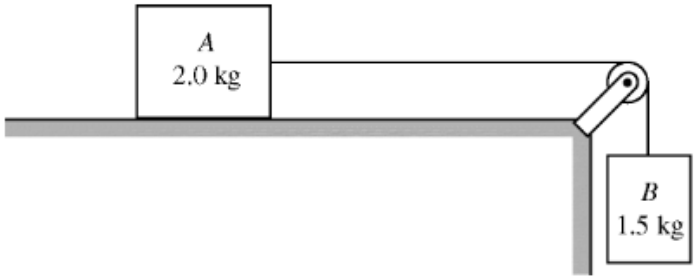
8.



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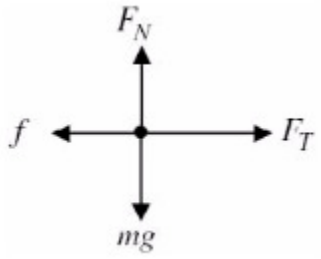
experimental value is found to be smaller than the value calculated above. If the given value for the coefficient of friction is correct and air resistance is negligible, explain briefly, but specifically, why the experimental value of the acceleration is smaller.

Part A

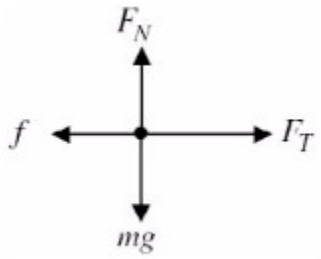


1 point is earned: For showing a complete vector diagram in the horizontal direction with proper labels and vectors pointing in the correct directions

1 point is earned: For showing a complete vector diagram in the vertical direction with proper labels and vectors pointing in the correct directions

0	1	2 ✓

The student response earns all of the following points:



1 point is earned: For showing a complete vector diagram in the horizontal direction with proper labels and vectors pointing in the correct directions

1 point is earned: For showing a complete vector diagram in the vertical direction with proper labels and vectors pointing in the correct directions

Part B

1 point is earned: For any use of Newton's second law to sum the forces in the horizontal direction

chapter1partd

$F_T - f = ma$
$a = \frac{F_T - f}{m}$

1 point is earned: For a correct expression for, or value of, the frictional force

$a = \frac{F_T - \mu mg}{m} = \frac{(15N) - (0.25)(2.0kg)(9.8m/s^2)}{(2.0kg)}$

1 point is earned: For a correct answer, with units

a = 5.1 m/s2 (or 5.0 m/s2 using *g* = 10 m/s2)

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For any use of Newton's second law to sum the forces in the horizontal direction

$F_T - f = ma$
$a = \frac{F_T - f}{m}$

1 point is earned: For a correct expression for, or value of, the frictional force

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1 point is earned: For a correct answer, with units

a = 5.1 m/s2 (or 5.0 m/s2 using *g* = 10 m/s2)

Part C

1 point is earned: For a proper summation of forces on block *A* in the x-direction

$\sum F_{m_A} = m_A a = F_T - f$

1 point is earned: For a proper summation of forces on block *B* in the y-direction

$\sum F_{m_B} = m_B a = m_B g - F_T$

1 point is earned: For a reasonable attempt to combine these two relationships

$(m_A + m_B) a_{system} = m_B g - f$
$a_{system} = \frac{m_B g - f}{(m_A + m_B)} = \frac{(1.5kg)(9.8m/s^2) - (0.25)(2.0kg)(9.8m/s^2)}{(3.5kg)}$

1 point is earned: For a correct answer with units

chapter1partd

a = 2.8 m/s2 (or 2.9 m/s2 using *g* = 10 m/s2)

Alternate solution

Treating the two blocks as one system with a total mass of MT = mA + mB

1 point is earned: *For a correct statement of the net force on the system*

1 point is earned: *For a correct expression for total mass of the system*

mBg - f = (mA + mB)a

1 point is earned: *For agreement between the sign of the net force and the direction of acceleration*

$a = \frac{m_B g - \mu m_A g}{(m_A + m_B)} = \frac{(1.5kg)(9.8m/s^2) - (0.25)(2.0kg)(9.8m/s^2)}{(2.0kg + 1.5kg)}$

1 point is earned: *For a correct answer*

a = 2.8 m/s2 (or 2.9 m/s2 using *g* = 10 m/s2)

✓

0	1	2	3	4

The student response earns all of the following points:

1 point is earned: For a proper summation of forces on block *A* in the x-direction

$\sum F_{m_A} = m_A a = F_T - f$

1 point is earned: For a proper summation of forces on block *B* in the y-direction

$\sum F_{m_B} = m_B a = m_B g - F_T$

1 point is earned: For a reasonable attempt to combine these two relationships

$(m_A + m_B) a_{system} = m_B g - f$

$a_{system} = \frac{m_B g - f}{(m_A + m_B)} = \frac{(1.5kg)(9.8m/s^2) - (0.25)(2.0kg)(9.8m/s^2)}{(3.5kg)}$

1 point is earned: For a correct answer with units

a = 2.8 m/s2 (or 2.9 m/s2 using *g* = 10 m/s2)

Alternate solution

Treating the two blocks as one system with a total mass of MT = mA + mB

1 point is earned: *For a correct statement of the net force on the system*

chapter1partd

1 point is earned: *For a correct expression for total mass of the system*

mBg - f = (mA + mB)a

1 point is earned: *For agreement between the sign of the net force and the direction of acceleration*

$a = \frac{m_B g - \mu m_A g}{(m_A + m_B)} = \frac{(1.5kg)(9.8m/s^2) - (0.25)(2.0kg)(9.8m/s^2)}{(2.0kg + 1.5kg)}$

1 point is earned: *For a correct answer*

a = 2.8 m/s2 (or 2.9 m/s2 using *g* = 10 m/s2)

Part D

1 point is earned: For a correct expression of the summation of forces on either block *A* or block *B*

$F_T - \mu m_A g = m_A a, or, m_B g - F_T = m_B a$

1 point is earned: For correct substitution of the acceleration determined in part (c) and the given masses

$F_T = m_A(a + \mu g)$
$= (2.0kg)\left(2.8m/s^2 + (0.25)\left(9.8m/s^2\right)\right)$ or $F_T = m_B(g - a)$
$F_T = 10.5N$ $= (1.5kg)\left(9.8m/s^2 - 2.8m/s^2\right)$

✓

0	1	2

The student response earns all of the following points:

1 point is earned: For a correct expression of the summation of forces on either block *A* or block *B*

$F_T - \mu m_A g = m_A a, or, m_B g - F_T = m_B a$

1 point is earned: For correct substitution of the acceleration determined in part (c) and the given masses

$F_T = m_A(a + \mu g)$
$= (2.0kg)\left(2.8m/s^2 + (0.25)\left(9.8m/s^2\right)\right)$ or $F_T = m_B(g - a)$
$F_T = 10.5N$ $= (1.5kg)\left(9.8m/s^2 - 2.8m/s^2\right)$

Part E

1 point is earned: For any proper kinematic approach to determine the displacement of block *B*

$\Delta y = \frac{1}{2}at^2$

1 point is earned: For a correct substitution of the acceleration found in part (c) into the kinematic relationship

chapter1partd

$\Delta y = \frac{1}{2}\left(2.8 m/s^2\right)(0.40 s)^2$
$\Delta y = 0.22 m$

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For any proper kinematic approach to determine the displacement of block *B*

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

1 point is earned: For a correct substitution of the acceleration found in part (c) into the kinematic relationship

$\Delta y = \frac{1}{2}\left(2.8 m/s^2\right)(0.40 s)^2$
$\Delta y = 0.22 m$

Part F

1 point is earned: For any reasonable statement of a physical factor that would alter the measured value of the acceleration

- The following are some common acceptable responses:
- The pulley has an appreciable amount of friction in the bearings.
- The string has an appreciable mass.
- The pulley has an appreciable rotational inertia.
- A small uphill incline exists in the horizontal surface.

Note: If a response contains both correct and incorrect factors, this point can be earned only if a correct justification for a correct factor is given.

1 point is earned: For a proper justification of how the physical factor listed causes the measured value of the acceleration to be smaller than the theoretical value of the acceleration

The following are examples of some common correct justifications:

- The friction in the bearings of the pulley does negative work on the system, leaving less energy available for the system's kinetic energy. This will result in a slightly smaller final velocity and therefore a slightly smaller acceleration than the theoretical value.
- The slightly inclined surface creates a small downward component of gravity, which works in opposition to the acceleration. This small opposing force will create a smaller net force and a decrease in the measured acceleration of block *B*.

chapter1partd

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For any reasonable statement of a physical factor that would alter the measured value of the acceleration

- The following are some common acceptable responses:
- The pulley has an appreciable amount of friction in the bearings.
- The string has an appreciable mass.
- The pulley has an appreciable rotational inertia.
- A small uphill incline exists in the horizontal surface.

Note: If a response contains both correct and incorrect factors, this point can be earned only if a correct justification for a correct factor is given.

1 point is earned: For a proper justification of how the physical factor listed causes the measured value of the acceleration to be smaller than the theoretical value of the acceleration

The following are examples of some common correct justifications:

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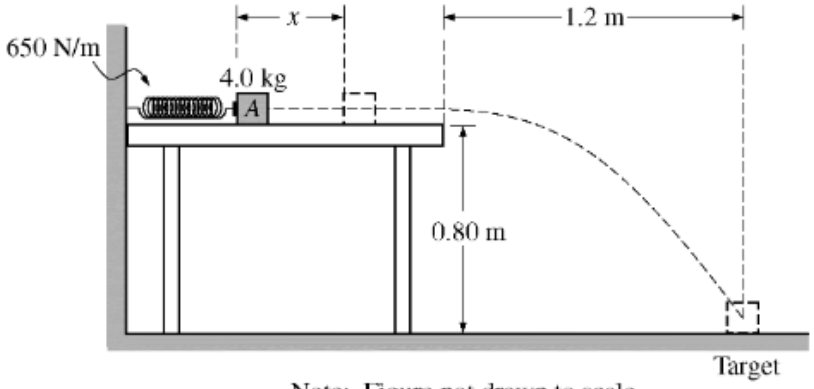
- The slightly inclined surface creates a small downward component of gravity, which works in opposition to the acceleration. This small opposing force will create a smaller net force and a decrease in the measured acceleration of block *B*.

chapter1partd

9.



Note: Figure not drawn to scale.

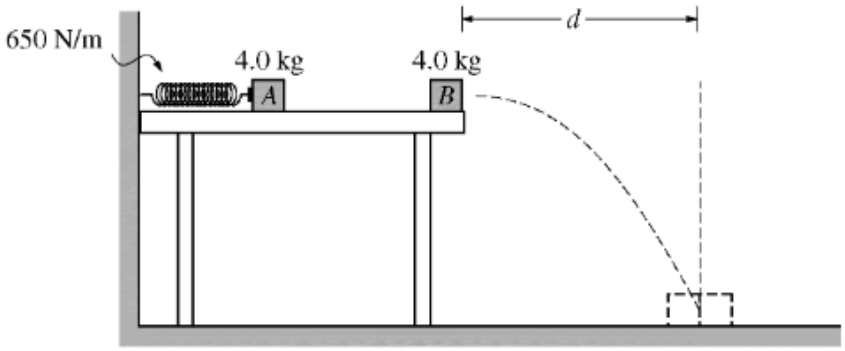
Block A of mass 4.0 kg is on a horizontal, frictionless tabletop and is placed against a spring of negligible mass and spring constant 650 N m. The other end of the spring is attached to a wall. The block is pushed toward the wall until the spring has been compressed a distance x, as shown above. The 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.

chapter1partd

(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.

Part A

1 point is earned: For a correct relationship between the vertical distance and time

$h = \frac{1}{2}gt^2$

1 point is earned: For substitution of the vertical height and the acceleration due to gravity

$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2(0.80m)}{9.8m/s^2}}$

1 point is earned: For the correct answer

t = 0.40 s

Note: Credit was awarded for an alternate solution using

$$v_y^2 = 2gh$$

with appropriate substitutions to find the vertical velocity when the block lands, followed by substitution of this velocity into

$$v_y = gt$$

(or equivalent) to find the time

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For a correct relationship between the vertical distance and time

$h = \frac{1}{2}gt^2$

1 point is earned: For substitution of the vertical height and the acceleration due to gravity

chapter1partd

$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2(0.80m)}{9.8m/s^2}}$

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$$v_y^2 = 2gh$$

with appropriate substitutions to find the vertical velocity when the block lands, followed by substitution of this velocity into

$$v_y = gt$$

(or equivalent) to find the time

Part B

1 point is earned: For a correct relationship between the horizontal distance and time

x = *vt*

1 point is earned: For a consistent substitution of time from part (a) into the correct equation

$v = \frac{x}{t} = \frac{1.2m}{0.40s}$
$v = 3.0m/s$

0	1	2

The student response earns all of the following points:

1 point is earned: For a correct relationship between the horizontal distance and time

x = *vt*

1 point is earned: For a consistent substitution of time from part (a) into the correct equation

$v = \frac{x}{t} = \frac{1.2m}{0.40s}$
$v = 3.0m/s$

Part C

1 point is earned: For any statement of conservation of energy

1 point is earned: For correct use of appropriate energy equations

$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$

chapter1partd

1 point is earned: For a consistent substitution of velocity from part (b) into the correct equation

$x = \sqrt{\frac{m}{k}}v = \sqrt{\frac{4kg}{650N/m}}(3.0m/s)$

$x = 0.24m$

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For any statement of conservation of energy

1 point is earned: For correct use of appropriate energy equations

$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$

1 point is earned: For a consistent substitution of velocity from part (b) into the correct equation

$x = \sqrt{\frac{m}{k}}v = \sqrt{\frac{4kg}{650N/m}}(3.0m/s)$

$x = 0.24m$

Part D

1 point is earned: For any statement of conservation of momentum

mAvi = (mA + mB)vf

1 point is earned: For substitution of both masses into the equation

1 point is earned: For substitution of the velocity from part (b) into the equation

$v_f = \left(\frac{m_A}{m_A+m_B}\right)v_i = \left(\frac{4kg}{4kg+4kg}\right)3.0m/s = 1.5m/s$

1 point is earned: For substitution of time from part (a) into a correct relationship between the horizontal distance and time

d = *vft* = (1.5 m/s)(0.40 s)

d = 0.60 m

0	1	2	3	4 ✓

The student response earns all of the following points:

chapter1partd

1 point is earned: For any statement of conservation of momentum

mAvi = (mA + mB)vf

1 point is earned: For substitution of both masses into the equation

1 point is earned: For substitution of the velocity from part (b) into the equation

$$v_f = \left(\frac{m_A}{m_A+m_B}\right)v_i = \left(\frac{4kg}{4kg+4kg}\right)3.0m/s = 1.5m/s$$

1 point is earned: For substitution of time from part (a) into a correct relationship between the horizontal distance and time

d = vft = (1.5 m/s)(0.40 s)

d = 0.60 m

Part E

1 point is earned: For indicating that *E2 < E1*

1 point is earned: For a correct justification stating one of the following:

- the kinetic energy (or energy) is transformed into other forms of energy during the collision (e.g., by reference to heat, internal energy, sound)
- the kinetic energy is not conserved in an inelastic collision
- a numerical calculation of the relevant energies

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For indicating that *E2 < E1*

1 point is earned: For a correct justification stating one of the following:

- the kinetic energy (or energy) is transformed into other forms of energy during the collision (e.g., by reference to heat, internal energy, sound)
- the kinetic energy is not conserved in an inelastic collision
- a numerical calculation of the relevant energies

Units

1 point is earned: For correct units on all completed answers

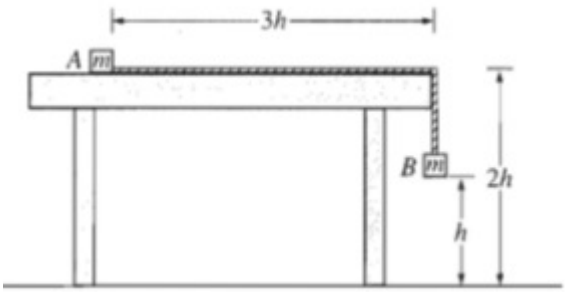
chapter1partd

0	1 ✓

The student response earns all of the following points:

1 point is earned: For correct units on all completed answers

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.

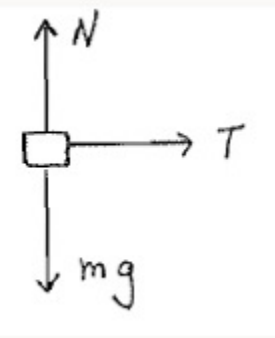
(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

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

Part A

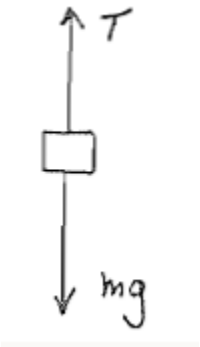
1 point is earned: For a force diagram or a correct application of Newton's second law for block A

chapter1partd



Or $ma = T$

1 point is earned: For a force diagram or a correct application of Newton's second law for block B



Or $ma = mg-T$

Combining the two equation to eliminate T

$ma = mg - ma$

$2ma = mg$

1 point is earned: For the correct answer

$a = g/2$

Alternate solution

For treating the system as a one-body problem (of mass 2m), with the proper gravitational force acting

For correctly applying Newton's second law

$2ma = mg$

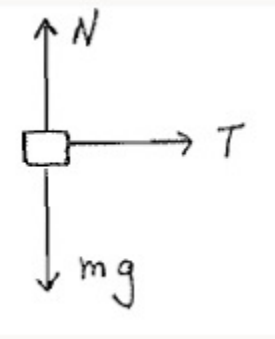
For the correct answer $a = g/2$

0	1	2	3 ✓

chapter1partd

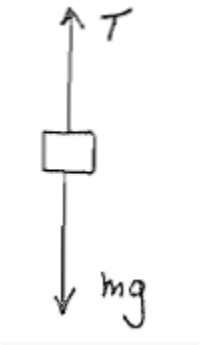
The student response earns three of the following points:

1 point is earned: For a force diagram or a correct application of Newton's second law for block A



Or $ma = T$

1 point is earned: For a force diagram or a correct application of Newton's second law for block B



Or $ma = mg-T$

Combining the two equation to eliminate T

$ma = mg - ma$

$2ma = mg$

1 point is earned: For the correct answer

$a = g/2$

Alternate solution

For treating the system as a one-body problem (of mass 2m), with the proper gravitational force acting

For correctly applying Newton's second law

$2ma = mg$

For the correct answer $a = g/2$

Part B

chapter1partd

1 point is earned: For using the kinematic equation for distance

s = s0 +v0t+ ½at2

1 point is earned: For correctly substituting values, including the value of acceleration from part (a)

h = ½(*g*/2)*t*2

1 point is earned: For the correct answer

$$t = 2\sqrt{\frac{h}{g}}$$

Alternate solution

For equating the work done as block B falls to the change in kinetic energy of the blocks during this time

W = ΔK

mgh= ½(2m)v2

For using the kinematic equation for speed to determine the velocity of the blocks just before block B strikes the floor

v = v0 + at

v = gt/2

For the correct answer

$$t = 2\sqrt{\frac{h}{g}}$$



0	1	2	3

The student response earns three of the following points:

1 point is earned: For using the kinematic equation for distance

s = s0 +v0t+ ½at2

1 point is earned: For correctly substituting values, including the value of acceleration from part (a)

h = ½(*g*/2)*t*2

1 point is earned: For the correct answer

chapter1partd

$$t = 2\sqrt{\frac{h}{g}}$$

Alternate solution

For equating the work done as block B falls to the change in kinetic energy of the blocks during this time

W = ΔK

mgh= ½(2m)v2

For using the kinematic equation for speed to determine the velocity of the blocks just before block B strikes the floor

v = v0 + at

v = gt/2

For the correct answer

$$t = 2\sqrt{\frac{h}{g}}$$

Part C

1 point is earned: For indicating that block *A* accelerates across the table

1 point is earned: For also having no incorrect statements about the block's motion (This point was only awarded if the previous point was received.)

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For indicating that block *A* accelerates across the table

1 point is earned: For also having no incorrect statements about the block's motion (This point was only awarded if the previous point was received.)

Part D

1 point is earned: For any indication that block A is still in motion after block B strikes the floor

(e.g. referring to the block's velocity)

1 point is earned: For indicating that the block's velocity is constant

Note: One point was awarded for a statement that the velocity would decrease if friction was present

chapter1partd

0	1	2 ✓

The student response earns two of the following points:

1 point is earned: For any indication that block A is still in motion after block B strikes the floor

(e.g. referring to the block's velocity)

1 point is earned: For indicating that the block's velocity is constant

Note: One point was awarded for a statement that the velocity would decrease if friction was present

Part E

Since block *B* falls straight to the floor and stops, the distance between the landing points is equal to the horizontal distance of block *A* from the edge of the table

1 point is earned: Determining the constant horizontal speed *v* at which block A travels:

For equating the work done as block *B* falls to the change in kinetic energy of the blocks during this time

W = ΔK

mgh = ½(2m)v2

1 point is earned: For determining the velocity of the blocks just before block *B* strikes the floor

$$v = \sqrt{hg}$$

1 point is earned: For the correct kinematic equation for the horizontal distance *x* traveled by block A, with zero acceleration

x = vt

1 point is earned: Determining the time *t* during which block *A* falls:

For using the correct kinematic equation for the distance *y* that block *A* falls

y = y0 + v0yt + ½at2

1 point is earned: For substituting the appropriate values and solving for the time of fall

$$2h = \tfrac{1}{2}gt^2$$
$$t = 2\sqrt{\tfrac{h}{g}}$$
$$x = \sqrt{hg}\left(2\sqrt{\tfrac{h}{g}}\right)$$

chapter1partd

0	1	2	3	4	5 ✓

The student response earns five of the following points:

Since block *B* falls straight to the floor and stops, the distance between the landing points is equal to the horizontal distance of block *A* from the edge of the table

1 point is earned: Determining the constant horizontal speed *v* at which block A travels:

For equating the work done as block *B* falls to the change in kinetic energy of the blocks during this time

W = ΔK

mgh = ½(2m)v2

1 point is earned: For determining the velocity of the blocks just before block *B* strikes the floor

$$v = \sqrt{hg}$$

1 point is earned: For the correct kinematic equation for the horizontal distance *x* traveled by block A, with zero acceleration

x = vt

1 point is earned: Determining the time *t* during which block *A* falls:

For using the correct kinematic equation for the distance *y* that block *A* falls

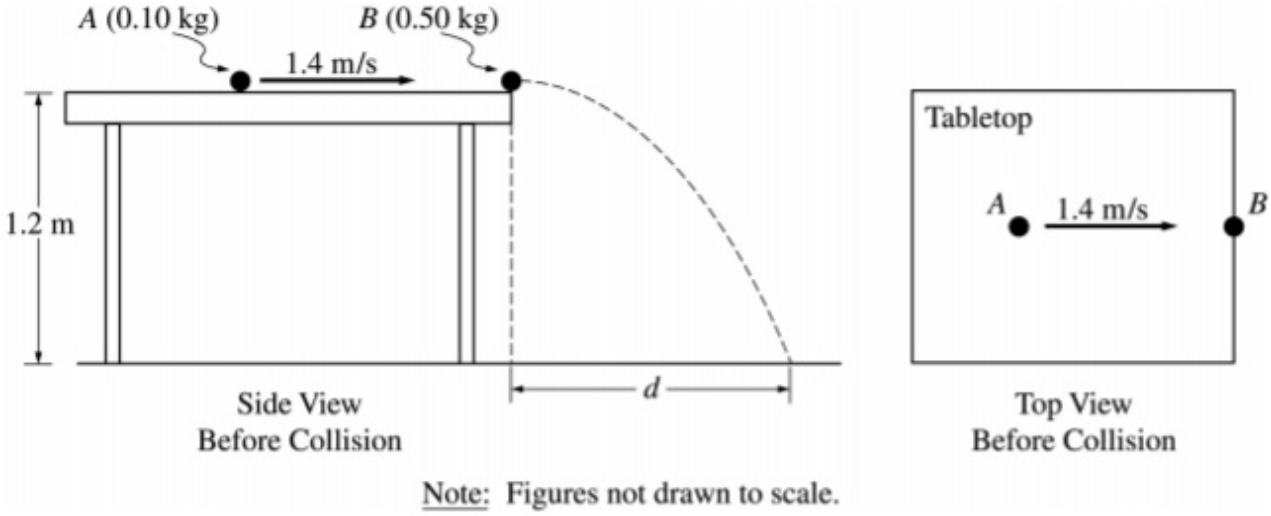
y = y0 + v0yt + ½at2

1 point is earned: For substituting the appropriate values and solving for the time of fall

$$2h = \tfrac{1}{2}gt^2$$
$$t = 2\sqrt{\tfrac{h}{g}}$$
$$x = \sqrt{hg}\left(2\sqrt{\tfrac{h}{g}}\right)$$

chapter1partd

11.

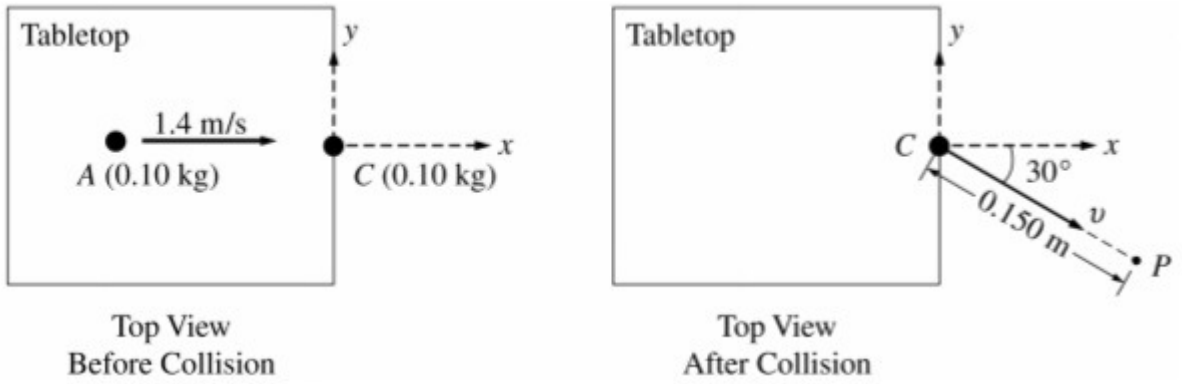


An incident ball *A* of mass 0.10 kg is sliding at 1.4 m/s on the horizontal tabletop of negligible friction shown above. It makes a head-on collision with a target ball *B* of mass 0.50 kg at rest at the edge of the table. As a result of the collision, the incident ball rebounds, sliding backwards at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

chapter1partd

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

Part A

1 point is earned: For any indication that conservation of momentum is applicable

pbefore = *pafter*

mAvAi = *mBvBf* + *mAvAf*

Solving for *vBf*

$v_{Bf} = \frac{m_A(v_{Ai} - v_{Af})}{m_B}$

1 point is earned: For correct substitution of values before the collision

1 point is earned: For correct substitution of values after the collision, including *vAf* = –0.70 m/s

$v_{Bf} = \frac{(0.10\ \text{kg})(1.4\ \text{m/s} + 0.70\ \text{m/s})}{0.50\ \text{kg}}$

1 point is earned: For the correct answer

vBf = 0.42 m/s

✓

0	1	2	3	4

The student response earns all of the following points:

1 point is earned: For any indication that conservation of momentum is applicable

pbefore = *pafter*

mAvAi = *mBvBf* + *mAvAf*

Solving for *vBf*

$v_{Bf} = \frac{m_A(v_{Ai} - v_{Af})}{m_B}$

1 point is earned: For correct substitution of values before the collision

1 point is earned: For correct substitution of values after the collision, including *vAf* = –0.70 m/s

$v_{Bf} = \frac{(0.10\ \text{kg})(1.4\ \text{m/s} + 0.70\ \text{m/s})}{0.50\ \text{kg}}$

1 point is earned: For the correct answer

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vBf = 0.42 m/s

Part B

1 point is earned: For any statement of an equation that can be used to find the time *t* for the ball to fall

For example:

$h = h_0 + v_0 t + \frac{1}{2} a t^2$

1 point is earned: For correct substitution

$0 = 1.2\ \text{m} + 0(t) + \frac{1}{2}(-9.8\ \text{m/s}^2)t^2$

1 point is earned: For the correct value for *t*

t = 0.49 s (same value obtained using *g* = 10 m/s2)

1 point is earned: For substituting the value of *v* from part (a) into a correct equation for the horizontal distance (i.e., having initial position and acceleration both zero)

d = *vt* = (0.42 m/s)(0.49 s)

1 point is earned: For the correct answer

d = 0.21 m



0	1	2	3	4	5

The student response earns all of the following points:

1 point is earned: For any statement of an equation that can be used to find the time *t* for the ball to fall

For example:

$h = h_0 + v_0 t + \frac{1}{2} a t^2$

1 point is earned: For correct substitution

$0 = 1.2\ \text{m} + 0(t) + \frac{1}{2}(-9.8\ \text{m/s}^2)t^2$

1 point is earned: For the correct value for *t*

t = 0.49 s (same value obtained using *g* = 10 m/s2)

1 point is earned: For substituting the value of *v* from part (a) into a correct equation for the horizontal distance (i.e., having initial position and acceleration both zero)

d = *vt* = (0.42 m/s)(0.49 s)

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1 point is earned: For the correct answer

$d = 0.21$ m

Part C

1 point is earned: For any statement of the equation for speed

$vC = d/t$

1 point is earned: For substituting the time from part (b) or correctly recalculating it

$vC = 0.15$ m/0.49 s

1 point is earned: For the correct answer

$vC = 0.31$ m/s

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For any statement of the equation for speed

$vC = d/t$

1 point is earned: For substituting the time from part (b) or correctly recalculating it

$vC = 0.15$ m/0.49 s

1 point is earned: For the correct answer

$vC = 0.31$ m/s

Part D

1 point is earned: For an indication that the momentum in the y-direction is conserved

$\mathbf{p}Ay = -\mathbf{p}Cy$

1 point is earned: For an indication that the y-component of ball C's momentum was calculated

$pAy = mCvC \sin 30°$

$pAy = (0.10 \text{ kg})(0.31 \text{ m/s})\sin 30°$

1 point is earned: For the correct answer

$pAy = 0.015 \text{ kg} \cdot \text{m/s}$

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0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For an indication that the momentum in the *y*-direction is conserved

$\mathbf{p}Ay = -\mathbf{p}Cy$

1 point is earned: For an indication that the *y*-component of ball *C*'s momentum was calculated

$pAy = mCvC \sin 30°$

$pAy = (0.10 \text{ kg})(0.31 \text{ m/s})\sin 30°$

1 point is earned: For the correct answer

$pAy = 0.015 \text{ kg} \cdot \text{m/s}$

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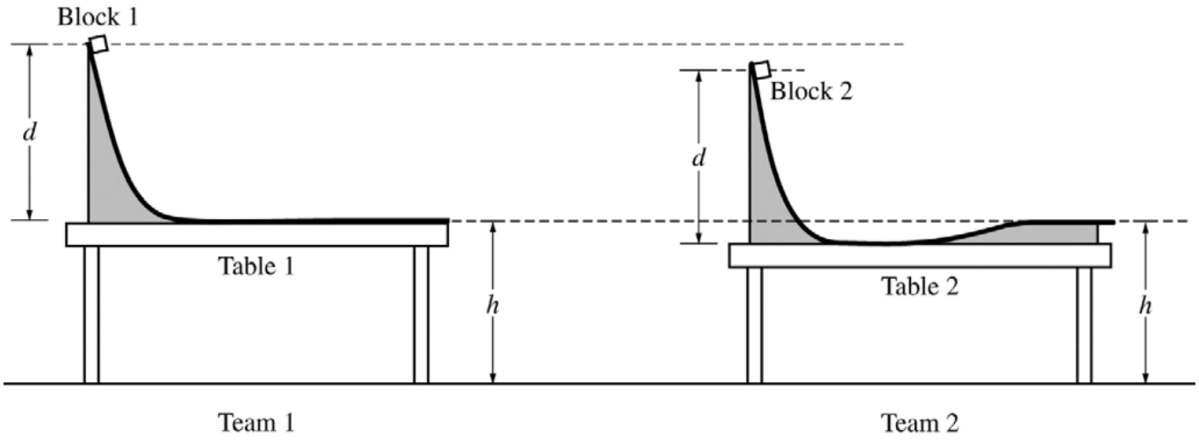
12.



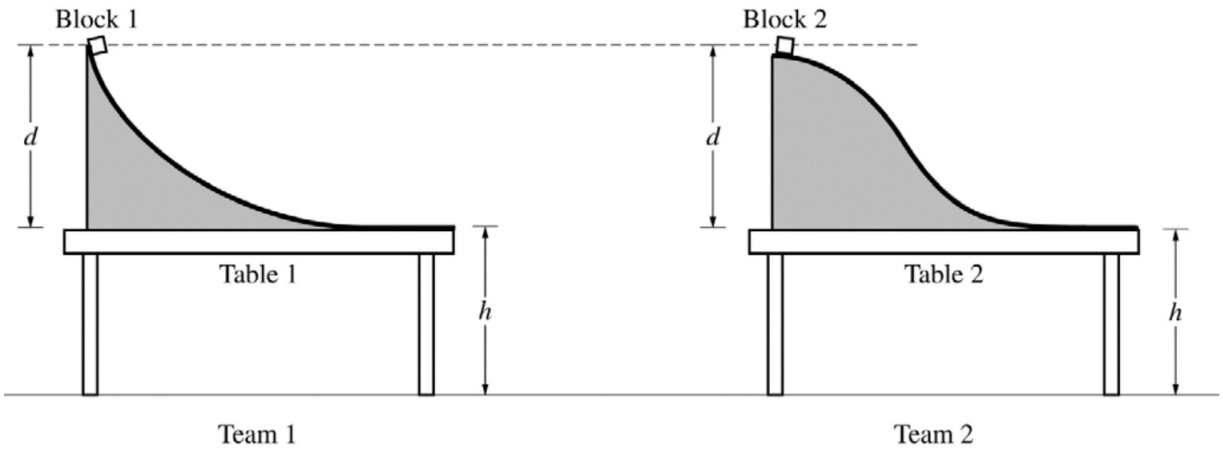
A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is 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.

Part A

Correct answer: “No”

Note: If the wrong answer is selected, partial credit can be earned for the justification.

1 point is earned: For attempting to use conservation of energy to compare the two blocks

1 point is earned: For explicitly or implicitly indicating that the launch velocities are different

1 point is earned: For stating or implying that the time to reach the ground is the same for both blocks

Example: The amount of potential energy converted to kinetic energy is different for the two blocks. The potential energy is proportional to the change in height, which is smaller for block 2. Therefore, at the edge of the table, block 1 will have more kinetic energy than block 2, and hence a larger speed. The launches are both horizontal and from the same height, so the blocks will spend the same amount of time in the air. Because d = vt, the distances will be different for the two blocks (as the speeds are different).



0	1	2	3

Student response earns 3 of the following 3 point(s)

Correct answer: “No”

Note: If the wrong answer is selected, partial credit can be earned for the justification.

1 point is earned: For attempting to use conservation of energy to compare the two blocks

1 point is earned: For explicitly or implicitly indicating that the launch velocities are different

1 point is earned: For stating or implying that the time to reach the ground is the same for both blocks

Example: The amount of potential energy converted to kinetic energy is different for the two blocks. The potential energy is proportional to the change in height, which is smaller for block 2. Therefore, at the edge of

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the table, block 1 will have more kinetic energy than block 2, and hence a larger speed. The launches are both horizontal and from the same height, so the blocks will spend the same amount of time in the air. Because d = vt, the distances will be different for the two blocks (as the speeds are different).

Part B

Part(i)

Correct answer: “The two blocks land the same distance from their respective tables.”

Note: If the wrong answer is selected, partial credit can be earned for the justification.

1 point is earned: For indicating that the change in potential energy from release to launch is the same for the two cases

1 point is earned: For an indication (explicit or implicit) that the launch velocities are the same

Part(ii)

Correct answer: “Block 1”

1 point is earned: For indicating that the average speed or velocity on the slide is higher for Team 1, OR that block 1 reaches its maximum speed in less time

1 point is earned: For a valid explanation of why the average speed or velocity is higher for team 1, OR why block 1 reaches its maximum speed in less time

Example: Because the ramp on Table 1 is initially steeper, block 1 has a higher average speed while it’s on the ramp so it launches off the table before block 2.

0	1	2	3	4 ✓

Student response earns 4 of the following 4 point(s)

Part(i)

Correct answer: “The two blocks land the same distance from their respective tables.”

Note: If the wrong answer is selected, partial credit can be earned for the justification.

1 point is earned: For indicating that the change in potential energy from release to launch is the same for the two cases

1 point is earned: For an indication (explicit or implicit) that the launch velocities are the same

Part(ii)

Correct answer: “Block 1”

1 point is earned: For indicating that the average speed or velocity on the slide is higher for Team 1, OR that block 1 reaches its maximum speed in less time

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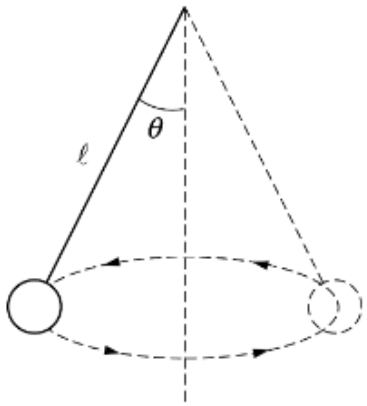
1 point is earned: For a valid explanation of why the average speed or velocity is higher for team 1, OR why block 1 reaches its maximum speed in less time

Example: Because the ramp on Table 1 is initially steeper, block 1 has a higher average speed while it's on the ramp so it launches off the table before block 2.

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.

Part A

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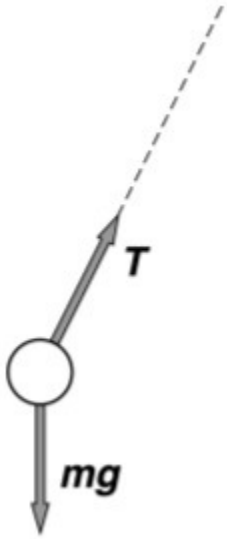


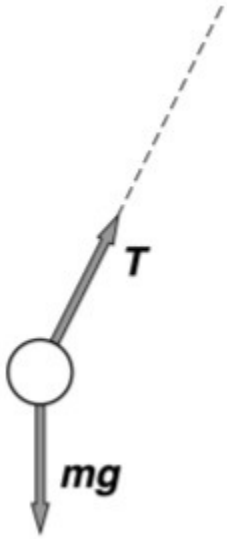
2 points are earned: For each correctly drawn and appropriately labeled force

1 point is earned: For no incorrect forces

The horizontal and vertical components of the tension were acceptable if properly labeled

0	1	2	3 ✓

The student response earns all of the following points:



2 points are earned: For each correctly drawn and appropriately labeled force

1 point is earned: For no incorrect forces

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The horizontal and vertical components of the tension were acceptable if properly labeled

Part B

1 point is earned: For indicating that the sum of the vertical forces is zero

$\sum Fy = 0$

1 point is earned: For correctly substituting the applicable forces

$T \cos \theta - mg = 0$

1 point is earned: For the correct answer

$m = \frac{T \cos \theta}{g}$

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For indicating that the sum of the vertical forces is zero

$\sum Fy = 0$

1 point is earned: For correctly substituting the applicable forces

$T \cos \theta - mg = 0$

1 point is earned: For the correct answer

$m = \frac{T \cos \theta}{g}$

Part C

The centripetal force is supplied by the horizontal component of the tension

$Fc = T \sin \theta$

1 point is earned: For using a correct expression for the centripetal force *Fc*

$\frac{mv^2}{r} = T \sin \theta$

1 point is earned: For eliminating the tension or the mass using the answer to part (b)

$\frac{mv^2}{r} = mg\frac{\sin \theta}{\cos \theta} = mg \tan \theta$ OR $\frac{T \cos \theta v^2}{gr} = T \sin \theta$

1 point is earned: For using the substitution $r = l \sin \theta$

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$\frac{mv^2}{\diamondsuit \sin\theta} = mg\tan\theta$ OR $\frac{T\cos\theta v^2}{g\diamondsuit \sin\theta} = T\sin\theta$

1 point is earned: For the correct answer

$v = \sqrt{g\diamondsuit \sin\theta\tan\theta}$ OR $\sqrt{\frac{g\diamondsuit \sin^2\theta}{\cos\theta}}$

0	1	2	3	4 ✓

The student response earns all of the following points:

The centripetal force is supplied by the horizontal component of the tension

Fc = *T* sin θ

1 point is earned: For using a correct expression for the centripetal force *Fc*

$\frac{mv^2}{r} = T\sin\theta$

1 point is earned: For eliminating the tension or the mass using the answer to part (b)

$\frac{mv^2}{r} = mg\frac{\sin\theta}{\cos\theta} = mg\tan\theta$ OR $\frac{T\cos\theta v^2}{gr} = T\sin\theta$

1 point is earned: For using the substitution *r* = *l* sin θ

$\frac{mv^2}{\diamondsuit \sin\theta} = mg\tan\theta$ OR $\frac{T\cos\theta v^2}{g\diamondsuit \sin\theta} = T\sin\theta$

1 point is earned: For the correct answer

$v = \sqrt{g\diamondsuit \sin\theta\tan\theta}$ OR $\sqrt{\frac{g\diamondsuit \sin^2\theta}{\cos\theta}}$

Part D

1 point is earned: For using a correct expression for period or frequency

$T = \frac{2\pi r}{v}$ OR $f = \frac{v}{2\pi r}$

1 point is earned: For substituting the velocity from part (c)

1 point is earned: For the correct answer (unsimplified acceptable)

$f = \frac{\sqrt{gl\sin\theta\tan\theta}}{2\pi l\sin\theta}$ OR $\frac{1}{2\pi}\sqrt{\frac{g\tan\theta}{l\sin\theta}}$ OR $\frac{1}{2\pi}\sqrt{\frac{g}{l\cos\theta}}$

chapter1partd

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For using a correct expression for period or frequency

$T = \frac{2\pi r}{v}$ OR $f = \frac{v}{2\pi r}$

1 point is earned: For substituting the velocity from part (c)

1 point is earned: For the correct answer (unsimplified acceptable)

$f = \frac{\sqrt{gl \sin\theta \tan\theta}}{2\pi l \sin\theta}$ OR $\frac{1}{2\pi}\sqrt{\frac{g \tan\theta}{l \sin\theta}}$ OR $\frac{1}{2\pi}\sqrt{\frac{g}{l \cos\theta}}$

Part E

1 point is earned: For any indication that the initial velocity of the ball is horizontal

1 point is earned: For any indication that the subsequent trajectory is parabolic

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For any indication that the initial velocity of the ball is horizontal

1 point is earned: For any indication that the subsequent trajectory is parabolic

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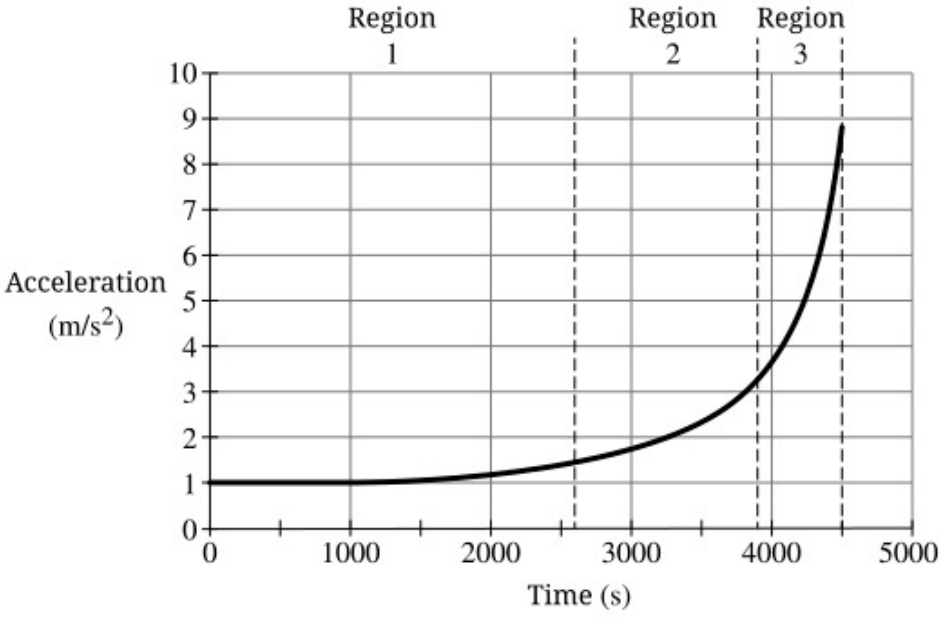
14. This question is a short free-response question. Show your work for each part of the question.



(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 $t = 0$ s and reaches the surface of the planet at time $t = 4500$ 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 $t = 4500$ s to the gravitational force exerted on the object by Planet A at time $t = 2600$ s.

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

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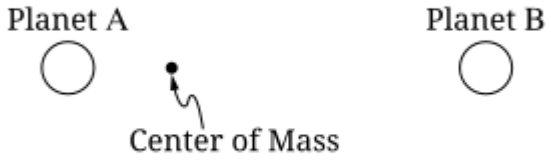
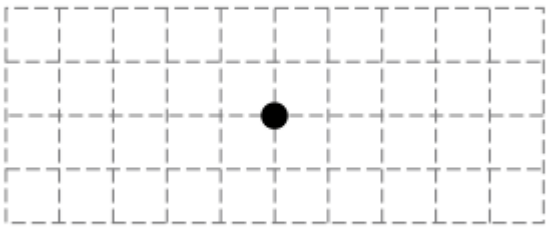


(c) At a later time, the object is launched from the surface of Planet A so that it travels to Planet B. The diagram shows Planet A, Planet B, and the center of mass of the two-planet system. The motion of each planet is negligible.

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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

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0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for selecting only "Mass of the Object."
- ☐ 1 point is earned for **one** of the following:
  - The correct ratio: $\frac{m(8.7\,\text{m/s}^2)}{m(1.5\,\text{m/s}^2)}$
  - The inverse of the correct ratio, $\frac{m(1.5\,\text{m/s}^2)}{m(8.7\,\text{m/s}^2)}$, with supporting work

Scoring Notes:

- A simplified ratio in the range of $5.33 - 6.42$ earns this point.
- A simplified ratio in the range of $0.156 - 0.188$ earns this point with supporting work.

Example Response

$\text{At } t = 2600\,\text{s}$
$F_g = mg$
$F_g = m(1.5\,\text{m/s}^2)$

$\text{At } t = 4500\,\text{s}$
$F_g = mg$
$F_g = m(8.7\,\text{m/s}^2)$

$\frac{m(8.7\,\text{m/s}^2)}{m(1.5\,\text{m/s}^2)} = 5.8$

The magnitude of the gravitational force on the object by Planet A *at time* $t = 4500\,\text{s}$ *is approximately* 5.8 *times larger than the magnitude of the gravitational force on the object by Planet* A *at time* $t = 2600\,\text{s}$.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

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- ☐ 1 point is earned for indicating that the speed of the object at time $t = 4500\,\text{s}$ is 3 times greater than the speed of the object at time $t = 2600\,\text{s}$.
  Scoring Note: Responses that indicate that the speed of the object at $t = 4500\,\text{s}$ is in the range of 2.95 times to 3.18 times the speed of the object at $t = 2600\,\text{s}$ earn this point.
- ☐ 1 point is earned for indicating that the area bound by the curve and the horizontal axis for a region is equal to the change in speed of the object during the time interval associated with the region.

Example Response

For each region, the area bound by the curve and the horizontal axis for a region is equal to the change in the speed of the object and the area bound by the curve and the horizontal axis for each region is equal. Therefore, the object's speed is three times greater at $t = 4500\,\text{s}$ *than at time* $t = 2600\,\text{s}$.

Part C

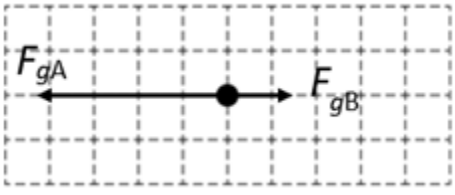
Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** the following criteria.

- ☐ 1 point is earned for drawing two labeled force vector arrows (representing the gravitational forces exerted by planets A and B) that indicate **both** of the following:
  - The correct direction (arrow for Planet A to the left and arrow for Planet B to the right)
  - The correct relative magnitude (arrow for Planet A noticeably longer than arrow for Planet B)
- ☐ 1 point is earned for **one** of the following:
  - Indicating that the speed of the object is decreasing with an attempt at a relevant justification
  - A response that is consistent with the free-body diagram drawn in part (c)(i) with an attempt at a relevant justification
- ☐ 1 point is earned for a correct justification, consistent with the free-body diagram drawn in part (c)(i), in terms of the net force exerted on, or acceleration of, the object.

Example Response



Scoring Note: Appropriate labels for the forces include: $F_{g\text{A}}$, $F_{g\text{B}}$, F_{A}, F_{B}, $F_{\text{Planet A}}$, $F_{\text{Planet B}}$. The labels G or g are

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not appropriate labels for the force due to gravity.

When the object is at the center of mass of the system and moving to the right, the speed of the object is decreasing. The speed is decreasing because the net force is directed to the left, toward Planet A*, which means that the acceleration is also directed to the left.*

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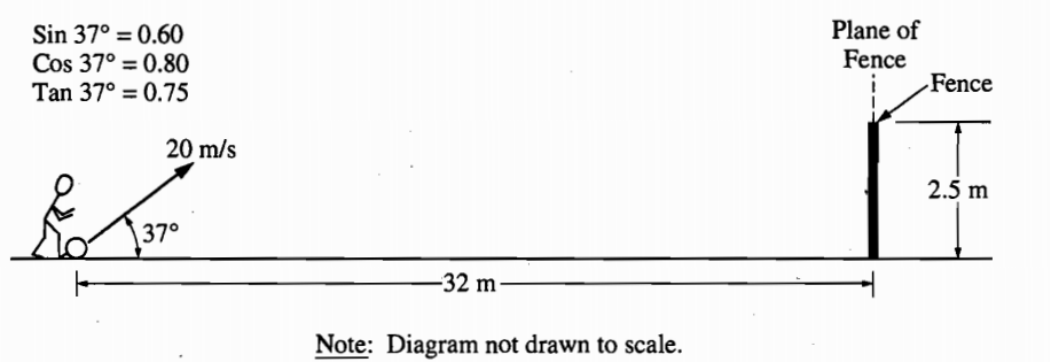
15.



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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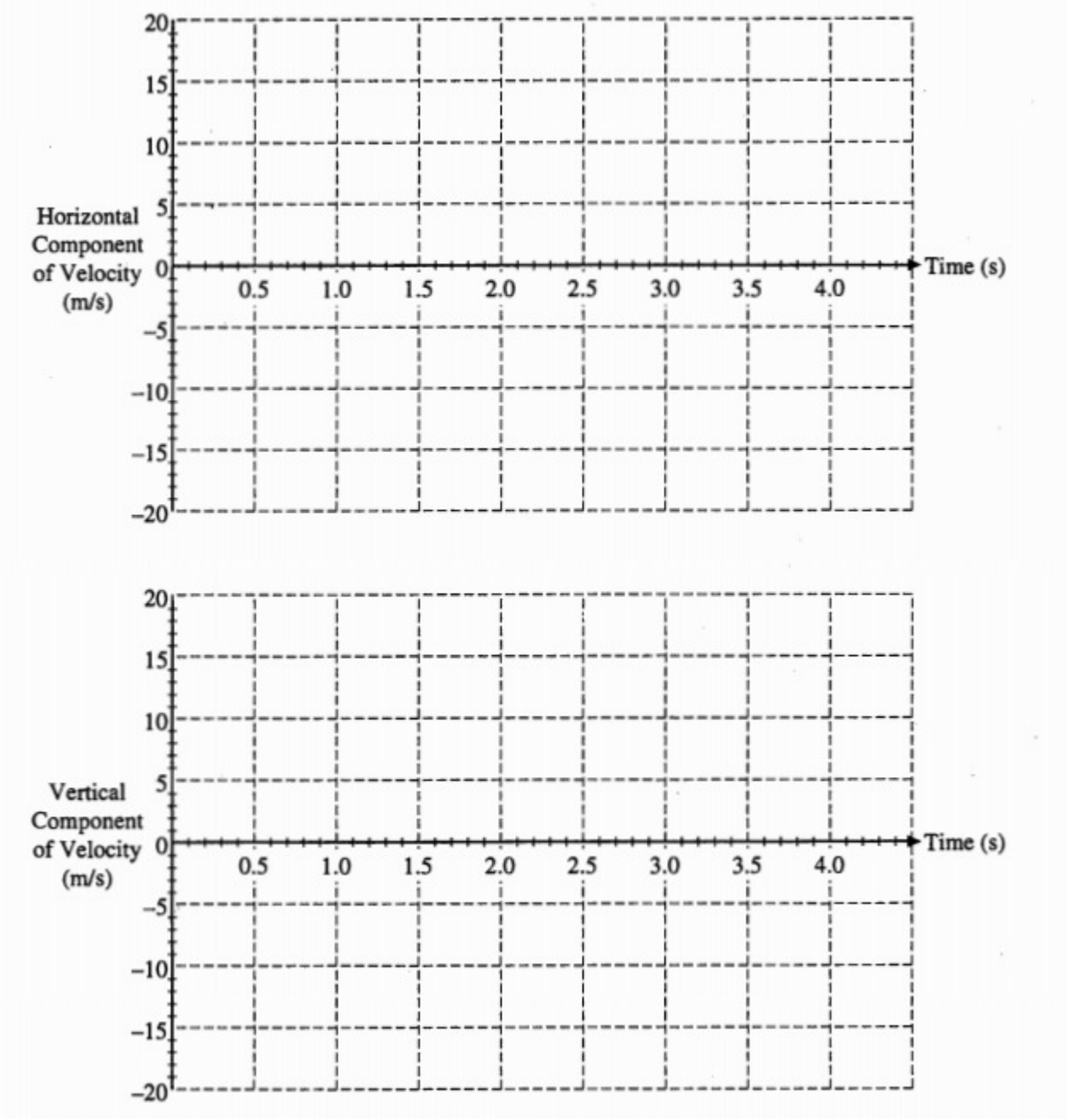

Part A

1 point is earned : From newton's second law,

F avg = ma avg

1 point is earned : $a_{avg} = \frac{\Delta v}{\Delta t}$

$F_{avg} = m\frac{\Delta v}{\Delta t} = (0.5kg)\left(\frac{20m/s}{0.05s}\right)$

1 point is earned : F avg = 200N

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0	1	2	3 ✓

The student response earns three of the following points:

1 point is earned : From newton's second law,

F avg = ma avg

1 point is earned : $a_{avg} = \frac{\Delta v}{\Delta t}$

$F_{avg} = m\frac{\Delta v}{\Delta t} = (0.5kg)\left(\frac{20m/s}{0.05s}\right)$

1 point is earned : F avg = 200N

Part B

The horizontal component of the velocity is constant

1 point is earned: Vhorizt=d

1 point is earned: Vhoriz =v0cos θ = (20m/s)(0.8)=16 m/s

t = d/ Vhoriz = 32 m / 16 m/s

1 point is earned: t = 2s

0	1	2 ✓

The student response earns two of the following points:

The horizontal component of the velocity is constant

1 point is earned: Vhorizt=d

1 point is earned: Vhoriz =v0cos θ = (20m/s)(0.8)=16 m/s

t = d/ Vhoriz = 32 m / 16 m/s

1 point is earned: t = 2s

Part C

The height y of the ball during its flight is given by

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1 point is earned: y = vvertt- ½ gt2 [point also given if a issued instead of *g*]

1 point is earned: vvert = v0 sin θ = (20 m/s)(0.8) = 12 m/s

At t=2 s:

y = (12 m/s)(2s) - ½(9.8 m/s2)(2s)2

1 point is earned: y = 4.4m [Answer is 4.0 m if g = m/s2 is used]

1 point is earned: The ball is 4.4 meters above the ground at the time it reaches the fence, which is 2.5 meters high, so it passes above the fence.

1 point is earned: The distance is passes above the fence is

4.4 m - 2.5 m = 1.9 m. [Answer is 1.5 m if g = 10 m/s2 is used]



0	1	2	3	4	5

The student response earns five of the following points:

The height y of the ball during its flight is given by

1 point is earned: y = vvertt- ½ gt2 [point also given if a issued instead of *g*]

1 point is earned: vvert = v0 sin θ = (20 m/s)(0.8) = 12 m/s

At t=2 s:

y = (12 m/s)(2s) - ½(9.8 m/s2)(2s)2

1 point is earned: y = 4.4m [Answer is 4.0 m if g = m/s2 is used]

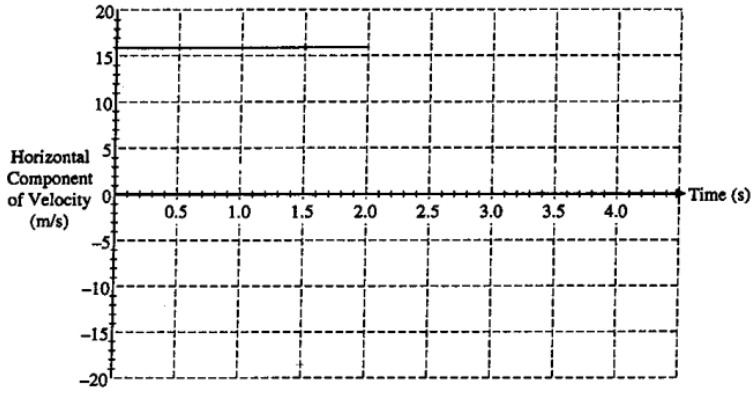
1 point is earned: The ball is 4.4 meters above the ground at the time it reaches the fence, which is 2.5 meters high, so it passes above the fence.

1 point is earned: The distance is passes above the fence is

4.4 m - 2.5 m = 1.9 m. [Answer is 1.5 m if g = 10 m/s2 is used]

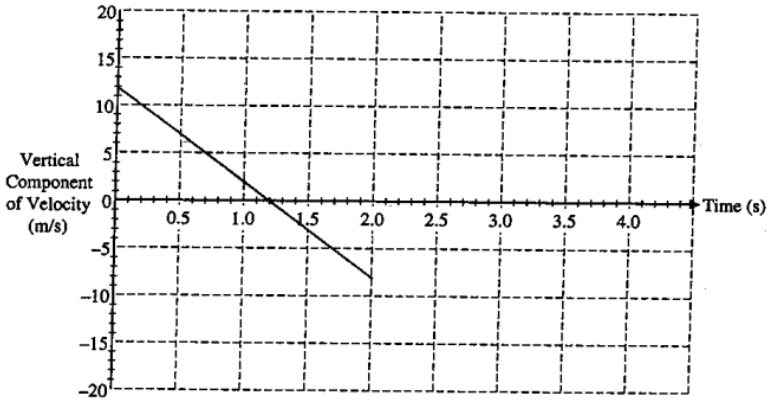
Part D

chapter1partd



1 point is earned: For graph at a constant value (zero slope) after initial impulse period

1 point is earned: For correct value of 16 m/s



1 point is earned: For linear decrease of graph after initial impulse period

1 point is earned: For first correct point on the line

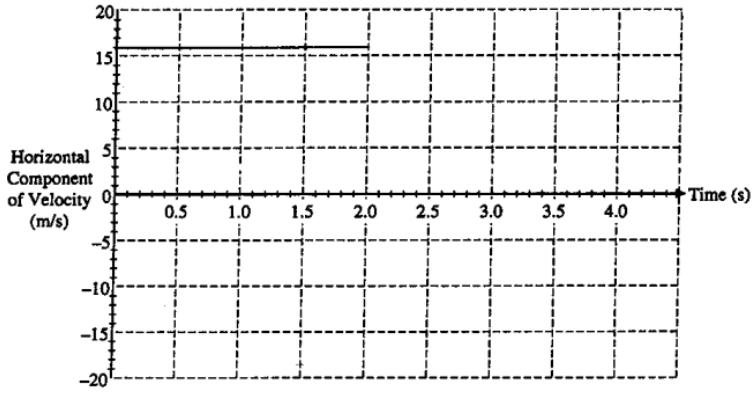
1 point is earned: For second correct point on the line or for correct slope

[Note: The graph above assume that time = 0 at the instant the ball leaves the foot.If time = 0 were assumed to be at the start of the kick, the graphs would show an initial impulse period of 0.05 second. Either assumption is OK. The graphs were graded only on the basis of the time after the initial impulse period. However, if the initial impulse period was too large by a factor of 10 on both graphs, students lost the shape point on the first part, but not on the second.]

0	1	2	3	4	5 ✓

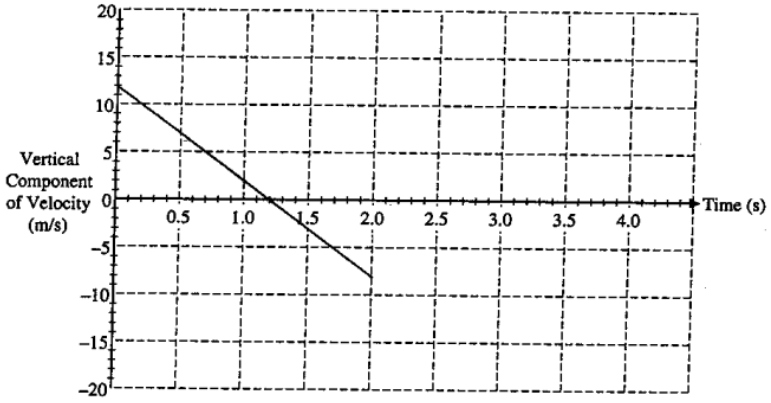
The student response earns five of the following points:

chapter1partd



1 point is earned: For graph at a constant value (zero slope) after initial impulse period

1 point is earned: For correct value of 16 m/s



1 point is earned: For linear decrease of graph after initial impulse period

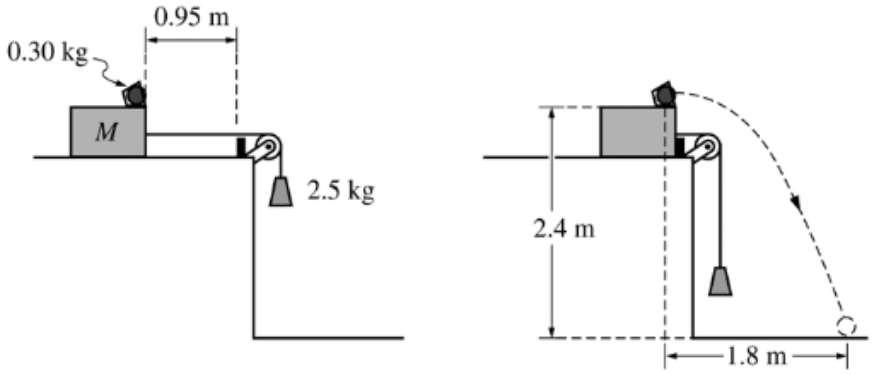
1 point is earned: For first correct point on the line

1 point is earned: For second correct point on the line or for correct slope

[Note: The graph above assume that time = 0 at the instant the ball leaves the foot.If time = 0 were assumed to be at the start of the kick, the graphs would show an initial impulse period of 0.05 second. Either assumption is OK. The graphs were graded only on the basis of the time after the initial impulse period. However, if the initial impulse period was too large by a factor of 10 on both graphs, students lost the shape point on the first part, but not on the second.]

chapter1partd

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.

Part A

1 point is earned: For using a correct expression for the vertical motion to determine time *t*

$\Delta y = v_{yi}t + \frac{1}{2}at^2$

$v_{yi} = 0, so, t = \sqrt{\frac{2(\Delta y)}{a}}$

1 point is earned: For substituting the correct height and acceleration into the vertical equation

$t = \sqrt{\frac{(2)(2.4m)}{(9.8m/s^2)}} = 0.70s$

1 point is earned: For substituting the correct values into the constant horizontal velocity equation

$v_x = \frac{\Delta x}{t}$

$v_x = \frac{(1.8m)}{(0.70s)} = 2.6m/s$

chapter1partd

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For using a correct expression for the vertical motion to determine time *t*

$\Delta y = v_{yi}t + \frac{1}{2}at^2$

$v_{yi} = 0, so, t = \sqrt{\frac{2(\Delta y)}{a}}$

1 point is earned: For substituting the correct height and acceleration into the vertical equation

$t = \sqrt{\frac{(2)(2.4m)}{(9.8m/s^2)}} = 0.70s$

1 point is earned: For substituting the correct values into the constant horizontal velocity equation

$v_x = \frac{\Delta x}{t}$

$v_x = \frac{(1.8m)}{(0.70s)} = 2.6m/s$

Part B

1 point is earned: For using a correct expression to determine the acceleration of the block

$v_x^2 = v_0^2 + 2ad$

$a = \frac{v_x^2}{2d}$

1 point is earned: For correct substitutions consistent with part (a)

$a = \frac{(2.6m/s)^2}{(2)(0.95m)} = 3.5m/s^2$

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For using a correct expression to determine the acceleration of the block

$v_x^2 = v_0^2 + 2ad$

$a = \frac{v_x^2}{2d}$

chapter1partd

1 point is earned: For correct substitutions consistent with part (a)

$a = \frac{(2.6m/s)^2}{(2)(0.95m)} = 3.5m/s^2$

Part C

For using Newton's second law

$\sum F = ma$
$m_{obj}g = (m_{obj} + M + m_{ball})a$

1 point is earned: For a correct value for the total force on the system

mobjg = (mobj + M + mball) a

1 point is earned: For correct values in the expression for the total mass being accelerated

$(m_{obj} + M + m_{ball})a = (2.5kg + 0.3kg + M)a = (2.8kg + M)a$

1 point is earned: For the correct substitution of the acceleration of the block from part (b)

25 N = (2.8 kg + *M*) (3.5 m/s2)

M =4.24 kg

0	1	2	3 ✓

The student response earns all of the following points:

For using Newton's second law

$\sum F = ma$
$m_{obj}g = (m_{obj} + M + m_{ball})a$

1 point is earned: For a correct value for the total force on the system

mobjg = (mobj + M + mball) a

1 point is earned: For correct values in the expression for the total mass being accelerated

$(m_{obj} + M + m_{ball})a = (2.5kg + 0.3kg + M)a = (2.8kg + M)a$

1 point is earned: For the correct substitution of the acceleration of the block from part (b)

25 N = (2.8 kg + *M*) (3.5 m/s2)

M =4.24 kg

chapter1partd

Part D

1 point is earned: For stating that with the same force, the horizontal acceleration of the ball will be less as a result of the increased mass of the system

1 point is earned: For stating the launch velocity will be lower

Example

A larger combined mass of the system will result in a smaller acceleration, so the ball has a smaller speed upon launch. However, the time to hit the floor will be the same since it's falling the same vertical distance with the same vertical acceleration in freefall. So the horizontal distant (*vlaunch* x *tfall*) will be less.

One earned point was deducted for any incorrect statement in the reasoning not included in the points shown.

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For stating that with the same force, the horizontal acceleration of the ball will be less as a result of the increased mass of the system

1 point is earned: For stating the launch velocity will be lower

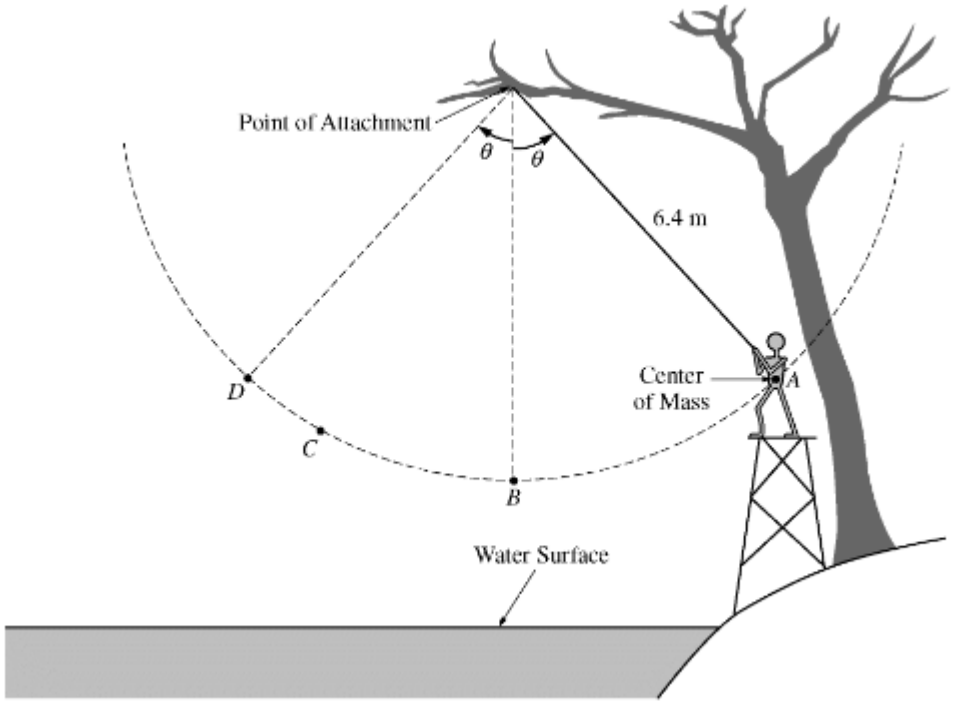
Example

A larger combined mass of the system will result in a smaller acceleration, so the ball has a smaller speed upon launch. However, the time to hit the floor will be the same since it's falling the same vertical distance with the same vertical acceleration in freefall. So the horizontal distant (*vlaunch* x *tfall*) will be less.

One earned point was deducted for any incorrect statement in the reasoning not included in the points shown.

chapter1partd

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.

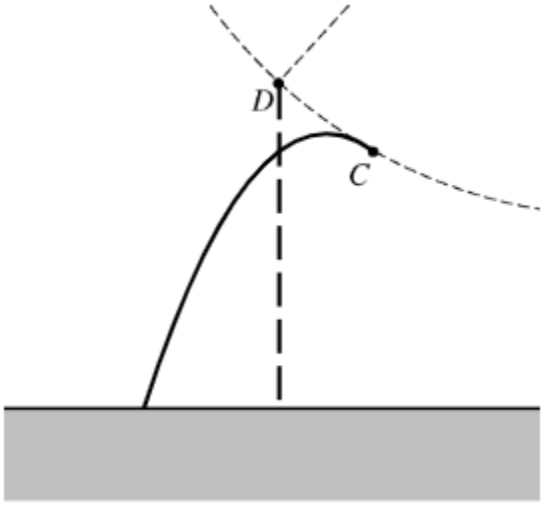
(e) If the person does not let go of the rope, how does the magnitude of the person's momentum p_C at point C compare with the magnitude of the person's momentum p_B at point B ?

chapter1partd

____ $p_C > p_B$ ____ $p_C < p_B$ ____ $p_C = p_B$

Provide a physical explanation to justify your answer.

Part A



1 point is earned: For showing a parabolic path from point *C* that is tangent to the arc at *C*

1 point is earned: For a maximum height of the parabolic path that is lower than point *D*

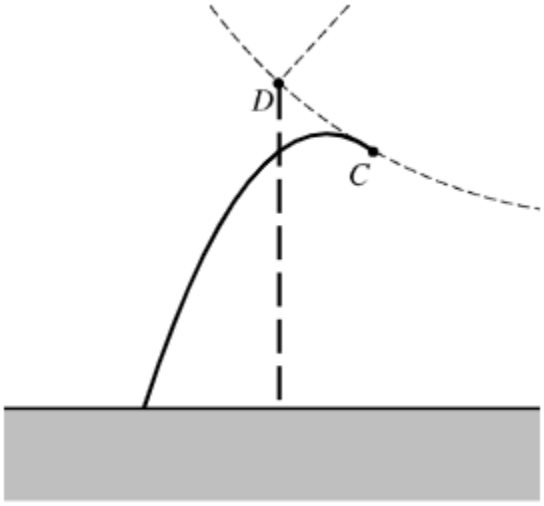
1 point is earned: For showing the person traveling straight downward from point *D*

Note: the two paths may, but need not, cross each other.

0	1	2	3 ✓

The student response earns all of the following points:

chapter1partd



1 point is earned: For showing a parabolic path from point *C* that is tangent to the arc at *C*

1 point is earned: For a maximum height of the parabolic path that is lower than point *D*

1 point is earned: For showing the person traveling straight downward from point *D*

Note: the two paths may, but need not, cross each other

Part B

1 point is earned: For using the gravitational potential energy equation

$\Delta U_g = mgh = (50kg)\left(9.8m/s^2\right)(4.1m)$

1 point is earned: For a correct answer

$\Delta U_g = 2010J\left(or, 2050J, u \sin g, g = 10m/s^2\right)$

✓

0	1	2

The student response earns all of the following points:

1 point is earned: For using the gravitational potential energy equation

$\Delta U_g = mgh = (50kg)\left(9.8m/s^2\right)(4.1m)$

1 point is earned: For a correct answer

$\Delta U_g = 2010J\left(or, 2050J, u \sin g, g = 10m/s^2\right)$

Part C

chapter1partd

1 point is earned: For using an expression of conservation of energy

$U_{g1} = U_{g2} + K_2$
$mgh_1 = mgh_2 + \frac{1}{2}mv^2$

1 point is earned: For correctly substituting values

$gh_1 = gh_2 + \frac{1}{2}v^2$
$v = \sqrt{2g(h_1 - h_2)}$
$v = \sqrt{2(9.8m/s^2)(4.1m - 2.4m)}$

1 point is earned: For a correct answer

v = 5.8 m/s

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For using an expression of conservation of energy

$U_{g1} = U_{g2} + K_2$
$mgh_1 = mgh_2 + \frac{1}{2}mv^2$

1 point is earned: For correctly substituting values

$gh_1 = gh_2 + \frac{1}{2}v^2$
$v = \sqrt{2g(h_1 - h_2)}$
$v = \sqrt{2(9.8m/s^2)(4.1m - 2.4m)}$

1 point is earned: For a correct answer

v = 5.8 m/s

Part D

1 point is earned: For using a correct expression to solve for the time of fall

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

1 point is earned: For correctly solving for the time of fall

chapter1partd

$\Delta y = \frac{1}{2}at^2$

$t = \sqrt{\frac{2\Delta y}{a}}$

$t = \sqrt{\frac{2(2.4m)}{(9.8m/s^2)}}$

$t = 0.70s\left(or, 0.69s, u\sin g, g = 10m/s^2\right)$

In the horizontal direction, the acceleration is zero.

R = *vxt*

1 point is earned: For substituting the speed from part (c) into the constant-velocity equation for horizontal motion

R = (5.8 m/s)(0.70 s)

R = 4.1 m (or 4.0 m using either unrounded speed of 5.77 m/s or g = 10 m/s2)

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For using a correct expression to solve for the time of fall

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

1 point is earned: For correctly solving for the time of fall

$\Delta y = \frac{1}{2}at^2$

$t = \sqrt{\frac{2\Delta y}{a}}$

$t = \sqrt{\frac{2(2.4m)}{(9.8m/s^2)}}$

$t = 0.70s\left(or, 0.69s, u\sin g, g = 10m/s^2\right)$

In the horizontal direction, the acceleration is zero.

R = *vxt*

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R = (5.8 m/s)(0.70 s)

R = 4.1 m (or 4.0 m using either unrounded speed of 5.77 m/s or g = 10 m/s2

Units

1 point is earned: For correct units in the calculated answers to parts (b), (c), and (d)

chapter1partd

0	1 ✓

The student response earns all of the following points:

1 point is earned: For correct units in the calculated answers to parts (b), (c), and (d)

Part E

1 point is earned: For selecting " $pC < pB$ "

1 point is earned: For any indication that the speed at C is less than the speed at B

1 point is earned: For an explanation of why the speed decreases from B to C, which includes the following or equivalent statements:

by conservation of energy: U increases as the person moves from B to C, therefore K decreases, resulting in a decrease in speed

OR gravitational force opposes motion as the person moves from B to C, which results in a negative acceleration and a decrease in speed

OR by the impulse-momentum theorem: momentum decreases because the force of gravity provides impulse opposing the motion of the person

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For selecting " $pC < pB$ "

1 point is earned: For any indication that the speed at C is less than the speed at B

1 point is earned: For an explanation of why the speed decreases from B to C, which includes the following or equivalent statements:

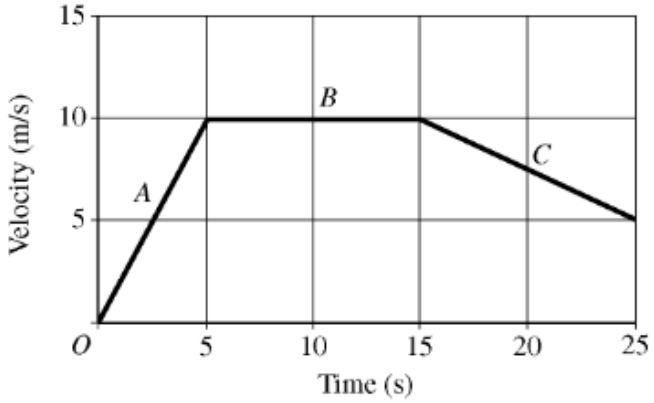
by conservation of energy: U increases as the person moves from B to C, therefore K decreases, resulting in a decrease in speed

OR gravitational force opposes motion as the person moves from B to C, which results in a negative acceleration and a decrease in speed

OR by the impulse-momentum theorem: momentum decreases because the force of gravity provides impulse opposing the motion of the person

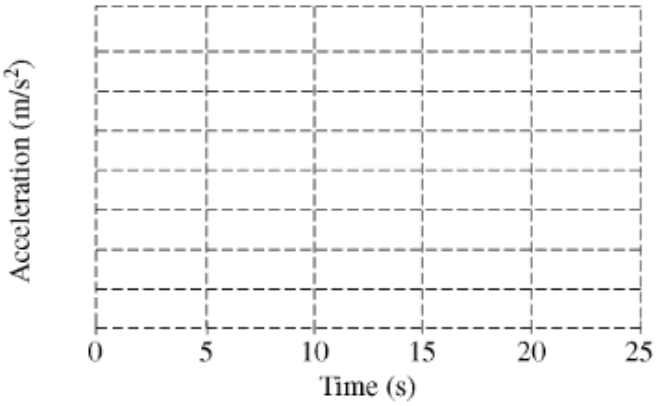
chapter1partd

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.

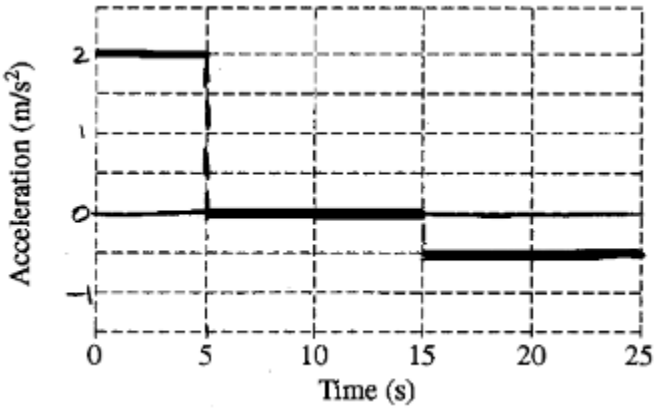
chapter1partd

(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.

Part A



1 point is earned: For using a linear scale on the vertical axis

1 point is earned: For showing horizontal lines in the three appropriate time frames

1 point is earned: For having the correct acceleration values for segments *B* and *C* (The correct value for segment *A* is accounted for in the answer point in part (d).)

a = $\Delta v / \Delta t$ (or the slope of the velocity versus time curve)

For segment A: a = (10m/s - 0m/s)/(5 s - 0 s) = 2 m/s2

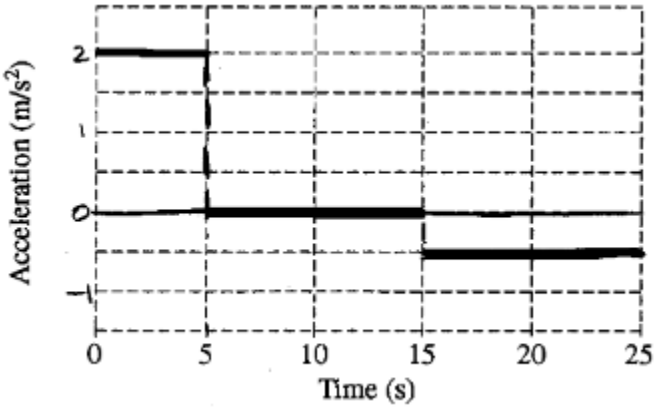
For segment B: slope is zero, so acceleration is zero

For segment C: a = (5m/s - 10m/s)/(25 s - 15 s) = -0.5 m/s2

0	1	2	3 ✓

The student response earns all of the following points:

chapter1partd



1 point is earned: For using a linear scale on the vertical axis

1 point is earned: For showing horizontal lines in the three appropriate time frames

1 point is earned: For having the correct acceleration values for segments *B* and *C* (The correct value for segment *A* is accounted for in the answer point in part (d).)

a = Δ*v*/ Δ*t* (or the slope of the velocity versus time curve)

For segment A: *a* = (10m/s - 0m/s)/(5 s - 0 s) = 2 m/s2

For segment B: slope is zero, so acceleration is zero

For segment C: *a* = (5m/s - 10m/s)/(25 s - 15 s) = -0.5 m/s2

Part B

x = *x0* + *v0t* + (1/2)at2, where *x0* = 0

1 point is earned: For substituting v0 = 0 and *t* = 5 s and into the equation above

1 point is earned: For substituting the value on the graph of the constant acceleration between 0 and 5 s or an explicit calculation of 2m/s2

x = (1/2)(2 m/s2)(5 s)2

x = 25 m

Alternate solution

Position is the area under the velocity versus time curve.

1 point is earned: *For correctly substituting into the expression for the area under the curve*

x = (1/2)(10 m/s)(5 s)

1 point is earned: *For the correct answer*

x = 25 m

chapter1partd

0	1	2 ✓

The student response earns all of the following points:

$x = x0 + v0t + (1/2)at2$, where $x0 = 0$

1 point is earned: For substituting v0 = 0 and $t = 5$ s and into the equation above

1 point is earned: For substituting the value on the graph of the constant acceleration between 0 and 5 s or an explicit calculation of 2m/s2

$x = (1/2)(2\ m/s2)(5\ s)2$

x = 25 m

Alternate solution

Position is the area under the velocity versus time curve.

1 point is earned: *For correctly substituting into the expression for the area under the curve*

x = (1/2)(10 m/s)(5 s)

1 point is earned: *For the correct answer*

x = 25 m

Part C

1 point is earned: For selecting segment *B*

1 point is earned: For an appropriate justification

Example: Fnet = ma = m ($\Delta v/\ \Delta t$), the velocity is constant for this segment, $\Delta v = 0$; therefore, *Fnet* = 0.

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For selecting segment *B*

1 point is earned: For an appropriate justification

Example: Fnet = ma = m ($\Delta v/\ \Delta t$), the velocity is constant for this segment, $\Delta v = 0$; therefore, *Fnet* = 0.

chapter1partd

Part D

1 point is earned: For using Newton's second law

Fnet = ma

Fnet = (0.40 kg)(2 m/s2)

1 point is earned: For the correct answer

Fnet = 0.80 N

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For using Newton's second law

Fnet = ma

Fnet = (0.40 kg)(2 m/s2)

1 point is earned: For the correct answer

Fnet = 0.80 N

Part E

1 point is earned: For using the work-energy theorem

W = FΔr cos θ

To move in a straight line, the net force must be in the direction of motion, so . *W* = *Fnetd*

1 point is earned: For substituting the value of the position determined in from part (b), which is equal to the displacement, to determine the work done for segment A

For segment A, *WA* = (0.8)(25 m) = 20 J

For segment B, *WB* = (0 N)(10 m/s)(10 s) = 0 J

Wtot = *WA* + *WB* = 20 J + 0 J = 20 J

Alternate solution

$W = \Delta K$

$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

chapter1partd

1 point is earned: *For correct substitutions into the equation above*

$W = \frac{1}{2}(0.40kg)(10m/s)^2 - \frac{1}{2}(0.40kg)(0m/s)^2$

1 point is earned: *For the correct answer*

W = 20 J

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For using the work-energy theorem

W = F Δr cos θ

To move in a straight line, the net force must be in the direction of motion, so . *W = Fnetd*

1 point is earned: For substituting the value of the position determined in from part (b), which is equal to the displacement, to determine the work done for segment A

For segment A, *WA* = (0.8)(25 m) = 20 J

For segment B, *WB* = (0 N)(10 m/s)(10 s) = 0 J

Wtot = WA + WB = 20 J + 0 J = 20 J

Alternate solution

$W = \Delta K$
$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

1 point is earned: *For correct substitutions into the equation above*

$W = \frac{1}{2}(0.40kg)(10m/s)^2 - \frac{1}{2}(0.40kg)(0m/s)^2$

1 point is earned: *For the correct answer*

W = 20 J

Part F

1 point is earned: For selecting “Negative”

1 point is earned: For an appropriate explanation using kinematic or dynamic principles

Examples:

chapter1partd

The velocity is decreasing, so the kinetic energy is also decreasing.

The acceleration is negative; therefore, the direction of the net force is opposite to the direction of the displacement.

1 point is earned: For connecting the explanation to the work done

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For selecting “Negative”

1 point is earned: For an appropriate explanation using kinematic or dynamic principles

Examples:

The velocity is decreasing, so the kinetic energy is also decreasing.

The acceleration is negative; therefore, the direction of the net force is opposite to the direction of the displacement.

1 point is earned: For connecting the explanation to the work done

Units

1 point is earned: For correct units on at least two parts with a calculated numerical answer and no incorrect units

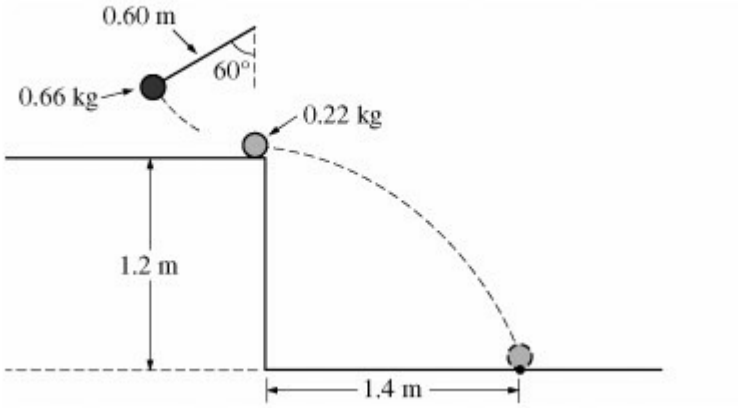
0	1 ✓

The student response earns all of the following points:

1 point is earned: For correct units on at least two parts with a calculated numerical answer and no incorrect units

chapter1partd

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.

Part A

One point is earned for work indicating use of conservation of energy

$U_{g1} = K_2$
$mgh_1 = \frac{1}{2}mv_2^2$

One point is earned for a correct expression for determining the vertical drop-distance

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$$h = L - L\cos 60^\circ$$
$$h = 0.60m - (0.60m)\cos 60^\circ$$
$$h = 0.30m$$

One point is earned for substitution of a drop distance (other than 0.60 m) into a correct expression for the speed of the 0.66 kg ball just before the collision

$v = \sqrt{2gh} = \sqrt{2(9.8m/s^2)(0.30)}$
$v = 2.4m/s$

0	1	2	3 ✓

The student earns all of the following points:

One point is earned for work indicating use of conservation of energy

$U_{g1} = K_2$
$mgh_1 = \frac{1}{2}mv_2^2$

One point is earned for a correct expression for determining the vertical drop-distance

$$h = L - L\cos 60^\circ$$
$$h = 0.60m - (0.60m)\cos 60^\circ$$
$$h = 0.30m$$

One point is earned for substitution of a drop distance (other than 0.60 m) into a correct expression for the speed of the 0.66 kg ball just before the collision

$v = \sqrt{2gh} = \sqrt{2(9.8m/s^2)(0.30)}$
$v = 2.4m/s$

Part B

The speed immediately after the collision equals the horizontal speed of the 0.22 kg ball as it leaves the table, which is the horizontal distance it travels divided by the time it takes to fall.

One point is earned for a correct expression for the time it takes the 0.22 kg ball to fall

$$\triangle y = \frac{1}{2}gt^2$$
$$t = \sqrt{2 \triangle y/g}$$
$$t = \sqrt{2(1.2m)/(9.8m/s^2)}$$
$$t = 0.49s (or\ 0.50s \text{ using } g = 10m/s^2)$$

One point is earned for consistent substitution of the time into a correct expression for the speed of the 0.22 kg ball after

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the collision

$v_{0.22} = x/t = (1.4m)/(0.49s)$

One point is earned for the correct numerical value of the speed

$$v_{0.22} = 2.8m/s \ (or \ 2.9m/s \text{ using } g = 10m/s^2)$$

0	1	2	3 ✓

The student earns all of the following points:

The speed immediately after the collision equals the horizontal speed of the 0.22 kg ball as it leaves the table, which is the horizontal distance it travels divided by the time it takes to fall.

One point is earned for a correct expression for the time it takes the 0.22 kg ball to fall

$$\triangle y = \tfrac{1}{2} g t^2$$
$$t = \sqrt{2 \triangle y / g}$$
$$t = \sqrt{2(1.2m)/(9.8m/s^2)}$$
$$t = 0.49s (or \ 0.50s \text{ using } g = 10m/s^2)$$

One point is earned for consistent substitution of the time into a correct expression for the speed of the 0.22 kg ball after the collision

$v_{0.22} = x/t = (1.4m)/(0.49s)$

One point is earned for the correct numerical value of the speed

$$v_{0.22} = 2.8m/s \ (or \ 2.9m/s \text{ using } g = 10m/s^2)$$

Part C

One point is earned for work indicating use of conservation of momentum

$m_{0.66} v_{0.66i} = m_{0.66} v_{0.66f} + m_{0.22} v_{0.22f}$

One point is earned for consistent substitution of the answer from part (a) as *v0.66i* in a correct expression for *v0.66f*

$v_{0.66f} = \frac{m_{0.66} v_{0.66i} - m_{0.22} v_{0.22f}}{m_{0.66}} = \frac{(0.66kg)(2.4m/s) - (0.22kg)(2.8m/s)}{(0.66kg)}$

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One point is earned for the correct numerical value of the speed

$$v_{0.66f} = 1.5m/s \ (or \ 1.4m/s \text{ using } g = 10m/s^2)$$

0	1	2	3 ✓

The student earns all of the following points:

One point is earned for work indicating use of conservation of momentum

$m_{0.66}v_{0.66i} = m_{0.66}v_{0.66f} + m_{0.22}v_{0.22f}$

One point is earned for consistent substitution of the answer from part (a) as *v0.66i* in a correct expression for *v0.66f*

$v_{0.66f} = \frac{m_{0.66}v_{0.66i} - m_{0.22}v_{0.22f}}{m_{0.66}} = \frac{(0.66kg)(2.4m/s) - (0.22kg)(2.8m/s)}{(0.66kg)}$

One point is earned for the correct numerical value of the speed

$$v_{0.66f} = 1.5m/s \ (or \ 1.4m/s \text{ using } g = 10m/s^2)$$

Part D

One point is earned for indicating “To the right” as the direction of motion of the 0.66 kg ball after the collision

0	1 ✓

The student earns all of the following points:

One point is earned for indicating “To the right” as the direction of motion of the 0.66 kg ball after the collision

Part E

One point is earned for an appropriate conservation of energy statement

$K_1 = U_{g2}$
$\frac{1}{2}mv_{0.66f}^2 = mgh'$

One point is earned for consistent substitution of *v0.66f* from part (c) into a correct expression for h'

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$h' = \frac{v_{0.66f}^2}{2g} = \frac{(1.5m/s)^2}{(2)(9.8m/s^2)}$
$h' = 0.11m$

0	1	2 ✓

The student earns all of the following points:

One point is earned for an appropriate conservation of energy statement

$K_1 = U_{g2}$
$\frac{1}{2}mv_{0.66f}^2 = mgh'$

One point is earned for consistent substitution of *v0.66f* from part (c) into a correct expression for h'

$h' = \frac{v_{0.66f}^2}{2g} = \frac{(1.5m/s)^2}{(2)(9.8m/s^2)}$
$h' = 0.11m$

Part F

One point is earned for any indication of comparing kinetic energies of the system before and after the collision

One point is earned for calculating the two values of kinetic energy

$K_i = \frac{1}{2}(0.66kg)\text{msup} = 1.9J$
$K_f = \frac{1}{2}(0.66kg)\text{msup} + \frac{1}{2}(0.22kg)(2.8m/s^2) = 1.6J$

One point is earned for indication that the difference in the kinetic energies means an inelastic collision

0	1	2	3 ✓

The student earns all of the following points:

One point is earned for any indication of comparing kinetic energies of the system before and after the collision

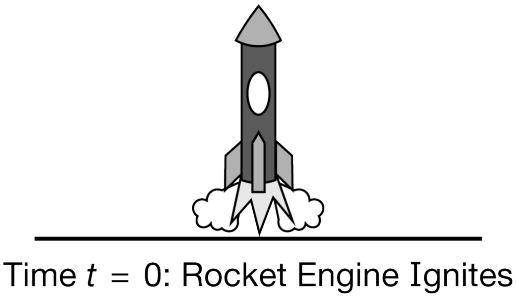
One point is earned for calculating the two values of kinetic energy

$K_i = \frac{1}{2}(0.66kg)\text{msup} = 1.9J$
$K_f = \frac{1}{2}(0.66kg)\text{msup} + \frac{1}{2}(0.22kg)(2.8m/s^2) = 1.6J$

One point is earned for indication that the difference in the kinetic energies means an inelastic collision

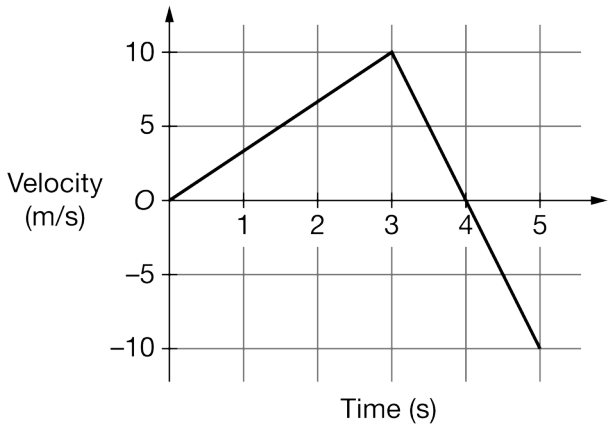
chapter1partd

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



(7 points, suggested time 13 minutes)

A model rocket of constant mass 0.5 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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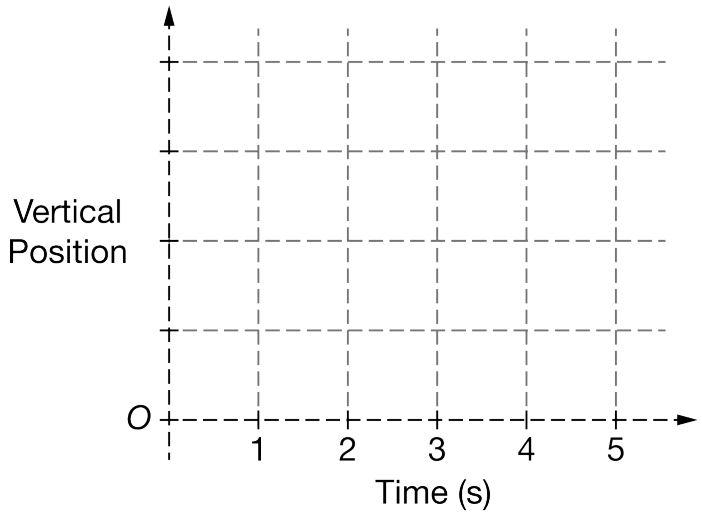

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for using the slope of the line from $t = 0$ to $t = 3$ seconds to find the acceleration of the rocket.
- ☐ 1 point is earned for using Newton's second law to correctly determine the force exerted by the engine.

Example Response for part (a):

Slope of the velocity graph from t=0 to t=3 seconds

Slope $= \frac{10\ \text{m/s}}{3\ \text{s}} = 3.3 \frac{\text{m}}{\text{s}^2}$

$\sum F_y = ma_y$

$F_{engine} - F_g = ma_y$

$F_{engine} = (0.5\ \text{kg})(3.3\ \frac{m}{s^2}) + (0.5\ \text{kg})(9.8\ \frac{\text{m}}{\text{s}^2}) = 6.6\ \text{N}$

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

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0	1	2	3 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for identifying that the rocket rises for 4 seconds before reaching the maximum height.
- ☐ 1 point is earned for calculating the area under the velocity graph for the first 4 seconds to find the maximum height of the rocket:
  $\text{Max height} = (0.5)(3\text{ s})(10\text{ m/s}) + (0.5)(1\text{ s})(10\text{ m/s}) = 20\text{ meters}$
- ☐ 1 point is earned for finding the time the rocket takes to fall from its maximum height consistent with the maximum height found in the second point:
  $T_{fall} = 2\text{ seconds}$
  Scoring note: Time from launch back to ground is 6 seconds
- ☐ **Alternate Solution to part (b)**
  1 point is earned for identifying that the rocket undergoes the acceleration calculated in part (a) for the first 3 seconds.
- ☐ 1 point is earned for calculating the height reached at $t = 3\text{ seconds}$ either by using the acceleration from part (a) in a correct kinematic equation:
  $\Delta y = v_0 t + 0.5at^2$
  $\Delta y = 0 + 0.5(\frac{10}{3}\frac{\text{m}}{\text{s}^2})(3\text{ s})^2$
  $\Delta y = 15\text{ m in first 3 seconds}$
  OR by calculating the area under the velocity graph for the first 3 seconds.
- ☐ 1 point is earned for finding the time the rocket undergoes freefall acceleration until it hits the ground consistent with the distance found in the second point:
  $\Delta y = v_0 t + 0.5at^2$
  $-15\text{ m} = (10\ \frac{\text{m}}{\text{s}})t + 0.5(-9.8\frac{\text{m}}{\text{s}^2})t^2$
  $t = 3.04\text{ s}$
  Scoring note: Time from launch back to ground is 6 seconds.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for a graph that is concave-up from $t = 0$ to $t = 3$ seconds.

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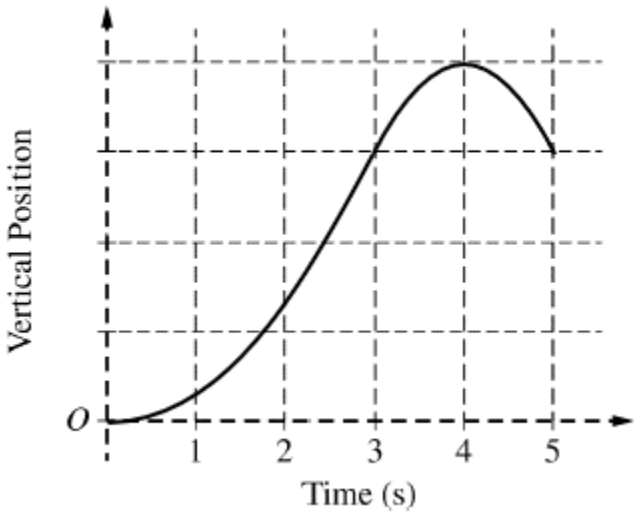
- [ ] 1 point is earned for a graph that is concave-down from $t = 3$ to $t = 5$ seconds **AND** has a maximum at 4 s.

Example Response for part (c):



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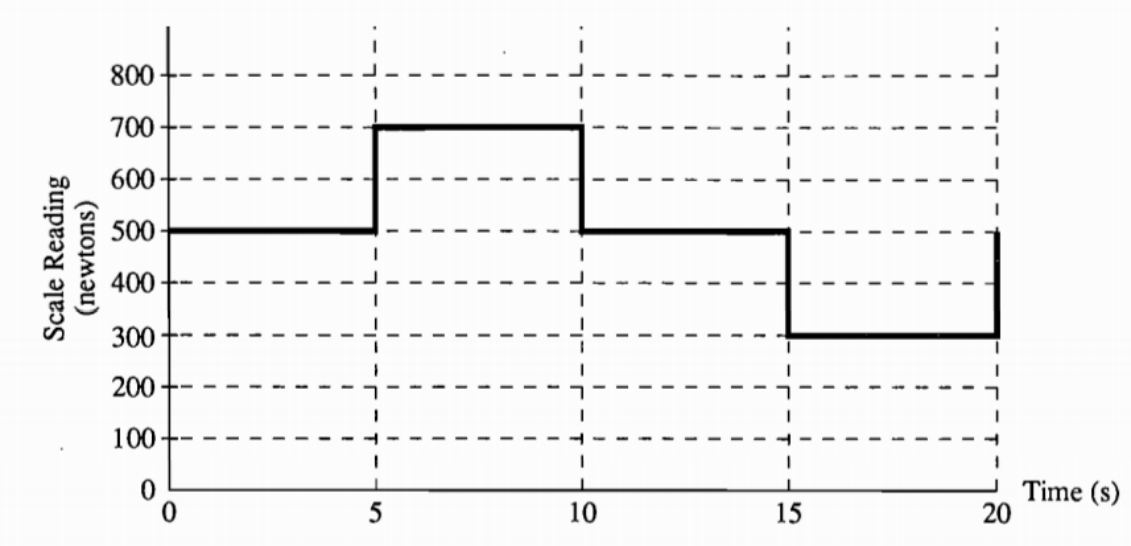
21.



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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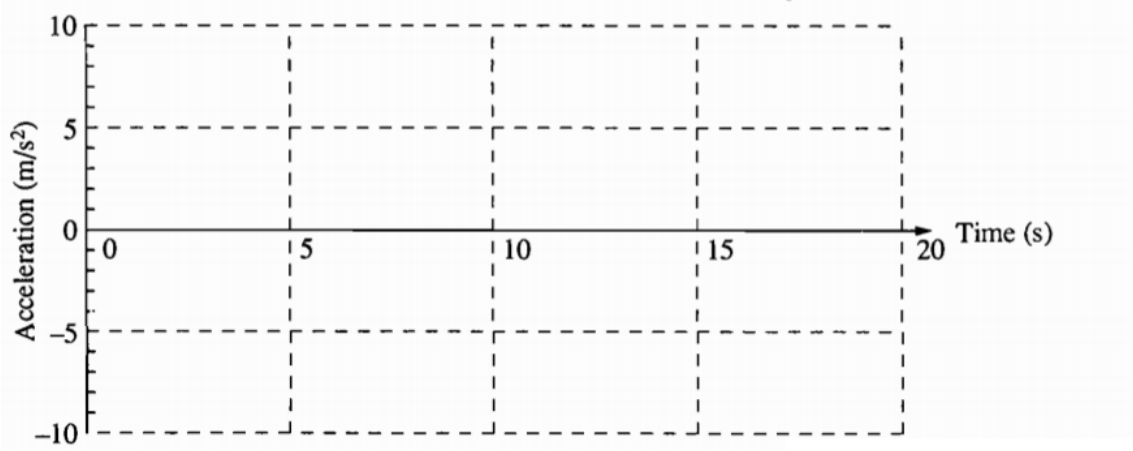
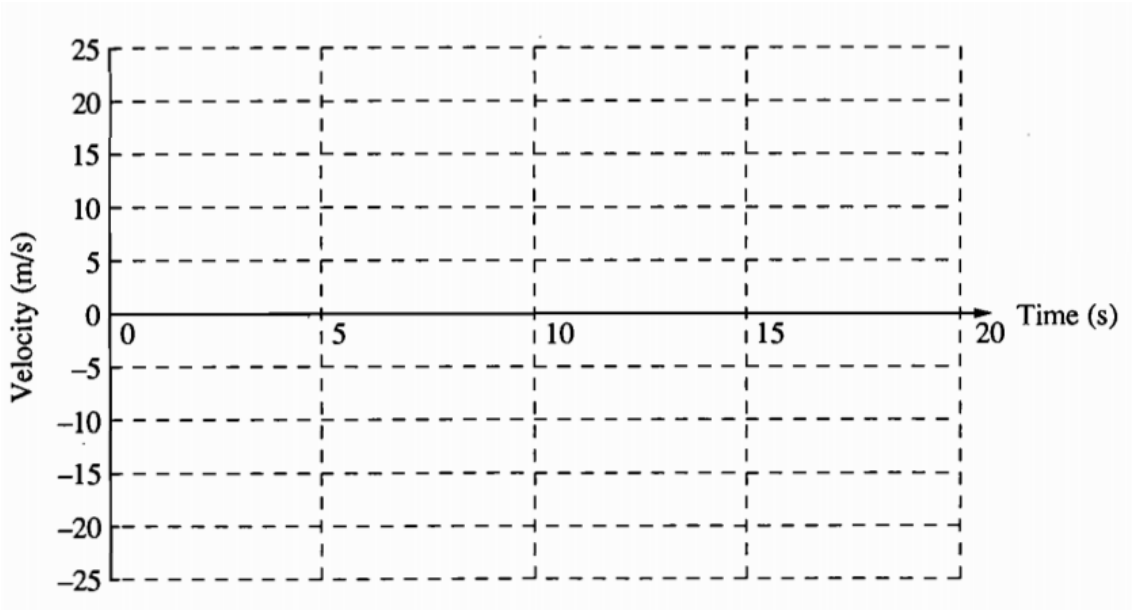


(c) Determine the velocity *v* of the elevator at the end of each 5-second interval.

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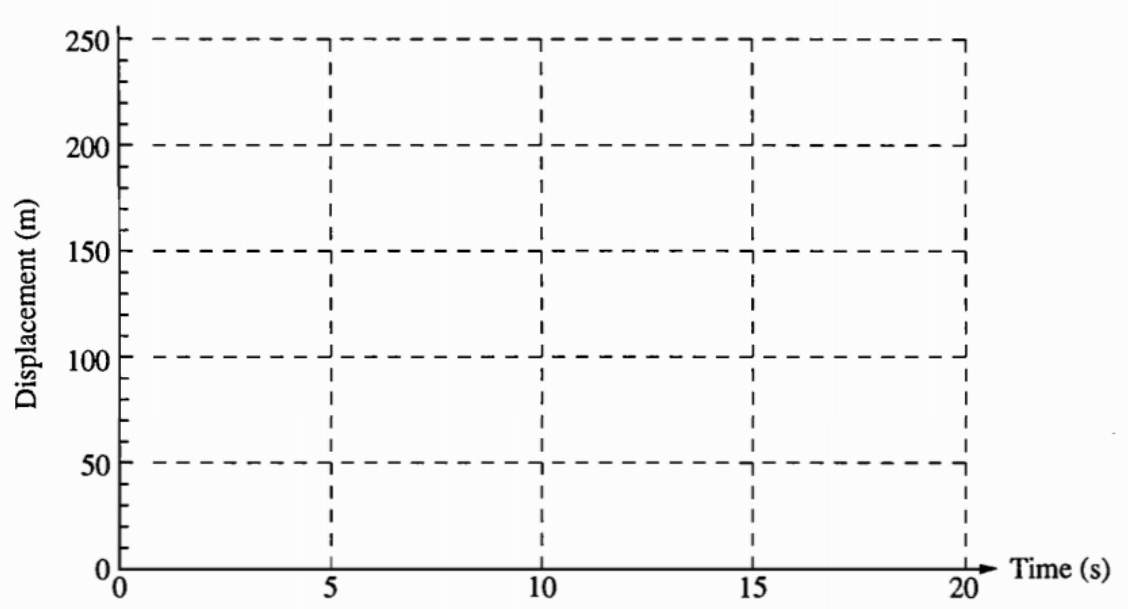
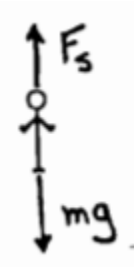
ii. Plot the displacement as a function of time on the following graph.



Part A

Note: To facilitate grading of this question, 30 points were counted and the total was divided by 2, with half points rounded up.



2 point is earned: for each vector drawn in the correct direction

1 point is earned: for correct labels on both vectors (e.g. Fs, Fn, Fe, and W, mg, gravity)

1 point is earned: for no extraneous vectors

0	1	2	3	4 ✓

The student response earns four of the following points:

Note: To facilitate grading of this question, 30 points were counted and the total was divided by 2, with half points rounded up.

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2 point is earned: for each vector drawn in the correct direction

1 point is earned: for correct labels on both vectors (e.g. Fs, Fn, Fe, and W, mg, gravity)

1 point is earned: for no extraneous vectors

Part B(i,ii)

(i)

1 point is earned : For any statement of Newton's Second Law:

$\sum$ F = ma

The mass of the student is found by applying this law to the student's weight , and where is $a = g$;

$$m = \frac{F}{a} = \frac{W}{g} = \frac{500\text{N}}{10\text{m/s}^2} = 50\text{kg}$$

1 point is earned : For the correct expression for the net force on the student:

F s -mg=ma

The upward force *F s* exerted on the student by the scale is equal to the scale reading. For each time interval, applying Newton's Second Law to find the acceleration requires diving the net force by the student's mass

1 point is earned : 0-5 seconds *a* = 0N/50k = 0

1 point is earned : 5-10 seconds *a* = 200N/50k = 4 m/s 2

1 point is earned : 10-15 seconds *a* = 0N/50k = 0

1 point is earned : 15-20 seconds *a* = -200N/50k = -4 m/s 2

If all four values of acceleration were correct,credit was given for the first two points for the equations even if they were not written explicitly.

(ii)

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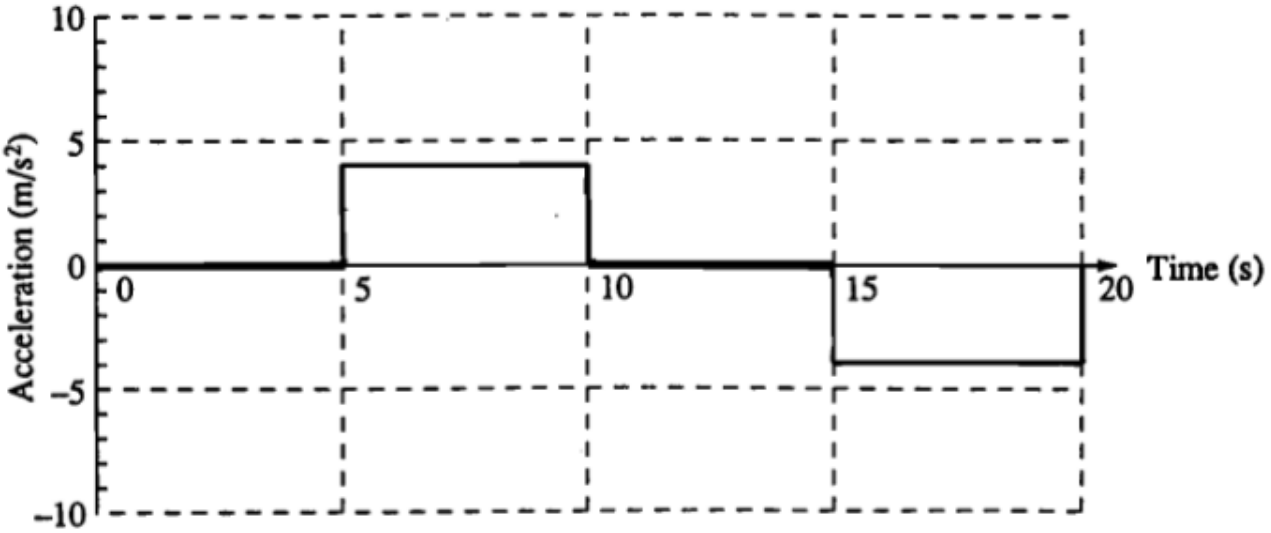

1 point is earned : For the correct shape of the graph (four horizontal segments,with correct two segments above and below the axis.)

1 point is earned : For correctly graphing the magnitudes of the acceleration

✓

0	1	2	3	4	5	6	7	8

The student response earns eight of the following points:

(i)

1 point is earned: For any statement of Newton's Second Law:

$\sum$ F = ma

The mass of the student is found by applying this law to the student's weight , and where is $a = g$;

$$m = \frac{F}{a} = \frac{W}{g} = \frac{500\text{N}}{10\text{m/s}^2} = 50\text{kg}$$

1 point is earned: For the correct expression for the net force on the student:

Fs-mg=ma

The upward force *Fs* exerted on the student by the scale is equal to the scale reading. For each time interval, applying Newton's Second Law to find the acceleration requires diving the net force by the student's mass

1 point is earned: 0-5 seconds *a* = 0N/50k = 0

1 point is earned: 5-10 seconds *a* = 200N/50k = 4 m/s2

1 point is earned: 10-15 seconds *a* = 0N/50k = 0

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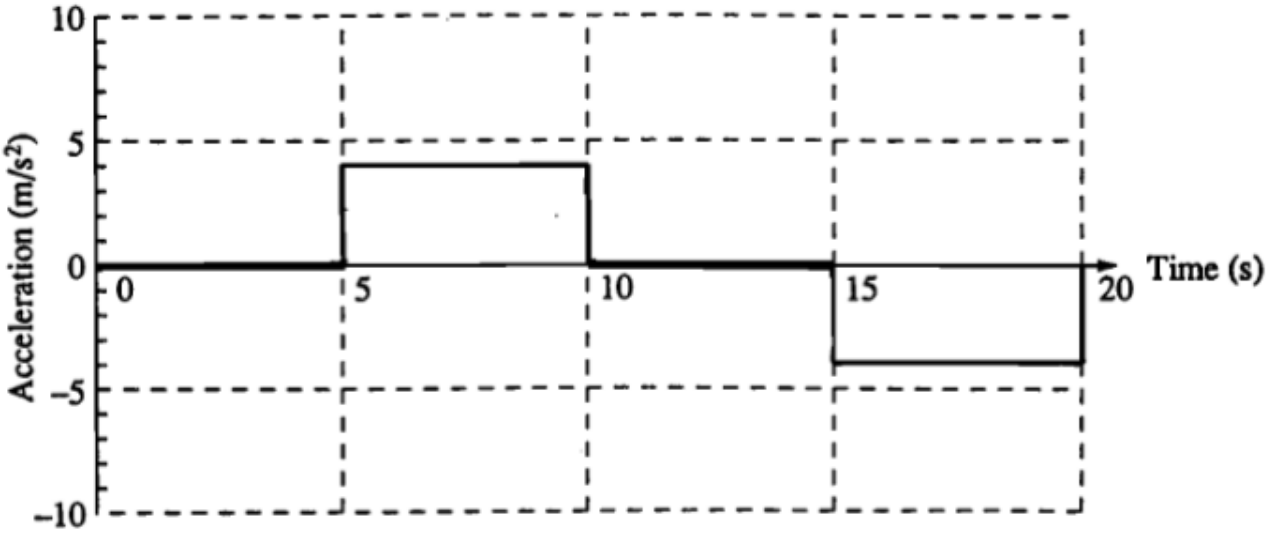
1 point is earned: 15-20 seconds *a* = -200N/50k = -4 m/s2

If all four values of acceleration were correct,credit was given for the first two points for the equations even if they were not written explicitly.

(ii)



1 point is earned: For the correct shape of the graph (four horizontal segments,with correct two segments above and below the axis.)

1 point is earned: For correctly graphing the magnitudes of the acceleration

Part C

(i)

1 point is earned: For the kinematic equation applicable for constant acceleration:

v - v0 + at (addition of v0 must be indicated)

For each time interval, substitute the initial velocity for that interval, the appropriate acceleration from part (b), and a time of 5 seconds.

1 point is earned: 5 seconds: v - 0 + (0)(5 s) - 0

1 point is earned: 10 seconds: v - 0 + (4 m/s2)(5 s) - 20 m/s

1 point is earned: 15 seconds: v - 20 m/s +(0)(5 s) - 20 m/s

1 point is earned: 20 seconds: v - 20 m/s +(-4 m/s2)(5 s) - 0

If all four values were correct credit was given for the equation even if it was not written explicitly

Alternate solution: For indicating that at the end of each interval v = v0 + Δv

(ii)

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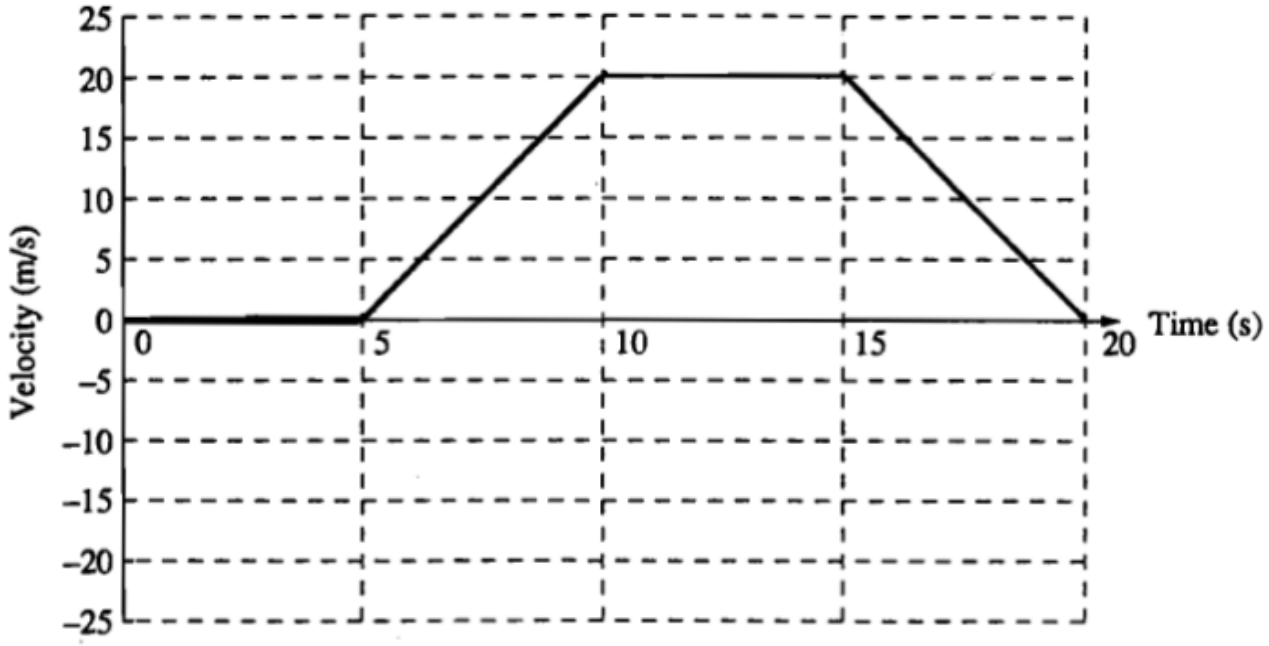

1 point is earned(max 4): for each segment having the correct shape and slope (or which is consistent with graph in part B.

0	1	2	3	4	5	6	7	8	9

The student response earns 9 of the following points:

(i)

1 point is earned: For the kinematic equation applicable for constant acceleration:

v - *v0* + at (addition of v0 must be indicated)

For each time interval, substitute the initial velocity for that interval, the appropriate acceleration from part (b), and a time of 5 seconds.

1 point is earned: 5 seconds: v - 0 + (0)(5 s) - 0

1 point is earned: 10 seconds: v - 0 + (4 m/s2)(5 s) - 20 m/s

1 point is earned: 15 seconds: v - 20 m/s +(0)(5 s) - 20 m/s

1 point is earned: 20 seconds: v - 20 m/s +(-4 m/s2)(5 s) - 0

If all four values were correct credit was given for the equation even if it was not written explicitly

Alternate solution: For indicating that at the end of each interval v = v0 + Δv

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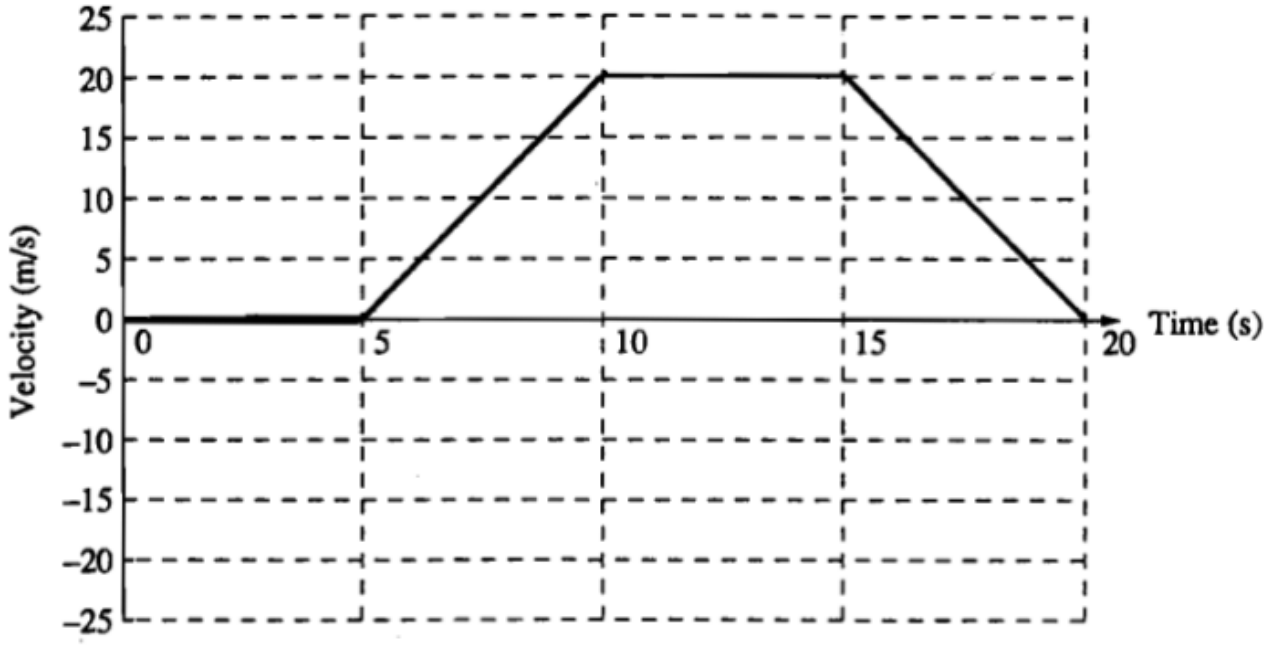
(ii)



1 point is earned(max 4): for each segment having the correct shape and slope (or which is consistent with graph in part B.

Part D

(i)

1 point is earned: For the kinematic equation applicable for constant acceleration, $x - x0 + v2t + (1/2)at2$ or equivalent

For each time interval,substitute the initial position for that interval, the initial velocity for that interval from part (c), the appropriate acceleration, and a time of 5 seconds.

1 point is earned: 5 seconds: x = 0 + (0)(5s) + (1/2)(0)(5 s)2 = 0

1 point is earned: 10 seconds: x = 0 + (0)(5s) + (1/2)(4 m/s2)(5 s)2 = 50 m

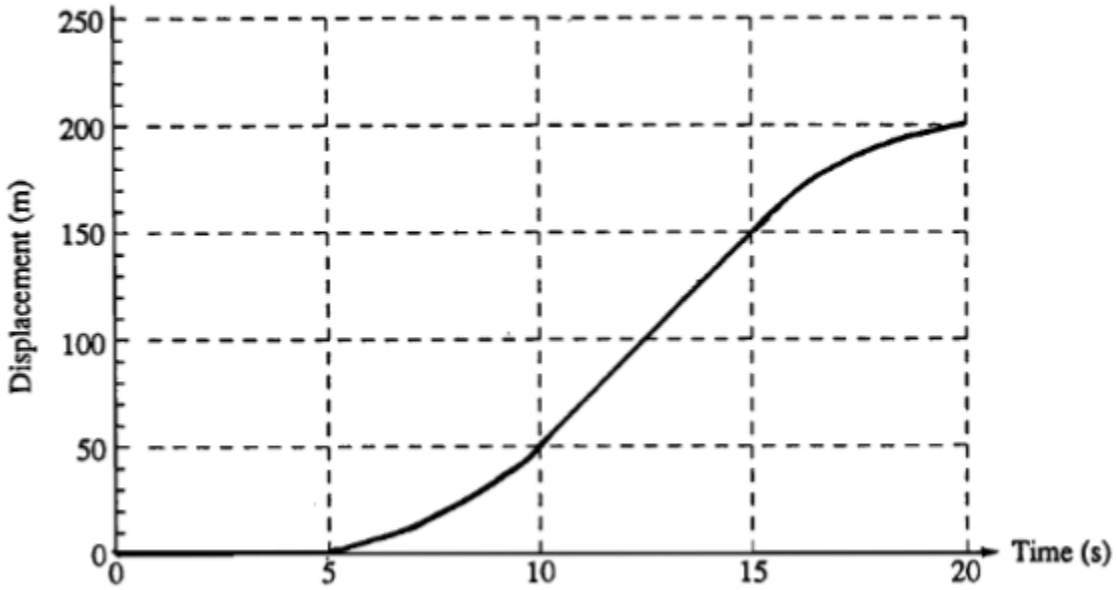
1 point is earned: 15 seconds: x = 50m + (20m/s)(5s) + (1/2)(0 m/s2)(5 s)2 = 150 m

1 point is earned: 20 seconds: x = 150 + (20 m/s)(5s) + (1/2)(-4 m/s2)(5 s)2 = 200 m

If all four values were correct, credit was given for the equation even if it was not explicitly written.)

(ii)

chapter1partd



1 point is earned(max 4): For each segment that has the correct shape and slope (or which is consistent with graph in part (c))

0	1	2	3	4	5	6	7	8	9 ✓

The student response earns 9 of the following points:

(i)

1 point is earned: For the kinematic equation applicable for constant acceleration, *x - x0 + v2t + (1/2)at*2 or equivalent

For each time interval,substitute the initial position for that interval, the initial velocity for that interval from part (c), the appropriate acceleration, and a time of 5 seconds.

1 point is earned: 5 seconds: x = 0 + (0)(5s) + (1/2)(0)(5 s)2 = 0

1 point is earned: 10 seconds: x = 0 + (0)(5s) + (1/2)(4 m/s2)(5 s)2 = 50 m

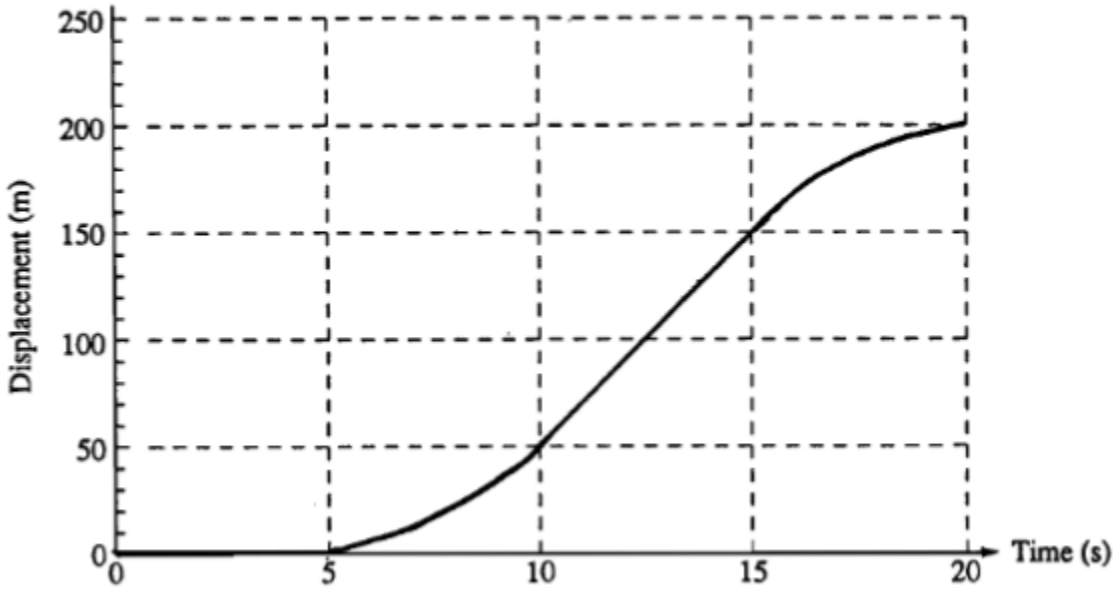
1 point is earned: 15 seconds: x = 50m + (20m/s)(5s) + (1/2)(0 m/s2)(5 s)2 = 150 m

1 point is earned: 20 seconds: x = 150 + (20 m/s)(5s) + (1/2)(-4 m/s2)(5 s)2 = 200 m

If all four values were correct, credit was given for the equation even if it was not explicitly written.)

(ii)

chapter1partd



1 point is earned(max 4): For each segment that has the correct shape and slope (or which is consistent with graph in part (c))

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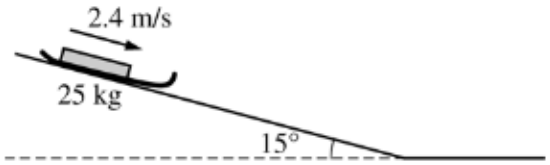
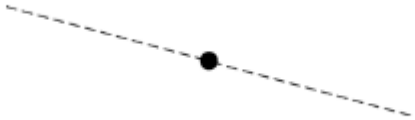
22.



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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Part A

1 point is earned: For using a correct equation relating distance, speed, and time

$x = v\Delta t$
$\Delta t = \frac{x}{v}$
$\Delta t = \frac{21m}{2.4m/s}$

1 point is earned: For the correct answer
Δt = 8.75s

Note: Only 1 point was awarded for the correct answer with no supporting work.

0	1	2 ✓

The student response earns all of the following points:

1 point is earned: For using a correct equation relating distance, speed, and time

$x = v\Delta t$
$\Delta t = \frac{x}{v}$
$\Delta t = \frac{21m}{2.4m/s}$

1 point is earned: For the correct answer

Δt = 8.75s

Note: Only 1 point was awarded for the correct answer with no supporting work.

Part B

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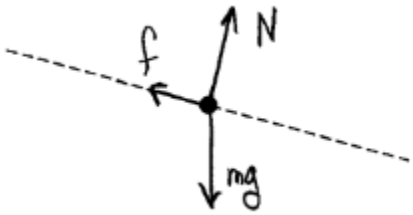
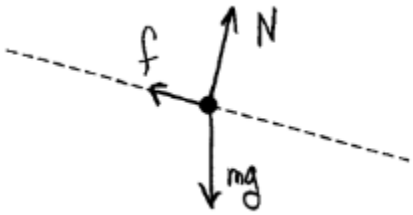


1 point is earned: For each correct force that is correctly labeled, is attached to the dot, and has an arrowhead pointing in the correct direction, 1 point was awarded.

1 point is earned: For each incorrect vector, a point was deducted, with the minimum possible score being 0.

0	1	2	3 ✓

The student response earns all of the following points:



1 point is earned: For each correct force that is correctly labeled, is attached to the dot, and has an arrowhead pointing in the correct direction, 1 point was awarded.

1 point is earned: For each incorrect vector, a point was deducted, with the minimum possible score being 0.

Part C

1 point is earned: For recognizing that the sum of the forces upon the sled is zero

$$\sum F = 0$$

Writing the equation for the forces acting along the slope,

$\sum F = mg \sin 15^\circ - f = 0$, where f represents the force of friction

1 point is earned: For equating the force of kinetic friction with the component of weight that acts down the slope
f = mg sin15°
f = (25kg) (9.8m/s2) sin 15°

1 point is earned: For the correct answer

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f = 63.4 N (64.7 N if g = 10 m/s2 is used)

Note: Only 1 point was awarded for the correct answer with no supporting work.

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For recognizing that the sum of the forces upon the sled is zero

$$\sum F = 0$$

Writing the equation for the forces acting along the slope,

$\sum F = mg\sin 15^\circ - f = 0$, where *f* represents the force of friction

1 point is earned: For equating the force of kinetic friction with the component of weight that acts down the slope

f = mg sin15°
f = (25kg) (9.8m/s2) sin 15°

1 point is earned: For the correct answer

f = 63.4 N (64.7 N if g = 10 m/s2 is used)

Note: Only 1 point was awarded for the correct answer with no supporting work.

Part D

1 point is earned: For equating the force of kinetic friction to the product of the coefficient of friction and the normal force

$$f = \mu N$$
$$\sum F = mg\cos 15^\circ - N = 0$$

1 point is earned: For equating the normal force to the component of the sled's weight that is normal to the slope

$$N = mg\cos 15^\circ$$
$$\mu = \frac{f}{N} = \frac{mg\sin 15^\circ}{mg\cos 15^\circ} = \tan 15^\circ$$

1 point is earned: For the correct answer or for an answer consistent with the friction force obtained in (c)

$$\mu = 0.27$$

Note: Only 1 point was awarded for the correct answer with no supporting work.

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0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For equating the force of kinetic friction to the product of the coefficient of friction and the normal force

$f = \mu N$

$\sum F = mg\cos 15^\circ - N = 0$

1 point is earned: For equating the normal force to the component of the sled's weight that is normal to the slope

$N = mg\cos 15^\circ$

$\mu = \frac{f}{N} = \frac{mg\sin 15^\circ}{mg\cos 15^\circ} = \tan 15^\circ$

1 point is earned: For the correct answer or for an answer consistent with the friction force obtained in (c)

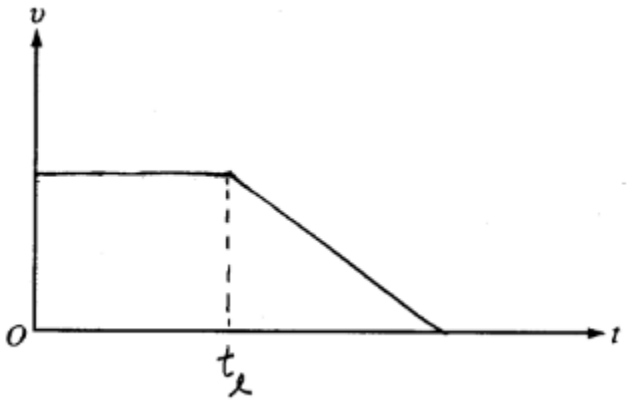
$\mu = 0.27$

Note: Only 1 point was awarded for the correct answer with no supporting work.

Part E

1 point is earned: For implicitly or explicitly stating that the velocity of the sled decreases

1 point is earned: For explicitly stating that the acceleration of the sled is constant



1 point is earned: For sketching a horizontal non-zero line

1 point is earned: For sketching a line of constant negative slope that begins at the right-hand end of the previously drawn horizontal line and also indicating the time on the graph

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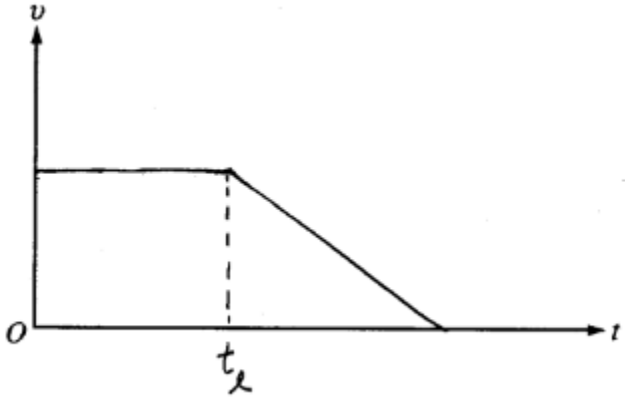
Note: The second point was awarded only if the first point was awarded.

0	1	2	3	4 ✓

The student response earns all of the following points:

1 point is earned: For implicitly or explicitly stating that the velocity of the sled decreases

1 point is earned: For explicitly stating that the acceleration of the sled is constant



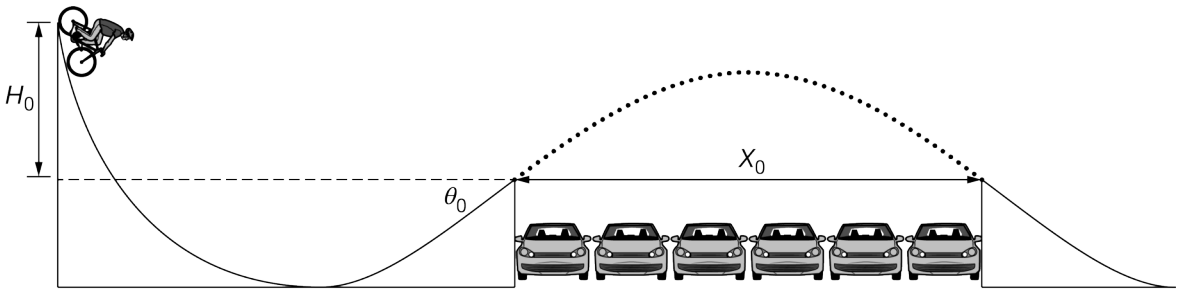
1 point is earned: For sketching a horizontal non-zero line

1 point is earned: For sketching a line of constant negative slope that begins at the right-hand end of the previously drawn horizontal line and also indicating the time on the graph

Note: The second point was awarded only if the first point was awarded.

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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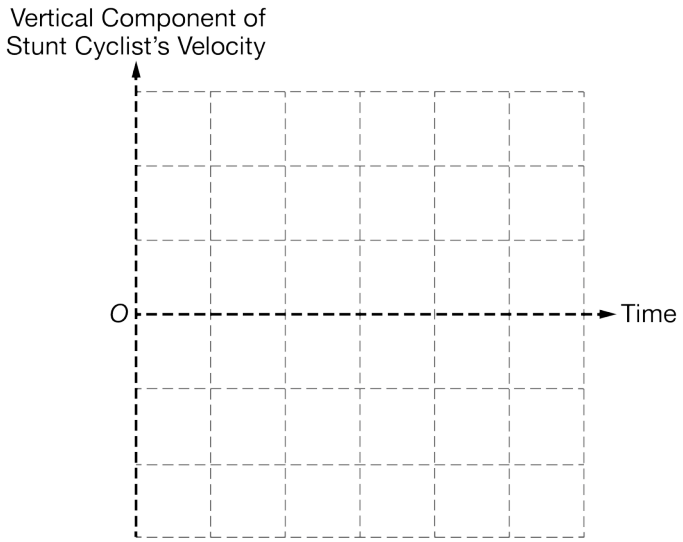

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** of the following criteria.

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

Example Response:

$$E_{top} = E_{bottom}$$
$$m_0 g H_0 = \tfrac{1}{2} m_0 v^2$$
$$v = \sqrt{2gH_0}$$
$$v_{fy} = v_{iy} + at$$
$$-v\sin\theta = v\sin\theta - gt$$
$$-2v\sin\theta = -gt$$

$$2\sin\theta_0\sqrt{2gH_0} = gt$$
$$t = \frac{2\sin\theta_0\sqrt{2gH_0}}{g}$$
$$X_0 = v_x t$$
$$X_0 = \cos\theta_0\sqrt{2gH_0}\,\frac{2\sin\theta_0\sqrt{2gH_0}}{g}$$
$$X_0 = 4H_0\cos\theta_0\sin\theta_0$$

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.

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Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for an answer and justification that attempts to use the functional dependence of the horizontal distance on the initial height.
- ☐ 1 point is earned for an answer consistent with the expression derived in part (a).

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for a linear graph with a constant negative slope.
- ☐ 1 point is earned for a graph that starts at v_y and ends at $-v_y$, using only allowed variables.

Example Response:

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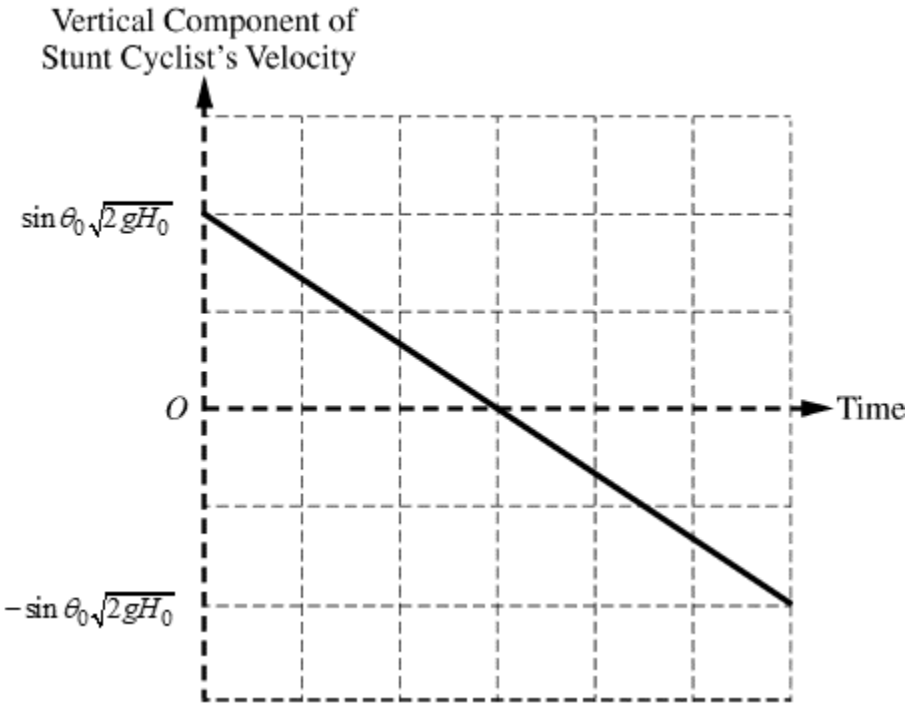
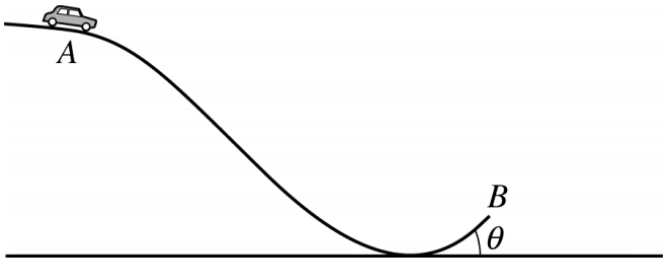


24.



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.

Part A

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Part(i)

1 point is earned: For indicating that the mechanical energy of the car-Earth system is constant between point A and the highest point in the car's trajectory

1 point is earned: For indicating that the car is still moving at its highest point and has some kinetic energy so the car-Earth system must have less gravitational potential energy, therefore must be at a lower height than it was at point A

Part(ii)

1 point is earned: For indicating that the velocity of the car at its highest point is equal to the horizontal speed at point B

1 point is earned: For stating that the speed at the highest point is cos v_B cosθ

0	1	2	3	✓ 4

Student response earns 4 of the following 4 point(s)

Part(i)

1 point is earned: For indicating that the mechanical energy of the car-Earth system is constant between point A and the highest point in the car's trajectory

1 point is earned: For indicating that the car is still moving at its highest point and has some kinetic energy so the car-Earth system must have less gravitational potential energy, therefore must be at a lower height than it was at point A

Part(ii)

1 point is earned: For indicating that the velocity of the car at its highest point is equal to the horizontal speed at point B

1 point is earned: For stating that the speed at the highest point is cos v_B cosθ

Part B

1 point is earned: For implicitly or explicitly applying conservation of energy

1 point is earned: For implicitly or explicitly indicating that the gravitational potential energy is the same at the beginning and at the end

1 point is earned: For indicating that the speed is the same at the beginning and at the end, so $v_A = v_B \cos \theta$, or consistent with the answer in part (a-ii)

0	1	2	✓ 3

Student response earns 3 of the following 3 point(s)

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1 point is earned: For implicitly or explicitly applying conservation of energy

1 point is earned: For implicitly or explicitly indicating that the gravitational potential energy is the same at the beginning and at the end

1 point is earned: For indicating that the speed is the same at the beginning and at the end, so $v_A = v_B \cos \theta$, or consistent with the answer in part (a-ii)

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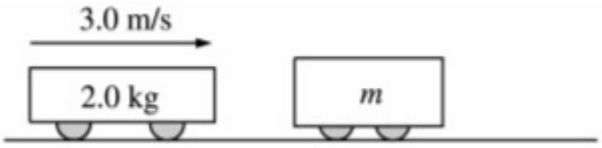
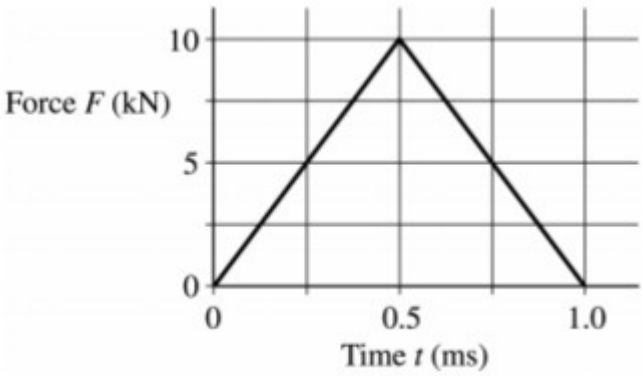
25.



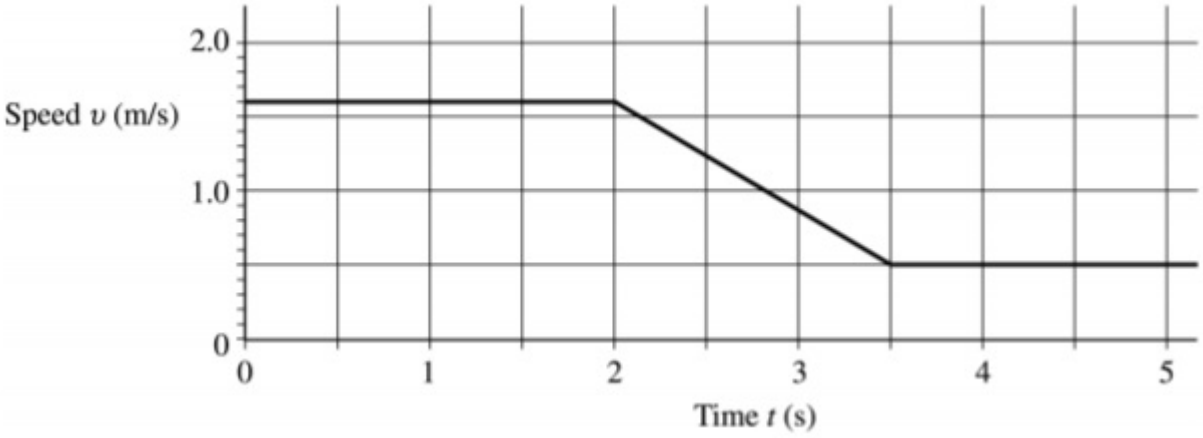
A 2.0 kg frictionless cart is moving at a constant speed of 3.0 m/s to the right on a horizontal surface, as shown above, when it collides with a second cart of undetermined mass m that is initially at rest. The force F of the collision as a function of time t is shown in the graph below, where $t = 0$ 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.

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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).

Part A

1 point is earned: For any statement indicating that impulse equals change in momentum

1 point is earned: For any statement indicating that impulse can be determined from the area under the graph

$\Delta p = F\Delta t$ = area under the curve

$$\Delta p = 2\left(\tfrac{1}{2}\right)(0.5 \times 10^{-3}\text{s})(10 \times 10^{3}\ \text{N}) = 5\ \text{N} \cdot \text{s}$$

1 point is earned: For recognizing that the impulse on the 2 kg cart is negative, and subtracting it from the initial momentum of the cart

p2 kg after = (2.0 kg)(3.0 m/s) – 5 N · s = 1 N · s

p2 kg after = (2 kg)v2 kg after = 1 N · s

1 point is earned: For the correct answer

p2 kg after = 0.5 m/s to the right

0	1	2	3	4 ✓

The student response earns all of the following points:

1 point is earned: For any statement indicating that impulse equals change in momentum

1 point is earned: For any statement indicating that impulse can be determined from the area under the graph

$\Delta p = F\Delta t$ = area under the curve

$$\Delta p = 2\left(\tfrac{1}{2}\right)(0.5 \times 10^{-3}\text{s})(10 \times 10^{3}\ \text{N}) = 5\ \text{N} \cdot \text{s}$$

1 point is earned: For recognizing that the impulse on the 2 kg cart is negative, and subtracting it from the initial momentum of the cart

p2 kg after = (2.0 kg)(3.0 m/s) – 5 N · s = 1 N · s

p2 kg after = (2 kg)v2 kg after = 1 N · s

1 point is earned: For the correct answer

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*v*2 kg after = 0.5 m/s to the right

Part B

1 point is earned: For any statement of conservation of momentum

*p*2 kg before = *p*2 kg after + *pm* after

1 point is earned: For correct substitutions

6 N · s = 1 N · s + *m*(1.6 m/s)

1 point is earned: For the correct answer

m = 3.1 kg

Alternate solution

The average acceleration is the average force divided by the mass

$\bar{a} = \overline{F}/m$

1 point is earned: For calculating the average acceleration

$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{1.6\ \text{m/s}}{1\times10^{-3}\ \text{s}} = 1600\ \text{m/s}^2$

1 point is earned: For calculating the average force

$\overline{F} = \frac{1}{2}(0 + 10,000)\ \text{N}{=}5000\ \text{N}$

m = (5000 N)/(1600 m/s2)

1 point is earned: For the correct answer

m = 3.1 kg

Note: An alternate solution is to do part (b) first using impulse, in which case the first two points noted above for part (a) could be earned. Then conservation of momentum can be used to solve part (a), so the first point noted above for part (b) could be earned.

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For any statement of conservation of momentum

*p*2 kg before = *p*2 kg after + *pm* after

1 point is earned: For correct substitutions

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6 N · s = 1 N · s + *m*(1.6 m/s)

1 point is earned: For the correct answer

m = 3.1 kg

Alternate solution

The average acceleration is the average force divided by the mass

$\bar{a} = \overline{F}/m$

1 point is earned: For calculating the average acceleration

$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{1.6\ \text{m/s}}{1\times10^{-3}\ \text{s}} = 1600\ \text{m/s}^2$

1 point is earned: For calculating the average force

$\overline{F} = \frac{1}{2}(0 + 10,000)\ \text{N} = 5000\ \text{N}$

m = (5000 N)/(1600 m/s2)

1 point is earned: For the correct answer

m = 3.1 kg

Note: An alternate solution is to do part (b) first using impulse, in which case the first two points noted above for part (a) could be earned. Then conservation of momentum can be used to solve part (a), so the first point noted above for part (b) could be earned.

Part C

1 point is earned: For using the slope of the graph to determine the acceleration

$a = \text{ slope} = \frac{(0.5-1.6)\ \text{m/s}}{(3.5-2)\ \text{s}}$

1 point is earned: For the correct answer

a = –0.73 m/s2

✓

0	1	2

The student response earns all of the following points:

1 point is earned: For using the slope of the graph to determine the acceleration

$a = \text{ slope} = \frac{(0.5-1.6)\ \text{m/s}}{(3.5-2)\ \text{s}}$

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1 point is earned: For the correct answer

a = –0.73 m/s2

Part D

1 point is earned: For using the area under the curve or one of the equations $d = vt$ or $d = \bar{v}t$

1 point is earned: For calculating a distance for each segment of the graph

$d1 = (1.6 \text{ m/s})(2 \text{ s}) = 3.2 \text{ m}$

$d_2 = \frac{(1.6+0.5) \text{ m/s}}{2}(1.5 \text{ s})$ or $(1.6 \text{ m/s})(1.5 \text{ s}) + \frac{1}{2}(-0.73 \text{ m/s}^2)(1.5 \text{ s})^2$

$d2 = 1.6 \text{ m}$

$d3 = (0.5 \text{ m/s})(1.5 \text{ s}) = 0.8 \text{ m}$

$dtot = d1 + d2 + ds$

1 point is earned: For the correct answer

$dtot = 5.5 \text{ m}$

0	1	2	3 ✓

The student response earns all of the following points:

1 point is earned: For using the area under the curve or one of the equations $d = vt$ or $d = \bar{v}t$

1 point is earned: For calculating a distance for each segment of the graph

$d1 = (1.6 \text{ m/s})(2 \text{ s}) = 3.2 \text{ m}$

$d_2 = \frac{(1.6+0.5) \text{ m/s}}{2}(1.5 \text{ s})$ or $(1.6 \text{ m/s})(1.5 \text{ s}) + \frac{1}{2}(-0.73 \text{ m/s}^2)(1.5 \text{ s})^2$

$d2 = 1.6 \text{ m}$

$d3 = (0.5 \text{ m/s})(1.5 \text{ s}) = 0.8 \text{ m}$

$dtot = d1 + d2 + ds$

1 point is earned: For the correct answer

$dtot = 5.5 \text{ m}$

Part E

The acceleration is negative, so the cart must be moving opposite to the force of gravity, which is the only force acting on

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it.

1 point is earned: For indicating that the ramp goes up

1 point is earned: For using conservation of energy

$mgh = \frac{1}{2}m(v_i^2 - v_f^2)$

$h = \frac{1}{2(10\ \mathrm{m/s^2})}\left((1.6\ \mathrm{m/s})^2 - (0.5\ \mathrm{m/s})^2\right)$

1 point is earned: For the correct answer

h = 0.12 m

0	1	2	3 ✓

The student response earns all of the following points:

The acceleration is negative, so the cart must be moving opposite to the force of gravity, which is the only force acting on it.

1 point is earned: For indicating that the ramp goes up

1 point is earned: For using conservation of energy

$mgh = \frac{1}{2}m(v_i^2 - v_f^2)$

$h = \frac{1}{2(10\ \mathrm{m/s^2})}\left((1.6\ \mathrm{m/s})^2 - (0.5\ \mathrm{m/s})^2\right)$

1 point is earned: For the correct answer

h = 0.12 m

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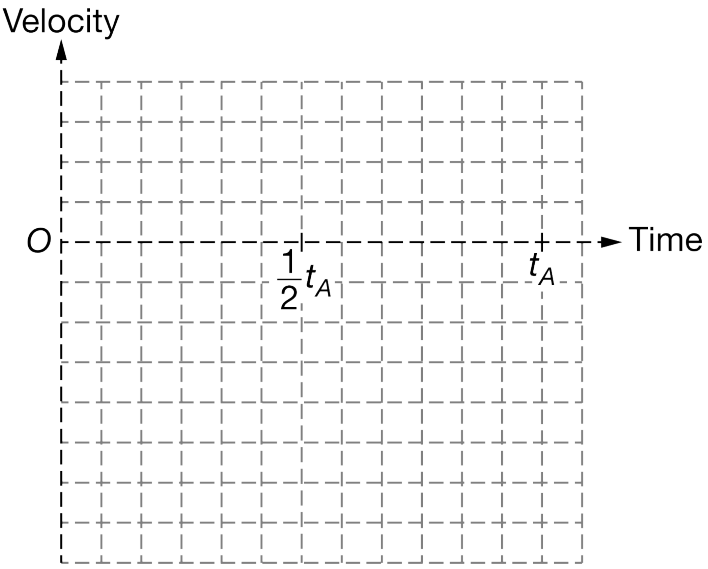
26. This question is a short free-response question. Show your work for each part of the question.

(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 $\frac{1}{2}t_A$ 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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Note: The amount of current that flows through each resistor must be indicated to earn the second point of part (a).

0	1	2	3	4 ✓

The response accurately includes **all** of the following criteria:

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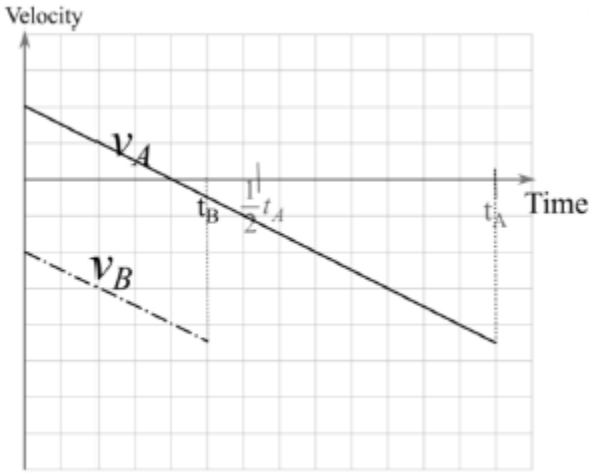
- [ ] For a graph that shows that the initial velocity of rock A is positive, and the initial velocity of rock B is the negative value of the initial velocity of rock A.
- [ ] For a graph that contains two parallel lines with the same negative slope
- [ ] For a graph of the velocity of rock A that only crosses the horizontal axis before $\frac{1}{2}t_A$.
- [ ] For a graph of the velocity of rock B where the velocity of rock B at t_{B} is the same as the velocity of rock A at t_{A}

Example Response:



Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** of the following criteria:

- [ ] For a correctly determining the time rock A takes to move upwards and return to its original position
  $v = v_0 + at$
  $-v_0 = v_0 - gt_{\text{return}}$
  $-2v_0 = -gt_1$
  $t_{\text{return}} = \frac{2v_0}{g}$
- [ ] For implicitly or explicitly recognizing that the time for both rocks to move downwards from the top of the cliff to the ground is the same.
  $t_{\text{ground}} = t_B$
- [ ] For a correct equation for t_{A} in terms of t_{B}
  $t_A = t_{\text{return}} + t_{\text{ground}}$
  $t_A = \frac{2v_0}{g} + t_B$

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Example Response:

$v = v_0 + at$
$-v_0 = v_0 - gt_{\text{return}}$
$-2v_0 = -gt_1$
$t_{\text{return}} = \frac{2v_0}{g}$

$t_{\text{ground}} = t_B$

$t_A = t_{\text{return}} + t_{\text{ground}}$
$t_A = \frac{2v_0}{g} + t_B$