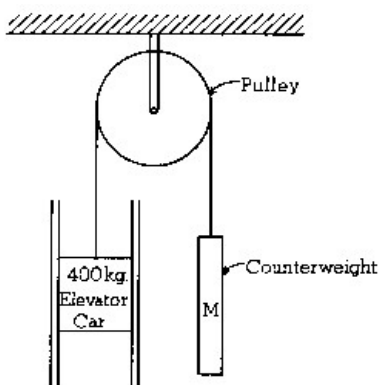


SECTION A – Linear Dynamics

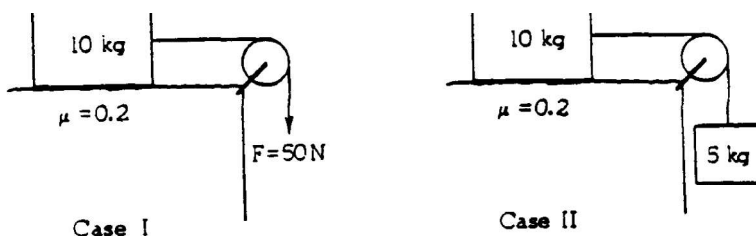


1976B1. The two guide rails for the elevator shown above each exert a constant friction force of 100 newtons on the elevator car when the elevator car is moving upward with an acceleration of 2 meters per second squared. The pulley has negligible friction and mass. Assume $g = 10 \text{ m/sec}^2$.

- a. On the diagram below, draw and label all forces acting on the elevator car. Identify the source of each force.

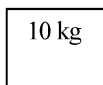


- b. Calculate the tension in the cable lifting the 400-kilogram elevator car during an upward acceleration of 2 m/sec^2 . (Assume $g = 10 \text{ m/sec}^2$.)
 c. Calculate the mass M the counterweight must have to raise the elevator car with an acceleration of 2 m/sec^2 .

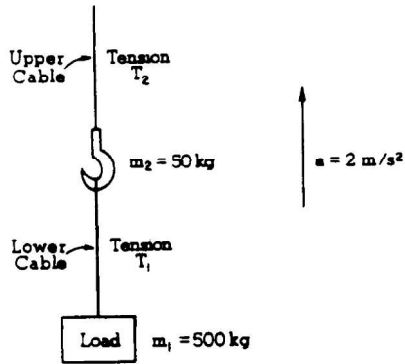


1979B2. A 10-kilogram block rests initially on a table as shown in cases I and II above. The coefficient of sliding friction between the block and the table is 0.2. The block is connected to a cord of negligible mass, which hangs over a massless frictionless pulley. In case I a force of 50 newtons is applied to the cord. In case II an object of mass 5 kilograms is hung on the bottom of the cord. Use $g = 10 \text{ meters per second squared}$.

- a. Calculate the acceleration of the 10-kilogram block in case I.
 b. On the diagrams below, draw and label all the forces acting on each block in case II



- c. Calculate the acceleration of the 10-kilogram block in case II.

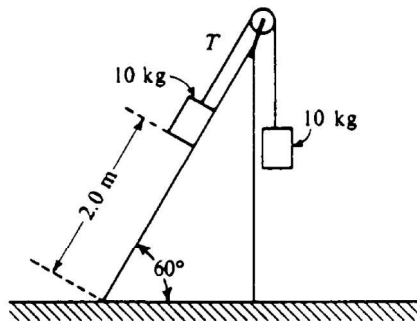


1982B2. A crane is used to hoist a load of mass $m_1 = 500$ kilograms. The load is suspended by a cable from a hook of mass $m_2 = 50$ kilograms, as shown in the diagram above. The load is lifted upward at a constant acceleration of 2 m/s^2 .

- a. On the diagrams below draw and label the forces acting on the hook and the forces acting on the load as they accelerate upward

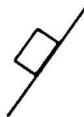


- b. Determine the tension T_1 in the lower cable and the tension T_2 in the upper cable as the hook and load are accelerated upward at 2 m/s^2 . Use $g = 10 \text{ m/s}^2$.

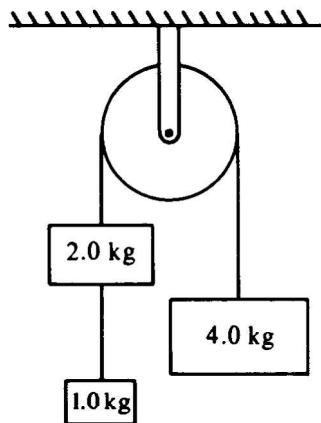


1985B2 (modified) Two 10-kilogram boxes are connected by a massless string that passes over a massless frictionless pulley as shown above. The boxes remain at rest, with the one on the right hanging vertically and the one on the left 2.0 meters from the bottom of an inclined plane that makes an angle of 60° with the horizontal. The coefficients of kinetic friction and static friction between the left-hand box and the plane are 0.15 and 0.30, respectively. You may use $g = 10 \text{ m/s}^2$, $\sin 60^\circ = 0.87$, and $\cos 60^\circ = 0.50$.

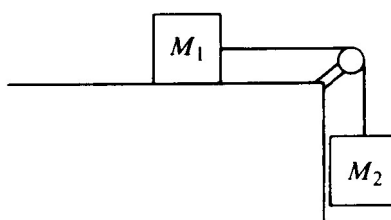
- a. What is the tension T in the string?
 b. On the diagram below, draw and label all the forces acting on the box that is on the plane.



- c. Determine the magnitude of the frictional force acting on the box on the plane.



- 1986B1. Three blocks of masses 1.0, 2.0, and 4.0 kilograms are connected by massless strings, one of which passes over a frictionless pulley of negligible mass, as shown above. Calculate each of the following.
- The acceleration of the 4-kilogram block
 - The tension in the string supporting the 4-kilogram block
 - The tension in the string connected to the 1-kilogram block
-



- 1987B1. In the system shown above, the block of mass M_1 is on a rough horizontal table. The string that attaches it to the block of mass M_2 passes over a frictionless pulley of negligible mass. The coefficient of kinetic friction μ_k between M_1 and the table is less than the coefficient of static friction μ_s .
- On the diagram below, draw and identify all the forces acting on the block of mass M_1 .



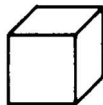
- In terms of M_1 and M_2 determine the minimum value of μ_s that will prevent the blocks from moving.

The blocks are set in motion by giving M_2 a momentary downward push. In terms of M_1 , M_2 , μ_k , and g , determine each of the following:

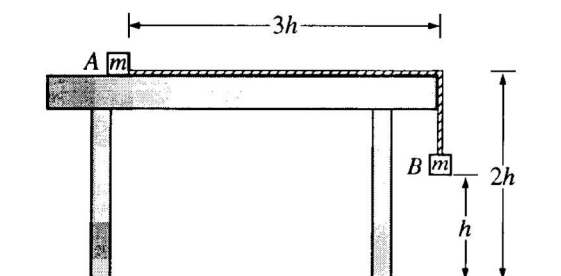
- The magnitude of the acceleration of M_1
 - The tension in the string.
-

1988B1. A helicopter holding a 70-kilogram package suspended from a rope 5.0 meters long accelerates upward at a rate of 5.2 m/s^2 . Neglect air resistance on the package.

- a. On the diagram below, draw and label all of the forces acting on the package.



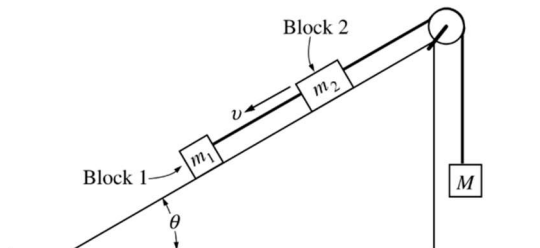
- b. Determine the tension in the rope.
 c. When the upward velocity of the helicopter is 30 meters per second, the rope is cut and the helicopter continues to accelerate upward at 5.2 m/s^2 . Determine the distance between the helicopter and the package 2.0 seconds after the rope is cut.



1998B1 Two small blocks, each of mass m , are connected by a string of constant length $4h$ and negligible mass.

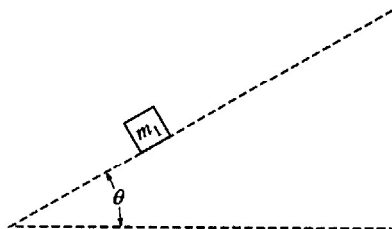
Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h , m , and g .

- Determine the acceleration of block B as it descends.
- Block B strikes the floor and does not bounce. Determine the time $t = t_1$ at which block B strikes the floor.
- Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.
- Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.
- Determine the distance between the landing points of the two blocks.



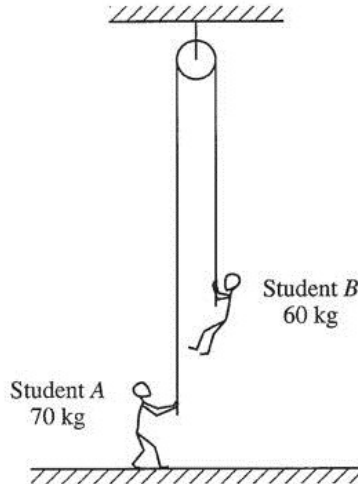
2000B2. Blocks 1 and 2 of masses m_1 and m_2 , respectively, are connected by a light string, as shown above. These blocks are further connected to a block of mass M by another light string that passes over a pulley of negligible mass and friction. Blocks 1 and 2 move with a constant velocity v down the inclined plane, which makes an angle θ with the horizontal. The kinetic frictional force on block 1 is f and that on block 2 is $2f$.

- a. On the figure below, draw and label all the forces on block m_1 .



Express your answers to each of the following in terms of m_1 , m_2 , g , θ , and f .

- b. Determine the coefficient of kinetic friction between the inclined plane and block 1.
 c. Determine the value of the suspended mass M that allows blocks 1 and 2 to move with constant velocity down the plane.
 d. The string between blocks 1 and 2 is now cut. Determine the acceleration of block 1 while it is on the inclined plane.



2003B1 A rope of negligible mass passes over a pulley of negligible mass attached to the ceiling, as shown above. One end of the rope is held by Student A of mass 70 kg, who is at rest on the floor. The opposite end of the rope is held by Student B of mass 60 kg, who is suspended at rest above the floor. Use $g = 10 \text{ m/s}^2$.

- a. On the dots below that represent the students, draw and label free-body diagrams showing the forces on Student A and on Student B.

• B

• A

- b. Calculate the magnitude of the force exerted by the floor on Student A.

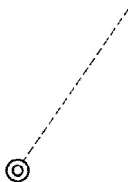
Student B now climbs up the rope at a constant acceleration of 0.25 m/s^2 with respect to the floor.

- c. Calculate the tension in the rope while Student B is accelerating.
 d. As Student B is accelerating, is Student A pulled upward off the floor? Justify your answer.
 e. With what minimum acceleration must Student B climb up the rope to lift Student A upward off the floor?
-



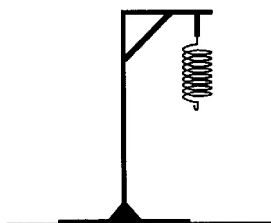
2003Bb1 (modified) An airplane accelerates uniformly from rest. A physicist passenger holds up a thin string of negligible mass to which she has tied her ring, which has a mass m . She notices that as the plane accelerates down the runway, the string makes an angle θ with the vertical as shown above.

- a. In the space below, draw a free-body diagram of the ring, showing and labeling all the forces present.



The plane reaches a takeoff speed of 65 m/s after accelerating for a total of 30 s.

- b. Determine the minimum length of the runway needed.
 c. Determine the angle θ that the string makes with the vertical during the acceleration of the plane before it leaves the ground.

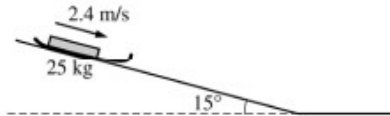


*1996B2 (modified) A spring that can be assumed to be ideal hangs from a stand, as shown above. You wish to determine experimentally the spring constant k of the spring.

- a. i. What additional, commonly available equipment would you need?
 ii. What measurements would you make?
 iii. How would k be determined from these measurements?

Suppose that the spring is now used in a spring scale that is limited to a maximum value of 25 N, but you would like to weigh an object of mass M that weighs more than 25 N. You must use commonly available equipment and the spring scale to determine the weight of the object without breaking the scale.

- b. i. Draw a clear diagram that shows one way that the equipment you choose could be used with the spring scale to determine the weight of the object,
 ii. Explain how you would make the determination.



B2007B1. 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.

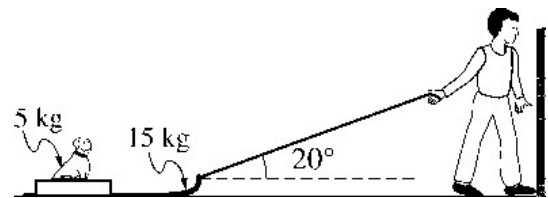
- Calculate the time it takes the sled to go 21 m down the slope.
- On the dot below that represents the sled, draw/label a free-body diagram for the sled as it slides down the slope



- Calculate the frictional force on the sled as it slides down the slope.
- Calculate the coefficient of friction between the sled and the muddy surface of the slope.
- The sled reaches the bottom of the slope and continues on the horizontal ground. Assume the same coefficient of friction.
 - In terms of velocity and acceleration, describe the motion of the sled as it travels on the horizontal ground.
 - 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_f the time at which the sled leaves the slope.



B2007b1 (modified) A child pulls a 15 kg sled containing a 5.0 kg dog along a straight path on a horizontal surface. He exerts a force of 55 N on the sled at an angle of 20° above the horizontal, as shown in the figure. The coefficient of friction between the sled and the surface is 0.22.

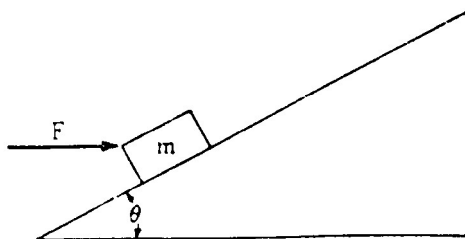


- On the dot below that represents the sled-dog system, draw and label a free-body diagram for the system as it is pulled along the surface.



- Calculate the normal force of the surface on the system.
- Calculate the acceleration of the system.
- At some later time, the dog rolls off the side of the sled. The child continues to pull with the same force. On the axes below, sketch a graph of speed v versus time t for the sled. Include both the sled's travel with and without the dog on the sled. Clearly indicate with the symbol t_f the time at which the dog rolls off.



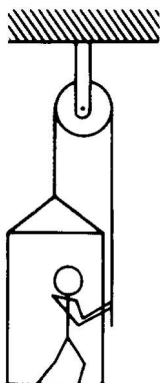


1981M1. A block of mass m , acted on by a force of magnitude F directed horizontally to the right as shown above, slides up an inclined plane that makes an angle θ with the horizontal. The coefficient of sliding friction between the block and the plane is μ .

- a. On the diagram of the block below, draw and label all the forces that act on the block as it slides up the plane.



- b. Develop an expression in terms of m , θ , F , μ , and g , for the block's acceleration up the plane.
 c. Develop an expression for the magnitude of the force F that will allow the block to slide up the plane with constant velocity. What relation must θ and μ satisfy in order for this solution to be physically meaningful?

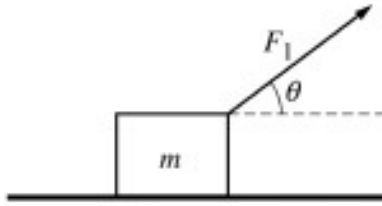


1986M1. The figure above shows an 80-kilogram person standing on a 20-kilogram platform suspended by a rope passing over a stationary pulley that is free to rotate. The other end of the rope is held by the person. The masses of the rope and pulley are negligible. You may use $g = 10 \text{ m/s}^2$. Assume that friction is negligible, and the parts of the rope shown remain vertical.

- a. If the platform and the person are at rest, what is the tension in the rope?

The person now pulls on the rope so that the acceleration of the person and the platform is 2 m/s^2 upward.

- b. What is the tension in the rope under these new conditions?
 c. Under these conditions, what is the force exerted by the platform on the person?

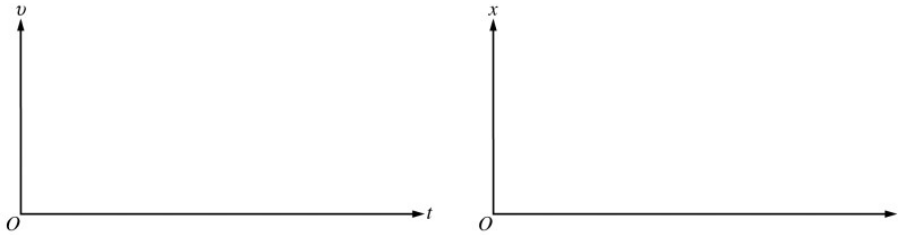


2007M1. A block of mass m is pulled along a rough horizontal surface by a constant applied force of magnitude F_1 that acts at an angle θ to the horizontal, as indicated above. The acceleration of the block is a_1 . Express all algebraic answers in terms of m , F_1 , θ , a_1 , and fundamental constants.

- a. On the figure below, draw and label a free-body diagram showing all the forces on the block.



- b. Derive an expression for the normal force exerted by the surface on the block.
 c. Derive an expression for the coefficient of kinetic friction μ between the block and the surface.
 d. On the axes below, sketch graphs of the speed v and displacement x of the block as functions of time t if the block started from rest at $x = 0$ and $t = 0$.



- e. If the applied force is large enough, the block will lose contact with the surface. Derive an expression for the magnitude of the greatest acceleration a_{\max} that the block can have and still maintain contact with the ground.

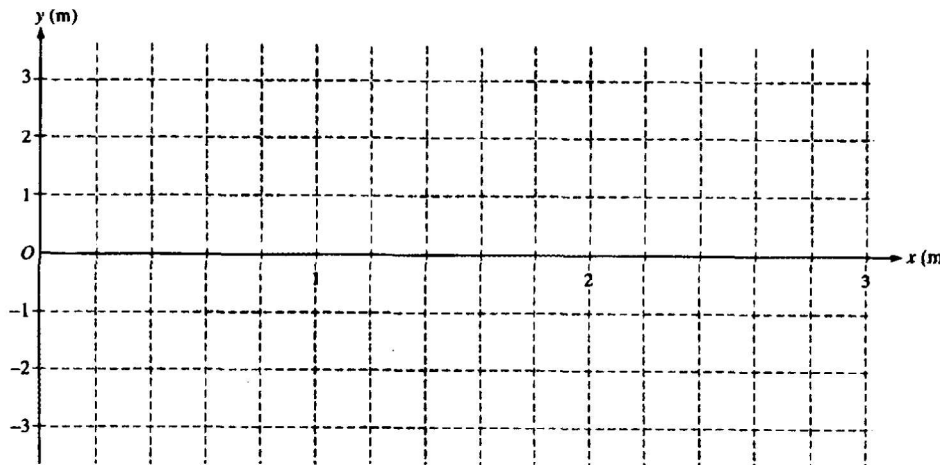


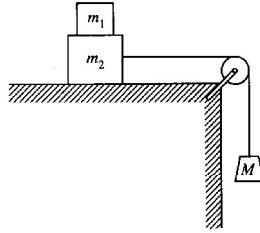
1996M2. A 300-kg box rests on a platform attached to a forklift, shown above. Starting from rest at time $t = 0$, the box is lowered with a downward acceleration of 1.5 m/s^2

- a. Determine the upward force exerted by the horizontal platform on the box as it is lowered.

At time $t = 0$, the forklift also begins to move forward with an acceleration of 2 m/s^2 while lowering the box as described above. The box does not slip or tip over.

- b. Determine the frictional force on the box.
 c. Given that the box does not slip, determine the minimum possible coefficient of friction between the box and the platform.
 d. Determine an equation for the path of the box that expresses y as a function of x (and not of t), assuming that, at time $t = 0$, the box has a horizontal position $x = 0$ and a vertical position $y = 2 \text{ m}$ above the ground, with zero velocity.
 e. On the axes below sketch the path taken by the box





1998M3. Block 1 of mass m_1 is placed on block 2 of mass m_2 which is then placed on a table. A string connecting block 2 to a hanging mass M passes over a pulley attached to one end of the table, as shown above. The mass and friction of the pulley are negligible. The coefficients of friction between blocks 1 and 2 and between block 2 and the tabletop are nonzero and are given in the following table.

	Coefficient Between Blocks 1 and 2	Coefficient Between Block 2 and the Tabletop
Static	μ_{s1}	μ_{s2}
Kinetic	μ_{k1}	μ_{k2}

Express your answers in terms of the masses, coefficients of friction, and g , the acceleration due to gravity.

- a. Suppose that the value of M is small enough that the blocks remain at rest when released. For each of the following forces, determine the magnitude of the force and draw a vector on the block provided to indicate the direction of the force if it is nonzero.

- i. The normal force N_1 exerted on block 1 by block 2

m_1

- ii. The friction force f_1 exerted on block 1 by block 2

m_1

- iii. The force T exerted on block 2 by the string

m_2

- iv. The normal force N_2 exerted on block 2 by the tabletop

m_2

- v. The friction force f_2 exerted on block 2 by the tabletop

m_2

- b. Determine the largest value of M for which the blocks can remain at rest.
- c. Now suppose that M is large enough that the hanging block descends when the blocks are released. Assume that blocks 1 and 2 are moving as a unit (no slippage). Determine the magnitude a of their acceleration.
- d. Now suppose that M is large enough that as the hanging block descends, block 1 is slipping on block 2. Determine each of the following.
- i. The magnitude a_1 of the acceleration of block 1
 - ii. The magnitude a_2 of the acceleration of block 2

*2005M1 (modified) A ball of mass M is thrown vertically upward with an initial speed of v_o . It experiences a force of air resistance given by $F = -kv$, where k is a positive constant. The positive direction for all vector quantities is upward. Express all algebraic answers in terms of M , k , v_o , and fundamental constants.

a. Does the magnitude of the acceleration of the ball increase, decrease, or remain the same as the ball moves upward?

_____ increases _____ decreases _____ remains the same

Justify your answer.

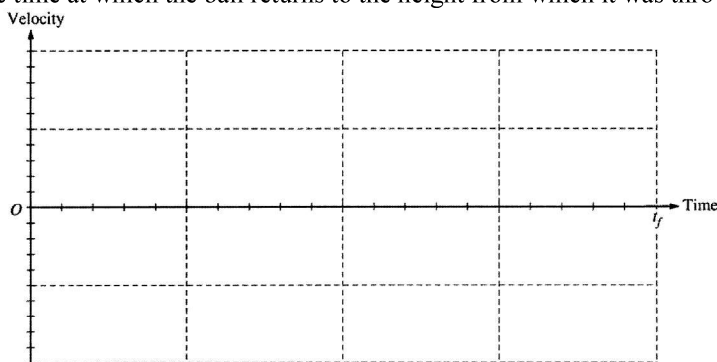
b. Determine the terminal speed of the ball as it moves downward.

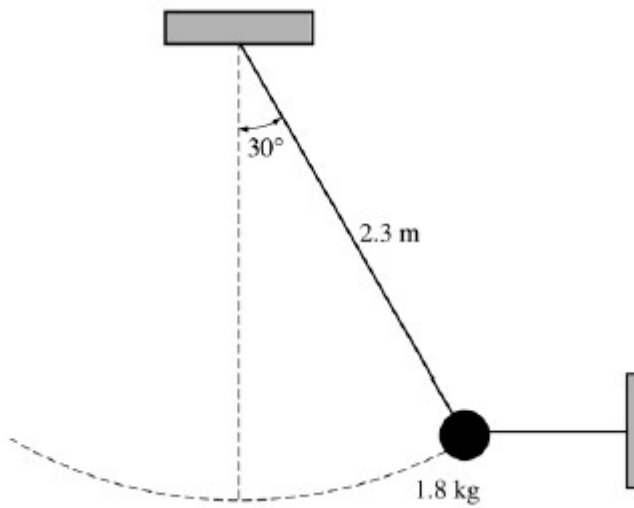
c. Does it take longer for the ball to rise to its maximum height or to fall from its maximum height back to the height from which it was thrown?

_____ longer to rise _____ longer to fall

Justify your answer.

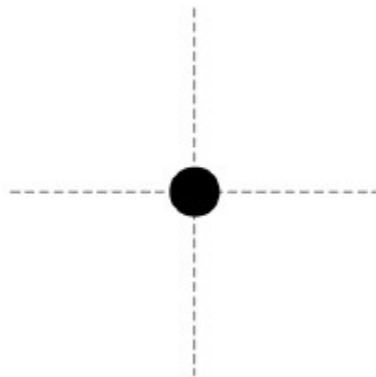
d. On the axes below, sketch a graph of velocity versus time for the upward and downward parts of the ball's flight, where t_f is the time at which the ball returns to the height from which it was thrown.



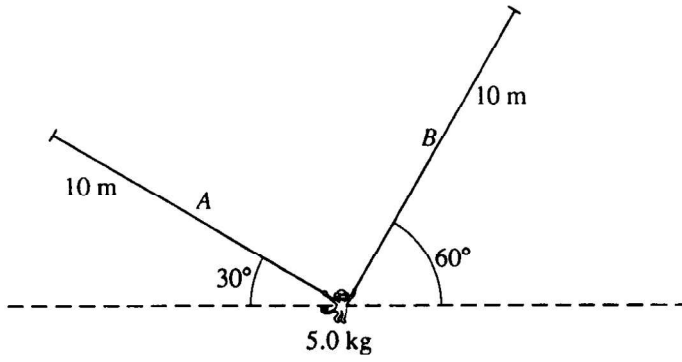


2005B2. A simple pendulum consists of a bob of mass 1.8 kg attached to a string of length 2.3 m. The pendulum is held at an angle of 30° from the vertical by a light horizontal string attached to a wall, as shown above.

(a) On the figure below, draw a free-body diagram showing and labeling the forces on the bob in the position shown above.



(b) Calculate the tension in the horizontal string.



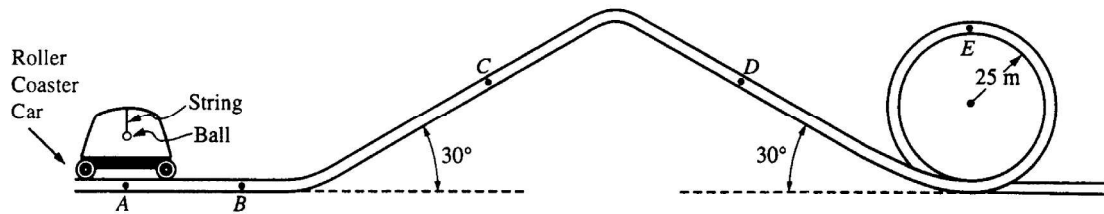
$\sin 30^\circ = 0.50$	$\sin 60^\circ = 0.87$
$\cos 30^\circ = 0.87$	$\cos 60^\circ = 0.50$
$\tan 30^\circ = 0.58$	$\tan 60^\circ = 1.73$

1991B1. A 5.0-kilogram monkey hangs initially at rest from two vines, A and B, as shown above. Each of the vines has length 10 meters and negligible mass.

a. On the figure below, draw and label all of the forces acting on the monkey. (Do not resolve the forces into components, but do indicate their directions.)



b. Determine the tension in vine B while the monkey is at rest.



Note: Figure not drawn to scale.

1995B3. Part of the track of an amusement park roller coaster is shaped as shown above. A safety bar is oriented lengthwise along the top of each car. In one roller coaster car, a small 0.10-kilogram ball is suspended from this bar by a short length of light, inextensible string.

- a. Initially, the car is at rest at point A.
 - i. On the diagram below, draw and label all the forces acting on the 0.10-kilogram ball.

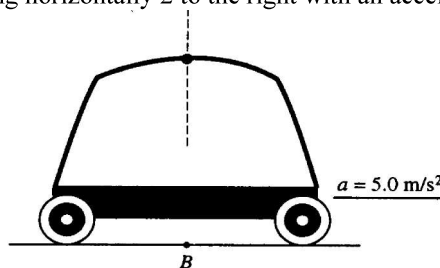


- ii. Calculate the tension in the string.

The car is then accelerated horizontally, goes up a 30° incline, goes down a 30° incline, and then goes around a vertical circular loop of radius 25 meters. For each of the four situations described in parts (b) to (e), do all three of the following. In each situation, assume that the ball has stopped swinging back and forth.

- 1) Determine the horizontal component T_h of the tension in the string in newtons and record your answer in the space provided.
- 2) Determine the vertical component T_v of the tension in the string in newtons and record your answer in the space provided.
- 3) Show on the adjacent diagram the approximate direction of the string with respect to the vertical. The dashed line shows the vertical in each situation.

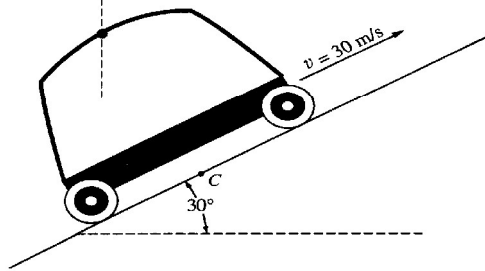
- b. The car is at point B moving horizontally to the right with an acceleration of 5.0 m/s^2 .



$T_h =$ _____

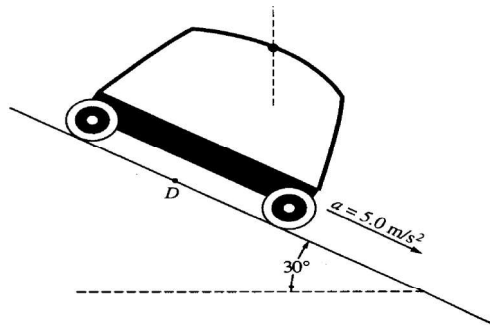
$T_v =$ _____

- c. The car is at point C and is being pulled up the 30° incline with a constant speed of 30 m/s.



$T_h =$ _____

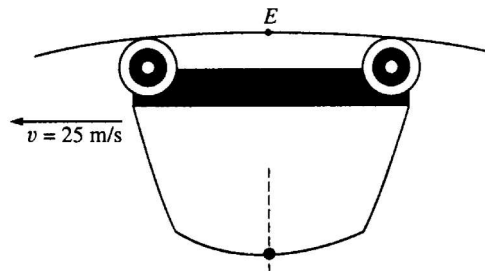
$T_v =$ _____



- d. The car is at point D moving down the incline with an acceleration of 5.0 m/s^2 .

$T_h =$ _____

$T_v =$ _____



- e. The car is at point E moving upside down with an instantaneous speed of 25 m/s and no tangential acceleration at the top of the vertical loop of radius 25 meters.

$T_h =$ _____

$T_v =$ _____