

End-of-Chapter Exercises

For all these exercises, assume that all strings are massless and all pulleys are both massless and frictionless. We will improve our model and learn how to account for the mass of a pulley in Chapter 10.

Exercises 1 – 12 are conceptual questions designed to see whether you understand the main concepts of the chapter. The first six exercises, in particular, are intended to give you more experience with free-body diagrams.

1. A box is placed in the middle of the floor of a truck. From the five free-body diagrams shown in Figure 5.22, which free-body diagram corresponds to the following situations? Assume the floor of the truck is horizontal at all times, and that for parts (a) - (d) the box does not slip on the floor of the truck. (a) The truck is moving at constant velocity to the right. (b) The truck is moving at constant velocity to the left. (c) The truck, while moving right, is speeding up. (d) The truck, while moving right, is slowing down. (e) The truck, while moving right, is stopping so quickly that the box slides over the floor of the truck. (f) The truck, while moving right, is speeding up so rapidly that the box slides over the floor of the truck.

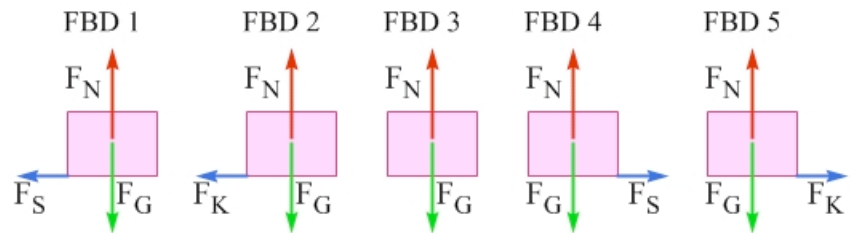


Figure 5.22: Possible free-body diagrams for a box in a truck, for Exercises 1 and 2.

2. Various possible free-body diagrams are shown in Figure 5.22 for a box on the floor of a moving truck. Imagine that you are in the back of the truck, looking forward at the box. As the truck makes a turn to the right, gently enough that the box does not slide over the floor of the truck, which free-body applies? Explain your choice.

3. Figure 5.23 shows five possible free-body diagrams (labeled FBD 1 through FBD 5) for a box on a ramp. (a) On the free-body diagrams, four different forces are shown. Briefly describe each of these forces and state what applies the force to the box. (b) Determine which free-body diagram, if any, matches each of the following situations: (i) the box remains at rest on the ramp; (ii) the box is sliding down the ramp, with some friction acting; (iii) the box is sliding up the ramp, which is frictionless.

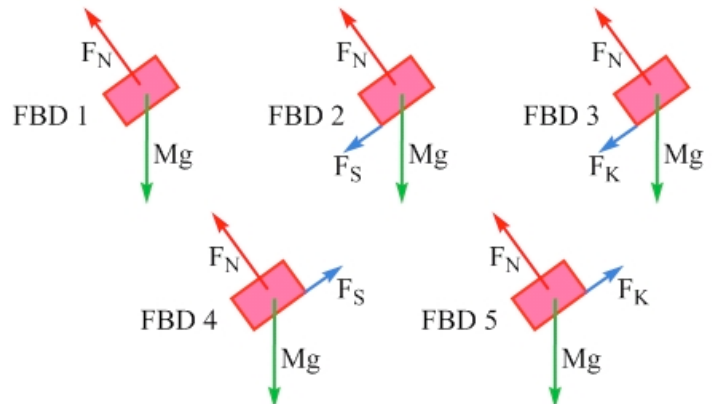


Figure 5.23: Five possible free-body diagrams for a box on a ramp, for Exercises 3 – 6.

4. Figure 5.23 shows five possible free-body diagrams (labeled FBD 1 through FBD 5) for a box on a ramp. Describe a situation in which the correct free-body diagram is FBD 3.
5. Let's say that the free-body diagrams shown in Figure 5.23 are possible free-body diagrams for a box placed on the floor of a truck that is traveling on a hill. Identify the free-body diagram that could apply in each of the following situations. For parts (a) – (d),

assume the box does not slide over the floor of the truck. (a) The truck is traveling at constant velocity up the hill. (b) The truck is traveling at constant velocity down the hill. (c) The truck is at rest at a red light halfway up the hill. (d) The truck is speeding up as it climbs the hill. (e) The truck's acceleration up the hill is so large that the box slides over the floor of the truck.

6. Consider again the situation described in Exercise 5, regarding a box on the floor of a truck traveling up a hill that has a constant angle θ with respect to the horizontal. Now the truck is traveling down the hill and its speed is increasing. Which of the free-body diagrams shown in Figure 5.23 could apply in that situation, assuming the box does not slide over the floor of the truck? Select all possible answers, and explain in what situation (s) each free-body diagram applies.
7. A box with a weight of mg is initially at rest on a board that is initially horizontal. The angle between the board and the horizontal, θ , is gradually increased until the box starts to slide on the board. The coefficient of static friction between the box and the board is $\mu_s = 1.00$. (a) Plot a graph of the magnitude of the normal force applied to the box by the board, as a function of θ from $\theta = 0$ to $\theta = 90^\circ$, when θ is gradually increased from zero. (b) What else could that graph represent? (c) On the same graph, plot the magnitude of the component of the force of gravity acting on the box, as a function of θ , as θ is gradually increased. (d) What else could the graph from part (c) represent? (e) On the same graph, plot the magnitude of the maximum possible force of static friction that could act on the box if the coefficient of static friction is reduced to 0.50. (f) Briefly describe how the graphs can be used to find the angle at which the block first starts to slide on the board.

8. Three situations involving a block with a weight of 10 N and a string are shown in Figure 5.24. In cases 2 and 3, the string passes through a hook on top of the block. (a) Rank these situations based on the tension in the string, from largest to smallest (e.g., $3 > 1 = 2$). (b) What is the tension in the string in case 3?

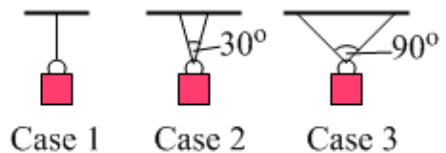


Figure 5.24: Three different situations of a block being supported by a string, for Exercise 8.

9. As shown in Figure 5.25, identical 20-N boxes are placed on identical horizontal surfaces. Each box has a string attached that passes over a pulley. In Case 1, the other end of the string is attached to a block with a weight of 8.0 N. In case 2, you simply exert an 8.0 N force straight down on the string. In both cases, enough friction acts on the box to keep the box at rest. (a) In which case is the force of friction acting on the box larger? (b) In which case is the tension in the string larger? (c) Calculate the force of friction acting on the box, and the tension in the string, in case 1. (d) What, if anything, can you say about the coefficient of static friction between the box and the surface in case 1?

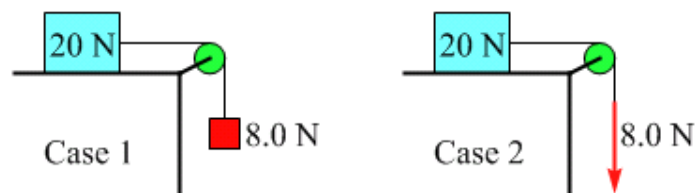


Figure 5.25: Two situations of a 20-N box on a level surface, for Exercise 9.

10. A box of mass m is placed on a frictionless ramp inclined at an angle of θ with respect to the horizontal. The ramp has a mass M and is on a frictionless horizontal surface. If the ramp remained at rest, the box would slide down the incline, but if the ramp is given a

horizontal acceleration of just the right magnitude, the box will remain at rest with respect to the ramp. (a) Using whole vectors, construct a right-angled triangle showing the normal force applied to the box, the force of gravity on the box, and the net force on the box. (b) Use the triangle to determine the acceleration of the system.

11. A disk is placed on a turntable at some distance from the center of the turntable. When the turntable rotates, the disk moves along with it without slipping. Which force, forces, or force components give rise to the disk's centripetal acceleration?
12. Take a metal coat hanger and stretch it out, as shown in Figure 5.26. It is best if a straight line through the hook of the hanger passes through the top vertex of the hanger, as shown by the dashed line in the figure. Holding the hanger vertically, balance a penny on the hook. After getting the hanger to rock back and forth on your finger, make the penny and coat hanger rotate so that at some times the penny is completely upside down. The penny should remain on the hanger at all times! (Bonus points if you can bring the system to a stop without the penny falling off.) Explain how this is possible.

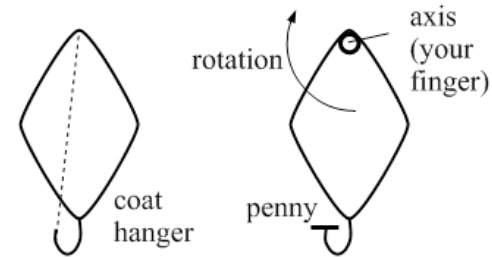


Figure 5.26: Spin a penny on the end of a stretched-out metal coat hanger, for Exercise 12.

Exercises 13 – 19 are designed to give you practice with the general method for solving a problem involving Newton's laws. For each of these exercises, start by doing the following: (a) Draw a diagram of the situation. (b) Draw one or more free-body diagram(s) showing all the forces that act on various objects or systems. (c) Choose an appropriate coordinate system for each free-body diagram. (d) If necessary, split forces into components that are parallel to the coordinate axes. (e) Apply Newton's second law enough times to obtain the necessary equations to solve the problem.

13. You pull a box, which has a weight of 20 N, across a horizontal floor at a constant velocity of 5.0 m/s. You do this by exerting a 10 N force horizontally on a string attached to the box. The goal here is to find the coefficient of kinetic friction between the box and the floor. Parts (a) – (e) as described above. (f) Find the coefficient of kinetic friction between the box and the floor.
14. Repeat Exercise 13, except that now the string between the box and your hand is at an angle of 30° with the horizontal, so your 10 N force has a component directed vertically up.
15. A box with a mass of 2.5 kg is initially at rest on a horizontal frictionless surface. You then pull on a string attached to the box, exerting a constant force F at an angle of 45° above the horizontal. This pull causes the box to travel 4.0 m horizontally in 2.0 s. Parts (a) – (e) as described above. (f) Find the box's acceleration by treating this as a one-dimensional constant-acceleration problem. (g) Find the magnitude of the force F . (h) Find the magnitude of the normal force acting on the box. Use $g = 9.8 \text{ m/s}^2$.
16. In Atwood's machine (see Figure 5.27), the two blocks connected by a string passing over the pulley have masses of 1.0 kg (on the left) and 3.0 kg (on the right). The system is initially held at rest by means of a second string tied from the lighter block to the ground. Use $g = 9.8 \text{ m/s}^2$. Parts (a) – (e) as described above. (f) What is the tension in the string connecting the two blocks? (g) What is the tension in the second string? (h) Without doing any calculations, describe whether the tension in the first string will increase,

decrease, or remain the same when the second string is cut. (i) Calculate the tension in the first string when the second string is cut.

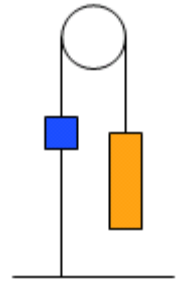


Figure 5.27: Atwood's machine, held at rest by a string connecting the smaller mass to the ground, for Exercise 16.

17. While moving out of your apartment, you push a box of textbooks, which has a mass of 20 kg, up the ramp of your moving truck. The coefficient of kinetic friction between the ramp and the box is 0.20, and the ramp is inclined at 30° with respect to the horizontal. Our goal here is to determine what force you push the box with, if the box travels at constant speed up the ramp and the force you exert is parallel to the ramp. Parts (a) – (e) as described above. (f) What is the magnitude of the force you exert on the box? Use $g = 9.8 \text{ m/s}^2$.

18. Three blocks, A, B, and C, are connected by massless strings, as shown in Figure 5.28. The two strings pass over massless frictionless pulleys. The mass of block A is $m_A = 4.00 \text{ kg}$. The mass of block B is $m_B = 8.00 \text{ kg}$. Use $g = 10.0 \text{ m/s}^2$. Our first goal will be to determine the acceleration of the system if the mass of block C is $m_C = 8.00 \text{ kg}$. Let's start by assuming that the table supporting block B is frictionless. Parts (a)-(e) as described above. (f) What is the acceleration of the system if $m_C = 8.00 \text{ kg}$? (g) What would the mass of the block C have to be for the system to have no acceleration? (h) If the coefficient of static friction between block B and the table is $\mu_s = 0.300$, the system will remain at rest if the mass of block C is between a maximum value m_{Cmax} and a minimum value m_{Cmin} . What are m_{Cmax} and m_{Cmin} ? (i) If the mass of block C is 5.00 kg, what is the force of friction exerted on block B by the table? Assume the system remains at rest.

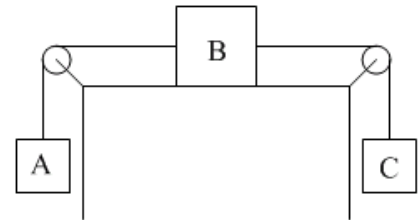


Figure 5.28: A diagram of three blocks connected by strings, for Exercise 18.

19. A box of mass $m = 3.0 \text{ kg}$ is placed in the center of a flatbed truck. The coefficients of friction between the box and the truck are $\mu_s = 0.40$ and $\mu_k = 0.30$. Our first goal will be to determine the force of friction acting on the box when the truck accelerates forward on a level road, starting from rest. Assume the box remains at rest relative to the truck. Parts (a) – (e) as described above. (f) If the truck's acceleration is 2.0 m/s^2 , what is the magnitude and direction of the force of friction acting on the box? Is it static friction or kinetic friction? (g) What is the largest magnitude that the truck's acceleration can be for the box to remain at rest relative to the truck? (h) Which of the values stated in the problem did you not need to solve the problem?

Exercises 20 – 22 are designed to give you practice with the general method for solving a uniform circular motion problem. For each of these exercises, start by doing the following: (a) Draw a diagram of the situation. (b) Draw one or more free-body diagram(s) showing all the forces that act on various objects or systems. (c) Choose an appropriate coordinate system for each free-body diagram. (d) If necessary, split forces into components that are parallel to the coordinate axes. (e) Apply Newton's second law enough times to get the equations necessary to solve the problem, and solve the resulting equations.

20. While driving your car on a hilly road, you pass over a hill that, at the top, is a circular arc with a radius of 20 m. Parts (a) – (e) as described above. (f) How fast are you traveling if, at the top of the hill, the normal force exerted by the road on your car is 30% less than it was the previous day, when you stopped your car there to admire the view? Assume the mass of the car is the same on the two days.

21. A *whirligig conical pendulum* consists of a ball of mass M being whirled in midair in a horizontal circle at a constant speed v (see Figure 5.29). The ball is tied to a string that passes over a pulley, which rotates on frictionless bearings as the ball travels around the circle, and down through a hollow tube. A block of mass m is tied to the other end of the string. As the ball travels around the circle, the string makes an angle of θ with the horizontal, and the part of the string that goes from the ball to the pulley has a fixed length L . Parts (a) – (e) as described above. (f) In terms of the variables M , m , and/or g only, what is the magnitude of the tension in the string? (g) In terms of M , m , g , L , and/or θ only, what is v , the constant speed of the ball?

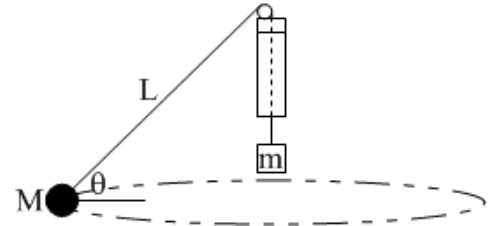


Figure 5.29: A whirligig conical pendulum, for Exercise 21.

22. Mary is whirling around on a merry-go-round at the playground that her friend Caitlin is gradually spinning faster and faster. The goal of the exercise is to determine the maximum speed Mary can travel at, if the coefficient of static friction between her shoes and the floor is μ_s . Assume that Mary is not hanging on, but is simply balancing on her feet at a distance r from the center. Parts (a) – (e) as described above. (f) Find Mary's maximum speed. (g) Which, if any, of the following would help Mary stay on the merry-go-round? (i) Moving closer to the center of the turntable. (ii) Moving closer to the edge of the turntable. (iii) Wearing a heavy backpack that increases her mass.

Exercises 23 – 27 are designed to give you practice with applying whole vectors, so take a whole-vector approach to the situations described.

23. A box with a weight of 20 N is initially at rest on a horizontal surface. The coefficients of friction between the box and the surface are $\mu_s = 0.30$ and $\mu_k = 0.20$. A force is then applied to the box at an angle of 30° with the horizontal so that the box has a non-zero acceleration directed entirely horizontally and no friction acts on the box. What is the magnitude of this applied force?
24. A box with a weight of 40 N remains at rest on a horizontal surface, even though a 25 N horizontal force is being applied to it. What are the magnitude and direction (the angle with respect to the horizontal) of the contact force exerted on the box by the surface?
25. A box with a weight of 40 N remains at rest on a flat surface inclined at 30° with respect to the horizontal, even though a 25 N horizontal force is being applied to it. (a) What are the magnitude and direction (the angle with respect to the horizontal) of the contact force exerted on the box by the surface? What are the magnitude of the (b) normal force and (c) friction force exerted on the box by the surface?
26. As shown in Figure 5.30, a disk with a weight of 2.0 N lies on a rotating turntable such that the disk does not slip on the turntable. The turntable spins at a steady rate of 1 revolution every second and the disk is 50 cm from the turntable's center. (a) Draw a right-angled triangle showing the contact force applied to the disk by the turntable, the force of gravity acting on the disk, and the disk's net force. (b) Using $g = 9.8 \text{ m/s}^2$, find the angle between the horizontal and the contact force.

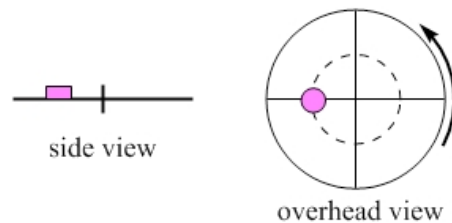


Figure 5.30: A disk on a rotating turntable, for Exercise 26.

27. A 5.0 kg box is at rest on a ramp that is at an angle of 15° with the horizontal. The coefficient of static friction between the box and the ramp is $\mu_s = 0.40$. Begin by sketching a free-body diagram for the box, showing the force of gravity and the contact force. (a) What are the magnitude and direction of the contact force applied by the ramp on the box? (b) What is the magnitude of the normal force applied by the ramp on the box? (c) What is the magnitude of the force of friction applied by the ramp on the box?

General problems and conceptual questions

28. Return to the situation described in Exercise 27, but this time use an approach in which you choose an appropriate coordinate system and split forces into components. A 5.0 kg box is at rest on a ramp that is at an angle of 15° with the horizontal. The coefficient of static friction between the box and the ramp is $\mu_s = 0.40$. Determine (a) the normal force applied by the ramp on the box, (b) the force of friction applied by the ramp on the box, and (c) the magnitude and direction of the contact force applied by the ramp on the box.
29. Return to the situation described in Exercises 27 and 28. If you would like the box to start moving, what is the minimum force you can apply if your force is directed (a) parallel to the slope? (b) perpendicular to the slope? (c) horizontally?
30. A shuffleboard disk with a mass m is sliding on a horizontal surface. The coefficient of kinetic friction between the disk and the surface is μ_k , and the acceleration due to gravity is g . In terms of the variables stated here, determine the magnitude of (a) the normal force acting on the disk, (b) the force of friction acting on the disk, and (c) the net contact force acting on the disk from the surface. (d) What is the angle between the contact force and the surface?
31. Return to the situation described in Exercise 30. If the disk has an initial speed of 4.0 m/s, $\mu_k = 0.20$, and $g = 9.8 \text{ m/s}^2$, how far does the disk slide?
32. A 4.0 kg box is initially at rest on a flat surface. The coefficient of static friction between the box and the surface is $\mu_s = 0.50$. Determine the minimum force you have to apply to start the box moving if your force is directed (a) horizontally; (b) at an angle of 20° from the horizontal with a vertical component down; (c) at an angle of 20° from the horizontal with a vertical component up.
33. Return to the situation described in Exercise 32. If the angle between the force you apply and the horizontal is larger than a particular critical angle, the box will not move, no matter what magnitude your force is. (a) Is this true when your force has a downward vertical component, an upward vertical component, or in both of these cases? (b) Find an expression for the critical angle θ_c in terms of the coefficient of static friction μ_s . (c) Solve for θ_c when $\mu_s = 0.50$.
34. A box with a weight of 20 N is initially at rest on a flat surface. The coefficients of friction for the box and the surface are $\mu_s = 0.50$ and $\mu_k = 0.40$. A horizontal force with a constant direction is then applied to the box. The magnitude of the force increases with time according to the equation $F = (2.0 \text{ N/s})t$ until the box starts to move. Then, the force remains constant at the value it has when the box starts to move. (a) Sketch a graph showing the magnitude of this horizontal force, and the magnitude of the force of friction

acting on the box, as a function of time for the first 8.0 s after the horizontal force is first applied. (c) Sketch a graph of the speed of the box as a function of time over the same 8.0-second interval.

35. Figure 5.31 shows a box with a mass of 2.5 kg remaining at rest on a horizontal table. A string is tied to the box and held in a horizontal position by means of a system of two other strings, one that hangs vertically and supports a small block with a mass of 500 g, and the other that makes a 30° angle with the horizontal and is tied to a wall. Use $g = 9.8 \text{ m/s}^2$. (a) What is the magnitude of the force of friction acting on the box? (b) What, if anything, can you say about the coefficient of static friction between the box and the table in this situation?

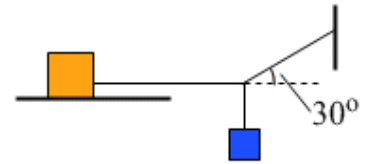
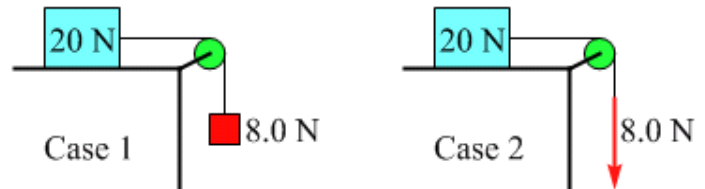


Figure 5.31: An equilibrium situation involving two blocks, for Exercise 35.

36. A box is placed at the bottom of a ramp that measures 3.00 m vertically by 4.00 m horizontally. The coefficients of friction for the box and the ramp are: $\mu_s = 0.60$ and $\mu_k = 0.50$. The box is then given an initial velocity up the ramp of 4.0 m/s. The box slows down as it slides up the ramp and eventually comes to a stop. (a) Will the box remain at rest, or will the stop just be for an instant before it slides down the ramp again? Justify your answer. (b) If you determine that the box slides down again, which takes more time, sliding up the ramp or sliding down the ramp? Justify your answer without calculating either time.
37. Return to the situation described in the previous exercise, and use $g = 10 \text{ m/s}^2$. (a) How far does the box travel up the ramp? (b) How long does the box spend sliding up the ramp? (c) If you determine that the box slides down the ramp again, how long does the box spend sliding down the ramp?
38. As shown in Figure 5.32, identical 20-N boxes are placed on identical horizontal surfaces. Each box has a string attached that passes over a pulley. In Case 1, the other end of the string is attached to a block with a weight of 8.0 N. In case 2, you simply exert an 8.0 N force straight down on the string. The coefficients of friction for the box-surface interaction are the same in both cases. Although there is some friction, in both cases the box accelerates from rest to the right. Try to answer parts (a) – (c) without doing any calculations. (a) In which case is the force of friction acting on the box larger? (b) In which case is the tension in the string larger? (c) In which case is the acceleration larger? (d) What, if anything, can you say about the coefficient of static friction between the box and the surface?



39. Return to the situations shown in Figure 5.32. In each case, the coefficients of friction are $\mu_s = 0.20$ and $\mu_k = 0.10$. Use $g = 10 \text{ m/s}^2$. Determine the acceleration of the 20-N box in (a) case 1 (b) case 2.

40. Consider the situation shown in case 1 in Figure 5.32. Assume now that the coefficients of friction between the box and the surface are $\mu_s = 0.25$

Figure 5.32: Two situations of a 20-N box on a level surface, for Exercises 38 – 40.

and $\mu_k = 0.20$. The 20-N box is given an initial velocity of 2.0 m/s away from the pulley.

- (a) How far will the box travel before coming instantaneously to rest? (b) How much time passes until the box comes instantaneously to rest? (c) Will the box remain at rest or

will it reverse direction and travel back toward the pulley? How can you tell? (d) If you decide that the box does travel back toward the pulley, determine (i) how fast it is going when it reaches its starting point; (ii) how long the return trip to the starting point takes.

41. Two identical boxes are linked by a string passing over a pulley, as in Figure 5.33. One box is on a horizontal surface, while the other is on an incline in the shape of a 3-4-5 triangle. If the surfaces are frictionless, what is the acceleration of the system?

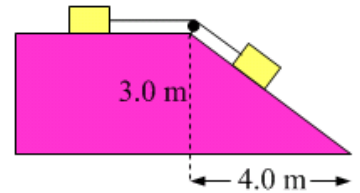


Figure 5.33: Two boxes connected by a string, for Exercises 41 – 45.

42. Return to the situation described in Exercise 41 and shown in Figure 5.33. Each of the following changes to the system is made separately – the changes are not sequential. State whether the change affects the acceleration of the system and, if so, state what happens to the acceleration. (a) Double the mass of both boxes. (b) Double the mass of the box on the incline only. (c) Double the mass of the box on the horizontal surface only. (d) Transfer the whole system to the Moon, where the acceleration due to gravity is about $1/6$ of the value here on Earth.

43. Two identical boxes are linked by a string passing over a pulley, as in Figure 5.33. One box is on a horizontal surface, while the other is on an incline in the shape of a 3-4-5 triangle. If the coefficients of friction for both box-surface interactions are $\mu_s = 0.15$ and $\mu_k = 0.10$ and the system is released from rest, what is the magnitude of the acceleration of the system?

44. Two identical boxes are linked by a string passing over a pulley, as in Figure 5.33. One box is on a horizontal surface, and the other is on an incline in the shape of a 3-4-5 triangle. Both boxes are moving such that the string between them remains taut. If the acceleration of each box has a magnitude of $g/10$, what is the coefficient of kinetic friction between the boxes and the surface? Assume the coefficient of kinetic friction is the same for both boxes. How many different solutions does this problem have? Find all the solutions.

45. Two identical boxes are linked by a string passing over a pulley, as in Figure 5.33. One box is on a horizontal surface, while the other is on an incline in the shape of a 3-4-5 triangle. Both boxes are moving with a constant non-zero velocity such that the string between them remains taut. What is the coefficient of kinetic friction between the boxes and the surface? Assume the coefficient of kinetic friction is the same for both boxes. How many different solutions does this problem have? Find all the solutions.

46. Fred pulls down on a massless rope (rope 1) with a constant force F (see Figure 5.34). This rope passes over a massless, frictionless pulley and is tied to a box with a mass $m_1 = 2.00$ kg. Rope 2 connects the first box to a second box with a mass $m_2 = 4.00$ kg. The two boxes accelerate upwards with an acceleration $a = 4.00$ m/s². Use $g = 10.0$ m/s². (a) Find the tension in rope 2. (b) Find the tension in rope 1. (c) If the boxes are initially at rest, what distance have they traveled 0.500 seconds after they start moving? (d) If the ground exerts an upward normal force on Fred of 500 N, what is Fred's mass?

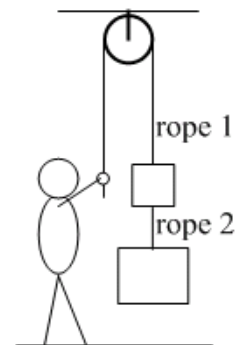


Figure 5.34: Fred accelerates a system of two boxes upward, for Exercise 46.

47. A 5.00 kg box is placed on a ramp that measures 3.00 m vertically by 4.00 m horizontally. As shown in Figure 5.33, the box is attached to a 1.00 kg ball by a massless rope that passes over a massless and frictionless pulley. A horizontal force of $F = 10.0$ N is also applied to the box. Use $g = 10.0$ m/s². (a) If there is no friction between the box and the ramp, what is the acceleration of the box? State clearly if the acceleration is directed up or down the ramp. (b) What value of the horizontal force F would result in zero acceleration for the box? (c) Let's introduce some friction between the box and the ramp, with a coefficient of static friction of $\mu_s = 1/3$. In this case, the box, if it starts from rest, will have no acceleration for all values of the horizontal force F between some minimum value F_{min} and some maximum value F_{max} . What are these minimum and maximum values?

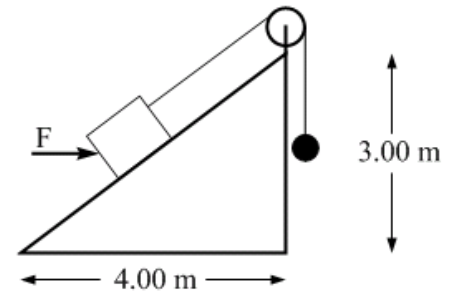


Figure 5.35: The situation described in Exercise 47.

48. A block of mass m is placed on top of a larger block of mass M and the two-block system rests on a horizontal frictionless surface. There is friction between the two blocks, with static and kinetic friction coefficients μ_s and μ_k , respectively. As shown in Figure 5.36, a horizontal force F is applied to the larger block. Express all your answers below in terms of m , M , g , F , and/or μ_s or μ_k . (a) For small values of F , the two blocks slide together on the surface. For this situation, what are: (i) the acceleration of the large block and (ii) the friction force on the small block? (b) For large values of F the small block slides with respect to the large block. What is the acceleration of the large block in this case? (c) What is the maximum value of F such that the small block does not move with respect to the large block?

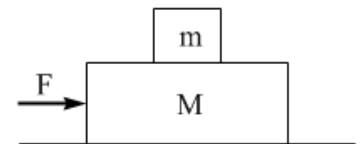


Figure 5.36: A stack of two blocks, with a force being applied to the lower block, for Exercises 48 and 49.

49. Return to the situation described in Exercise 48 and shown in Figure 5.36, but now we will use numerical values for the variables. We will also introduce some friction between the large box and the horizontal surface. Let's use $m = 5.0$ kg, $M = 10$ kg, $g = 10$ m/s², and say that $\mu_s = 0.40$ and $\mu_k = 0.30$ for the interaction between the blocks as well as the interaction between the large block and the horizontal surface. (a) If the blocks are initially at rest, what is the minimum value of the horizontal force F necessary to start the system moving? (b) Once the blocks are moving, what is the minimum value of the horizontal force F necessary to keep the system moving at constant velocity? (c) If the blocks are initially at rest, what is the maximum value the horizontal force F can be such that the small block does not slide on the large block?

50. As shown in Figure 5.37, Joe is placed in a large bucket that is suspended in mid-air by a rope that passes over a pulley. In Case 1, Joe holds the other end of the rope. In Case 2, Bill, on the ground, holds the other end of the rope. If Joe and the bucket are stationary, in which case is the tension in the rope larger?

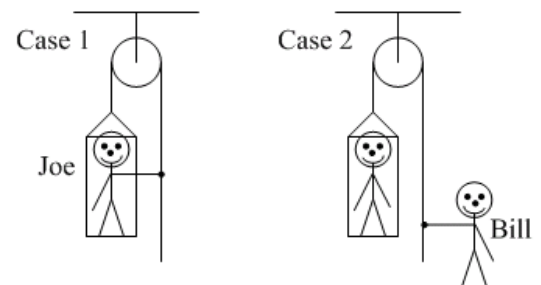


Figure 5.37: Two cases of Joe in a bucket, for Exercises 50 and 51.

51. Return to the situation described in Exercise 50. If Bill's mass is 70 kg, the combined mass of Joe and the bucket is 50 kg, and the bucket is accelerating up at the rate of 2.0 m/s², what is the tension in the rope in (a) Case 1? (b) Case 2?

52. Two boxes are side-by-side on a horizontal floor as shown in Figure 5.38. The coefficient of kinetic friction between each box and the floor is μ_K . In Case 1, a horizontal force F directed right is applied to the box of mass M and the boxes are moving to the right. In Case 2, the horizontal force F is instead directed left and applied to the box of mass m , and the boxes are moving to the left. Find an expression for the magnitude of F_{Mm} , the force the box of mass M exerts on the box of mass m , in (a) Case 1 (b) Case 2. Express your answers in terms of variables given in the problem.



Figure 5.38: Two cases involving two boxes on a horizontal floor, with an applied force, for Exercises 52 and 53.

53. Consider again the situation described in Exercise 52 and shown in Figure 5.38. Let's use $m = 5.0 \text{ kg}$, $M = 10 \text{ kg}$, $g = 10 \text{ m/s}^2$, $F = 20 \text{ N}$, and say that $\mu_K = 0.40$ for the interaction between the boxes and the floor. What are the magnitude and direction of the acceleration of the system if the boxes are initially moving to the right in (a) Case 1; (b) Case 2? What are the magnitude and direction of the acceleration of the system if the boxes are initially moving to the left in (c) Case 1; (d) Case 2?

54. Three blocks are placed side-by-side on a horizontal surface and subjected to a horizontal force F , as shown in case 1 of Figure 5.39. Doing so causes the blocks to accelerate from rest to the right. The coefficients of friction between each box and the surface are $\mu_s = 0.30$ and

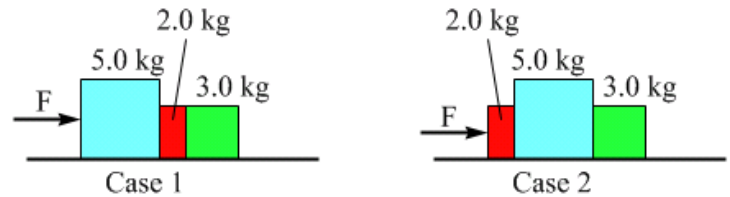


Figure 5.39: Two situations involving three blocks being pushed from the left by a horizontal force F , for Exercises 54 – 55.

$\mu_K = 0.20$. Use $g = 10 \text{ m/s}^2$, and consider case 1 only. If the horizontal force F is 40 N , what are (a) the acceleration of the system? (b) the net force acting on the 2.0 kg block? (c) the force exerted by the 5.0 kg block on the 2.0 kg block?

55. Repeat Exercise 54, but now answer the questions for case 2, instead.
56. You get off a bus, take a plastic cube out of your pocket, and hold the cube against the front of the bus, which is vertical. When the bus starts to move, you carefully let the cube go, and step away from the bus. As the bus accelerates at 4.0 m/s^2 , you notice that the cube remains in place on the front of the bus. What does this tell you about the coefficient of static friction between the cube and the bus?
57. While on a train, you are holding a string with a ball attached to it. At first, the train's velocity is constant and the string is vertical. When the train changes direction while going around a curve with a radius of 200 m , you measure the angle between the string and the vertical to be 20° . What is the speed of the train?

58. A hockey puck, with a mass of 160 g, is placed 75 cm from the center of a horizontal turntable. The turntable begins to rotate, gradually spinning faster as its rate of rotation increases at a steady rate. The speed of the puck, as a function of time, is given by $v = (0.10 \text{ m/s}^2)t$. The coefficients of friction between the puck and the turntable are $\mu_s = 0.60$ and $\mu_k = 0.50$. (a) Assuming the force of friction is directed toward the center of the turntable, determine at what time the puck starts to slide on the turntable. Plot graphs, as a function of time, of (b) the maximum possible force of static friction, and (c) the magnitude of the actual force of friction acting on the puck.

59. A cube of mass m is placed in a funnel that is rotating around the vertical axis shown in Figure 5.40. There is no friction between the cube and the funnel, but the funnel is rotating at just the right speed needed to keep the cube rotating with the funnel. The cube travels in a circular path of radius r , and the angle between the vertical and the wall of the funnel is θ . Express your answers in terms of m , r , g , and/or θ . (a) Which force, forces, or force components give rise to the centripetal acceleration in this situation? (b) What is the normal force acting on the cube? (c) What is the speed v of the cube?

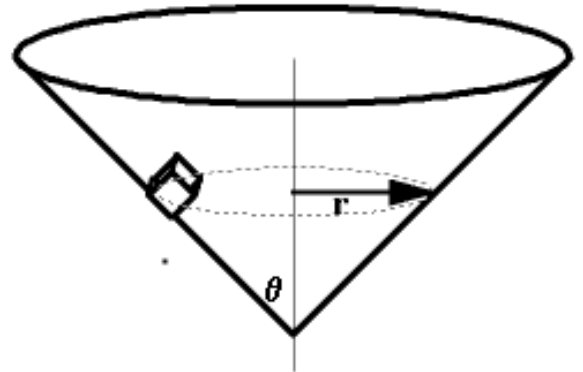


Figure 5.40: A cube in a rotating funnel, for Exercises 59 and 60.

60. Return to the situation described in Exercise 59, except now there is some friction between the cube and the funnel. Let's use the following values: $\theta = 45^\circ$, $m = 500$ grams, $r = 20$ cm, and $g = 9.8 \text{ m/s}^2$, with coefficients of friction between the cube and the funnel of $\mu_s = 0.20$ and $\mu_k = 0.10$. (a) What is the cube's speed, if there is no force of friction acting on the cube? (b) What are the maximum and minimum values that the cube's speed can be, so that the cube will not slide up or down in the funnel?
61. Matt, with a mass of 22.0 kg, is swinging on a tire swing (a tire attached to a rope hanging from a tree). The tire itself has a mass of 5.0 kg, and the rope has a length of 4.0 m. (a) If Matt's speed is 3.0 m/s when the tire reaches the bottom of its circular arc, what is the tension in the rope at that point? (b) Matt's father, Bob, thinks that the tire swing looks like fun. If the rope will break when the tension exceeds 750 N, is it safe for Bob to jump on the swing with Matt, should Bob swing by himself, or should he not swing at all? Justify your answer. Bob's mass is 70.0 kg, and he would reach the same 3.0 m/s speed that Matt does at the bottom of the swing.
62. You are traveling on a hilly road. At a particular spot, when your car is perfectly horizontal, the road follows a circular arc of some unknown radius. Your speedometer reads 80 km/h, and your apparent weight is 30% larger than usual. (a) Are you at the bottom of a hill or the top of a hill at that instant? (b) What is the radius of the circular arc?