CHAPTER 5

Using Newton's Laws: Friction, Circular Motion, Drag Forces

Windows OS

Problems

5–1 Friction and Newton's Laws

1. (I) If the coefficient of kinetic friction between a 22-kg crate and the floor is 0.30, what horizontal force is required to move the crate at a steady speed across the floor? What horizontal force is required if μ_k is zero?

2. (I) A force of 35.0 N is required to start a 6.0-kg box moving across a horizontal concrete floor. (*a*) What is the coefficient of static friction between the box and the floor? (*b*) If the 35.0-N force continues, the box accelerates at $0.60\ \mathrm{m/s^2}$. What is the coefficient of kinetic friction?

3. (I) Suppose you are standing on a train accelerating at 0.20 *g*. What minimum coefficient of static friction must exist between your feet and the floor if you are not to slide?

4. (I) The coefficient of static friction between hard rubber and normal street pavement is about 0.90. On how steep a hill (maximum angle) can you leave a car parked?

5. (I) What is the maximum acceleration a car can undergo if the coefficient of static friction between the tires and the ground is 0.90?

6. (II) (*a*) A box sits at rest on a rough 33° inclined plane. Draw the free-body diagram, showing all the forces acting on the box. (*b*) How would the diagram change if the box were sliding down the plane. (*c*) How would it change if the box were sliding up the plane after an initial shove?

7. (II) A 25.0-kg box is released on a 27° incline and accelerates down the incline at $0.30\ \mathrm{m/s^2}$. Find the friction force impeding its motion. What is the coefficient of kinetic friction?

8. (II) A car can decelerate at 2 $3.80\ \mathrm{m/s^2}$ without skidding when coming to rest on a level road. What would its deceleration be if the road is inclined at 9.3° and the car moves uphill? Assume the same static friction coefficient.

9. (II) A skier moves down a 27° slope at constant speed. What can you say about the coefficient of friction, μ_k? Assume the speed is low enough that air resistance can be ignored.

10. (II) A wet bar of soap slides freely down a ramp 9.0 m long inclined at 8.0°. How long does it take to reach the bottom? Assume $\mu_k = 0.060$.

11. (II) A box is given a push so that it slides across the floor. How far will it go, given that the coefficient of kinetic friction is 0.15 and the push imparts an initial speed of 3.5 m / s?

12. (II) (*a*) Show that the minimum stopping distance for an automobile traveling at speed v is equal to $v^2/2\mu_s g$, where μ_s is the coefficient of static friction between the tires and the road, and *g* is the acceleration of gravity. (*b*) What is this distance for a 1200-kg car traveling 95 km / h if $\mu_s = 0.65$? (*c*) What would it be if the car were on the Moon (the acceleration of gravity on the Moon is about *g* / 6) but all else stayed the same?

13. (II) A 1280-kg car pulls a 350-kg trailer. The car exerts a horizontal force of 3.6×10^3 N against the ground in order to accelerate. What force does the car exert on the trailer? Assume an effective friction coefficient of 0.15 for the trailer.

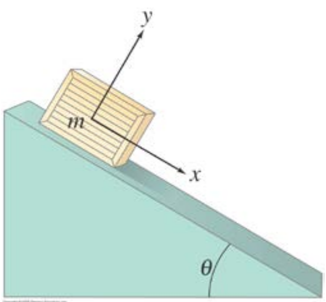
14. (II) Police investigators, examining the scene of an accident involving two cars, measure 72-m-long skid marks of one of the cars, which nearly came to a stop before colliding. The coefficient of kinetic friction between rubber and the pavement is about 0.80. Estimate the initial speed of that car assuming a level road.

15. (II) Piles of snow on slippery roofs can become dangerous projectiles as they melt. Consider a chunk of snow at the ridge of a roof with a slope of 34°. (*a*) What is the minimum value of the coefficient of static friction that will keep the snow from sliding down? (*b*) As the snow begins to melt the coefficient of static friction decreases and the snow finally slips. Assuming that the distance from the chunk to the edge of the roof is 6.0 m and the coefficient of kinetic friction is 0.20, calculate the speed of the snow chunk when it slides off the roof. (*c*) If the edge of the roof is 10.0 m above ground, estimate the speed of the snow when it hits the ground.

16. (II) A small box is held in place against a rough vertical wall by someone pushing on it with a force directed upward at 28° above the horizontal. The coefficients of static and kinetic friction between the box and wall are 0.40 and 0.30, respectively. The box slides down unless the applied force has magnitude 23 N. What is the mass of the box?

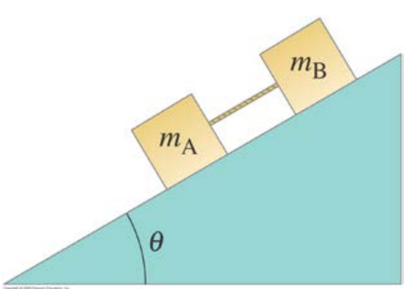
17. (II) Two crates, of mass 65 kg and 125 kg, are in contact and at rest on a horizontal surface (Fig. 5–32). A 650-N force is exerted on the 65-kg crate. If the coefficient of kinetic friction is 0.18, calculate (*a*) the acceleration of the system, and (*b*) the force that each crate exerts on the other. (*c*) Repeat with the crates reversed.

18. (II) The crate shown in Fig. 5–33 lies on a plane tilted at an angle $u = 25.08$ to the horizontal, with $m_k = 0.19$. (*a*) Determine the acceleration of the crate as it slides down the plane. (*b*) If the crate starts from rest 8.15 m up the plane from its base, what will be the crate's speed when it reaches the bottom of the incline?



19. (II) A crate is given an initial speed of 3.0 m / s up the 25.0° plane shown in Fig. 5–33. (*a*) How far up the plane will it go? (*b*) How much time elapses before it returns to its starting point? Assume $m_k = 0.17$.

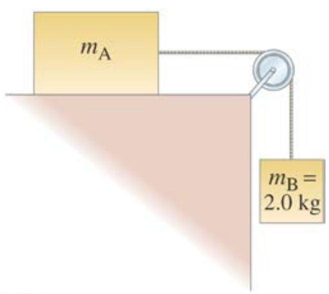
20. (II) Two blocks made of different materials connected together by a thin cord, slide down a plane ramp inclined at an angle u to the horizontal as shown in Fig. 5–34 (block B is above block A). The masses of the blocks are m_A and m_B, and the coefficients of friction are m_A and m_B. If $m_A = m_B = 5.0$ kg, and $m_A = 0.20$ and $m_B = 0.30$, determine (*a*) the acceleration of the blocks and (*b*) the tension in the cord, for an angle $u = 328$



21. (II) For two blocks, connected by a cord and sliding down the incline shown in Fig. 5–34 (see Problem 20), describe the motion (a) if $\mu_A < \mu_B$, and (b) if $\mu_A > \mu_B$. (c) Determine a formula for the acceleration of each block and the tension F_T in the cord in terms of m_A, m_B, and θ; interpret your results in light of your answers to (a) and (b).

22. (II) A flatbed truck is carrying a heavy crate. The coefficient of static friction between the crate and the bed of the truck is 0.75. What is the maximum rate at which the driver can decelerate and still avoid having the crate slide against the cab of the truck?

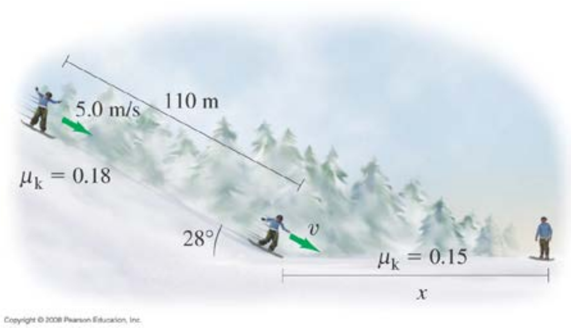
23. (II) In Fig. 5–35 the coefficient of static friction between mass m_A and the table is 0.40, whereas the coefficient of kinetic friction is 0.30 (a) What minimum value of m_A will keep the system from starting to move? (b) What value(s) of m_A will keep the system moving at constant speed?



24. (II) Determine a formula for the acceleration of the system shown in Fig. 5–35 in terms of m_A, m_B, and the mass of the cord, m_C. Define any other variables needed.

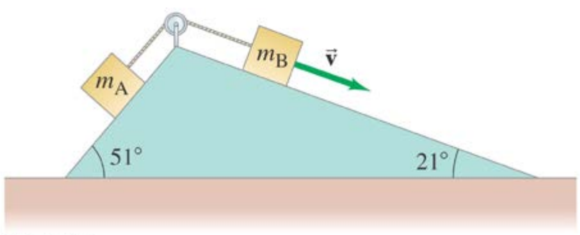
25. (II) A small block of mass m is given an initial speed v_0 up a ramp inclined at angle θ to the horizontal. It travels a distance d up the ramp and comes to rest. (a) Determine a formula for the coefficient of kinetic friction between block and ramp. (b) What can you say about the value of the coefficient of static friction?

26. (II) A 75-kg snowboarder has an initial velocity of 5.0 m / s at the top of a 28° incline (Fig. 5–36). After sliding down the 110-m long incline (on which the coefficient of kinetic - friction is $\mu_k = 0.18$), the snowboarder has attained a velocity v. The snowboarder then slides along a flat surface (on which $\mu_k = 0.15$) and comes to rest after a distance x. Use Newton's second law to find the snowboarder's acceleration while on the incline and while on the flat surface. Then use these accelerations to determine x.



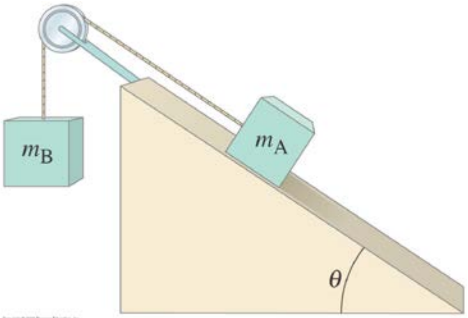
27. (II) A package of mass *m* is dropped vertically onto a horizontal conveyor belt whose speed is $v = 1.5\ \mathrm{m/s}$, and the coefficient of kinetic friction between the package and the belt is $\mu_k = 0.70$. (*a*) For how much time does the package slide on the belt (until it is at rest relative to the belt)? (*b*) How far does the package move during this time?

28. (II) Two masses $m_A = 2.0\ \mathrm{kg}$ and $m_B = 5.0\ \mathrm{kg}$ are on inclines and are connected together by a string as shown in Fig. 5–37. The coefficient of kinetic friction between each mass and its incline is $\mu_k = 0.30$. If m_A moves up, and m_B moves down, determine their acceleration.

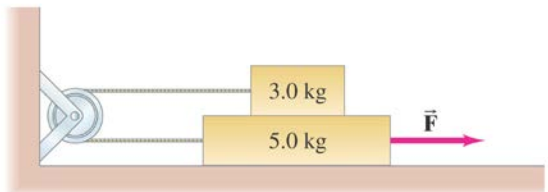


29. (II) A child slides down a slide with a 34° incline, and at the bottom her speed is precisely half what it would have been if the slide had been frictionless. Calculate the coefficient of kinetic friction between the slide and the child.

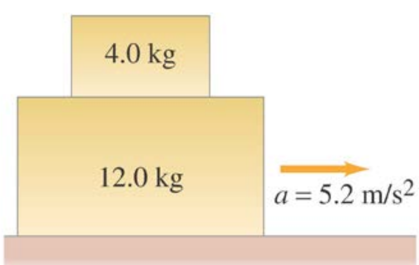
30. (II) (*a*) Suppose the coefficient of kinetic friction between m_A and the plane in Fig. 5–38 is $\mu_k = 0.15$, and that $m_A = m_B = 2.7\ \mathrm{kg}$. As m_B moves down, determine the magnitude of the acceleration of m_A and m_B, given $\theta = 34^\circ$ (*b*) What smallest value of μ_k will keep the system from accelerating?



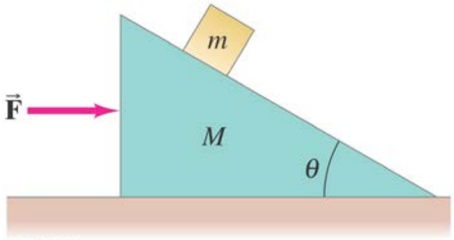
31. (III) A 3.0-kg block sits on top of a 5.0-kg block which is on a horizontal surface. The 5.0-kg block is pulled to the right with a force $\vec{\mathbf{F}}$ as shown in Fig. 5–39. The coefficient of static friction between all surfaces is 0.60 and the kinetic coefficient is 0.40. (*a*) What is the minimum value of *F* needed to move the two blocks? (*b*) If the force is 10% greater than your answer for (*a*), what is the acceleration of each block?



32. (III) A 4.0-kg block is stacked on top of a 12.0-kg block, which is accelerating along a horizontal table at $a = 5.2\ \text{m/s}^2$ (Fig. 5–40). Let $\mu_k = \mu_s = \mu$. (*a*) What minimum coefficient of friction μ between the two blocks will prevent the 4.0-kg block from sliding off? (*b*) If μ is only half this minimum value, what is the acceleration of the 4.0-kg block with respect to the table, and (*c*) with respect to the 12.0-kg block? (*d*) What is the force that must be applied to the 12.0-kg block in (*a*) and in (*b*), assuming that the table is frictionless?



33. (III) A small block of mass *m* rests on the rough, sloping side of a triangular block of mass *M* which itself rests on a horizontal frictionless table as shown in Fig. 5–41. If the coefficient of static friction is μ, determine the minimum horizontal force *F* applied to *M* that will cause the small block *m* to start moving up the incline.



5–2 to 5–4 Uniform Circular Motion

34. (I) What is the maximum speed with which a 1200-kg car can round a turn of radius 80.0 m on a flat road if the coefficient of friction between tires and road is 0.65? Is this result independent of the mass of the car?

35. (I) A child sitting 1.20 m from the center of a merry-go-around moves with a speed of 1.30 m / s. Calculate (*a*) the centripetal acceleration of the child and (*b*) the net horizontal force exerted on the child $(\text{mass} = 22.5\text{ kg})$.

36. (I) A jet plane traveling 1890 km / h (525 m / s) pulls out of a dive by moving in an arc of radius 4.80 km. What is the plane's acceleration in *g*'s?

37. (II) Is it possible to whirl a bucket of water fast enough in a vertical circle so that the water won't fall out? If so, what is the minimum speed? Define all quantities needed.

38. (II) How fast (in rpm) must a centrifuge rotate if a particle 8.00 cm from the axis of rotation is to experience an acceleration of 125,000 *g*'s?

39. (II) Highway curves are marked with a suggested speed. If this speed is based on what would be safe in wet weather, estimate the radius of curvature for a curve marked 50 km / h. Use Table 5–1.

40. (II) At what minimum speed must a roller coaster be traveling when upside down at the top of a circle (Fig. 5–42) so that the passengers do not fall out? Assume a radius of curvature of 7.6 m.

41. (II) A sports car crosses the bottom of a valley with a radius of curvature equal to 95 m. At the very bottom, the normal force on the driver is twice his weight. At what speed was the car traveling?

42. (II) How large must the coefficient of static friction be between the tires and the road if a car is to round a level curve of radius 85 m at a speed of 95 km / h?

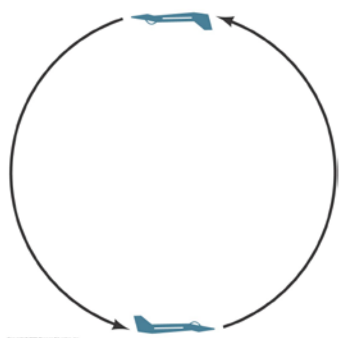
43. (II) Suppose the space shuttle is in orbit 400 km from the Earth's surface, and circles the Earth about once every 90 min. Find the centripetal acceleration of the space shuttle in its orbit. Express your answer in terms of *g*, the gravitational acceleration at the Earth's surface.

44. (II) A bucket of mass 2.00 kg is whirled in a vertical circle of radius 1.10 m. At the lowest point of its motion the tension in the rope supporting the bucket is 25.0 N. (*a*) Find the speed of the bucket. (*b*) How fast must the bucket move at the top of the circle so that the rope does not go slack?

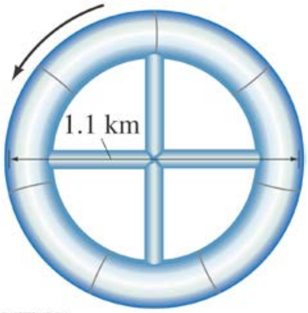
45. (II) How many revolutions per minute would a 22-m-diameter Ferris wheel need to make for the passengers to feel "weightless" at the topmost point?

46. (II) Use dimensional analysis (Section 1 – 7) to obtain the form for the centripetal acceleration, $a_{R} = v^2/r$.

47. (II) A jet pilot takes his aircraft in a vertical loop (Fig. 5–43). (*a*) If the jet is moving at a speed of 1200 km / h at the lowest point of the loop, determine the minimum radius of the circle so that the centripetal acceleration at the lowest point does not exceed 6.0 *g*'s. (*b*) Calculate the 78-kg pilot's effective weight (the force with which the seat pushes up on him) at the bottom of the circle, and (*c*) at the top of the circle (assume the same speed).



48. (II) A proposed space station consists of a circular tube that will rotate about its center (like a tubular bicycle tire), Fig. 5–44. The circle formed by the tube has a diameter of about 1.1 km. What must be the rotation speed (revolutions per day) if an effect equal to gravity at the surface of the Earth (1.0 *g*) is to be felt?



49. (II) On an ice rink two skaters of equal mass grab hands and spin in a mutual circle once every 2.5 s. If we assume their arms are each 0.80 m long and their individual masses are 60.0 kg, how hard are they pulling on one another?

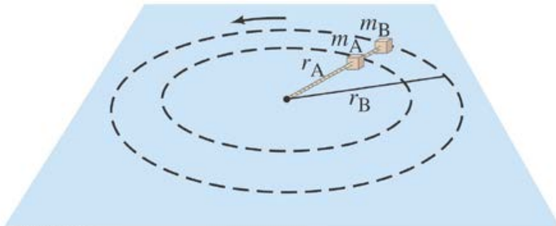
50. (II) Redo Example 5 – 11, precisely this time, by not ignoring the weight of the ball which revolves on a string 0.600 m long. In particular, find the magnitude of $\vec{\mathbf{F}}_{\mathrm{T}}$, and the angle it makes with the horizontal. [*Hint*: Set the horizontal component of $\vec{\mathbf{F}}_{\mathrm{T}}$ equal to ma_{R}; also, since there is no vertical motion, what can you say about the vertical component of $\vec{\mathbf{F}}_{\mathrm{T}}$?]

51. (II) A coin is placed 12.0 cm from the axis of a rotating turntable of variable speed. When the speed of the turntable is slowly increased, the coin remains fixed on the turntable until a rate of 35.0 rpm (revolutions per minute) is reached, at which point the coin slides off. What is the coefficient of static friction between the coin and the turntable?

52. (II) The design of a new road includes a straight stretch that is horizontal and flat but that suddenly dips down a steep hill at 22°. The transition should be rounded with what minimum radius so that cars traveling 95 km / h will not leave the road (Fig. 5–45)?

53. (II) A 975-kg sports car (including driver) crosses the rounded top of a hill $(\text{radius} = 88.0\ \text{m})$ at 12.0 m / s. Determine (*a*) the normal force exerted by the road on the car, (*b*) the normal force exerted by the car on the 72.0-kg driver, and (*c*) the car speed at which the normal force on the driver equals zero.

54. (II) Two blocks, with masses m_A and m_B, are connected to each other and to a central post by cords as shown in Fig. 5–46. They rotate about the post at frequency f (revolutions per second) on a frictionless horizontal surface at distances r_A and r_B from the post. Derive an algebraic expression for the tension in each segment of the cord (assumed massless).



55. (II) Tarzan plans to cross a gorge by swinging in an arc from a hanging vine (Fig. 5–47). If his arms are capable of exerting a force of 1350 N on the rope, what is the maximum speed he can tolerate at the lowest point of his swing? His mass is 78 kg and the vine is 5.2 m long.

56. (II) A pilot performs an evasive maneuver by diving vertically at 310 m / s. If he can withstand an acceleration of 9.0 *g*'s without blacking out, at what altitude must he begin to pull out of the dive to avoid crashing into the sea?

57. (III) The position of a particle moving in the *xy* plane is given by $\vec{\mathbf{r}} = 2.0\cos(3.0\text{ rad/s } t)\,\hat{\mathbf{i}} + 2.0\sin(3.0\text{ rad/s t})\,\hat{\mathbf{j}}$, where *r* is in meters and *t* is in seconds. (*a*) Show that this represents circular motion of radius 2.0 m centered at the origin. (*b*) Determine the velocity and acceleration vectors as functions of time. (*c*) Determine the speed and magnitude of the acceleration. (*d*) Show that $a = v^2/r$. (*e*) Show that the acceleration vector always points toward the center of the circle.

58. (III) If a curve with a radius of 85 m is properly banked for a car traveling 65 km / h, what must be the coefficient of static friction for a car not to skid when traveling at 95 km / h?

59. (III) A curve of radius 68 m is banked for a design speed of 85 km / h. If the coefficient of static friction is 0.30 (wet pavement), at what range of speeds can a car safely make the curve? [*Hint*: Consider the direction of the friction force when the car goes too slow or too fast.]

***5–5 Nonuniform Circular Motion**

***60.** (II) A particle starting from rest revolves with uniformly increasing speed in a clockwise circle in the *xy* plane. The center of the circle is at the origin of an *xy* coordinate system. At $\mathbf{t} = 0$**,** the particle is at $x = 0.0$, $y = 2.0\ \text{m}$. At $t = 2.0\ \text{s}$, it has made one-quarter of a revolution and is at $x = 2.0\ \text{m}$, $y = 0.0$. Determine (*a*) its speed at $t = 2.0\ \text{s}$, (*b*) the average velocity vector, and (*c*) the average acceleration vector during this interval.

***61.** (II) In Problem 60 assume the tangential acceleration is constant and determine the components of the instantaneous acceleration at (*a*) $t = 0.0$, (*b*) $t = 1.0\ \text{s}$, and (*c*) $t = 2.0\ \text{s}$.

***62.** (II) An object moves in a circle of radius 22 m with its speed given by $\mathrm{y} = 3.6 + 1.5t^2$, with y in meters per second and t in seconds. At $t = 3.0\ \text{s}$, find (*a*) the tangential acceleration and (*b*) the radial acceleration.

***63.** (III) A particle rotates in a circle of radius 3.80 m. At a particular instant its acceleration is $1.15\ \text{m/s}^2$ in a direction that makes an angle of 38.0° to its direction of motion. Determine its speed (*a*) at this moment and (*b*) 2.00 s later, assuming constant tangential acceleration.

***64.** (III) An object of mass *m* is constrained to move in a circle of radius *r*. Its tangential acceleration as a function of time is given by $a_{\tan} = b + ct^2$, where *b* and *c* are constants. If $\mathrm{y} = \mathrm{y}_0$ at $t = 0$, determine the tangential and radial components of the force, $F_{\tan}$ and F_{R}, acting on the object at any time $t > 0$.

***5 – 6 Velocity-Dependent Forces**

***65.** (I) Use dimensional analysis (Section 1–7) in Example 5–17 to determine if the time constant t is $\mathrm{t} = m/b$ or $\mathrm{t} = b/m$.

***66.** (II) The terminal velocity of a $3 3\ 10^{2\,5}$ kg raindrop is about 9 m / s. Assuming a drag force $F_{\mathrm{D}} = 2\,bv$, determine (*a*) the value of the constant *b* and (*b*) the time required for such a drop, starting from rest, to reach 63% of terminal velocity.

*__67.__ (II) An object moving vertically has $\vec{\mathbf{y}} = \vec{\mathbf{y}}_0$ at $t = 0$. Determine a formula for its velocity as a function of time assuming a resistive force $F = 2\,b\mathrm{y}$ as well as gravity for two cases: (*a*) $\vec{\mathbf{y}}_0$ is downward and (*b*) $\vec{\mathbf{y}}_0$ is upward.

*__68.__ (III) The drag force on large objects such as cars, planes, and sky divers moving through air is more nearly $F_{\mathrm{D}} = 2\,b\mathrm{y}^2$. (*a*) For this quadratic dependence on y, determine a formula for the terminal velocity y_{T}, of a vertically falling object. (*b*) A 75-kg sky diver has a terminal velocity of about 60 m / s; determine the value of the constant *b*. (*c*) Sketch a curve like that of Fig. 5–27b for this case of $F_{\mathrm{D}} \sim \mathrm{y}^2$. For the same terminal velocity, would this curve lie above or below that in Fig. 5–27? Explain why.

*__69.__ (III) A bicyclist can coast down a 7.0° hill at a steady 9.5 km / h. If the drag force is proportional to the square of the speed y, so that $F_{\mathrm{D}} = 2\,c\mathrm{y}^2$, calculate (*a*) the value of the constant *c* and (*b*) the average force that must be applied in order to descend the hill at 25 km / h. The mass of the cyclist plus bicycle is 80.0 kg. Ignore other types of friction.

*__70.__ (III) Two drag forces act on a bicycle and rider: $F_{\mathrm{D}1}$ due to rolling resistance, which is essentially velocity independent; and $F_{\mathrm{D}2}$ due to air resistance, which is proportional to y^2. For a specific bike plus rider of total mass 78 kg, $F_{\mathrm{D}1} < 4.0\ \mathrm{N}$; and for a speed of 2.2 m / s, $F_{\mathrm{D}2} < 1.0\ \mathrm{N}$. (*a*) Show that the total drag force is

$$F_{\mathrm{D}} = 4.0 + 0.21\mathrm{y}^2,$$

where y is in m / s, and F_{D} is in N and opposes the motion. (*b*) Determine at what slope angle u the bike and rider can coast downhill at a constant speed of 8.0 m / s.

*__71.__ (III) Determine a formula for the position and acceleration of a falling object as a function of time if the object starts from rest at $t = 0$ and undergoes a resistive force $F = 2\,b\mathrm{y}$, as in Example 5–17.

*__72.__ (III) A block of mass *m* slides along a horizontal surface lubricated with a thick oil which provides a drag force proportional to the square root of velocity:

$$F_{\mathrm{D}} = 2\,b\mathrm{y}^{\frac{1}{2}}.$$

If $\mathrm{y} = \mathrm{y}_0$ at $t = 0$, determine y and *x* as functions of time.

*__73.__ (III) Show that the maximum distance the block in Problem 72 can travel is $2m\,\mathrm{y}_0^{3/2}/3b$.

***74.** (III) You dive straight down into a pool of water. You hit the water with a speed of 5.0 m / s, and your mass is 75 kg. Assuming a drag force of the form $F_D = 2\left(1.00\,3\ 10^4\ \text{kg/s}\right) y$, how long does it take you to reach 2% of your original speed? (Ignore any effects of buoyancy.)

***75.** (III) A motorboat traveling at a speed of 2.4 m / s shuts off its engines at $t = 0$. How far does it travel before coming to rest if it is noted that after 3.0 s its speed has dropped to half its original value? Assume that the drag force of the water is proportional to y.

General Problems

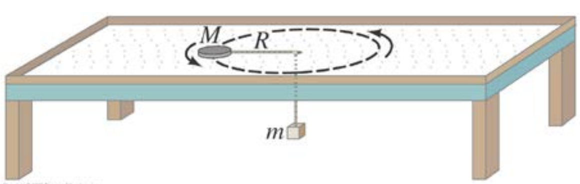
76. A coffee cup on the horizontal dashboard of a car slides forward when the driver decelerates from 45 km / h to rest in 3.5 s or less, but not if she decelerates in a longer time. What is the coefficient of static friction between the cup and the dash? Assume the road and the dashboard are level (horizontal).

77. A 2.0-kg silverware drawer does not slide readily. The owner gradually pulls with more and more force, and when the applied force reaches 9.0 N, the drawer suddenly opens, throwing all the utensils to the floor. What is the coefficient of static friction between the drawer and the cabinet?

78. A roller coaster reaches the top of the steepest hill with a speed of 6.0 km / h. It then descends the hill, which is at an average angle of 45° and is 45.0 m long. What will its speed be when it reaches the bottom? Assume $m_k = 0.12$.

79. An 18.0-kg box is released on a 37.0° incline and accelerates down the incline at $0.220\ \text{m/s}^2$. Find the friction force impeding its motion. How large is the coefficient of friction?

80. A flat puck (mass *M*) is revolved in a circle on a frictionless air hockey table top, and is held in this orbit by a light cord which is connected to a dangling mass (mass *m*) through a central hole as shown in Fig. 5–48. Show that the speed of the puck is given by $y = \sqrt{mgR/M}$.



81. A motorcyclist is coasting with the engine off at a steady speed of 20.0 m / s but enters a sandy stretch where the coefficient of kinetic friction is 0.70. Will the cyclist emerge from the sandy stretch without having to start the engine if the sand lasts for 15 m? If so, what will be the speed upon emerging?

82. In a "Rotor-ride" at a carnival, people rotate in a vertical cylindrically walled "room." (See Fig. 5–49). If the room radius was 5.5 m, and the rotation frequency 0.50 revolutions per second when the floor drops out, what minimum coefficient of static friction keeps the people from slipping down? People on this ride said they were "pressed against the wall." Is there really an outward force pressing them against the wall? If so, what is its source? If not, what is the proper description of their situation (besides nausea)? [*Hint:* Draw a free-body diagram for a person.]

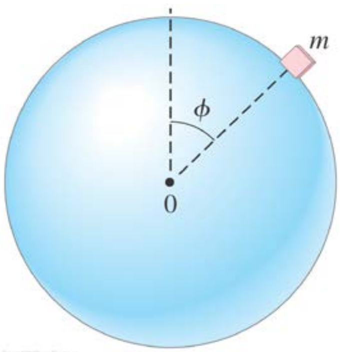
83. A device for training astronauts and jet fighter pilots is designed to rotate the trainee in a horizontal circle of radius 11.0 m. If the force felt by the trainee is 7.45 times her own weight, how fast is she rotating? Express your answer in both m / s and rev / s.

84. A 1250-kg car rounds a curve of radius 72 m banked at an angle of 14°. If the car is traveling at 85 km / h, will a friction force be required? If so, how much and in what direction?

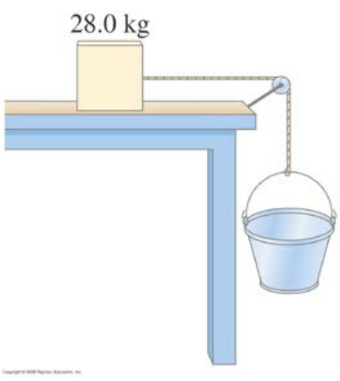
85. Determine the tangential and centripetal components of the net force exerted on a car (by the ground) when its speed is 27 m / s, and it has accelerated to this speed from rest in 9.0 s on a curve of radius 450 m. The car's mass is 1150 kg.

86. The 70.0-kg climber in Fig. 5–50 is supported in the "chimney" by the friction forces exerted on his shoes and back. The static coefficients of friction between his shoes and the wall, and between his back and the wall, are 0.80 and 0.60, respectively. What is the minimum normal force he must exert? Assume the walls are vertical and that the static friction forces are both at their maximum. Ignore his grip on the rope.

87. A small mass *m* is set on the surface of a sphere, Fig. 5–51. If the coefficient of static friction is $\mu_s = 0.70$, at what angle ϕ would the mass start sliding?



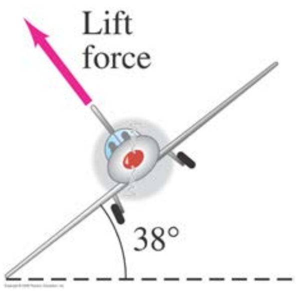
88. A 28.0-kg block is connected to an empty 2.00-kg bucket by a cord running over a frictionless pulley (Fig. 5–52). The coefficient of static friction between the table and the block is 0.45 and the coefficient of kinetic friction between the table and the block is 0.32. Sand is gradually added to the bucket until the system just begins to move. (*a*) Calculate the mass of sand added to the bucket. (*b*) Calculate the acceleration of the system.



89. A car is heading down a slippery road at a speed of 95 km / h. The minimum distance within which it can stop without skidding is 66 m. What is the sharpest curve the car can negotiate on the icy surface at the same speed without skidding?

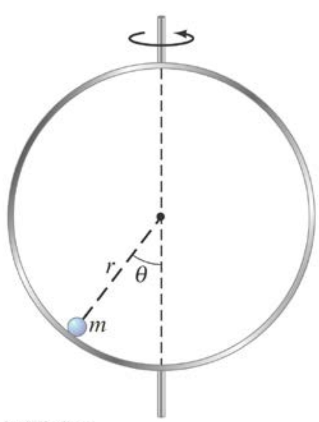
90. What is the acceleration experienced by the tip of the 1.5-cm-long sweep second hand on your wrist watch?

91. An airplane traveling at 480 km / h needs to reverse its course. The pilot decides to accomplish this by banking the wings at an angle of 38°. (*a*) Find the time needed to reverse course. (*b*) Describe any additional force the passengers experience during the turn. [*Hint:* Assume an aerodynamic "lift" force that acts perpendicularly to the flat wings; see Fig. 5–53.]



92. A banked curve of radius *R* in a new highway is designed so that a car traveling at speed y_0 can negotiate the turn safely on glare ice (zero friction). If a car travels too slowly, then it will slip toward the center of the circle. If it travels too fast, it will slip away from the center of the circle. If the coefficient of static friction increases, it becomes possible for a car to stay on the road while traveling at a speed within a range from y_{min} to y_{max}. Derive formulas for y_{min} and y_{max} as functions of m_s, y_0, and *R*.

93. A small bead of mass *m* is constrained to slide without friction inside a circular vertical hoop of radius *r* which rotates about a vertical axis (Fig. 5–54) at a frequency *f*. (*a*) Determine the angle u where the bead will be in equilibrium—that is, where it will have no tendency to move up or down along the hoop. (*b*) If $f = 2.00$ rev/s and $r = 22.0$ cm, what is u? (*c*) Can the bead ride as high as the center of the circle $(u = 908)$? Explain.



94. *Earth is not quite an inertial frame*. We often make measurements in a reference frame fixed on the Earth, assuming Earth is an inertial reference frame. But the Earth rotates, so this assumption is not quite valid. Show that this assumption is off by 3 parts in 1000 by calculating the acceleration of an object at Earth's equator due to Earth's daily rotation, and compare to $g = 9.80\ \mathrm{m/s^2}$, the acceleration due to gravity.

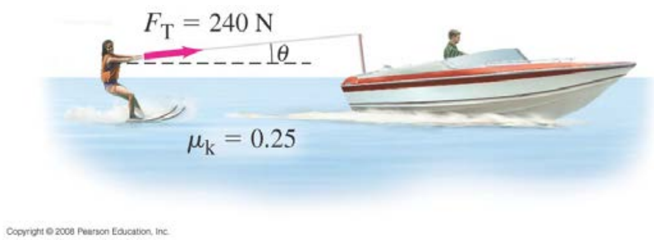
95. While fishing, you get bored and start to swing a sinker weight around in a circle below you on a 0.45-m piece of fishing line. The weight makes a complete circle every 0.50 s. What is the angle that the fishing line makes with the vertical? [*Hint*: See Fig. 5–20.]

96. Consider a train that rounds a curve with a radius of 570 m at a speed of 160 km / h (approximately 100 mi / h). (*a*) Calculate the friction force needed on a train passenger of mass 75 kg if the track is not banked and the train does not tilt. (*b*) Calculate the friction force on the passenger if the train tilts at an angle of 8.0° toward the center of the curve.

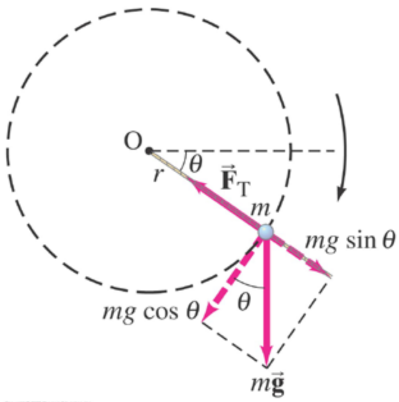
97. A car starts rolling down a 1-in-4 hill (1-in-4 means that for each 4 m traveled along the road, the elevation change is 1 m). How fast is it going when it reaches the bottom after traveling 55 m? (*a*) Ignore friction. (*b*) Assume an effective coefficient of friction equal to 0.10.

98. The sides of a cone make an angle ϕ with the vertical. A small mass *m* is placed on the inside of the cone and the cone, with its point down, is revolved at a frequency *f* (revolutions per second) about its symmetry axis. If the coefficient of static friction is μ_s, at what positions on the cone can the mass be placed without sliding on the cone? (Give the maximum and minimum distances, *r*, from the axis).

99. A 72-kg water skier is being accelerated by a ski boat on a flat ("glassy") lake. The coefficient of kinetic friction between the skier's skis and the water surface is $\mu_k = 0.25$ (Fig. 5–55). (*a*) What is the skier's acceleration if the rope pulling the skier behind the boat applies a horizontal tension force of magnitude $F_T = 240\ \mathrm{N}$ to the skier $(\theta = 0°)$? (*b*) What is the skier's horizontal acceleration if the rope pulling the skier exerts a force of $F_T = 240\ \mathrm{N}$ on the skier at an upward angle $\theta = 12°$? (*c*) Explain why the skier's acceleration in part (*b*) is greater than that in part (*a*).



100. A ball of mass $m = 1.0$ kg at the end of a thin cord of length $r = 0.80$ m revolves in a vertical circle about point O, as shown in Fig. 5–56. During the time we observe it, the only forces acting on the ball are gravity and the tension in the cord. The motion is circular but not uniform because of the force of gravity. The ball increases in speed as it descends and decelerates as it rises on the other side of the circle. At the moment the cord makes an angle $u = 308$ below the horizontal, the ball's speed is 6.0 m / s. At this point, determine the tangential acceleration, the radial acceleration, and the tension in the cord, F_T. Take u increasing downward as shown.



101. A car drives at a constant speed around a banked circular track with a diameter of 127 m. The motion of the car can be described in a coordinate system with its origin at the center of the circle. At a particular instant the car's acceleration in the horizontal plane is given by

$$\vec{\mathbf{a}} = \left(2\ 15.7\hat{\mathbf{i}} - 23.2\hat{\mathbf{j}}\right)\ \text{m/s}^2.$$

(*a*) What is the car's speed? (*b*) Where (*x* and *y*) is the car at this instant?

***Numerical/Computer**

***102.**(III) The force of air resistance (drag force) on a rapidly falling body such as a skydiver has the form $F_D = 2\ kv^2$, so that Newton's second law applied to such an object is

$$m\ \frac{dy}{dt} = mg - kv^2,$$

where the downward direction is taken to be positive. (*a*) Use numerical integration [Section 2 – 9] to estimate (within 2%) the position, speed, and acceleraton, from $t = 0$ up to $t = 15.0\text{ s},$ for a 75-kg skydiver who starts from rest, assuming $k = 0.22\text{ kg/m}.$ (*b*) Show that the diver eventually reaches a steady speed, the *terminal speed*, and explain why this happens. (*c*) How long does it take for the skydiver to reach 99.5% of the terminal speed?

***103.**(III) The coefficient of kinetic friction m_k between two surfaces is not strictly independent of the velocity of the object. A possible expression for m_k for wood on wood is

$$m_k = \frac{0.20}{\left(1 + 0.0020y^2\right)^2},$$

where y is in m/s. A wooden block of mass 8.0 kg is at rest on a wooden floor, and a constant horizontal force of 41 N acts on the block. Use numerical integration [Section 2 – 9] to determine and graph (*a*) the speed of the block, and (*b*) its position, as a function of time from 0 to 5.0 s. (*c*) Determine the percent difference for the speed and position at 5.0 s if m_k is constant and equal to 0.20.

***104.**(III) Assume a net force $F = 2\, mg - kv^2$ acts during the upward vertical motion of a 250-kg rocket, starting at the moment $(t = 0)$ when the fuel has burned out and the rocket has an upward speed of 120 m / s. Let $k = 0.65\text{ kg/m}.$ Estimate y and y at 1.0-s intervals for the upward motion only, and estimate the maximum height reached. Compare to free-flight conditions without air resistance $(k = 0).$