1. A box of mass 40.0 kg is pushed across a rough flat floor at the constant speed of 1.50 m/s. When the force is removed, the box slides a further distance of 1.20 m before coming to rest. Calculate the frictional force acting on the box when it slides. (Ans: 37.5 N)

2. A box with a weight of 50 N rests on a horizontal surface with \( \mu_s = 0.40 \). A person pulls horizontally on it with a force of \( F_2 = 10 \) N and it does not move. To start it moving, a second person pulls vertically upward on the box with a force \( F_1 \) (see figure 1). What is the smallest vertical force \( (F_1) \) for which the box starts moving? (Ans: 25 N)

3. An 8.0-kg block is pushed against a vertical wall by a horizontal force \( F \), as shown in figure 2. If the coefficients of friction between the block and the wall are \( \mu_s = 0.60 \) and \( \mu_k = 0.30 \) then what is the minimum value for \( (F) \) that will prevent the block from slipping? (Ans: 130 N)

4. A 5.0-kg block is at rest on a rough horizontal surface. The coefficient of static friction between the block and the surface is 0.40. If a horizontal force of 15 N is acted on the block, what would be the magnitude of the frictional force? (Ans: 15 N)

5. A 5.0-kg block is sliding on a rough horizontal plane \( (\mu_k = 0.10) \) under the effect of a horizontal force \( F \). Figure 3 shows the velocity of the block as a function of time. Calculate \( F \). (Ans: 15 N)

6. In figure 4, a boy is dragging a box (mass = 8.0 kg) attached to a string. The box is moving horizontally with an acceleration of \( a = 2.0 \) m/s\(^2\). If the frictional force is 12 N, calculate the applied force \( F \) at an angle \( \theta = 60^\circ \). (Ans: 56 N)

7. A 400-N block is pushed along a rough horizontal surface \( (\mu_k = 0.25) \) by an applied force \( F \), as shown in figure 5. The block moves at constant velocity. What is the magnitude of \( F \)? (Ans: 101 N)

8. A 25-kg box is pushed across a rough horizontal floor with a 200-N force, directed at 20\(^\circ\) below the horizontal (see figure 6). The coefficient of kinetic friction between the box and the floor is 0.2. What is the acceleration of the box? (Ans: 5.0 m/s\(^2\))

9. Block A, with mass \( m_A \), is initially at rest on a frictionless horizontal floor. Block B, with mass \( m_B \), is initially at rest on the top surface of A (see figure 7). The coefficient of static friction between the two blocks is \( (\mu) \). Block A is pulled with a force \( F \). For what value of the acceleration will block A start to slide out from under block B? (Ans: \( \mu g \))
10. Two masses $M$ and $3M$ are connected by a light cord, as shown in figure 8. The coefficient of kinetic friction between the surface and the $3M$ block is 0.20, and the coefficient of kinetic friction between the surface and the $M$ block is 0.30. If $F = 14 \text{ N}$, and $M = 1.0 \text{ kg}$, what is the magnitude of the acceleration of either block? (Ans: $1.3 \text{ m/s}^2$)

11. A block ($m_1 = 3.0 \text{ kg}$) on a rough horizontal plane is connected to a second block ($m_2 = 5.0 \text{ kg}$) by a cord over a massless pulley. Calculate the coefficient of kinetic friction between the block $m_1$ and the table if the acceleration of the descending block $m_2$ is $4.3 \text{ m/s}^2$. (see figure 9) (Ans: 0.50)

12. A 5.0-kg block is moving with constant velocity down a rough inclined plane. The coefficients of static and kinetic friction between the block and the incline are 0.25 and 0.20, respectively. What is the incline angle of the incline plane? (Ans: $11^\circ$)

13. A 10.0-kg box is pushed up an incline ($\theta = 30.0^\circ$) by a horizontal force of 298 N. The box moves at a constant velocity, as shown in figure 10. What is the frictional force on the box? (Ans: 209 N)

14. A box of mass $M$ is placed on a $30^\circ$ inclined plane. The box is sliding with an acceleration that is equal to $g/2$. What is the magnitude of the force of friction between the box and the plane? (Ans: zero)

15. A 2.0-kg block is released from rest at the top of a ramp (point A), as shown in figure 11. The coefficient of kinetic friction between the block and the ramp is 0.20. What is the speed of the block at the bottom (point B)? (Ans: 6.6 m/s)

16. A block rests on a rough incline and has coefficients of friction $\mu_k = 0.20$ and $\mu_s = 0.30$. If the incline angle increases, at what angle does the block start moving? (Ans: $16.7^\circ$)

17. A car rounds a flat curved road ($r = 92 \text{ m}$) at a speed of 26 m/s and is on the verge of sliding at this speed. What is the coefficient of static friction between the tires of the car and the road? (Ans: 0.75)

18. A car is rounding a flat curve of radius $R = 220 \text{ m}$ with speed $v = 94 \text{ km/h}$. What is the magnitude of the force exerted by the seat on the passenger whose mass $m$ is 85 kg? (Ans: 263 N)

19. On a rainy day, the coefficient of friction between the tires of a car and a level circular track is reduced to half its usual value. What is the ratio of the maximum safe speed on a rainy day for rounding the circular track to its usual value (when it is not raining)? (Ans: 0.71)

20. At what angle should a circular roadway of 50-m radius, be banked to allow cars to round the curve without slipping at 12 m/s? (Ignore friction) (Ans: 16°)

21. A 0.20-kg stone is attached to a string and whirled in a circle of radius $r = 0.60 \text{ m}$ on a horizontal frictionless surface, as shown in figure 12. If the stone makes 150 revolutions per minute, what is the tension in the string? (Ans: 30 N)

22. A 0.50-kg ball tied to the end of a string 100 cm in length swings in a vertical circle with a constant speed of 9.2 m/s. What is the tension in the string when the ball is at the bottom of the circle? (Ans: 47 N)

23. The iron ball shown in figure 13 is being swung in a vertical circle at the end of a 0.70-m string. What is the speed the ball can have at top of the circle for the tension in the string to be zero at that point? (Ans: 2.6 m/s)

24. A roller-coaster car has a mass of 500 kg when fully loaded with passengers. The car passes over a hill of radius 15 m (see figure 14). At the top of the hill, the car has a speed of 8 m/s. What is the force of the track on the car at the top of the hill? (Ans: 2800 N up)
25. A ball of mass 100 g is connected to a string that can withstand a maximum tension of 50 N before it breaks. The ball rotates in a circle of radius 20 cm on a horizontal frictionless plane. What is the maximum speed the ball can have before the string breaks? (Ans: 10 m/s)

26. A 2.0-kg block is initially at rest on a horizontal surface. A 15-N horizontal force and a vertical force \( P \) are applied to the block, as shown in figure 15. If the coefficient of static friction for the block and the surface is 0.60, what is the magnitude of force \( P \) that makes the block start moving? (Ans: 5.4 N)

27. A box of mass \( m \) is sliding down a rough inclined plane (which makes an angle of 30° with the horizontal, and has a coefficient of kinetic friction \( \mu_k \)) at a constant acceleration of \( g/4 \). Find \( \mu_k \). (Ans: 0.29)

28. A 500-kg car moves in a vertical roller coaster of radius 10.0 m at a constant speed of 18.0 m/s (see figure 16). What is the magnitude of the force exerted by the track on the car at the bottom of the circle? (Ans: 0.29)

29. A constant horizontal force of 36 N is acting on a block of mass 4.0 kg. Another block of mass 2.0 kg sits on the 4.0-kg block. The 4.0-kg block moves on a frictionless horizontal floor. Find the magnitude of the frictional force maintaining the 2.0-kg block in its position above the 4.0-kg block during the motion. (Ans: 12 N)

30. A block is 3.0 m up above the ground and is in contact with the inner side of a rotating cylinder of 2.0 m radius, as shown in figure 17. If the coefficient of static friction between the block and the cylinder is 0.50, what is the minimum speed the cylinder must have in order for the block not to fall down? (Ans: 6.3 m/s)

31. A 12-N horizontal force is trying to move a 40-N block initially at rest on a rough horizontal surface. The coefficients of static and kinetic friction between the block and the surface are 0.50 and 0.40, respectively. Find the frictional force on the block. (Ans: 2.0 N)

32. A car goes around a flat circular track of radius \( R \) at a constant speed of 10 m/s. The net force exerted on the car has a magnitude of 100 N. What is the magnitude of the net force exerted on the car if the speed is increased to 20 m/s? (Ans: 400 N)

33. A 2.0-kg block slides on a horizontal surface. Part of the surface is smooth and the other part is rough. A horizontal force is applied to the block. On the smooth part, the acceleration of the block is 3.0 m/s², while it is 2.0 m/s² on the rough part. What is the magnitude of the frictional force on the rough part? (Ans: 2.0 N)

34. A particle of mass \( m = 2.0 \) kg is attached to a string and swings in a vertical circle of radius \( r = 0.50 \) m, as shown in figure 18. What is the tension \( (T) \) in the string at the moment the string makes an angle of 60° with the vertical and has a speed of 3.0 m/s? (Ans: 46 N)

35. Figure 19 shows two forces, 12.0 N and 15.0 N, acting on a block of mass \( m = 2.00 \) kg. The block slides along a rough horizontal table with coefficient of kinetic friction \( \mu \) between the block and the table equal to 0.200. Find the acceleration \( a \) of the block (Ans: 2.54 m/s²)

36. A car goes over the top of a hill the cross section of which can be approximated to a circle of radius \( R = 255 \) m, as shown in figure 20. What is the maximum speed the car can have at the top of the hill without leaving the road? (Ans: 50 m/s)

37. An 80-kg passenger in a car presses against the car door with a 200N force when the car makes a turn at 20 m/s on the circular horizontal part of the road. Find the radius of the circular part of the road. (Ans: 160 m)

38. Consider a ball of mass 0.04 kg attached to a string of negligible mass and length \( L \) moving in a horizontal circle of radius 0.20 m at constant speed, as shown in figure 21. Find the speed of the ball. (Ans: 1.1 m/s)
39. A pilot of mass 75.0 kg in a jet aircraft executes a loop-the-loop, as shown in figure 22. In this maneuver, the aircraft moves in a vertical circle of radius \( R = 3.00 \) km at a constant speed of 250 m/s. Determine the magnitude of the force exerted by the seat on the pilot at the bottom of the loop. (Ans: \( 2.30 \times 10^3 \) N)

40. A block of mass 3.0 kg is pushed against a rough wall (coefficient of kinetic friction is 0.20) by a force \( P = 30 \) N that makes an angle of 50° with the horizontal, as shown in figure 23. Assuming the block is sliding down, find the magnitude of its acceleration. (Ans: 0.85 m/s²)

41. As shown in figure 24, a block weighing 5.0 N is held at rest against a vertical wall by a horizontal force of magnitude 10 N. The coefficient of static friction between the wall and the block is 0.60, and the coefficient of kinetic friction is 0.40. In unit vector notation, find the force on the block from the wall. (Ans: -10 \( \hat{i} + 5.0 \hat{j} \) N)

42. A 20.0-kg block is initially at rest on a rough, horizontal surface. A horizontal force of 75.0 N is required to set the block in motion. After it is in motion, a horizontal force of 60.0 N is required to keep the block moving with constant speed. Find the coefficients of static and kinetic friction, respectively. (Ans: 0.383, 0.306)

43. Figure 25 shows two blocks with masses \( m_1 = 8.0 \) kg and \( m_2 = 4.0 \) kg, connected by a light string. The coefficient of kinetic friction between \( m_2 \) and the horizontal surface is 0.50 while the inclined plane is frictionless. Find the acceleration of the system (neglect the mass of the pulley). (Ans: 1.6 m/s²)

44. A box rests on the flatbed of a truck that is initially traveling at 15 m/s on a level road. The driver applies the brakes and the truck is brought to a stop in a distance of 38 m. If the deceleration of the truck is constant, what is the minimum coefficient of static friction between the box and the flatbed of the truck that is required to keep the box from sliding? (Ans: 0.30)

45. As shown in figure 26, a boy pulls a box of total mass \( m = 5.0 \) kg with a rope that makes an angle of 60° with the horizontal. The boy pulls on the rope with a force of 10 N; and the box moves with constant velocity. What is the coefficient of kinetic friction between the box and the surface? (Ans: 0.12)

46. A force \( F \) is applied to a block of mass 3.00 kg resting on a rough horizontal surface. The force makes an angle of 37.0° with the horizontal, as shown in figure 27. The coefficient of static friction between the block and the surface is 0.450. If the block is just about to slide, calculate the magnitude of the force \( F \). (Ans: 12.4 N)

47. Three blocks of masses \( m_1 = 1.5 \) kg, \( m_2 = 2.0 \) kg, and \( m_3 = 1.0 \) kg are pushed by a horizontal force \( F \) of magnitude 9.0 N, as shown in figure 28. The coefficient of kinetic friction between each block and the table is \( \mu_k = 0.20 \). What is the magnitude \( F_{32} \) of the force on mass \( m_3 \) from mass \( m_2 \)? (Ans: 2.0 N)

48. In figure 29, a 10.0-kg block is pushed at constant speed up an inclined plane (\( \theta = 45° \)) with a horizontal force \( F \). The coefficient of kinetic friction between block and the plane is \( \mu_k = 0.50 \). What is the magnitude of the force \( F \)? (Ans: 290 N)

49. In figure 30, blocks “A” and “B” have masses \( m_A = m_B = 25.0 \) kg. Find the magnitude of the acceleration of mass “A” if the coefficient of kinetic friction between the block “A” and the horizontal table is \( \mu_k = 0.20 \). Assume the pulley is massless and frictionless. (Ans: 3.92 m/s²)

50. In Figure 32, a man drives a car over the top of a hill, the cross section of which can be approximated by a circle of radius \( R = 250 \) m. What is the greatest speed at which he can drive without the car leaving the road at the top of the hill? (Ans: 49.5 m/s)
51. As shown in figure 34, blocks $m_1$ and $m_2$ have masses of 4.00 kg and 8.00 kg, respectively. The coefficient of kinetic friction between $m_1$ and the horizontal surface is 0.500. The incline plane ($\theta = 30^\circ$) is frictionless. Find the magnitude of the acceleration of the system. (Assume that the pulley is massless and frictionless). (Ans: 1.63 m/s²)

52. Figure 35 shows an object of mass $m = 0.10$ kg tied to a rope rotating in a horizontal circle of radius $r = 0.25$ m, on a frictionless table top. It rotates at constant speed of 4.0 m/s while the mass $M$ is stationary. Find the value of mass $M$. (Ans: 0.65 kg)

53. Figure 36 shows a constant horizontal force $F = 20.0$ N applied to block A (mass = 2.00 kg) which pushes against block B (mass = 3.00 kg) to the right. The coefficient of kinetic friction between the surface and object A is 0.220 and between the surface and object B is 0.350. Find the magnitude of the contact force between object A and object B. (Ans: 13.5 N)

54. Find the coefficient of kinetic friction for which a body of mass $m = 2.0$ kg will slide down a 10° inclined plane with constant velocity. (Ans: 0.18)

55. A block is released from rest on a 27° incline and moves 6.0 m during the next 2.0 s. What is the coefficient of kinetic friction between the block and the incline? (Ans: 0.17)

56. A car goes around a flat, horizontal circle at a constant speed of 18 m/s. A ball is suspended by a string from the ceiling of the car. The ball then describes a circle of radius 75 m as the car rounds the curve. What is the angle between the string and the vertical? (Ans: 24°)

57. A block of mass $m = 5.00$ kg slides on a horizontal rough surface under the action of a steady force $F$ applied to the block at a constant angle of $\theta = 45^\circ$ (figure 38). The coefficient of kinetic friction between the block and the surface is 0.400. Find the maximum value of the force $F$ for which the block will move only horizontally. (Ans: 69.3 N)

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**Conceptual Problems** 1 2 3 4 5

1. An object moving in a circle at constant speed:
   A. has an acceleration of constant magnitude.
   B. has a constant acceleration.
   C. has a constant velocity.
   D. is held to its path by centrifugal force (a force directed away from the center).
   E. has an acceleration that is tangent to the circle.

2. A block of mass $M$ slides on a horizontal surface. Which of the following would increase the magnitude of the frictional force on the block?
   A. Increasing $M$
   B. Keeping $M$ constant but decreasing the surface area of contact
   C. Keeping $M$ constant but increasing the surface area of contact
   D. Decreasing $M$
   E. None of the other answers
3. A block slides down an inclined plane at constant velocity. Which one of the following statements is true?
   A. A frictional force must be acting on it.
   B. A net downward force along the plane is acting on it.
   C. A net upward force along the plane is acting on it.
   D. Its acceleration is increasing.
   E. Its acceleration is decreasing.

4. The coefficient of kinetic friction:
   A. is a dimensionless quantity
   B. is greater than the coefficient of static friction
   C. is the ratio of force to area
   D. can have units of Newtons
   E. is in the direction of the frictional force

5. A car travels at a constant speed around a horizontal circular track. Which one of the following statements about this car is true?
   A. The velocity of the car is changing.
   B. The velocity of the car is constant.
   C. The acceleration vector of the car is constant.
   D. The car has a velocity vector that points along the radius of the circular track.
   E. The car has an acceleration vector that is tangent to the circular track at all times.

6. When you travel, you always exert less force to pull a block M instead of pushing it, see figure 31. That is F(pull) < F(push). Why?
   A. Because the normal force becomes less while pulling
   B. Because the normal force becomes more while pulling
   C. Because the normal force becomes zero while pulling
   D. Because the gravitational forces decreases while pulling
   E. No scientific reason it is just a habit.

7. Friction and normal forces are always
   A. Perpendicular to each other
   B. Opposite to each other
   C. Equal to each other
   D. In the same direction
   E. None of the others

8. A block with mass \( m_1 \) is placed on an inclined plane with slope angle \( \alpha \) and is connected to a second hanging block with mass \( m_2 \) by a light cord passing over a massless and frictionless pulley (see figure 33). The coefficients of static and kinetic friction are \( \mu_s \) and \( \mu_k \) respectively. If the blocks are released from rest, for what range of values of \( m_2 \) will they remain at rest?
   A. \( m_1 (\sin \alpha - \mu_k \cos \alpha) < m_2 < m_1 (\sin \alpha + \mu_s \cos \alpha) \)
   B. \( m_1 (\sin \alpha - \mu_k \cos \alpha) < m_2 < m_1 (\sin \alpha + \mu_s \cos \alpha) \)
   C. \( m_1 (\sin \alpha - \mu_s \cos \alpha) < m_2 < m_1 (\sin \alpha + \mu_k \cos \alpha) \)
   D. \( m_1 (\sin \alpha - \mu_k \cos \alpha) < m_2 < m_1 (\sin \alpha + \mu_s \cos \alpha) \)
   E. \( m_1 (\cos \alpha - \mu_s \sin \alpha) < m_2 < m_1 (\cos \alpha + \mu_s \sin \alpha) \)
9. A block attached to a string, rotates counter-clockwise in a circle on a smooth horizontal surface. The string breaks at point P (see figure 37). What path will the block follow?)
   A. path B
   B. path A
   C. path C
   D. path D
   E. path E