**Answers to selected problems from Essential Physics, Chapter 11**

1. Calculating the angular acceleration in the four cases gives:

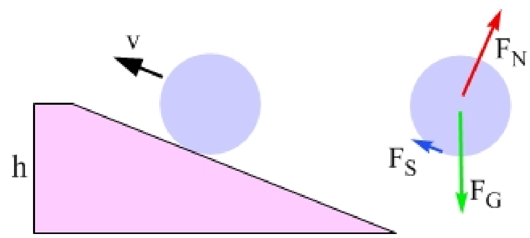
(a) $\alpha = \frac{3F}{ML}$ (b) $\alpha = \frac{3F}{2ML}$ (c) $\alpha = \frac{12F}{ML}$ (d) $\alpha = \frac{6F}{ML}$

Thus, ranking by angular acceleration gives c > d > a > b

3. (a) Yes, the spool will move (and accelerate) to the right (b) Yes, the spool will rotate (and have an angular acceleration) counterclockwise

5. No, because the net velocity of any point is the vector sum of the translational velocity and the velocity associated with pure rotation. The rotational velocity can be at most equal in magnitude to the translational velocity. If the vectors are in opposite directions, the net velocity can be zero, but not in the opposite direction as the translational velocity.

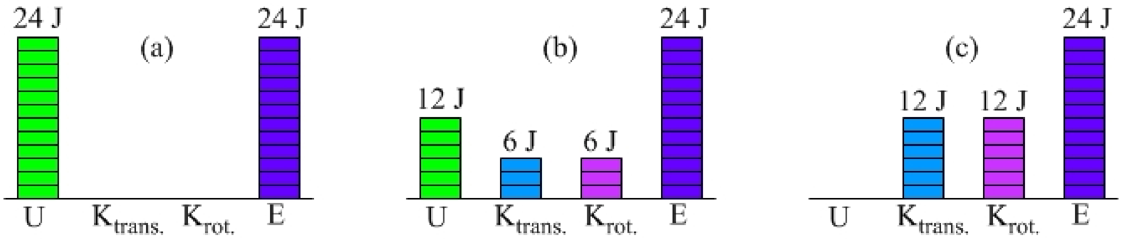
7. (a) Note that the force of static friction acts up the slope. The object rotates counterclockwise as it rolls up the slope, but the angular speed decreases. This requires a clockwise torque, about the center of the object. A torque about the center can only come from the force of friction, and we can only get a clockwise torque if the force of friction is directed up the slope.



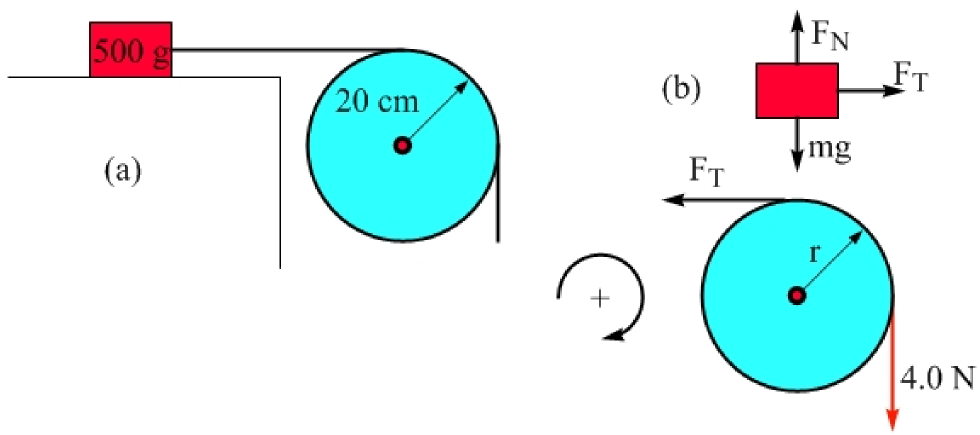

(b) The ring will travel farther up the ramp. Both objects have the same translational kinetic energy at the bottom but the ring, because of its larger rotational inertia, will have more rotational kinetic energy (the angular speeds at the bottom are equal, because the angular speed is the speed divided by the radius). Thus, the ring has a larger total kinetic energy than the sphere. All of the kinetic energy gets turned into gravitational potential energy at the highest point, so the ring ends up with a larger gravitational potential energy, which means it goes higher up the slope.

9. (a) The figure skater’s angular speed increases. This is all because of angular momentum conservation – pulling her arms in reduces the skater’s angular momentum, so, to keep the angular momentum (the product of the rotational inertia and the angular velocity) constant, the angular velocity increases in magnitude. (b) In this process, the skater’s rotational kinetic energy increases. The extra energy comes from the work done by the skater on her arms and hands to pull them in closer to her body.

11.




13.




(c) $\sum \tau = I\alpha$

$(4\text{ N})r - F_T r = \frac{1}{2} M r^2 \frac{a}{r}$

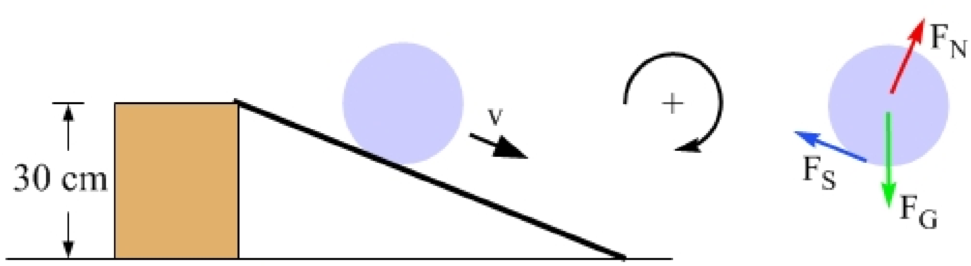
$(4\text{ N}) - F_T = \frac{1}{2} M a$

(d) $\sum \vec{F} = m\vec{a}$

$F_T = ma$

(e) $a = \dfrac{4\text{ N}}{\frac{1}{2}M + m} = 2.7\text{ m/s}^2$

15.




(c) $\sum \vec{\tau} = I\vec{\alpha}$

$F_S r = \frac{2}{5} m r^2 \frac{a}{r}$

$F_S = \frac{2}{5} m a$

(d) $\sum \vec{F} = m\vec{a}$

$mg\sin\theta - F_S = ma$

(e) $mg\sin\theta = ma + F_S = \frac{7}{5}ma$

(f) $2.0\text{ m} = \frac{1}{2}at^2$

17. $a = \frac{5g\sin\theta}{7} = \frac{5(9.8\text{ m/s}^2)(0.3\text{ m})}{7\,(2.0\text{ m})} = 1.05\text{ m/s}^2$ $\quad t = \sqrt{\frac{4.0\text{ m}}{a}} = 1.95\text{ s}$

(a) $\frac{\pi}{2}$ m

(b) $\frac{\pi}{2}$ m (c) No. First, we have to add the displacements as vectors, and the displacements are in different directions. Second, the displacement associated with the rotational motion has a smaller magnitude than the distance associated with the rotational motion, because the direction of motion changes as the wheel rotates. (d) The displacement has components of 1.0 m vertically and $\frac{\pi}{2}$ m horizontally. Using the Pythagorean theorem with these components gives 1.9 m for the magnitude of the displacement.

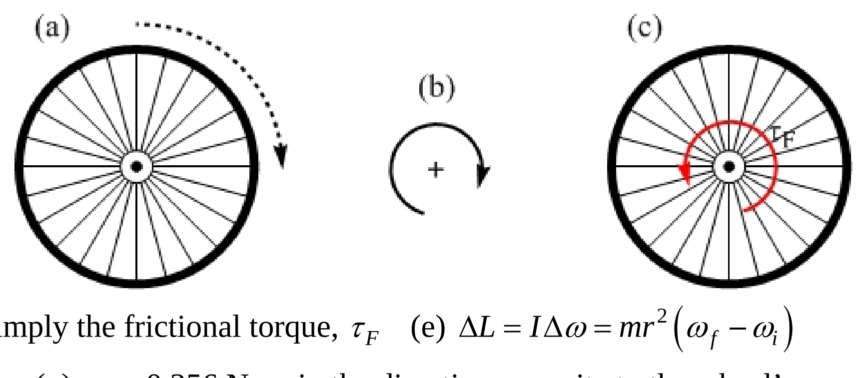
19. 22.5 m/s

21. The speeds are the same in the two cases. Because the sphere rolls without slipping, mechanical energy is conserved, so the gravitational potential energy is transformed into rotational kinetic energy and translational kinetic energy. The gravitational potential energy is the same in the two cases, and the fraction of the total kinetic energy that is translational kinetic energy is the same in both cases, so the speed must be the same.

23. (a) A's kinetic energy is larger by a factor of two. (b) A's angular speed is larger by a factor of two. (c) They have the same angular momentum.

25. (a) the stopping time would double (b) the stopping time would double
(c) the stopping time would be half as long

27. We actually don't have enough information to solve this problem. Let's take the wheel's mass to be 800 grams and its radius to be 40 cm, with all the wheel's mass concentrated around the rim of the wheel.




(d) The net torque is simply the frictional torque, $\tau_F$ (e) $\Delta L = I\Delta\omega = mr^2\left(\omega_f - \omega_i\right)$

(f) $\tau_F = mr^2\left(\omega_f - \omega_i\right)$ (g) $\tau_F$ = 0.256 N m, in the direction opposite to the wheel's direction of rotation.

29. (a) At any instant in time, the speed of block A is equal to the speed of block B, because they are connected by the same fixed-length string.   (b) 34.5 kg

31. The assumption here is that the ball rolls without slipping. In that case, $h = 2.7\,R$. This is a little larger than the result of 2.5 $R$ we got previously for a frictionless block. The extra height in this case gives us a little more gravitational potential energy to start with, which goes into the ball's rotational kinetic energy at the top of the loop.

33. 39 m/s

35. (a) $U_i + K_i + W_{nc} = U_f + K_f$ , and define the zero level for gravitational potential energy to be the lowest point (the final point).

(b) $K_i = 0$ , because the disk starts from rest; $U_f = 0$ , because the disk ends up at the zero level for gravitational potential energy; $W_{nc} = 0$ , because no non-conservative forces act on the disk (there is a friction force acting, but because it is static friction the energy associated with friction is the rotational kinetic energy of the disk).

(c) $U_i = K_f$

$$\begin{aligned} mgh &= \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \\ &= \frac{1}{2}mv^2 + \frac{1}{2}\left(\frac{1}{2}mr^2\right)\frac{v^2}{r^2} \\ &= \frac{3}{4}mv^2 \end{aligned}$$

(d) $v = \sqrt{\frac{4}{3}gh} = 2.6$ m/s

37. Let's assume that the sphere rotates only, and that there is no translational motion.

(a) $U_i + K_i + W_{nc} = U_f + K_f$ , and define the zero level for gravitational potential energy to be the level of the sphere's center of mass.

(b) $K_i = 0$ , because the sphere starts from rest; $U_i = 0$ and $U_f = 0$ , because the sphere's center of mass does not move, and the center of mass starts and ends at the zero level for gravitational potential energy.

(c) $W_{nc} = K_f$

$$Fd = \frac{1}{2}I\omega^2 = \frac{1}{5}mr^2\omega^2$$

(d) $\omega = \sqrt{\frac{5Fd}{mr^2}} = 18$ rad/s

39. (a) 5.0 rad/s$^2$ , clockwise  (b) 2.5 rad/s$^2$ , clockwise
(c) 20 rad/s$^2$ , clockwise  (b) 10 rad/s$^2$ , clockwise

41. The tension only needs to be different when the system accelerates. In that case, the pulley has an angular acceleration, which requires a net torque. The only way to have a net torque acting on the pulley is for the two tensions to be different. (a) With everything at rest, the two tensions are the same. (b) In this case, the system accelerates. In particular, the pulley's angular acceleration is directed counterclockwise, so the tension above the block of mass *M* is larger than the tension in the part of the string that is above the block of mass *m*. (c) In this case, there is no acceleration, so the tension is the same at all points in the string.

43. (a) $a = g/5$. If we use $g = 9.8$ m/s$^2$, we get $a = 1.96$ m/s$^2$. (b) The speed of either block at this time is 3.92 m/s. To get the angular velocity, we need to know the radius of the pulley. If $r = 10$ cm, then the angular velocity is 39 rad/s, directed counterclockwise.

45. (b) 4.1 m/s$^2$, down (c) 1.6 m/s$^2$, up

47. 1.1 m/s$^2$, down

49. (a) 2.0 m/s$^2$ (b) The tension is larger between block B and the pulley. In this situation, the pulley has an angular acceleration directed clockwise, so there must be a net torque acting clockwise on the pulley. The net torque is proportional to the difference between the two tensions, with the clockwise torque from the tension in the vertical part of the string being larger than the counterclockwise torque from the tension in the horizontal part of the string. This is true only if the tension in the vertical part of the string is larger than the tension in the horizontal part of the string.
(c) 24 N in the vertical part of the string, and 21 N in the horizontal part

51. Yes, the spool can remain motionless in this case, if there is an appropriate force of static friction acting down the slope. Then, the force you exert on the spool up the slope would balance the sum of the force of static friction and the component of the force of gravity that acts down the slope. The torque you exert about the center of the spool would balance the torque the force of static friction exerts about the center of the spool.

53. (a) $\frac{9}{8}MR^2$ (b) $\frac{33}{19}Mg$

55. The bicycle wheel will spin for twice as long as the solid disk, because the rotational inertia of the wheel is two times larger than the rotational inertia of the disk.

57. (a) The pennies farther from the axis are more likely to lose contact with the meter stick than are the pennies close to the axis. All points on the meter stick will have the same angular acceleration, but the linear acceleration of any point is the angular acceleration multiplied by the distance from the axis to the point. Thus, points farther from the axis will have the greatest linear acceleration and, if the linear acceleration exceeds *g*, the pennies won't keep up with the meter stick. (b) The acceleration at the far end of the stick is $a = \frac{3}{2}g$, while at the center it is only half of this, $\frac{3}{4}g$.

59. (a) The system's angular momentum stays the same – there is no net external torque being applied to the system. When you get farther from the center, the system's rotational inertia increases - the angular speed decreases so the angular momentum stays the same.
(b) The system's rotational kinetic energy decreases. The merry-go-round applies an inward directed force to you, so when you move out from the center negative work is done by the turntable on you. This accounts for the loss of mechanical energy.
(c) When you get to the outer edge and you are rotating with the turntable, the system's angular velocity is 1.8 rad/s directed clockwise. To conserve this angular velocity with the merry-go-round at rest, you would have to run with an angular velocity of 3.6 rad/s, directed clockwise.

61. (a) 3.7 m/s (b) 3.8 s (c) 3.8 revolutions

63. (a) Angular momentum is conserved. (b) Translational kinetic energy is not conserved. (c) Gravitational potential energy is not conserved. (d) Total mechanical energy is conserved. The total mechanical energy (the sum of the kinetic energy and the potential energy) is conserved, but the gravitational potential energy increases with the comet's distance from the Sun. Thus, the translational kinetic energy must decrease to compensate for the increase in potential energy as the comet moves farther from the Sun. On its return journey toward the Sun, the kinetic energy increases as the potential energy decreases.