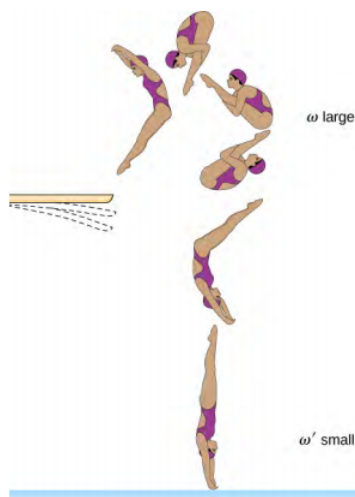


6.E: Angular Momentum (Exercises)

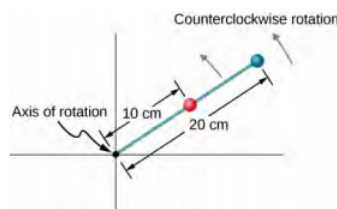
Conceptual Questions

1. A clock is mounted on the wall. As you look at it, what is the direction of the angular velocity vector of the second hand?
2. What is the value of the angular acceleration of the second hand of the clock on the wall?
3. The blades of a blender on a counter are rotating clockwise as you look into it from the top. If the blender is put to a greater speed what direction is the angular acceleration of the blades?
5. If a rigid body has a constant angular acceleration, what is the functional form of the angular velocity in terms of the time variable?
6. If a rigid body has a constant angular acceleration, what is the functional form of the angular position?
7. If the angular acceleration of a rigid body is zero, what is the functional form of the angular velocity?
8. A massless tether with a masses tied to both ends rotates about a fixed axis through the center. Can the total acceleration of the tether/mass combination be zero if the angular velocity is constant?
9. If a child walks toward the center of a merry-go-round, does the moment of inertia increase or decrease?
10. A discus thrower rotates with a discus in his hand before letting it go. (a) How does his moment of inertia change after releasing the discus? (b) What would be a good approximation to use in calculating the moment of inertia of the discus thrower and discus?
11. The moment of inertia of a long rod spun around an axis through one end perpendicular to its length is $\frac{mL^2}{3}$. Why is this moment of inertia greater than it would be if you spun a point mass m at the location of the center of mass of the rod (at $\frac{L}{2}$) (that would be $\frac{mL^2}{4}$)
12. Why is the moment of inertia of a hoop that has a mass M and a radius R greater than the moment of inertia of a disk that has the same mass and radius?
13. Can you assign an angular momentum to a particle without first defining a reference point?
14. What is the purpose of the small propeller at the back of a helicopter that rotates in the plane perpendicular to the large propeller?
15. Suppose a child walks from the outer edge of a rotating merry-go-round to the inside. Does the angular velocity of the merry-go-round increase, decrease, or remain the same? Explain your answer. Assume the merry-go-round is spinning without friction.
16. As the rope of a tethered ball winds around a pole, what happens to the angular velocity of the ball?
17. Suppose the polar ice sheets broke free and floated toward Earth's equator without melting. What would happen to Earth's angular velocity?
18. Explain why stars spin faster when they collapse.
19. Competitive divers pull their limbs in and curl up their bodies when they do flips. Just before entering the water, they fully extend their limbs to enter straight down (see below). Explain the effect of both actions on their angular velocities. Also explain the effect on their angular momentum.

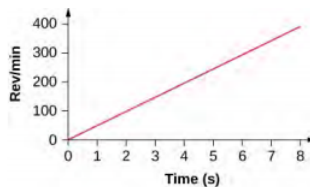


Problems

20. Calculate the angular velocity of Earth.
21. A track star runs a 400-m race on a 400-m circular track in 45 s. What is his angular velocity assuming a constant speed?
22. A wheel rotates at a constant rate of 2.0×10^3 rev/min. (a) What is its angular velocity in radians per second? (b) Through what angle does it turn in 10 s? Express the solution in radians and degrees.
23. A particle moves 3.0 m along a circle of radius 1.5 m. (a) Through what angle does it rotate? (b) If the particle makes this trip in 1.0 s at a constant speed, what is its angular velocity? (c) What is its acceleration?
24. A compact disc rotates at 500 rev/min. If the diameter of the disc is 120 mm, (a) what is the tangential speed of a point at the edge of the disc? (b) At a point halfway to the center of the disc?
25. **Unreasonable results.** The propeller of an aircraft is spinning at 10 rev/s when the pilot shuts off the engine. The propeller reduces its angular velocity at a constant 2.0 rad/s^2 for a time period of 40 s. What is the rotation rate of the propeller in 40 s? Is this a reasonable situation?
26. A gyroscope slows from an initial rate of 32.0 rad/s at a rate of 0.700 rad/s^2 . How long does it take to come to rest?
27. On takeoff, the propellers on a UAV (unmanned aerial vehicle) increase their angular velocity for 3.0 s from rest at a rate of $\omega = (25.0t) \text{ rad/s}$ where t is measured in seconds. (a) What is the instantaneous angular velocity of the propellers at $t = 2.0 \text{ s}$? (b) What is the angular acceleration?
28. The angular position of a rod varies as $20.0t^2$ radians from time $t = 0$. The rod has two beads on it as shown in the following figure, one at 10 cm from the rotation axis and the other at 20 cm from the rotation axis. (a) What is the instantaneous angular velocity of the rod at $t = 5 \text{ s}$? (b) What is the angular acceleration of the rod? (c) What are the tangential speeds of the beads at $t = 5 \text{ s}$? (d) What are the tangential accelerations of the beads at $t = 5 \text{ s}$? (e) What are the centripetal accelerations of the beads at $t = 5 \text{ s}$?



29. A wheel has a constant angular acceleration of 5.0 rad/s^2 . Starting from rest, it turns through 300 rad. (a) What is its final angular velocity? (b) How much time elapses while it turns through the 300 radians?
30. During a 6.0-s time interval, a flywheel with a constant angular acceleration turns through 500 radians that acquire an angular velocity of 100 rad/s . (a) What is the angular velocity at the beginning of the 6.0 s? (b) What is the angular acceleration of the flywheel?
31. The angular velocity of a rotating rigid body increases from 500 to 1500 rev/min in 120 s. (a) What is the angular acceleration of the body? (b) Through what angle does it turn in this 120 s?
32. A flywheel slows from 600 to 400 rev/min while rotating through 40 revolutions. (a) What is the angular acceleration of the flywheel? (b) How much time elapses during the 40 revolutions?
33. A wheel 1.0 m in radius rotates with an angular acceleration of 4.0 rad/s^2 . (a) If the wheel's initial angular velocity is 2.0 rad/s , what is its angular velocity after 10 s? (b) Through what angle does it rotate in the 10-s interval? (c) What are the tangential speed and acceleration of a point on the rim of the wheel at the end of the 10-s interval?
34. A vertical wheel with a diameter of 50 cm starts from rest and rotates with a constant angular acceleration of 5.0 rad/s^2 around a fixed axis through its center counterclockwise. (a) Where is the point that is initially at the bottom of the wheel at $t = 10 \text{ s}$? (b) What is the point's linear acceleration at this instant?
35. A circular disk of radius 10 cm has a constant angular acceleration of 1.0 rad/s^2 ; at $t = 0$ its angular velocity is 2.0 rad/s . (a) Determine the disk's angular velocity at $t = 5.0 \text{ s}$. (b) What is the angle it has rotated through during this time? (c) What is the tangential acceleration of a point on the disk at $t = 5.0 \text{ s}$?
36. The angular velocity vs. time for a fan on a hovercraft is shown below. (a) What is the angle through which the fan blades rotate in the first 8 seconds? (b) Verify your result using the kinematic equations.



37. A rod of length 20 cm has two beads attached to its ends. The rod with beads starts rotating from rest. If the beads are to have a tangential speed of 20 m/s in 7 s, what is the angular acceleration of the rod to achieve this?
38. A satellite is spinning at 6.0 rev/s. The satellite consists of a main body in the shape of a sphere of radius 2.0 m and mass 10,000 kg, and two antennas projecting out from the center of mass of the main body that can be approximated with rods of length 3.0 m each and mass 10 kg. The antenna's lie in the plane of rotation. What is the angular momentum of the satellite?
39. A propeller consists of two blades each 3.0 m in length and mass 120 kg each. The propeller can be approximated by a single rod rotating about its center of mass. The propeller starts from rest and rotates up to 1200 rpm in 30 seconds at a constant rate. (a) What is the angular momentum of the propeller at $t = 10$ s; $t = 20$ s? (b) What is the change in angular momentum of the propeller?
40. A pulsar is a rapidly rotating neutron star. The Crab nebula pulsar in the constellation Taurus has a period of 33.5×10^{-3} s, radius 10.0 km, and mass 2.8×10^{30} kg. The pulsar's rotational period will increase over time due to the release of electromagnetic radiation, which doesn't change its radius but reduces its rotational energy. (a) What is the angular momentum of the pulsar? (b) Suppose the angular velocity decreases at a rate of 10^{-14} rad/s². What is the change in angular momentum of the pulsar?
41. A bicycle wheel has a mass of 2 kg and a radius of 0.5 m. It is rotating with an angular speed of 10 rad/s when a brake is applied that exerts a constant frictional torque of 0.5 N m on the wheel. How long does it take for the wheel to stop? How many revolutions does the wheel make before stopping?
42. The blades of a wind turbine are 30 m in length and rotate at a maximum rotation rate of 20 rev/min. (a) If the blades are 6000 kg each and the rotor assembly has three blades, calculate the angular momentum of the turbine at this rotation rate. (b) What is the change in angular momentum require to rotate the blades up to the maximum rotation rate?
43. A merry-go-round with 5 kids on it has a mass of 500 kg and a radius of 2 m. It is initially at rest when a child runs up and starts pushing it. The child exerts a torque of 200 N*m on the merry-go-round for 3 seconds. What is the angular speed of the merry-go-round after the child stops pushing it?
44. A disk of mass 2.0 kg and radius 60 cm with a small mass of 0.05 kg attached at the edge is rotating at 2.0 rev/s. The small mass suddenly separates from the disk. What is the disk's final rotation rate?
45. The Sun's mass is 2.0×10^{30} kg, its radius is 7.0×10^5 km, and it has a rotational period of approximately 28 days. If the Sun should collapse into a white dwarf of radius 3.5×10^3 km, what would its period be if no mass were ejected and a sphere of uniform density can model the Sun both before and after?
46. A cylinder with rotational inertia $I_1 = 2.0 \text{ kg} \cdot \text{m}^2$ rotates clockwise about a vertical axis through its center with angular speed $\omega_1 = 5.0$ rad/s. A second cylinder with rotational inertia $I_2 = 1.0 \text{ kg} \cdot \text{m}^2$ rotates counterclockwise about the same axis with angular speed $\omega_2 = 8.0$ rad/s. If the cylinders couple so they have the same rotational axis what is the angular speed of the combination?
47. A diver off the high board imparts an initial rotation with his body fully extended before going into a tuck and executing three back somersaults before hitting the water. If his moment of inertia before the tuck is $16.9 \text{ kg} \cdot \text{m}^2$ and after the tuck during the somersaults is $4.2 \text{ kg} \cdot \text{m}^2$, what rotation rate must he impart to his body directly off the board and before the tuck if he takes 1.4 s to execute the somersaults before hitting the water?
48. A bug of mass 0.020 kg is at rest on the edge of a solid cylindrical disk ($M = 0.10$ kg, $R = 0.10$ m) rotating in a horizontal plane around the vertical axis through its center. The disk is rotating at 10.0 rad/s. The bug crawls to the center of the disk. (a) What is the new angular velocity of the disk? (b) What is the change in the kinetic energy of the system? (c) If the bug crawls back to the outer edge of the disk, what is the angular velocity of the disk then? (d) What is the new kinetic energy of the system? (e) What is the cause of the increase and decrease of kinetic energy?
49. A uniform rod of mass 200 g and length 100 cm is free to rotate in a horizontal plane around a fixed vertical axis through its center, perpendicular to its length. Two small beads, each of mass 20 g, are mounted in grooves along the rod. Initially, the two beads are held by catches on opposite sides of the rod's center, 10 cm from the axis of rotation. With the beads in this position, the rod is rotating with an angular velocity of 10.0 rad/s. When the catches are released, the beads slide

- outward along the rod. (a) What is the rod's angular velocity when the beads reach the ends of the rod? (b) What is the rod's angular velocity if the beads fly off the rod?
50. A merry-go-round has a radius of 2.0 m and a moment of inertia $300 \text{ kg} \cdot \text{m}^2$. A boy of mass 50 kg runs tangent to the rim at a speed of 4.0 m/s and jumps on. If the merry-go-round is initially at rest, what is the angular velocity after the boy jumps on?
 51. A playground merry-go-round has a mass of 120 kg and a radius of 1.80 m and it is rotating with an angular velocity of 0.500 rev/s. What is its angular velocity after a 22.0-kg child gets onto it by grabbing its outer edge? The child is initially at rest.
 52. Three children are riding on the edge of a merry-go-round that is 100 kg, has a 1.60-m radius, and is spinning at 20.0 rpm. The children have masses of 22.0, 28.0, and 33.0 kg. If the child who has a mass of 28.0 kg moves to the center of the merry-go-round, what is the new angular velocity in rpm?
 53. In 2015, in Warsaw, Poland, Olivia Oliver of Nova Scotia broke the world record for being the fastest spinner on ice skates. She achieved a record 342 rev/min, beating the existing Guinness World Record by 34 rotations. If an ice skater extends her arms at that rotation rate, what would be her new rotation rate? Assume she can be approximated by a 45-kg rod that is 1.7 m tall with a radius of 15 cm in the record spin. With her arms stretched take the approximation of a rod of length 130 cm with 10% of her body mass aligned perpendicular to the spin axis. Neglect frictional forces.
 52. A gymnast does cartwheels along the floor and then launches herself into the air and executes several flips in a tuck while she is airborne. If her moment of inertia when executing the cartwheels is $13.5 \text{ kg} \cdot \text{m}^2$ and her spin rate is 0.5 rev/s, how many revolutions does she do in the air if her moment of inertia in the tuck is $3.4 \text{ kg} \cdot \text{m}^2$ and she has 2.0 s to do the flips in the air?
 53. The centrifuge at NASA Ames Research Center has a radius of 8.8 m and can produce forces on its payload of 20 gs or 20 times the force of gravity on Earth. (a) What is the angular momentum of a 20-kg payload that experiences 10 gs in the centrifuge? (b) If the driver motor was turned off in (a) and the payload lost 10 kg, what would be its new spin rate, taking into account there are no frictional forces present?
 54. A ride at a carnival has four spokes to which pods are attached that can hold two people. The spokes are each 15 m long and are attached to a central axis. Each spoke has mass 200.0 kg, and the pods each have mass 100.0 kg. If the ride spins at 0.2 rev/s with each pod containing two 50.0-kg children, what is the new spin rate if all the children jump off the ride?
 55. An ice skater is preparing for a jump with turns and has his arms extended. His moment of inertia is $1.8 \text{ kg} \cdot \text{m}^2$ while his arms are extended, and he is spinning at 0.5 rev/s. If he launches himself into the air at 9.0 m/s at an angle of 45° with respect to the ice, how many revolutions can he execute while airborne if his moment of inertia in the air is $0.5 \text{ kg} \cdot \text{m}^2$?
 56. A space station consists of a giant rotating hollow cylinder of mass 10^6 kg including people on the station and a radius of 100.00 m. It is rotating in space at 3.30 rev/min in order to produce artificial gravity. If 100 people of an average mass of 65.00 kg spacewalk to an awaiting spaceship, what is the new rotation rate when all the people are off the station?
 57. Neptune has a mass of $1.0 \times 10^{26} \text{ kg}$ and is $4.5 \times 10^9 \text{ km}$ from the Sun with an orbital period of 165 years. Planetesimals in the outer primordial solar system 4.5 billion years ago coalesced into Neptune over hundreds of millions of years. If the primordial disk that evolved into our present day solar system had a radius of 10^{11} km and if the matter that made up these planetesimals that later became Neptune was spread out evenly on the edges of it, what was the orbital period of the outer edges of the primordial disk?
 58. A proton is accelerated in a cyclotron to $5.0 \times 10^6 \text{ m/s}$ in 0.01 s. The proton follows a circular path. If the radius of the cyclotron is 0.5 km, (a) What is the angular momentum of the proton about the center at its maximum speed? (b) What is the change in angular momentum on the proton about the center as it accelerates to maximum speed?
 59. A DVD is rotating at 500 rpm. What is the angular momentum of the DVD if has a radius of 6.0 cm and mass 20.0 g?
 60. A potter's disk spins from rest up to 10 rev/s in 15 s. The disk has a mass 3.0 kg and radius 30.0 cm. What is the angular momentum of the disk at $t = 10 \text{ s}$? What is the torque being applied? (Assuming the torque is constant.)
 61. A solid cylinder of mass 2.0 kg and radius 20 cm is rotating counterclockwise around a vertical axis through its center at 600 rev/min. A second solid cylinder of the same mass is rotating clockwise around the same vertical axis at 900 rev/min. If the cylinders couple so that they rotate about the same vertical axis, what is the angular velocity of the combination?
 62. A boy stands at the center of a platform that is rotating without friction at 1.0 rev/s. The boy holds weights as far from his body as possible. At this position the total moment of inertia of the boy, platform, and weights is $5.0 \text{ kg} \cdot \text{m}^2$. The boy draws the weights in close to his body, thereby decreasing the total moment of inertia to $1.5 \text{ kg} \cdot \text{m}^2$. (a) What is the final angular velocity of the platform?

63. Eight children, each of mass 40 kg, climb on a small merry-go-round. They position themselves evenly on the outer edge and join hands. The merry-go-round has a radius of 4.0 m and a moment of inertia $1000.0 \text{ kg} \cdot \text{m}^2$. After the merry-go-round is given an angular velocity of 6.0 rev/min, the children walk inward and stop when they are 0.75 m from the axis of rotation. What is the new angular velocity of the merry-go-round? Assume there is negligible frictional torque on the structure.
64. A thin meter stick of mass 150 g rotates around an axis perpendicular to the stick's long axis at an angular velocity of 240 rev/min. What is the angular momentum of the stick if the rotation axis (a) passes through the center of the stick? (b) Passes through one end of the stick?
65. A satellite in the shape of a sphere of mass 20,000 kg and radius 5.0 m is spinning about an axis through its center of mass. It has a rotation rate of 8.0 rev/s. Two antennas deploy in the plane of rotation extending from the center of mass of the satellite. Each antenna can be approximated as a rod has mass 200.0 kg and length 7.0 m. What is the new rotation rate of the satellite?

Contributors and Attributions

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