

Chapter 7

Rotational Motion

7.1 Angular Quantities

Homework #51

I

- Convert the following angle measurements to radians.
a.) 30.0° b.) 45.0° c.) 90.0°
- The Empire State Building has a total height of 443.2 m (including the lightning rod). From one observation point on a street in New York, it subtends an angle of 5.50° . How far from the building is this observation point?
- A laser beam, shining from the earth's surface, is directed at the moon whose distance from the earth on this day is 370,000 km. If the beam diverges at an angle of only 1.65×10^{-5} rad, what diameter circle will it make on the moon?
- A Compact Disc (CD) has a diameter of 12.0 cm, rotates at a constant 207 rpm, and has a total playing time of 74.0 minutes.
 - What is the angular velocity of the CD?
 - What is the linear speed of a point on the edge of the disc?
 - What is the angular displacement of the CD during its total play time?
 - What is the distance traveled by a point on the edge of the CD?
 - What is the distance traveled by a point 4.00 cm from the center of the CD?
 - What is the angular acceleration of the CD during its total play time?
 - What is the tangential acceleration of a point on the edge of the CD?
 - What is the centripetal acceleration of a point on the edge of the CD?
- An antique grinding wheel rotating at 85.0 rpm is brought to rest in 22.5 s. What is its angular acceleration?

II

- A centrifuge is rotated from rest to 18,000 rpm in 4 minutes and 45 seconds. What is the average angular acceleration of the centrifuge during this time?
- A bicycle with tires of diameter 68.0 cm travels 13.5 km. How many revolutions do the wheels make?
- Calculate the angular velocity of the earth _____.
 - in its orbit around the sun
 - about its axis
- What is the linear speed of a point _____ due to the earth's rotation about its axis. (See [Homework #26](#) in "Chapter 4-Circular Motion & Gravitation" for the table of "Planetary Data")
 - on the equator
 - at a latitude of 60.0° N
- A phonograph record with a diameter of 30.0 cm reaches its rated speed of 33 rpm in 3.5 s.
 - What is the tangential component of the linear acceleration of a point on the edge of the record?
 - What is the centripetal component of the linear acceleration of a point on the edge of the record 2.50 s after it starts rotating?

ANSWERS: **01.** a.) 0.524 rad b.) 0.785 rad c.) 1.57 rad **02.** 4617 m **03.** 6105 m **04.** a.) 21.7 rad/s
04. b.) 1.30 m/s c.) 9.62×10^4 rad d.) 5775 m e.) 3850 m f.) 0 rad/s² g.) 0 m/s² h.) 28.2 m/s²
05. -0.396 rad/s² **06.** 6.61 rad/s² **07.** 6320 rev **08.** a.) 1.99×10^{-7} rad/s b.) 7.27×10^{-5} rad/s
09. a.) 464 m/s b.) 232 m/s **10.** a.) 0.148 m/s² b.) 0.914 m/s²

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7.2 Uniformly Accelerated Rotational Motion

Homework #52

I

01. A phonograph turntable reaches its rated speed of 33 rpm in 2.25 revolutions. What is its angular acceleration?
02. A centrifuge accelerates from rest to 12,000 rpm in 235 s. What was the centrifuge's angular acceleration?

II

03. A truck engine slows down from 3700 rpm to 1800 rpm in 4.25 s. How many revolutions were made by the engine during this time?
04. A car, with 26-inch (66.0-cm)-diameter wheels, accelerates from rest to 72.5 km/h (45.0 mi/h) in 295 m.
- What is the angular displacement of the wheels?
 - What is the **AVERAGE** angular velocity of the wheels?
 - What is the angular acceleration of the wheels?
 - How long did it take to reach this speed?
05. A train that has wheels with a diameter of 91.44 cm (36 inches used for 100 ton capacity cars) slows down from 82.5 km/h to 32.5 km/h as the train approaches a town. The wheels of the train make 95.0 revolutions in this time.
- What is the angular acceleration of the wheels?
 - How long does it take the train to make this reduction in speed?
 - How far does the train travel during this deceleration period?
 - Assuming the same rate of deceleration, how many **MORE** revolutions will the wheels make before stopping?
 - Assuming the same rate of deceleration, how much **FARTHER** will the train travel before stopping?
06. A bicycle wheel (Wheel 1) with a diameter of 68.0 cm is mounted such that its circular edge touches that of a second bicycle wheel (Wheel 2) with a diameter of 42.0 cm. Wheel 1 accelerates at a rate of 1.28 rad/s^2 and drives the second wheel through its contact with negligible slipping.
- How long will it take Wheel 1, starting from rest, to reach a rotation rate of 25.0 rpm?
 - What is the linear speed of a point on the edge of Wheel 1 when it rotates at 25.0 rpm?
 - How far does a point on the edge of Wheel 1 travel in the time needed to reach a rotation rate of 25.0 rpm?
 - What is the angular acceleration of Wheel 2?
 - How long will it take Wheel 2, starting from rest, to reach a rotation rate of 25.0 rpm?
 - What is the linear speed of a point on the edge of Wheel 2 when it rotates at 25.0 rpm?
 - How far does a point on the edge of Wheel 2 travel in the time needed to reach a rotation rate of 25.0 rpm?

III

07. A 68.0-cm bicycle wheel accelerates from 165 rpm to 280 rpm in 8.45 s. How far will the bicycle have traveled in this time?

ANSWERS: **01.** 0.422 rad/s^2 **02.** 5.35 rad/s^2 **03.** 195 rev **04.** a.) 894 rad b.) 30.5 rad/s
04. c.) 2.08 rad/s^2 d.) 29.3 s **05.** a.) -1.78 rad/s^2 b.) 17.1 s c.) 273 m d.) 17.5 rev e.) 50.1 m
06. a.) 2.05 s b.) 0.890 m/s c.) 0.910 m d.) 2.07 rad/s^2 e.) 1.26 s f.) 0.550 m/s g.) 0.348 m
07. 66.9 m

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7.3 Torque

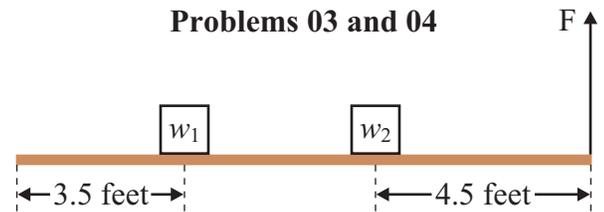
Homework #53

I

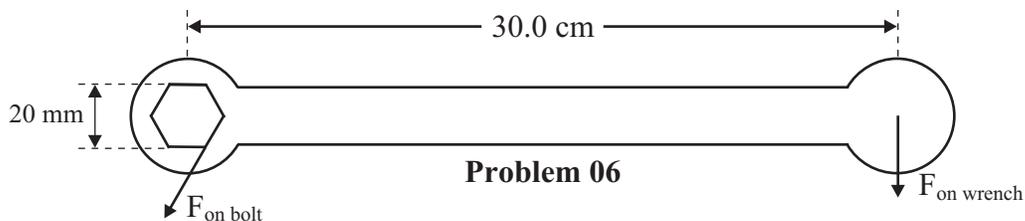
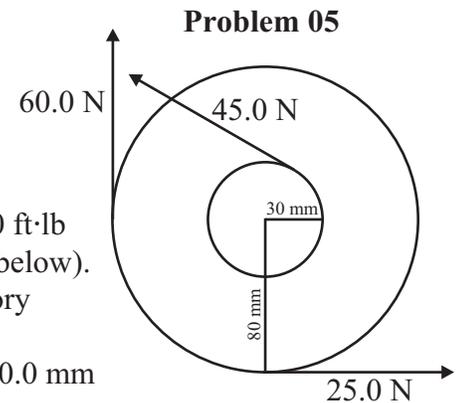
01. A 76.5-kg person is riding a bike whose pedals rotate in a circle with a diameter of 34.6 cm. What is the maximum torque exerted by the rider on the pedals assuming he puts all of his weight on the pedals?
02. A woman opens an 75.8-cm wide door for a man by applying a force of 34.3 N to the edge of the door.
 - a.) Calculate the maximum torque applied to the door.
 - b.) Calculate the torque applied to the door if the force is applied at a 60.0° angle to the face of the door.
03. A 12 foot length of 2" x 12" lumber (white pine), weighing 72.0 lbs, is sitting on the ground. What minimum upward force is needed to lift the one end of the wood, assuming the other end does not slide, but rather acts as the axis of rotation. Ignore any bending of the wood.

II

04. Assume the same piece of lumber as problem 03 above is again sitting on the ground. This time there are two packages of roofing shingles sitting on the wood. One package, that is unopened, weighs 80 lbs (w_1) and is positioned 3.50 feet from the left end of the board; while the other package, that is not a full package, weighs 55 lbs (w_2) and is positioned 4.50 feet from the right end of the board as shown in the diagram to the right. What minimum upward force is needed to lift the right end of the board? Ignore any bending of the wood.



05. What is the net torque applied to the wheel and axle assembly shown in the diagram to the right? Assume a frictional torque of $0.40 \text{ m}\cdot\text{N}$. The axle has a radius of 30.0 mm and the wheel has a radius of 80.0 mm. All forces are tangent.
06. The wheel lug nuts of a 1988 Jeep Wrangler require tightening to a torque of 80 ft·lb ($108.6 \text{ m}\cdot\text{N}$). A mechanic uses a 30.0-cm long wrench (shown in the diagram below).
 - a.) What is the minimum force needed by a mechanic to tighten this nut to factory specifications?
 - b.) What force is applied to each point on the six-sided nut with a diameter of 20.0 mm when the bolt is tightened to factory specifications?



ANSWERS: 01. $130 \text{ m}\cdot\text{N}$ 02. a.) $26.0 \text{ m}\cdot\text{N}$ b.) $22.5 \text{ m}\cdot\text{N}$ 03. 36.0 lbs 04. 93.7 lbs 05. $-1.05 \text{ m}\cdot\text{N}$
 06. a.) 362 N b.) 1810 N

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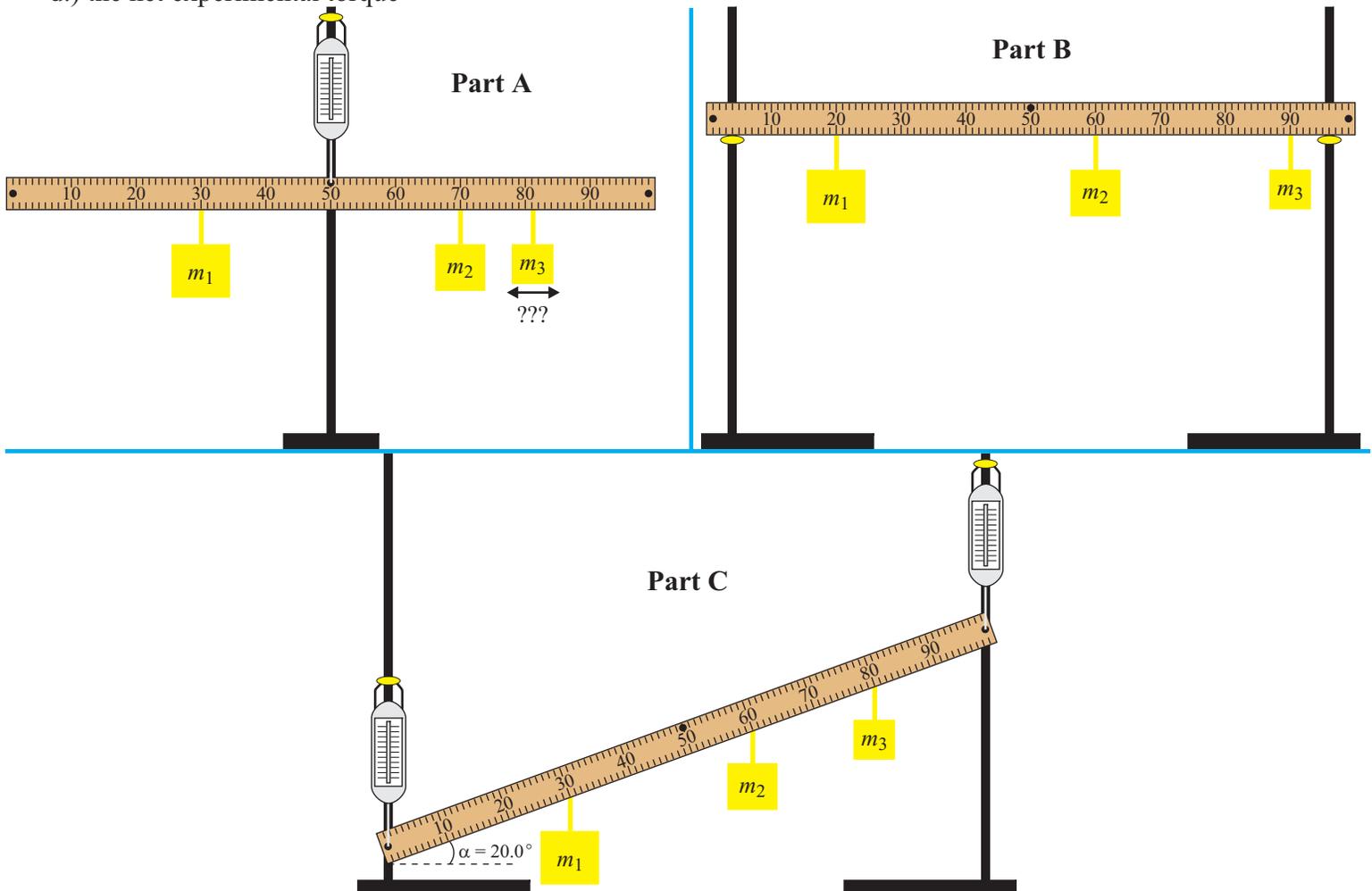
7.4 Torques at Equilibrium

Homework #54

I

Numbers 01-03 refer to three different parts of a torque lab whose assemblies are shown below. There are holes drilled in the meter stick exactly 1.00 cm from the ends of the meter stick and at 50.00 cm (near the top of the meter stick) so that the hooks of the spring scales can be inserted into the meter stick as needed in the different parts of the lab. These spring scales are then supported by clamps attached to the ring stand(s). Three masses ($m_1 = 200$ g, $m_2 = 100$ g, and $m_3 = 50$ g) are hung from paper clips (of negligible mass) that have been reshaped so that they can be hung from the meter stick. The mass of the meter stick is 135.0 g. The apparatus is at rest and in dynamic equilibrium in all parts.

01. For Part A of the lab, determine _____.
- a.) where mass m_3 should be placed to ensure dynamic equilibrium b.) the reading on the spring scale
02. For Part B of the lab, determine _____.
- a.) the force the student must exert to lift the meter stick apparatus off the supporting clamps
b.) where a student's finger must be placed to balance the system as the he lifts the meter stick off the clamps
03. For Part C of the lab, spring scale 1 (on the left) has a reading of 2.53 N. Determine _____.
- a.) the reading on spring scale 2 b.) the net clockwise torque c.) the net counter-clockwise torque
d.) the net experimental torque



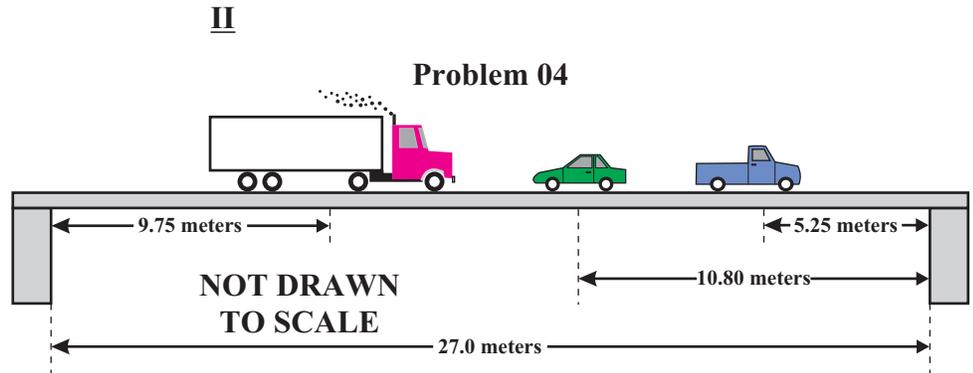
ANSWERS: 01. a.) 90 cm mark b.) 4.75 N 02. a.) 4.75 N b.) 43.8 cm mark
03. a.) 2.22 N (2.23 N) b.) -2.05 m·N c.) 2.04 m·N d.) -0.01 m·N

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7.4 Torques at Equilibrium

Homework #55

04. A bridge consists of a long central span of 27.00 meters supported at each end by a pier. The bridge itself has a weight of 250 tons. A picture of the bridge is taken as three vehicles are in the process of crossing the bridge as shown to the right. The picture is analyzed to determine the position of the center of mass of each vehicle on the bridge at the moment the picture was taken. Research (such as examining weighing station data and obtaining manufacturer's information) is also done to determine the weight of each vehicle. The first vehicle is a tractor-trailer truck that has a weight of 16.40 tons and is positioned 9.75 meters from the left end of the bridge. The second vehicle is a car weighing 1.75 tons located 10.80 m from the right side of the bridge. The third vehicle is a pickup truck weighing 2.65 tons and positioned 5.25 m from the right side of the bridge.



The first vehicle is a tractor-trailer truck that has a weight of 16.40 tons and is positioned 9.75 meters from the left end of the bridge. The second vehicle is a car weighing 1.75 tons located 10.80 m from the right side of the bridge. The third vehicle is a pickup truck weighing 2.65 tons and positioned 5.25 m from the right side of the bridge.

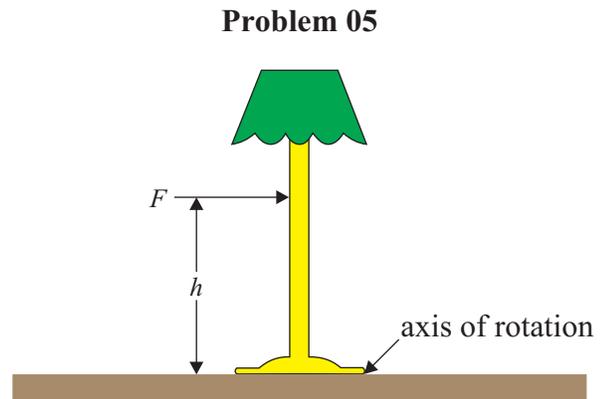
- a.) What is the upward force exerted by the pier on the right to support the bridge.
- b.) What is the upward force exerted by the pier on the left to support the bridge.

Suppose that this bridge, including the three vehicles, is to somehow be lifted upward at a constant velocity by some single force.

- c.) What will be the magnitude of this upward force?
- d.) Where must this upward force be applied to lift the system so that rotational equilibrium is maintained?

05. A 2.73-kg lamp is sitting on a table as shown in the diagram to the right. The lamp has a base with a diameter of 18.0 cm, a height of 68.7 cm, and a very thin central column that supports the light bulb and lamp shade. The coefficient of kinetic friction between the base of the lamp and the table is $\mu_k = 0.32$. A horizontal force, F , is applied to the central column of the lamp at a height of $h = 24.5$ cm so as to move the lamp at a constant speed across the table.

- a.) What is the magnitude of the frictional force acting on the lamp as it slides across the table?
- b.) What is the magnitude of the applied force, F ?
- c.) What is the torque (magnitude and direction) exerted on the lamp by the applied force, F , about the axis of rotation shown in the diagram?
- d.) What is the torque (magnitude and direction) on the lamp by the weight of the lamp about this axis of rotation?
- e.) What is the torque (magnitude and direction) on the lamp by the frictional force about this axis of rotation?
- f.) Why don't these torques [from parts c.), d.), and e.) above] add to zero? In other words, what other force is creating a torque that balances these torques already discussed?
- g.) What is the maximum height, h_m , above the base that the force, F , can act without toppling the lamp?



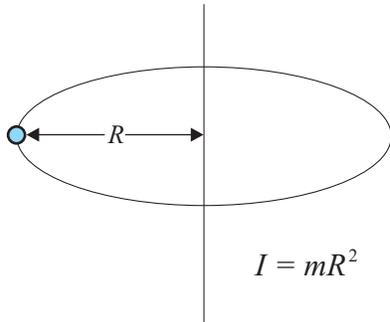
ANSWERS: 04. a.) 134.1 tons b.) 136.7 tons c.) 270.8 tons d.) 13.37 m from the left edge of the span
 05. a.) 8.56 N b.) 8.56 N c.) 2.10 m·N (clockwise) d.) 2.41 m·N (counter clockwise) e.) 0 m·N
 05. f.) the normal force g.) 28.1 cm

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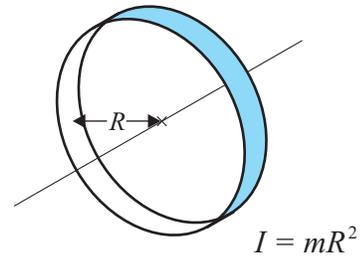
7.5 Moment of Inertia

Homework #56

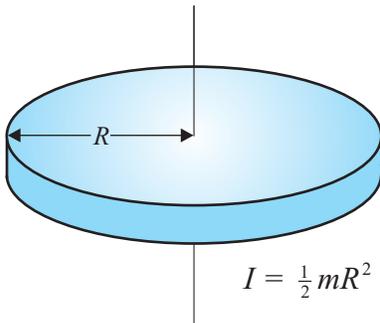
1.) Mass on a String, Planet Orbiting a Star



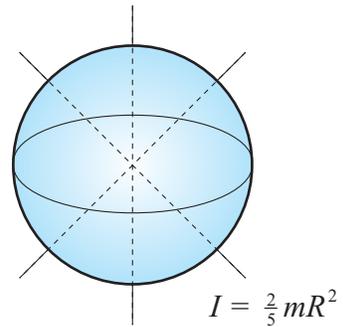
2.) Ring, Hoop



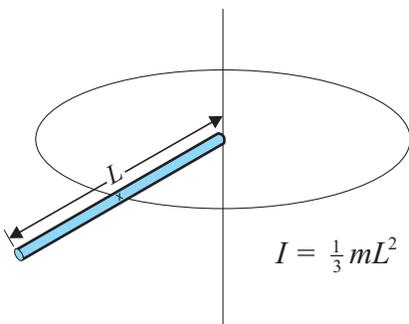
3.) Disk, Cylinder



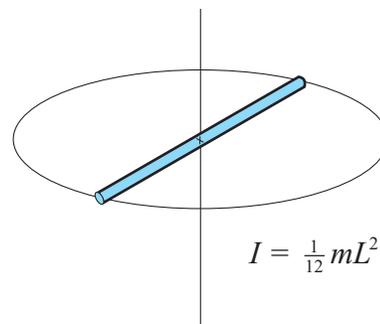
4.) Solid Sphere



5.) Thin Rod Rotating About One End



6.) Thin Rod Rotating About Center



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7.6 Rotational Dynamics

Homework #57

I

01. What is the moment of inertia of a 6.75-kg solid sphere with a radius of 0.682 m with a rotation axis passing through the center of the sphere?
02. A bicycle wheel has a diameter of 68.0 cm. The combined mass of its tire and rim is 1.18 kg while the inertial factor of the hub can be ignored. What is the moment of inertia of the wheel?

II

03. A 0.875-kg solid ball is tied to a string and rotated in a circle of radius 0.925 m. A force of air resistance of 0.0245 N acts as the ball rotates.
- What is the moment of inertia of the ball?
 - What torque must be applied to the ball to keep it rotating at a constant angular velocity?
04. A pottery wheel is a uniform cylinder that has a diameter of 30.48 cm and a mass of 5.00 kg. The wheel starts from rest and accelerates to 125 rpm in 10.5 s. A frictional torque of $0.0460 \text{ m}\cdot\text{N}$ acts as it rotates. What is the torque applied to this wheel to cause this acceleration?
05. A solid sphere with a diameter of 0.784 m is spun around an axis passing through the center of the sphere. If a torque of $17.5 \text{ m}\cdot\text{N}$ is applied for 22.5 s causing the sphere to rotate from rest through 215 revolutions. What is the mass of the sphere?
06. Treat a merry-go-round as a uniform disc that has a diameter of 19.0 m and a mass of 35,000 kg. Assuming a frictional torque of $1220 \text{ m}\cdot\text{N}$, what torque is needed to accelerate it from rest to 2.25 rad/s in 12.5s?
07. A 15.4-lb (7.00-kg) medicine ball with a diameter of 28.0 cm is sitting on the gym floor. A force of 178 N is applied to the top edge of the ball (tangent to the surface) for 0.125 s.
- What is the moment of inertia of the ball?
 - What is the torque applied to the ball?
 - What is the angular acceleration of the ball while the force is being applied?
 - What is the angular velocity of the ball after the acceleration period of 0.125 s?
 - What is the angular displacement of the ball during the acceleration period?
 - How far across the floor will the ball roll during the acceleration period?
08. A centrifuge rotor rotating at 12,000 rpm is shut off. The centrifuge has a radius of gyration of 0.0685 m and a frictional torque of $1.48 \text{ m}\cdot\text{N}$. The mass of the rotor is 4.45 kg.
- How many revolutions will the rotor make before coming to rest?
 - How long will it take to stop?

ANSWERS: **01.** $1.26 \text{ kg}\cdot\text{m}^2$ **02.** $0.136 \text{ kg}\cdot\text{m}^2$ **03.** a.) $0.749 \text{ kg}\cdot\text{m}^2$ b.) $0.0227 \text{ m}\cdot\text{N}$ **04.** $0.118 \text{ m}\cdot\text{N}$
05. 53.3 kg **06.** $2.85 \times 10^5 \text{ m}\cdot\text{N}$
07. a.) $0.0549 \text{ kg}\cdot\text{m}^2$ b.) $24.9 \text{ m}\cdot\text{N}$ c.) 454 rad/s^2 d.) 56.8 rad/s e.) 3.55 rad f.) 0.497 m
08. a.) 1773 rev b.) 17.7 s

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7.7 Rotational Work and Kinetic Energy

Homework #58

I

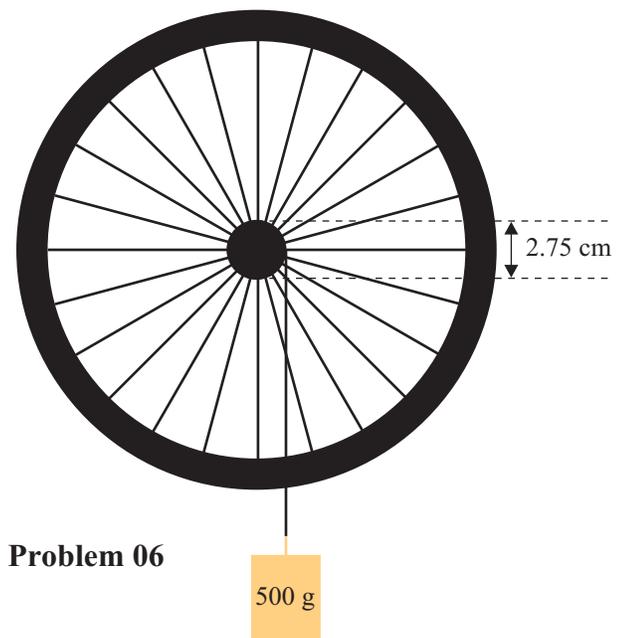
01. A phonograph record (uniform disc) has a mass of 112 g and a diameter of 30.0 cm. It is rotating on a turntable at 33 rpm when the turntable is turned off. How much energy does the record lose in coming to rest?
02. A 68.0-cm bicycle wheel, with a mass of 4.50 kg, is mounted on a lab table. A student grabs the tire and applies a 65.0-N force tangentially for $\frac{1}{2}$ of a rotation and releases it.
- How much work was done by the student?
 - What is the kinetic energy of the wheel after the student releases it?
 - What is the angular velocity of the wheel after the student releases it?

II

03. What is the kinetic energy of the earth _____? (See [Homework #26](#) in "Chapter 4-Circular Motion & Gravitation" for the table of "Planetary Data")
- in rotating about its axis
 - in revolving around the sun
04. A 3.50-kg solid ball, with a radius of 0.345 m, begins rolling down a 4.50-m high incline without slipping.
- What speed will it have when it reaches the ground?
 - What is the angular velocity it is rolling at when it reaches the ground?
 - What is the **TOTAL** kinetic energy of the ball when it reaches the ground?
05. A car has a mass of 1400 kg including the four tires which each have a mass of 35.0 kg (including the wheels), a diameter of 86.36 cm, and a radius of gyration (of tire and wheel) of 32.5 cm.
- What is the translational kinetic energy of the car when it is traveling 90.0 km/h?
 - How much total (trans. + rot.) kinetic energy is in the wheels of the car when it is traveling 90.0 km/h?
 - If the car is pulled by a tow truck with a force of 2500 N, what will be the acceleration of the car?
Hint: The force of friction on the tires from the road creates a torque on the tires and rotates them.

III

06. A 68.0-cm bicycle wheel, with a mass of 4.50 kg, is mounted on a lab table. A string that is 60.0 cm long has loops tied on both ends. One loop is placed over a nail sticking out of the hub of the wheel and the length of the string is wrapped around the hub that has a diameter of 2.75 cm. A 500-g mass is hung from the other loop. The mass is released and the wheel begins to rotate as the weight falls and unwraps the string. All questions below refer to the time when the string is completely unraveled. See the diagram to the right. Ignore frictional losses.
- How much work is done by the mass?
 - What is the angular velocity of the wheel?
 - What is the kinetic energy of the wheel?
 - What is the kinetic energy of the falling mass?
 - What is the total kinetic energy of the system?



ANSWERS: **01.** 0.00754 J **02.** a.) 69.4 J b.) 69.4 J c.) 16.3 rad/s **03.** a.) 2.57×10^{29} J b.) 2.64×10^{33} J
04. a.) 7.94 m/s b.) 23.0 rad/s c.) 154 J **05.** a.) 4.38×10^5 J b.) 6.85×10^4 J c.) 1.69 m/s^2
06. a.) 2.94 J b.) 3.36 rad/s c.) 2.94 J (2.939465 J) d.) 5.34×10^{-4} J e.) 2.94 J

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Rotational Motion

Conceptual Review

Homework #60

01. How can you determine the height of a telephone pole or tree using only your finger, a meter stick, and a calculator. Explain!!!
02. Could an odometer designed for bicycles with 27-inch wheels be used accurately on a bike with 24-inch wheels? Explain!!!
03. Consider a 33-rpm record rotating at its rated speed on a turntable.
 - a.) Does a point on the outer edge have centripetal and/or tangential acceleration? Explain!!!
 - b.) Does a point on the outer edge have centripetal and/or tangential acceleration during the time the record increases its angular velocity from rest to its rated speed? Explain!!!
 - c.) Discuss when the magnitudes of the centripetal and tangential acceleration change in parts a.) and b.) above.
04. Is it possible for a small force to create a larger torque on an object than a larger force acting on this object? Explain!!!
05. A force acts on object at such an orientation that its lever arm, r , is zero. Does this force have any effect on the object's motion? Explain!!!
06. Racing bicyclists use very lightweight "sew-up" (tubular) tires. The assumption is that reducing the mass of the tires is more significant than an equal reduction in mass elsewhere on the bike. Explain why this is true.
07. Mammals that must run quickly to survive have slender lower legs and most of the muscle and flesh of the leg concentrated high, close to the body. Why is this advantageous to speed for the animal? Explain!!!
08. Why do tightrope walkers carry a long, narrow beam? Explain!!!
09. Is the net torque on a system zero if the net force is zero? Explain!!!
10. Is the net force on a system zero if the net torque is zero? Explain!!!
11. A meter stick stands vertically on one end on a **FRICTIONLESS** surface. Describe the motion of its cm and of each end when it is tipped slightly to one side and falls? Explain!!!
12. A ring, a disc, and a solid ball all start from rest and begin simultaneously rolling down an incline. Give the order of their finish. Explain!!!
13. Solid ball 1 is rolled down an incline while an identical ball, solid ball 2, starting at the same height as ball 1, is rolled down another incline with a larger angle.
 - a.) Which ball will have the greatest speed at the bottom if they both start from rest? Explain!!!
 - b.) Which ball will reach the bottom first if they both start from rest? Explain!!!
14. Two solid balls simultaneously begin rolling from rest down an incline. Ball 2 has twice the mass and twice the radius of ball 1.
 - a.) Which ball has the greater speed at the bottom? Explain!!!
 - b.) Which ball reaches the bottom of the incline first? Explain!!!
 - c.) Which ball has the greater total kinetic energy at the bottom? Explain!!!
15. A solid ball and a disc with the same mass and radius simultaneously begin rolling from rest down an incline.
 - a.) Which object has the greater speed at the bottom? Explain!!!
 - b.) Which object has the greater total kinetic energy at the bottom? Explain!!!
 - c.) Which object has the greater translational kinetic energy at the bottom? Explain!!!
 - d.) Which object has the greater rotational kinetic energy at the bottom? Explain!!!
16. A cyclist rides over the top of a hill. Is the bike's motion considered rotational, translational, or a combination? Explain!!!
17. If there were a great migration of people toward the equator, how would this affect the length of the day? Explain!!!
18. In our experience, rotating objects eventually slow down and stop. Is this a violation of the law of conservation of momentum? Explain!!!
19. Describe the direction of the earth's angular velocity in its daily rotation about its axis.

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Conceptual Review

Homework #61

20. Evil Knevil jumps a line of cars. While in the air, the motorcycle's throttle is left open causing the rear wheel to spin. Why does this cause the front of the motorcycle to rise up?
21. Consider the second hand of a clock that moves continuously.
 - a.) What is the direction of the angular velocity? Explain!!!
 - b.) What is the direction of the angular acceleration? Explain!!!
 - c.) What is the direction of the **NET** torque? Explain!!!
 - d.) What is the direction of the angular momentum? Explain!!!
22. A wheel is rotating such that its angular velocity has a horizontal direction pointing due west.
 - a.) What is the direction of the linear velocity of a point on the top edge of the wheel? Explain!!!
 - b.) Is the angular velocity increasing or decreasing if the angular acceleration of the wheel has a direction east? Explain!!!
23. A quarterback leaps into the air to throw a forward pass. While in the air, his upper body rotates to make the pass. Why does his hips and legs rotate in the opposite direction? Explain!!!
24. Use the law of conservation of momentum to explain why a helicopter must have a rotor, or propeller, on its tail section at right angles to its main rotor on the top of the cab. How does this affect stability? Explain!!!
25. A physics teacher is sitting on a stool that is free to rotate. The teacher is currently at rest and is holding a bicycle wheel with one hand on either side of the axle. The wheel is spinning very quickly and is oriented so that its angular momentum is in a direction straight up toward the ceiling. With his feet off the ground, the physics teacher quickly rotates the wheel's orientation $\frac{1}{2}$ turn such that the direction of the angular momentum of the wheel is now down. Describe the resulting motion of the physics teacher. Explain!!!