Chapter 10 - Torque and Rotational Dynamics

Physics 206

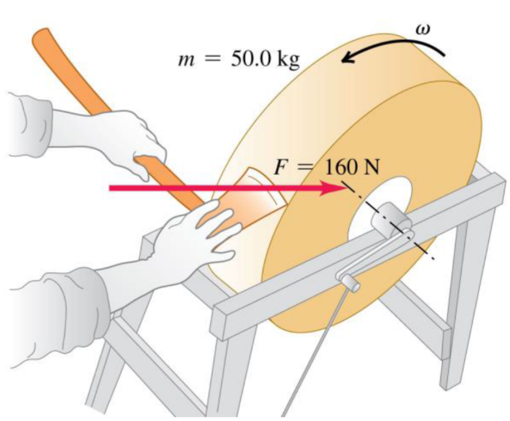
For any problems where you are given a variable/symbol and a value for that variable, make sure to solve the problem symbolically first. Your final answer should then only contain the variables that you are given values for in the problem, constants that appear on the equation sheet and numbers like 2 or π.

Group 1 Problems:
Problem 1: The automatic flag raising system on a horizontal flagpole attached to the vertical outside wall of a tall building has become stuck. The management of the building wants to send a person crawling out along the flagpole to fix the problem. Because of your physics knowledge, you have been asked to consult with a group to decide whether or not this is possible. You are all too aware that no one could survive the 250 foot fall from the flagpole to the ground. The flagpole is a 120 lb steel I-beam which is very strong and rigid. One side of the flagpole is attached to the wall of the building by a hinge so that it can rotate vertically. Nine feet away, the other end of the flagpole is attached to a strong, lightweight cable. The cable goes up from the flagpole at an angle of 30o until it reaches the building where it is bolted to the wall. The mechanic who will climb out on the flagpole weighs 150 lbs including equipment. From the specifications of the building construction, both the bolt attaching the cable to the building and the hinge have been tested to hold a force of 500 lbs. Your boss has decided that the worst case is when the mechanic is at the far end of the flagpole, nine feet from the building.

Problem 2: Because of your physics background, you have been asked to be a stunt consultant for a motion picture about a genetically synthesized prehistoric creature that escapes from captivity and terrorizes the city. The scene you are asked to review has the three main characters of the movie being chased by the creature through an old warehouse. At the exit of the warehouse is a thick steel fire door 10 feet high and 6.0 feet wide weighing about 2,000 pounds. In the scene, the three actors are to flee from the building and close the fire door (initially at rest), thus sealing the creature inside the building. With the creature running at 30 mph, they have 5.0 seconds to shut the door. You are asked to determine if they can do it. You estimate that each actor can each push on the door with a force of 50 pounds. When they push together, each actor needs a space of about 1.5 feet between them and the next actor. The door, which has a moment of inertia of $(1/3)MR^2$ around its hinges, needs to rotate 120 degrees for it to close completely.

Problem 3: While watching the local TV news show, you see a report about ground water contamination and how it effects farms which get their water from wells. For dramatic effect, the reporter stands next to an old style well which still works by lowering a bucket at the end of a rope into a deep hole in the ground to get water. At the top of the well a single vertical pulley is mounted to help raise and lower the bucket. The thin rope passes over the large pulley which is essentially a heavy steel ring supported by light spokes. To demonstrate the depth of the well, the reporter completely wraps the rope around the pulley and suspends the bucket from one end. She then releases the bucket, at rest near the pulley, and it descends to the bottom of the well unwinding the rope from the pulley as it falls. It takes 2.5 seconds. She doesn't tell you the depth of the well so you decide to calculate it. You estimate that the pulley has the same mass of the bucket and assume that the mass of the rope and any friction can be neglected.

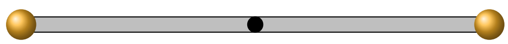
Problem 4: A grindstone in the shape of a solid disk with diameter 0.520 m and a mass of 50.0 kg is rotating at 850 rev/min. You press an ax against the rim with a normal force of 160 N and the grindstone comes to rest in 7.50 s. Find the coefficient of friction between the ax and the grindstone. You can ignore friction in the bearings.



Group 2 Problems:

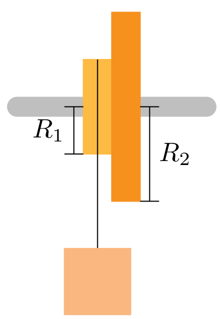
Problem 5: A bowling ball rolls without slipping up a ramp that slopes upward at an angle β to the horizontal. Treat the ball as a uniform solid sphere, ignoring the finger holes. (a) Draw the free body diagram for the ball. Explain why the friction force must be directed uphill. (b) What is the acceleration of the center of mass of the ball? (c) What minimum coefficient of static friction is needed to prevent slipping?

Problem 6: A thin, uniform, 3.80 kg bar, 80.0 cm long, has very small 2.50 kg balls glued on at either end. It is supported horizontally by a thin, horizontal, frictionless axle passing through its center and perpendicular to the bar. Suddenly the right-hand ball becomes detached and falls off, but the other ball remains glued to the bar. (a) Find the angular acceleration of the bar just after the ball falls off. (b) Will the angular acceleration remain constant as the bar continues to swing? If not, will it increase or decrease? (c) Find the angular velocity of the bar just as it swings through its vertical position.



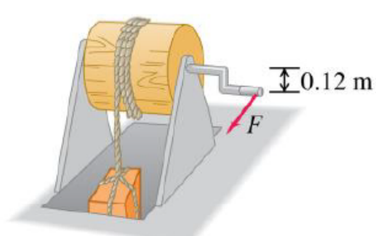
Problem 7: A uniform, 8.40 kg, spherical shell 50.0 cm in diameter has four small 2.00 kg masses attached to its outer surface and equally spaced around it. This combination is spinning about an axis running through the center of the sphere and two of the small masses. What friction torque is needed to reduce its angular speed from 75.0 rpm to 50.0 rpm in 30.0 s?

Problem 8: Two metal disks, one with radius $R_1 = 2.50$ cm and mass $M_1 = 0.80$ kg and the other with radius $R_2 = 5.00$ cm and mass $M_2 = 1.60$ kg, are welded together and mounted on a frictionless axis through their common center (see figure). (a) A light string is wrapped around the edge of the smaller disk, and a 1.50 kg block is suspended from the free end of the string. What is the magnitude of the downward acceleration of the block after it is released? (b) Repeat the calculation of part (a), this time with the string wrapped around the edge of the larger disk. In which case is the acceleration of the block greater? Does your answer make sense?

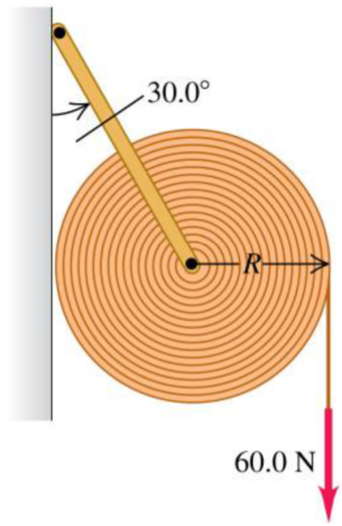


Group 3 Problems:

Problem 9: The mechanism shown in the figure is used to raise a crate of supplies from a ship's hold. The crate has total mass 50 kg. A rope is wrapped around a wooden cylinder that turns on a metal axle. The cylinder has a radius 0.25 m and moment of inertia I = 2.9 kg·m^2 about the axle. The crate is suspended from the free end of the rope. One end of the axle pivots on frictionless bearings; a crank handle is attached to the other end. When the crank is turned, the end of the handle rotates about the axle in a vertical circle of radius 0.12 m, the cylinder turns, and the crate is raised. What magnitude of the force $\vec{F}$ applied tangentially to the rotating crank is required to raise the crate with an acceleration of 1.40 m/s^2? (You can ignore the mass of the rope as well as the moments of inertia of the axle and the crank.)



Problem 10: A large 16.0 kg roll of paper with radius $R = 18.0$ cm rests against a wall and is held in place by a bracket attached to a rod through the center of the roll (see figure). The rod turns without friction in the bracket, and the moment of inertia of the paper and rod about the axis is 0.260 kg$\cdot$m^2. The other end of the bracket is attached by a frictionless hinge to the wall such that the bracket makes an angle of 30.0 degrees with the wall. The weight of the bracket is negligible. The coefficient of kinetic friction between the paper and the wall is $\mu_k = 0.25$. A constant vertical force $F = 60.0$ N is applied to the paper, and the paper unrolls. What is the magnitude of (a) the force that the rod exerts on the paper as it unrolls, and (b) the angular acceleration of the roll?



Problem 11: You complain about fire safety to the landlord of your high-rise apartment building. He is willing to install an evacuation device if it is cheap and reliable, and he asks you to design it. Your proposal is to mount a large wheel (radius 0.400 m) on an axle at its center and wrap a long, light rope around the wheel, with the free end of the rope hanging just past the edge of the roof. Residents would evacuate to the roof and, one at a time, grasp the free end of the rope, step off the roof, and be lowered to the ground below. (Ignore friction at the axle.) You want a 90.0 kg person to descend with an acceleration of $g/4$. (a) If the wheel can be treated as a uniform disk, what mass must it have? (b) As the person descends, what is the tension in the rope?

Problem 12: You are designing a system for moving aluminum cylinders from the ground to a loading dock. You use a sturdy wooden ramp that is 6.00 m long and inclined at 37.0 degrees above the horizontal. Each cylinder is fitted with a light, frictionless yoke through its center, and a light (but strong) rope is attached to the yoke. Each cylinder is uniform and has mass 460 kg and radius 0.300 m. The cylinders are pulled up the ramp by applying a constant force F to the free end of the rope. F is parallel to the surface of the ramp and exerts no torque on the cylinder. The coefficient of static friction between the ramp surface and the cylinder is 0.120. (a) What is the largest magnitude F can have so that the cylinder still rolls without slipping as it moves up the ramp? (b) If the cylinder starts from rest at the bottom of the ramp and rolls without slipping as it moves up the ramp, what is the shortest time it can take the cylinder to reach the top of the ramp?