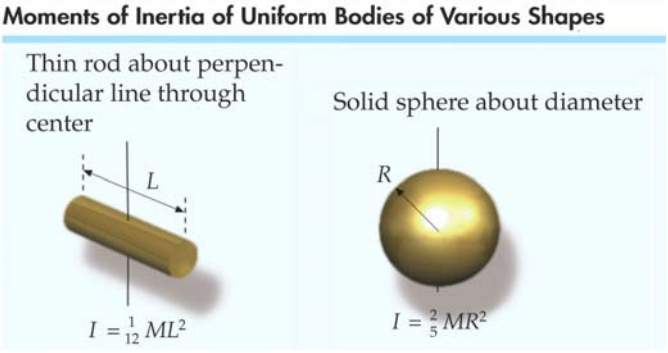
INSTRUCTIONS: Write your NAME and LECTURE SECTION (I: Ruchti, II: Hildreth) on the front of the blue exam booklet. The exam is closed book, and you may have only pens/pencils and a calculator (no stored equations or programs and no graphing). Show all of your work in the blue book. For problems II-V, an answer alone is worth very little credit, even if it is correct – so show how you get it.

Suggestions: Draw a diagram when possible, circle or box your final answers, and cross out parts which you do not want us to consider.

Moments of Inertia of Uniform Bodies of Various Shapes



I. Multiple Choice Questions (4 points each) Please write the letter corresponding to your answer for each question in the grid stamped on the first *inside* page of your blue book. No partial credit is given for these questions.

1. An object of mass 1 kg is moving initially with a velocity 3 m/s, moving in the positive direction along the *x* axis. A force then acts on the object for 0.5 seconds. Afterwards, the object moves with a velocity of 4 m/s in the positive direction along the *y* axis. The average force that acted on the object had a magnitude of:

(a) 5 N (b) 10 N (c) 1 N (d) 7 N (e) none of these

2. A truck of mass 2000 kg engages in a head-on, perfectly inelastic collision with a water buffalo of mass 500 kg (*i.e.*, their initial velocities are in opposite directions.). The initial velocity of the truck is 5 m/s, and the initial velocity of the buffalo is 2 m/s. What is the ratio of the final to the initial kinetic energy of the system?

(a) 1.25 (b) 0.62 (c) 0.68 (d) 0.31 (e) 1.96

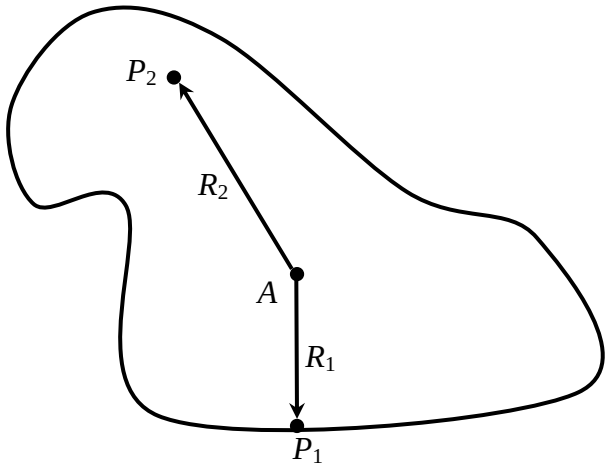
3. A solid disk spins about its axis of symmetry with an angular velocity $\omega_0 = 2\pi$ rad/s. It is decelerated to rest in 10 seconds. The total angle (in radians) through which the disk turns in this time interval is:

(a) 20π (b) 4π (c) π (d) 2π (e) 10π

4. In the figure below, $R_2 > R_1$, and the point *A* marks the center of mass of the object. The following moments of inertia are calculated about axes perpendicular to the plane of the paper: the moment of inertia about an axis through point P_1 is I_1, the moment of inertia about an axis through P_2 is I_2, and the moment of inertia about an axis through point *A*, the center of mass, is I_{cm}. Which of the relationships among the moments of inertia shown below is true?

(a) $I_1 = I_2 > I_{cm}$ (b) $I_1 = I_2 < I_{cm}$ (c) $I_1 > I_2 > I_{cm}$

(d) $I_2 > I_1 > I_{cm}$ (e) $I_2 < I_2 < I_{cm}$



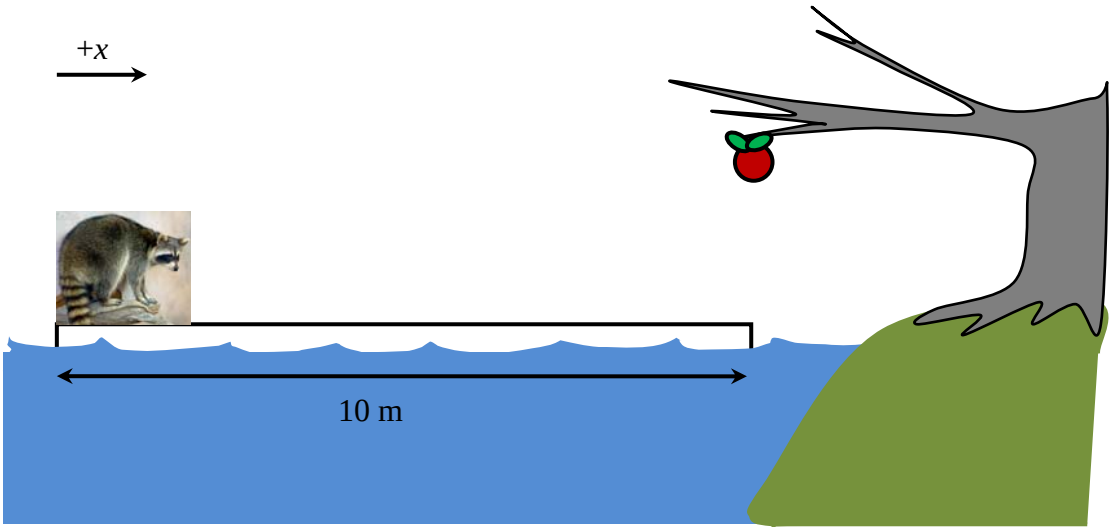
5. A cylindrical winch of radius 0.5 m rotates at a constant 100 revolutions per minute. The winch is driven by a motor that generates a total torque of 50000 Nm while lifting a heavy container off of a cargo ship. The total power generated by the winch is

(a) 83 kW (b) 261 kW (c) 400 kW (d) 523 kW (e) 5000 kW

Problems (20 points each)

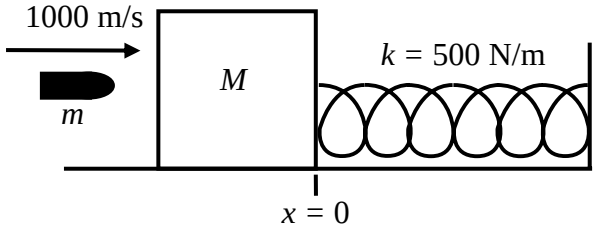
II. A raccoon standing at one end of a 10 meter-long floating log notices an apple hanging from a tree branch directly over the far end of the log. The raccoon starts walking along the log at a constant velocity of $\boldsymbol{u} = 0.1$ m/s $\hat{\mathbf{i}}$ toward the apple; this is the velocity of the raccoon *with respect to the log*. Assume the mass of the raccoon is m = 25 kg and the mass of the log is M = 100 kg. Neglect the size of the raccoon. (Depending on your choice of method, you may answer (b) before (a).)

a) As the raccoon is walking, what is the velocity of the log with respect to the shore?
b) When the raccoon reaches the opposite end of the log, how far is he horizontally from the apple he desires?



III. A bullet of mass m = 5 grams travelling at 1000 m/s strikes and sticks instantaneously in a massive block of mass M = 20 kg which is attached to a massless spring that is initially uncompressed. The spring constant of the spring is k = 500 N/m.

a) Find the recoil velocity V of the block/bullet system at the moment immediately after impact, before the string begins to compress.
b) Assuming the surface on which the block rests is frictionless, find the distance of maximum compression of the spring after the collision.
c) Assuming the surface on which the block rests has a coefficient of kinetic friction $\mu_k = 0.2$, find the distance of maximum compression of the spring after the collision. (Hint: use the Work-Energy Theorem.)



IV. A barbell spins in the vertical plane about a horizontal axis perpendicular to the bar separating the two uniform spherical weights, as shown in the figure below, left. Each of the spherical weights has mass *M* and radius *R*; the thin bar separating them has mass *m* and length *L*.

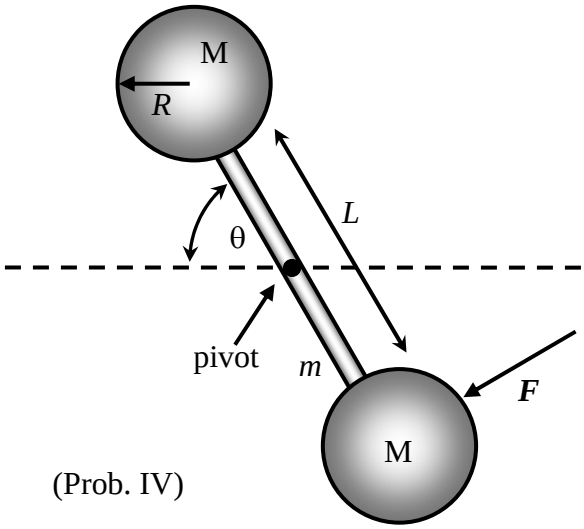
a) Find the moment of inertia of the barbell as it spins about the axis shown, which lies midway between the two spheres. (Hint: the parallel axis theorem may be useful here.)

b) At an arbitrary angle θ away from the horizontal, what is the total torque due to gravity on the barbell? Show your calculation.

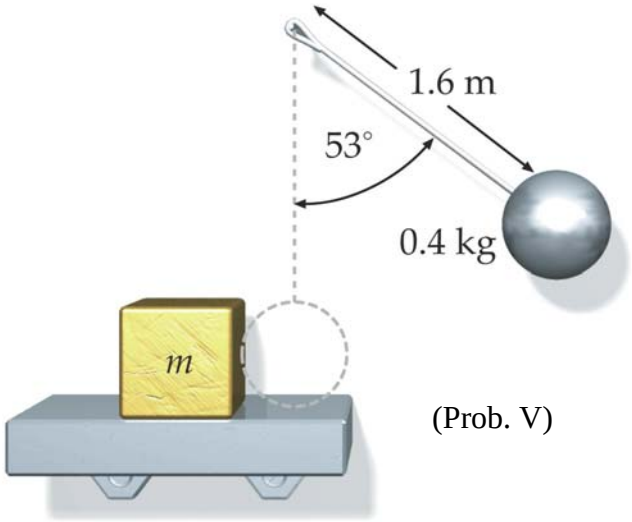
Now, a uniform force ***F*** = 44 N is applied to one of the weights, as shown. The force ***F*** remains perpendicular to the central bar as the system rotates. You are given the following dimensions: *m*=0.2 kg, *L*=20 cm, *R*=10 cm.

c) What is the torque due to the force ***F*** ?

d) If the observed angular acceleration is 10 rad/s^2, what is the mass *M* ?



(Prob. IV)



(Prob. V)

V. As show in the figure, above right, a pendulum consists of a 0.4 kg bob attached to a string of length 1.6 m. A block of mass *m* rests on a horizontal frictionless surface. The pendulum is released from rest at an angle of 53° with the vertical, and the bob collides *elastically* with the block. Following the collision, the block slides away and the pendulum swings back up to a maximum angle of 5.73° from the vertical. Each of the velocities requested below should be given with an appropriate sign in your chosen coordinate system to indicate direction.

a) Find the velocity of the pendulum bob just as is strikes the block.

b) Find the velocity of the pendulum bob just after it strikes the block.

c) Find the velocity of the block after the collision.

d) Find the unknown mass *m*.