Physics 8, Fall 2019, Homework #4.

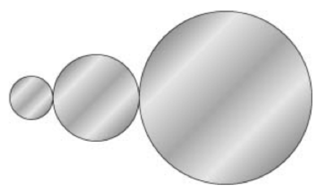
Due at start of class on Friday, September 27, 2019

Problems marked with (*) must include your own drawing or graph representing the problem and at least one complete sentence describing your reasoning.

Remember **online response** at `positron.hep.upenn.edu/wja/jitt/?date=2019-09-27`

(Chapter 6 problem.)

1. Let $x = 0$ be the left side of the left circle shown below, and let the x axis point to the right. (a) Find the x coordinate of the center of mass of the system shown below. All three circles are made of sheet metal of the same material, and the diameters are 2.00 m, 4.00 m, and 6.00 m. (b) Repeat the calculation for three solid spheres all made of the same material and having the same diameters as in part a. Hint: to find the CoM, you can replace each circle or sphere with a point mass (of the same mass) at the circle or sphere's own CoM, then find the CoM of those three point masses.



(Chapter 7 problems.)

2. Two toy cars ($m_1 = 0.350\,\mathrm{kg}$, $m_2 = 0.225\,\mathrm{kg}$) are held together rear to rear with a compressed spring between them. When they are released, the cars are free to roll away from the ends of the spring. If you measure the acceleration of car 1 (the 0.350 kg car) to be $2.75\,\mathrm{m/s^2}$ to the right, what is the acceleration of the other car?

3*. Two blocks of inertia (i.e. mass) 3.3 kg each are connected by a string that is draped over the edge of a table, so that one block is on the slippery table and the other is just hanging off the edge. A restraint holds the block on the table in place, and the string is 0.75 m long. After the restraint is released, what speed does each block have at the instant the upper block is pulled off the table? (Think about the two blocks' changes in K.E., and think about the second block's change in G.P.E. Assume that the string stays taut.)

4. You drop a rubber ball from a height of 5.00 m. It bounces off a concrete surface to a height of 4.05 m. (a) What is the coefficient of restitution, e, for this collision? (b) You want to get the ball to bounce upward (assuming same e) to a height of 7.55 m. How fast must you throw it (from the initial height 5.00 m), and in which direction?

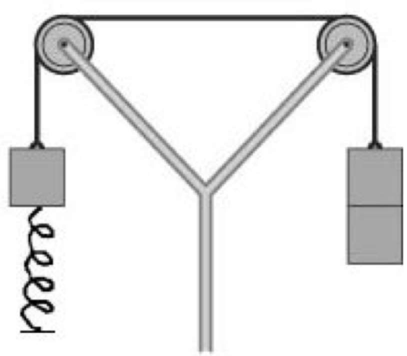
(Or maybe the direction doesn't matter?) Use the same restitution coefficient that you found in the first part. Neglect air resistance.

(Chapter 8 problems)

5*. You want to hang a potted plant from the ceiling of an elevator that has a maximum acceleration of $3.1\,\mathrm{m/s^2}$. (a) If you hang the plant with fishing line that supports a maximum tension of $54\,\mathrm{N}$ (i.e. its tensile strength is $54\,\mathrm{N}$), what is the maximum inertia the plant can have if the line is not to break? (b) What combination(s) of slowing down, speeding up, going up, and going down will cause the most tension? (Explain.)

6. You are climbing a rope straight up toward the ceiling. (a) What are the magnitude and direction of the force you must exert on the rope in order to accelerate upward at $1.05\,\mathrm{m/s^2}$, assuming your inertia is $65.0\,\mathrm{kg}$? (b) If the maximum tension the rope can support (a.k.a. its tensile strength) is $1035\,\mathrm{N}$, what is the maximum inertia the rope can support at this acceleration? Assume that the inertia of the rope is so small that the graviational force on the rope itself can be ignored.

7*. A modified Atwood machine is shown below. Each of the three blocks has the same inertia m. One end of the vertical spring, which has spring constant k, is attached to the single block, and the other end of the spring is fixed to the floor. The positions of the blocks are adjusted until the spring is at its **relaxed** length. The blocks are then released from rest. What is the acceleration of the two blocks on the right after they have fallen a distance D? (Your answer should be a symbolic expression for a_x, expressed in terms of m, g, k, and D. Be sure to indicate what convenion you use for the meaning of the sign of a_x.)



8. A 1700 kg truck and a 950 kg car are parked with their rear bumpers nearly touching each other in a level parking lot. Both vehicles have their brakes off so that they are free to roll. A woman sitting on the rear bumper of the truck exerts a constant horizontal force on the rear bumper of the car with her feet, and the car

accelerates east at $1.5\,\mathrm{m/s^2}$. (a) What are the magnitude and acceleration of the center of mass of the car+truck system? (You can consider the woman to be part of the truck that she sits on, and consider her mass to be included in the stated mass of the truck.) (b) What are the forces (magnitude and direction) exerted on each vehicle by the woman? (c) What are the magnitude and direction of the acceleration of the truck? Ignore any friction between tires and parking lot surface.

9*. A tugboat pulls two barges (connected in series, like a train) down a river. The barge connected to the tugboat, carrying coal, has inertia $2.20 \times 10^3\,\mathrm{kg}$. The other barge, carrying pig iron, has inertia $3.30 \times 10^3\,\mathrm{kg}$. The frictional force between the coal barge and the water is $6.50 \times 10^3\,\mathrm{N}$, and that between the pig-iron barge and the water is $9.70 \times 10^3\,\mathrm{N}$. The common acceleration of all three boats is $0.250\,\mathrm{m/s^2}$. Even though the ropes are huge, the gravitational force exerted on them is negligible, as are their inertias. (a) What is the tension in the rope conecting the tugboat to the coal barge? (b) What is the tension in the rope connecting the two barges? (c) Repeat parts (a) and (b) for the case in which the order of the barges is reversed.

10*. A red 10.0 kg cart is connected to a green 10.0 kg cart by a relaxed spring of spring constant 30.0 N/m. The green cart is resting against another 10.0 kg cart, this one blue. All are on a low-friction track. You push the red cart to the right, in the direction of the green cart, with a constant force of 15.0 N. (a) What is the acceleration of the center-of-mass of the three-cart system? (b) What is the acceleration of each cart the instant you begin to push? (c) What is the acceleration of each cart when the spring is compressed 0.200 m? (d) What is the vector sum of forces (sometimes called "the net force," though not in our textbook) on each cart in part (c)?

(Chapter 8 conceptual questions. These questions require no calculations. Just think about them and write your answer as either (a) a sentence, or (b) a few words and a quick drawing — whichever is more appropriate for the problem. Very short answers are fine, as long as your reasoning is clear. You will probably learn a lot by discussing these questions with your fellow students. To make Greg's job easier, please try to make these answers as clear and succinct as possible.)

11. A worker pushes boxes in a factory. In each case decide which force has the greater magnitude — the force exerted by the worker on the box or the force exerted by the box on the worker. (a) The box is heavy and does not move no matter how hard she pushes. (b) Some contents are removed, and now when pushed the box slides across the floor at constant speed. (c) The worker pushes harder, and the box accelerates.

12. A pitcher has thrown a fastball toward home plate. (a) When it is halfway to

the plate, does the ball still feel the pitcher's push? Explain your answer. (b) What forces does the ball feel, if any?

13. You push on a refrigerator, but it does not move. Explain how this can be.

14. You are in a stationary elevator, so that the contact force exerted by the floor on you is equal in magnitude to the force of gravity acting on you. When the elevator starts downward, which force changes? What happens to its magnitude?

15. When you are standing motionless on the ground, your feet are exerting a force on Earth. Why doesn't Earth move away from you?

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XC1*. Optional / extra-credit. (From Chapter 6.) An 0.045 kg golf ball moving at 79 m/s collides inelastically with a 1.9 kg heavy-duty plastic flowerpot sitting on a windowsill. The coefficient of restitution for the collision is 0.50. Find the final velocities of the ball and the pot. Do this problem by first transforming to the zero-momentum frame, where the collision is much simpler, and then transforming back to the Earth frame. (Assume that all the action happens in one dimension and that the friction between pot and sill is insignificant.)

XC2*. Optional / extra-credit. (From Chapter 6.) A golf club of mass M is moving at speed V_i when it strikes (elastically) a stationary golf ball of mass m. Work in the ZM frame of the collision. Show that in the limit $M \gg m$, the golf ball's speed after the collision is $v_f = 2V_i$. Hint 1: in the limit $M \gg m$, the ZM frame is the same as the rest frame of the golf club. Hint 2: for an elastic collision as seen in the ZM frame, each final velocity is just the negative of the corresponding initial velocity. You can see this factor of two at `youtu.be/U3j-o3UXRSI` .

XC3*. Optional / extra-credit. (From Chapter 6.) A baseball bat of mass M and swing speed V_s elastically hits an incoming baseball of mass m moving with pitch speed v_p. As in XC2, work in the limit $M \gg m$ and analyze in the ZM frame (which in the $M \gg m$ limit is the rest frame of the bat). Show that in this limit, the final speed v_f of the ball is $v_f = v_p + 2V_s$. So a faster pitch makes it easier to hit a home run. Notice that for $v_p = 0$ this problem becomes XC2.

XC4*. Optional / extra-credit. (From Chapter 6.) A tennis ball of mass m is put on top of a basketball of mass M, and the combination is dropped from a given height. (a) If the speed that the tennis ball has just before the basketball hits the ground is v_i, show that the speed at which the tennis ball rebounds is $v_f = 3v_i$. To do this, assume $M \gg m$ and analyze from the ZM frame (which in the limit $M \gg m$ is the rest frame of the basketball). (b) If the tennis ball rebounds at $3\times$ the speed of the basketball, how should the maximum height (after rebounding) of the tennis ball compare with the maximum height (after rebounding) of the basketball?

XC5*. Optional / extra-credit. (From Chapter 7.) A 50.0 kg woman standing on a frozen lake tosses an 0.500 kg football to her dog. (a) If the ball leaves her hands at a speed of 15.0 m/s, how much source energy did she have to provide? (Remember that the woman will recoil when she throws the ball!) (b) Her 20.0 kg dog, standing still, catches the ball and slides with it. How much energy is dissipated in the catch?

XC6*. Optional / extra-credit. (From Chapter 7.) Two 1.20 kg carts on an air track are rigged with magnets so that the carts repel each other when they approach one another. One cart has an initial velocity of 0.323 m/s, and the other has an initial velocity of -0.147 m/s. What is the maximum energy stored in the magnetic field during the collision, assuming that the carts never actually make contact with each other?

XC7*. Optional/extra-credit. (From Chapter 8.) A 15 kg bunch of bananas is tied to a rope thrown over a tree limb (see figure below), and a 12 kg monkey wants to hide the bananas in the tree, away from other hungry animals. Monkeys don't take physics classes, but you can probably figure out a method to help your friend the monkey understand how to get all the bananas into the tree without having to eat any first. Ignore any friction between rope and branch, and assume that all the force the monkey exerts on the rope is transmitted undiminished to the bananas. Be quantitative!