Physics 8, Fall 2019, Homework #3.

Due at start of class on Friday, September 20, 2019

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

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(Chapter 4 problems. The first one mixes Chapters 3 and 4. The last one mixes chapters 4 and 5.)

1*. In the process of moving out of your house, you are dropping stuff out a second-floor window to a friend 7.25 m below. You are about to drop a 9.25 kg stereo speaker when you remember that your friend cannot catch anything that has a momentum greater than 100. kg·m/s (that's 1.00×10^2 kg·m/s). Should you drop the speaker?

2. At an amusement park, a 145 kg bumper car traveling east at 2.85 m/s collides head-on with a 175 kg bumper car traveling at 1.35 m/s in the opposite direction. The bumper cars do not have brakes. You do not know anything about the type of material used in the bumper cars' bumpers, e.g. how well it regains its initial shape after being deformed. So the cars may stick together, may recoil, or something in between. (a) From the given information, is it possible to predict the velocities of the two cars after the collision? Explain your answer. (b) Is it possible to predict the value that any pertinent physical quantity has after the collision? If so, state that quantity and its final value. (Hint: think of a quantity whose units are kg·m/s.)

3*. A green shopping cart of inertia 15.3 kg rolls into a stationary blue cart of inertia 24.5 kg. The green cart's initial velocity is 0.475 m/s eastward. After the collision, the blue cart has a velocity of 0.245 m/s eastward. (a) What is the final velocity (magnitude and direction) of the green cart? (b) What is the coefficient of restitution of this collision?

(Chapter 5 problems. Note that Equation 5.4 hugely simplifies calculations involving elastic collisions.)

4*. A wagon is coasting along a level sidewalk at 15.0 m/s. Its wheels have very good bearings. You are standing on a very low wall and drop vertically (a very short distance) into the wagon as it passes by. The wagon has an inertia of 75.0 kg, and your inertia is 55.0 kg. (a) Use conservation of momentum to determine the (horizontal) speed of the wagon after you are in it. (b) Use conservation of energy to determine that speed. (c) After comparing your answers, explain which method is correct and which is incorrect (and why). [Hint: notice that you and the wagon are stuck together after you land in it. Also assume for part (b) that your vertical motion before landing in the wagon is negligibly slow, since you dropped only a very short distance.]

5. You have an inertia of 57.0 kg and are standing at rest on an iced-over pond in your skates. Suddenly, your 73.0 kg brother skates in from the left at $v_x = +4.0\,\mathrm{m/s}$ and collides elastically with you. (a) What is the two siblings' relative speed before the collision? (b) Given the details stated of the collision, what do you expect the two siblings' relative speed to be after the collision? (c) If your brother's final velocity is $v_x = +0.492\,\mathrm{m/s}$, what is your final velocity (computed using momentum conservation)? (d) Is your answer to part c consistent with your answer to part b? (e) What is the change in kinetic energy of the you+brother system? (You can either calculate this change explicitly or else argue from the problem details what the physics says this change must be.)

6*. An experienced bartender knows just how fast to push a glass of beer to get it to come to a stop in front any customer sitting along the bar. Say the initial speed needed to move a glass all the way to the end of the bar is v_{end}. In terms of v_{end}, how fast (i.e. what fraction of v_{end}) does she have to push an identical glass of beer if it is to stop at a customer sitting halfway down the bar? (The only thing you need to know about friction at this stage is that the kinetic energy converted to thermal energy because of friction is proportional to the distance the glass skids. The glass of beer comes to a stop when all of its initial kinetic energy has been dissipated by friction into thermal energy.)

7. A 2500 kg truck is sitting at rest (in neutral) when it is rear-ended by a 1500 kg car going 20.0 m/s. After the collision, the two vehicles stick together. (a) What is the final speed of the car-truck combination? (b) What is the kinetic energy of the two-vehicle system before the collision? (c) What is the kinetic energy of the system after the collision? (d) Based on the results of (b) and (c), what can you conclude about which type of collision this is? [You can learn from (b) and (c) whether or not the collision is elastic, but you can't easily tell from (b) and (c) whether the collision is inelastic vs. totally inelastic.] (e) Calculate the coefficient of restitution for this collision. Is this the result you would expect for the coefficient in this type of collision?

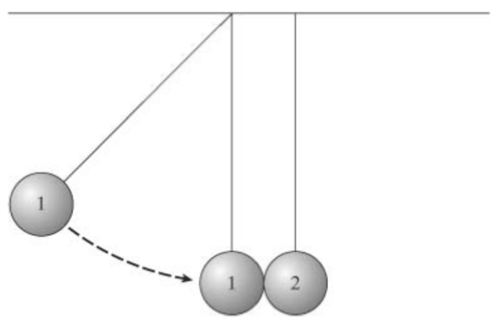
8*. Two carts, of inertias m_1 and m_2, collide head-on on a low-friction track. Before the collision, which is elastic, cart 1 is moving to the right at 6.0 m/s and cart 2 is at rest. After the collision, cart 1 is moving to the left at 2.0 m/s. (a) What are the speed and direction of motion of cart 2 after the collision? (b) If $m_2 = 6.0\,\mathrm{kg}$, what is the value of m_1?

9. A 41.0 kg (including clothing and several 1.00 kg snowballs) ice skater is at rest on the ice. She throws a snowball to the right at 20.0 m/s. (a) What is her speed after the throw? Is her velocity to the left or to the right? (b) Calculate the coefficient of restitution for this event. [The result is a very special "number."] She next throws a second snowball but this time at a speed of 10.0 m/s to the left (10.0 m/s is the snowball's speed in the Earth frame after the throw). (c) What is her speed after this throw? Is her velocity to the left or to the right? (d) Calculate the change in kinetic energy in the **first** event (from part a). Where does the added kinetic energy come from? (e) If one food Calorie equals 4184 J,

how many Calories does the skater burn when she throws the first snowball? (Assume, unrealistically, that all of the energy burned goes into motion of the snowball and of the skater.)

10. A system consists of a 2.00 kg cart and a 1.00 kg cart attached to each other by a compressed spring. Initially, the system is at rest on a low-friction track. When the spring is released, an explosive separation occurs at the expense of the internal energy of the compressed spring. If the decrease in the spring's internal energy during the separation is 10.0 J (that's 10.0 joules), what is the speed of each cart right after the separation?

11. Two solid spheres hung by thin threads from a horizontal support (figure below) are initially in contact with each other. Sphere 1 has inertia $m_1 = 1.00\,\text{kg}$, and sphere 2 has inertia $m_2 = 2.00\,\text{kg}$. When pulled to the left and then released, sphere 1 collides elastically with sphere 2. At the instant just before the collision takes place, sphere 1 has kinetic energy $K_1 = 0.500\,\text{J}$. (a) What is the velocity of sphere 1 right before the collision? (b) What is the kinetic energy of the system before the collision? (c) What is the velocity of each sphere after the collision? (d) From part c, calculate the kinetic energy after the collision. Does the value you get equal the result from part b? Explain why or why not. (e) Calculate the coefficient of restitution of the collision. Is this the result you expect?



12. Let's redo the previous problem, but now with two spheres made of modeling clay. As before, sphere 1 has inertia $m_1 = 1.00\,\text{kg}$, and sphere 2 has inertia $m_2 = 2.00\,\text{kg}$. Again, sphere 1 is pulled left, is released, and collides with sphere 2. This time, though, the two spheres stick together. Assume that sphere 1 again has a kinetic energy of 0.500 J just before the collision. (a) What is the initial velocity of sphere 1? (b) What is the kinetic energy of the system before the collision? (c) What is the final velocity of each sphere? (d) What is the kinetic energy of the system after the collision? Is this the same value you calculated in part b? (e) Based on what you have calculated so far, what kind of collision is this? (f) Calculate the coefficient of restitution. Is the value you get consistent with your answer to part e?

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XC1*. Optional / extra-credit. The extinction of the dinosaurs has been attributed to a collision between Earth and an asteroid about 10 km in diameter. Assume that the asteroid had about the same density as Earth. (Earth's mass is 6.0×10^{24} kg, and its **circumference** is 40,000 km.) Also assume that the asteroid's initial speed with respect to Earth is about the same as Earth's orbital speed around the sun. (This is equivalent to assuming that the moving Earth slams (totally inelastically) into a stationary asteroid.) Estimate the energy released by such an impact. Express your estimate in terms of "megatons of TNT equivalent." (Detonating 1 megaton of TNT releases an energy of 4.2×10^{15} joules. Earth's orbital speed around the sun is about 30 km/s.)

XC2*. Optional / extra-credit. (a) Show that in an elastic collision between two objects of inertias m_1 and m_2, with initial velocities $v_{1i} > 0$ and $v_{2i} = 0$, the final velocities are

$$v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_{1i}, \qquad v_{2f} = \left(\frac{2m_1}{m_1 + m_2}\right) v_{1i}.$$

Hint: The easy way to do this is to use Equation 5.4 for elastic collisions, along with momentum conservation. The difficult way (which I did when I first solved this problem) is to use the equation for energy conservation instead of Equation 5.4.
(b) Discuss the cases $m_1 \ll m_2$, $m_1 = m_2$, and $m_1 \gg m_2$. Using everyday objects, give an example of each of these three cases.

XC3*. Optional / extra-credit. Consider a two-stage rocket comprising two engine stages, each of inertia m when empty, and payload of inertia m. Stages 1 and 2 each contain fuel of inertia m, so that the rocket's inertia before any fuel is spent is $5m$. Each stage exhausts fuel at speed $v_{\text{fuel}} = v_{\text{ex}} - v_i$, where v_i is the speed of the rocket at the time the fuel is spent. (In other words, the fuel is ejected at a relative speed of v_{ex} with respect to the rocket.) The rocket is initially at rest in deep space. Stage 1 fires, ejects its fuel all at once, and then detaches from the remainder of the rocket. The same process is repeated with stage 2. (a) What is the final speed of the payload? (Hint: Determine the speed of the rocket after stage 1 fires. Then, because stage 1 is detached from the rocket, redefine the system to include only the payload and stage 2, and determine the speed of the rocket after stage 2 fires.) (b) Now consider another rocket of inertia $5m$ but with only a single engine stage, of inertia $2m$, carrying fuel of inertia $2m$. What is the final speed of the payload in this case? (c) Which design yields higher payload speed, the two-stage or the single-stage? Why?

XC4*. Optional / extra-credit. A common energy unit used in food chemistry is the Calorie (1 Cal = 1000 cal = 4184 J). What must be the speed of a 75.0 kg person whose kinetic energy numerically equals the food energy in a 220 Cal jelly donut? What is this speed in km/h? In miles/hour?