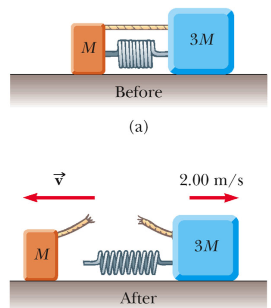
Homework 4 Momentum

1. How fast can you set the Earth moving? In particular, when you jump straight up as high as you can, what is the order of magnitude of the maximum recoil speed that you give to the Earth? Model the Earth as a perfectly solid object. In your solution, state the physical quantities you take as data and the values you measure or estimate for them.

2. (a) A particle of mass m moves with momentum p. Show that the kinetic energy of the particle is given by $K = p^2/2m$. (b) Express the magnitude of the particles momentum in terms of its kinetic energy and mass.

3. Two blocks with masses M and 3M are placed on a horizontal, frictionless surface. A light spring is attached to one of them, and the blocks are pushed together with the spring between them (see figure below). A cord initially holding the blocks together is burned; after this, the block of mass 3M moves to the right with a speed of 2.00 m/s. (a) What is the speed of the block of mass M? (b) Find the original elastic potential energy in the spring, taking M = 0.350 kg.

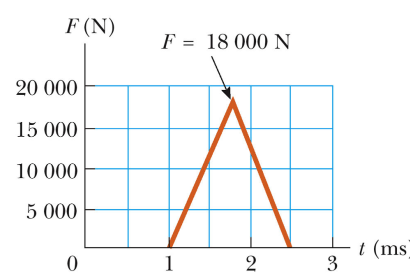


4. A railroad car of mass 2.50×10^4 kg is moving with a speed of 4.00 m/s. It collides and couples with three other coupled railroad cars, each of the same mass as the single car and moving in the same direction with an initial speed of 2.00 m/s. (a) What is the speed of the four cars after the collision? (b) How much mechanical energy is lost in the collision?

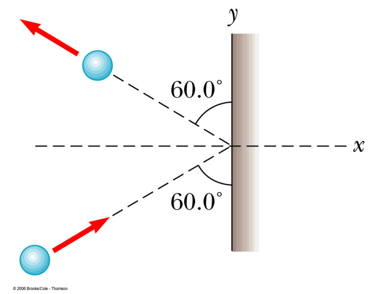
5. You are an astronaut on the International Space Station (ISS) and you have to go outside to repair a broken antenna. You don your spacesuit with its jet-pack for moving around in the zero-g environment and grab a large, $10-kg$ wrench. The total weight of you and your spacesuit (with attached jet-pack) is 100 kg. While outside on your EVA (Extra-Vehicular Activity) you decide to go on a joyride with your jet-pack, but end up running out of fuel and stuck about 30 m away from the ISS (oopps!). You don't want to call for help because it's too embarrassing and you only have enough air for another 30 minutes. Can you throw the wrench in any particular way so that you will drift back over to the ISS? Explain. What is the slowest speed you would have to throw it to reach the ISS before your air ran out?

6. A friend claims that as long as he has his seat belt on, he can hold on to a 12.0-kg child in a 60.0 mi/h head-on collision (which is about 27 m/s) with a brick wall in which the car passenger compartment comes to a stop in 0.050 0 s. Show that the violent force during the collision will tear the child from his arms. (A child should always be in a toddler seat secured with a seat belt in the back seat of a car.)

7. An estimated force-time curve for a baseball struck by a bat is shown in the figure. From this curve, determine (a) the impulse delivered to the ball, (b) the average force exerted on the ball, and (c) the peak force exerted on the ball.



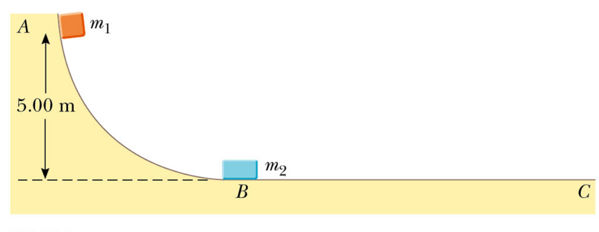
8. A 3.00-kg steel ball strikes a wall with a speed of 10.0 m/s at an angle of 60.0 deg with the surface. It bounces off with the same speed and angle (see figure). If the ball is in contact with the wall for 0.200 s, what is the average force exerted on the ball by the wall? Assume the force exerted by the wall is entirely normal/perpendicular to the wall



9. Most of us know intuitively that in a head-on collision between a dump truck and a subcompact car, you are better off being in the truck than in the car. Consider what happens to the two drivers. Suppose each vehicle is initially moving with a speed $v_0 = 10\ m/s$ and they undergo a perfectly inelastic, head-on collision. Each driver has a mass $m = 50\ kg$. Including the drivers the total vehicle masses are $m_c = 1000\ kg$ for the car and $m_t = 4000\ kg$ for the truck. What is the change in momentum $\Delta\vec{p}$ for each driver?

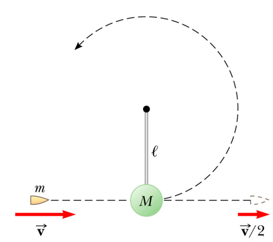
10. A space vehicle is traveling at $2.000 \times 10^3\ m/s$ relative to the Earth when the spent rocket motor is detached and sent backwards at a speed of 20.0 m/s relative to the remaining command module. The motor weighs five times the mass of the command module. What is the speed of the rocket motor relative to the Earth?

11. Two blocks with masses $m_1 = 5.00\ kg$ and $m_2 = 10.0\ kg$ are on a frictionless track shown to the right. The mass m_1 is released from A. It undergoes an elastic collision with the block of mass m_2 which is initially at rest. Calculate the maximum height to which m_1 rises after the elastic collision.

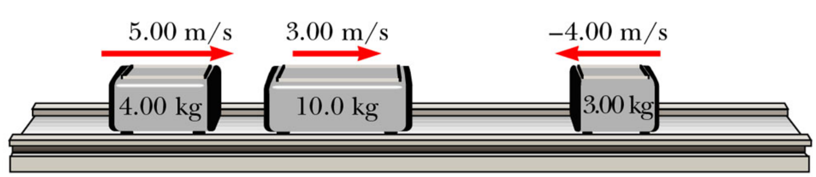


12. A neutron in a nuclear reactor makes an elastic head-on collision with the nucleus of a carbon atom initially at rest. (a) What fraction of the neutrons kinetic energy is transferred to the carbon nucleus? (b) Assume that the initial kinetic energy of the neutron is $1.60 \times 10^{-13}\ J$. Find its final kinetic energy and the kinetic energy of the carbon nucleus after the collision. (The mass of the carbon nucleus is nearly 12.0 times the mass of the neutron.)

13. As shown in the figure, a bullet of mass m and speed v passes completely through a pendulum bob of mass M. The bullet emerges with a speed of $v/2$. The pendulum bob is suspended by a stiff rod of length ℓ and negligible mass. What is the minimum value of v such that the pendulum bob will barely swing through a complete vertical circle?



14. a) Three carts of masses 4.00 kg, 10.0 kg, and 3.00 kg move on a frictionless, horizontal track with speeds of 5.00 m/s, 3.00 m/s, and -4.00 m/s, respectively, as shown in the figure below. Velcro couplers make the carts stick together after colliding. Find the final velocity of the train of three carts. (b) Does your answer require that all the carts collide and stick together at the same time? What if they collide in a different order?



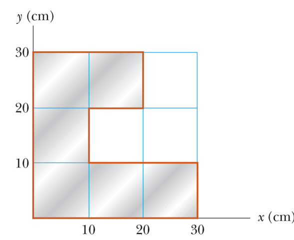
15. Much of our knowledge of the subatomic world is extracted with the help of the conservation laws. Consider this example of 'particle identification'. A particle known as a Δ^+ (a 'delta') is created by a nuclear collision in an accelerator with a momentum of $1.32 \times 10^{-20}\ kg-m/s$. After traveling a short distance it disintegrates into two other particles, a proton and an unknown object. The proton has a momentum of $8.35 \times 10^{-21}\ kg - m/s$ directed at an angle of 30° away from the original direction of the Δ^+. The unknown particle's kinetic energy is measured to be $1.11 \times 10^{-13} J$. What is it? You might find the table helpful.

Particle	Mass(kg)
Proton	1.67×10^{-27}
Neutron	1.67×10^{-27}
Pion	2.40×10^{-28}
Delta	2.19×10^{-27}
Kaon	8.87×10^{-28}
Muon	1.89×10^{-28}

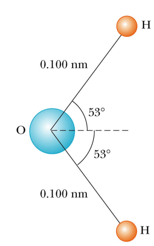
16. A football player of mass $m = 110\ kg$ is gliding across very smooth, frictionless ice at a speed $v_0 = 1.50\ m/s$ carrying a football of mass $m_b = 0.45\ kg$ (unless you're Tom Brady). He throws the football straight forward. What is the player's speed afterward if the ball is thrown at a speed $v_b = 20\ m/s$ relative to the ground?

17. Four objects are situated along the y axis as follows: a 2.00-kg object is at +3.00 m, a 3.00-kg object is at +2.50 m, a 2.50-kg object is at the origin, and a 4.00-kg object is at -0.500 m. Where is the center of mass of these objects?

18. A uniform piece of sheet steel is shaped as shown in the figure. Compute the x and y coordinates of the center of mass of the piece.



19. A water molecule consists of an oxygen atom with two hydrogen atoms bound to it (see figure). The angle between the two bonds is 106°. If the bonds are 0.100 nm long, where is the center of mass of the molecule?



20. A car of mass $m_1 = 1400\ kg$ heading north and moving at $v_1 = 35\ mph$ collides in a perfectly inelastic collision with a truck of mass $m_2 = 4000\ kg$ going East at $v_2 = 20\ mph$. What percentage of the total mechanical energy is lost from the collision?

21. A 90.0-kg fullback running east with a speed of 5.00 m/s is tackled by a 95.0-kg opponent running north with a speed of 3.00 m/s. Noting that the collision is perfectly inelastic, (a) calculate the speed and direction of the players just after the tackle and (b) determine the mechanical energy lost as a result of the collision. Account for the missing energy.

22. Two automobiles of equal mass approach an intersection. One vehicle is traveling with velocity 13.0 m/s toward the east, and the other is traveling north with speed v_{2i}. Neither driver sees the other. The vehicles collide in the intersection and stick together, leaving parallel skid marks at an angle of 55.0° north of east. The speed limit for both roads is 35 mi/h, and the driver of the northward-moving vehicle claims that he was within the speed limit when the collision occurred. Is he telling the truth?

23. Radioactive isotopes are now routinely used for a wide variety of biological, medical, and chemical tasks. To store these materials requires shielding to protect workers from different types of radiation. Shielding for one type of radiation, the emission of neutrons, works best if the neutrons lose a large fraction of their initial kinetic energy in colliding with the nuclei of the shielding material. Consider a neutron that scatters

elastically through 180° (a head-on collision) with the nucleus of a shielding atom. What is the ratio of the final kinetic to initial kinetic energy of the neutron? Get your answer in terms of the masses of the nuclei. Would heavy or light atomic nuclei make better shielding?

24. Two shuffleboard disks of equal mass, one orange and the other yellow, are involved in an elastic, glancing collision. The yellow disk is initially at rest and is struck by the orange disk moving with a speed v_i. After the collision, the orange disk moves along a direction that makes an angle θ with its initial direction of motion. The velocities of the two disks are perpendicular after the collision. Determine the final speed of each disk in terms of v_i and θ.

25. A billiard ball moving at 5.00 m/s strikes a stationary ball of the same mass. After the collision, the first ball moves at 4.33 m/s, at an angle of 30.0° with respect to the original line of motion. Assuming an elastic collision (and ignoring friction and rotational motion), find the struck balls velocity.

26. Show that if a neutron is scattered through 90° in an elastic collision with a deuteron that is initially at rest, the neutron loses two-thirds of its initial kinetic energy to the deuteron. The mass of the neutron is 1.0 u and the mass of the deuteron is 2.0 u.

27. An unstable atomic nucleus of mass 17.0×10^{-27} kg initially at rest disintegrates into three particles. One of the particles, of mass 5.00×10^{-27} kg, moves along the y axis with a velocity of 6.00×10^{6} m/s. Another particle, of mass 8.40×10^{-27} kg, moves along the x axis with a speed of 4.00×10^{6} m/s. Find (a) the velocity of the third particle and (b) the total kinetic energy increase in the process.

28. A 30 ton rail car and a 90 ton rail car, initially at rest, are connected together with a giant but massless compressed spring between them. When released, the 30 ton car is pushed away at a speed of 4.0 m/s relative to the 90 ton car. What is the speed of the 30 ton car relative to the ground?

29. A proton (mass 1 u) is shot at a speed of 5.0×10^{7} m/s toward a gold target. The nucleus of a gold atom (mass 197 u) repels the proton and deflects it straight back toward the source with 90of its initial speed. What is the recoil speed of the gold nucleus?