Chapter 8

Conservation of Linear Momentum
Problems: 4, 6, 7[!], 11, 18, 20, 33, 47, 87, 104
Think about: 40, 61, 106

4 • True or false:
(*a*) The total linear momentum of a system may be conserved even when the mechanical energy of the system is not.
(*b*) For the total linear momentum of a system to be conserved, there must be no external forces acting on the system.
(*c*) The velocity of the center of mass of a system changes only when there is a net external force on the system.

(*a*) **True**. Consider the collision of two objects of equal mass traveling in opposite directions with the same speed. Assume that they collide inelastically. The mechanical energy of the system is not conserved (it is transformed into other forms of energy), but the momentum of the system is the same after the collision as before the collision; that is, zero. Therefore, for any inelastic collision, the momentum of a system may be conserved even when mechanical energy is not.
(*b*) **False**. The *net* external force must be zero if the linear momentum of the system is to be conserved.
(*c*) **True**. This non-zero net force accelerates the center of mass. Hence its velocity changes.

6 • A child jumps from a small boat to a dock. Why does she have to jump with more effort than she would need if she were jumping through an identical displacement, but from a boulder to a tree stump?

Determine the Concept When she jumps from a boat to a dock, she must, in order for momentum to be conserved, give the boat a recoil momentum, i.e., her forward momentum must be the same as the boat's backward momentum. When she jumps through an identical displacement from a boulder to a tree stump, the mass of the boulder plus the Earth is so large that the momentum she imparts to them is essentially zero.

7 •• **[SSM]** Much early research in rocket motion was done by Robert Goddard, physics professor at Clark College in Worcester, Massachusetts. A quotation from a 1920 editorial in the *New York Times* illustrates the public opinion of his work: ″That Professor Goddard with his ′chair′ at Clark College and the countenance of the Smithsonian Institution does not know the relation between action and reaction, and the need to have something better than a vacuum against which to react—to say that would be absurd. Of course, he only seems to lack the knowledge ladled out daily in high schools.″ The belief that a rocket needs something to push against was a prevalent misconception before rockets in space were commonplace. Explain why that belief is wrong.

Determine the Concept In a way, the rocket does need something to push upon. It pushes the exhaust in one direction, and the exhaust pushes it in the opposite direction. However, the rocket does not push against the air.

11 • Several researchers in physics education claim that part of the cause of physical misconceptions amongst students comes from special effects they observe in cartoons and movies. Using the conservation of linear momentum, how would you explain to a class of high school physics students what is conceptually wrong with a superhero hovering at rest in midair while tossing massive objects such as cars at villains? Does this action violate conservation of energy as well? Explain.

Determine the Concept Hovering in midair while tossing objects violates the conservation of linear momentum! To throw something forward requires being pushed backward. Superheroes are not depicted as experiencing this backward motion that is predicted by conservation of linear momentum. This action also violates conservation of energy in that, with no change in the superheroes potential or kinetic energy resulting from the tossing of objects, the mechanical energy of the hero-object-Earth system is greater after the toss than it was before the toss.

18 •• Under what conditions can all the initial kinetic energy of an isolated system consisting of two colliding objects be lost in a collision? Explain how this result can be, and yet the momentum of the system can be conserved.

Determine the Concept If the collision is perfectly inelastic, the objects stick together and neither will be moving after the collision. Therefore the final kinetic energy will be zero and all of it will have been lost (that is, transformed into some other form of energy). Momentum is conserved because in an isolated system the net external force is zero.

20 •• A double-barreled pea shooter is shown in Figure 8-41. Air is blown into the left end of the pea shooter, and identical peas A and B are positioned inside the straw as shown. If the shooter is held horizontally while the peas are shot off, which pea, A or B, will travel farther after leaving the straw? Explain. Base your explanation on the impulse–momentum theorem.

Determine the Concept An impulse on an object changes the object's momentum. A will travel farther. Both peas are acted on by the same force, but pea A is acted on by that force for a longer time (which results in a greater impulse). By the impulse-momentum theorem, its momentum (and, hence, speed) will be higher than pea B's speed on leaving the shooter.

33 • **[SSM]** Tyrone, an 85-kg teenager, runs off the end of a horizontal pier and lands on a free-floating 150-kg raft that was initially at rest. After he lands on the raft, the raft, with him on it, moves away from the pier at 2.0 m/s. What was Tyrone's speed as he ran off the end of the pier?

Picture the Problem Let the system include the raft, the earth, and Tyrone and apply conservation of linear momentum to find Tyrone's speed when he ran off the end of the pier.

Apply conservation of linear momentum to the system consisting of the raft and Tyrone to obtain:

$$\Delta\vec{p}_{\text{system}} = \Delta\vec{p}_{\text{Tyrone}} + \Delta\vec{p}_{\text{raft}} = 0$$

or, because the motion is one-dimensional,

$$p_{\text{f,Tyrone}} - p_{\text{i, Tyrone}} + p_{\text{f,raft}} - p_{\text{i,raft}} = 0$$

Because the raft is initially at rest:

$$p_{\text{f,Tyrone}} - p_{\text{i, Tyrone}} + p_{\text{f,raft}} = 0$$

Use the definition of linear momentum to obtain:

$$m_{\text{Tyrone}}v_{\text{f,Tyrone}} - m_{\text{Tyrone}}v_{\text{i,Tyrone}} + m_{\text{raft}}v_{\text{f,raft}} = 0$$

Solve for $v_{\text{i,Tyrone}}$ to obtain:

$$v_{\text{i,Tyrone}} = \frac{m_{\text{raft}}}{m_{\text{Tyrone}}}v_{\text{f,raft}} + v_{\text{f,Tyrone}}$$

Letting v represent the common final speed of the raft and Tyrone yields:

$$v_{\text{i,Tyrone}} = \left(1 + \frac{m_{\text{raft}}}{m_{\text{Tyrone}}}\right)v$$

Substitute numerical values and evaluate $v_{\text{i,Tyrone}}$:

$$v_{\text{i, Tyrone}} = \left(1 + \frac{150\ \text{kg}}{85\ \text{kg}}\right)(2.0\ \text{m/s}) = \boxed{5.5\ \text{m/s}}$$

34 •• A 55-kg woman contestant on a reality television show is at rest at the south end of a horizontal 150-kg raft that is floating in crocodile-infested waters. She and the raft are initially at rest. She needs to jump from the raft to a platform that is several meters off the north end of the raft. She takes a running start. When she reaches the north end of the raft she is running at 5.0 m/s relative to the raft. At that instant, what is her velocity relative to the water?

Picture the Problem Let the system include the woman, the canoe, and the earth. Then the *net* external force is zero and linear momentum is conserved as she jumps off the canoe. Let the direction she jumps be the positive *x* direction.

Apply conservation of linear momentum to the system:

$$\sum m_i \vec{\mathbf{v}}_i = m_{\text{woman}} \vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}} + m_{\text{raft}} \vec{\mathbf{v}}_{\text{raft}\cdot\text{h2o}} = 0$$

Solving for $\vec{\mathbf{v}}_{\text{raft}\cdot\text{h2o}}$ yields:

$$\vec{\mathbf{v}}_{\text{raft}\cdot\text{h2o}} = -\frac{m_{\text{woman}}}{m_{\text{raft}}} \vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}}$$

The woman's velocity relative to the water is a vector sum:

$$\vec{\mathbf{v}}_{\text{woman}\cdot\text{raft}} = \vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}} + \vec{\mathbf{v}}_{\text{h2o}\cdot\text{raft}}$$
$$\vec{\mathbf{v}}_{\text{woman}\cdot\text{raft}} = \vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}} - \vec{\mathbf{v}}_{\text{raft}\cdot\text{h2o}}$$

Solve for $\vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}}$

$$\vec{\mathbf{v}}_{\text{woman}\cdot\text{raft}} = \vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}} + \frac{m_{\text{woman}}}{m_{\text{raft}}} \vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}}$$

Substitute numerical values and evaluate $\vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}}$:

$$\vec{\mathbf{v}}_{\text{woman}\cdot\text{h2o}} = \frac{(5.0\,\text{m/s})\hat{\mathbf{i}}}{\left(1 + \frac{55\,\text{kg}}{150\,\text{kg}}\right)} = \boxed{(3.66\text{ m/s})\hat{\mathbf{i}}}$$

40 ••• A wedge of mass *M*, as shown in Figure 8-46, is placed on a frictionless, horizontal surface, and a block of mass *m* is placed on the wedge, whose surface is also frictionless. The center of mass of the block moves downward a distance *h*, as the block slides from its initial position to the horizontal floor. (*a*) What are the speeds of the block and of the wedge, as they separate from each other and each go their own way? (*b*) Check your calculation plausibility by considering the limiting case when *M* >>*m*.

Picture the Problem Let the system include the earth, block, and wedge and apply conservation of energy and conservation of linear momentum.

(*a*) Apply conservation of energy with no frictional forces to the system to obtain:

$$W_{\text{ext}} = \Delta K + \Delta U$$

or, because $W_{\text{ext}} = 0$,

$$\Delta K + \Delta U = 0$$

Substituting for ΔK and ΔU yields:

$$\boldsymbol{K}_{\text{f}} - \boldsymbol{K}_{\text{i}} + \boldsymbol{U}_{\text{f}} - \boldsymbol{U}_{\text{i}} = 0$$

Because $K_i = U_f = 0$:

$$\boldsymbol{K}_{\text{f}} - \boldsymbol{U}_{\text{i}} = 0$$

Letting ″b″ refer to the block and ″w″ to the wedge yields:

$$K_{b,f} + K_{w,f} - U_{b,i} = 0$$

Substitute for $K_{b,f}$, $K_{w,f}$, and $U_{b,i}$ to obtain:

$$\tfrac{1}{2} m v_b^2 + \tfrac{1}{2} M v_w^2 - mgh = 0 \qquad (1)$$

Applying conservation of linear momentum to the system yields:

$$\Delta\vec{p}_{sys} = \Delta\vec{p}_b + \Delta\vec{p}_w = 0$$

or

$$\vec{p}_{b,f} - \vec{p}_{b,i} + \vec{p}_{w,f} - \vec{p}_{w,i} = 0$$

Because $\vec{p}_{b,i} = \vec{p}_{w,i} = 0$:

$$\vec{p}_{b,f} + \vec{p}_{w,f} = 0$$

Substituting for $\vec{p}_{b,f}$ and $\vec{p}_{w,f}$ yields:

$$-mv_b\hat{i} + Mv_w\hat{i} = 0$$

or

$$-mv_b + Mv_w = 0$$

Solve for v_w to obtain:

$$v_w = \frac{m}{M} v_b \qquad (2)$$

Substituting for v_w in equation (1) yields:

$$\tfrac{1}{2} m v_b^2 + \tfrac{1}{2} M \left(\frac{m}{M} v_b\right)^2 - mgh = 0$$

Solve for v_b to obtain:

$$v_b = \boxed{\sqrt{\frac{2ghM}{M+m}}} \qquad (3)$$

Substitute for v_b in equation (2) and simplify to obtain:

$$v_w = \frac{m}{M}\sqrt{\frac{2ghM}{M+m}} = \boxed{\sqrt{\frac{2ghm^2}{M(M+m)}}} \qquad (4)$$

(*b*) Rewriting equation (3) by dividing the numerator and denominator of the radicand by M yields:

$$v_b = \sqrt{\frac{2gh}{1+\frac{m}{M}}}$$

When $M >> m$:

$$v_b = \sqrt{2gh}$$

Rewriting equation (4) by dividing the numerator and denominator of the radicand by M yields:

$$\boldsymbol{v}_{\mathrm{w}} = \sqrt{\frac{2gh\left(\frac{m}{M}\right)^2}{1+\frac{m}{M}}}$$

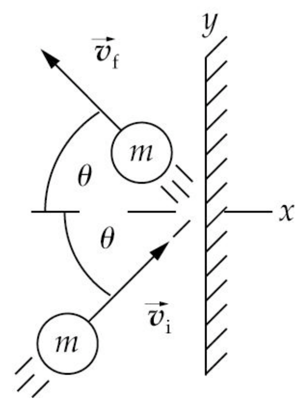
When $M >> m$:

$$\boldsymbol{v}_{\mathrm{w}} = 0$$

These results are exactly what we'd expect in this case: the physics is that of a block sliding down a fixed wedge incline with no movement of the incline.

47 •• A 60-g handball moving with a speed of 5.0 m/s strikes the wall at an angle of 40º with the normal, and then bounces off with the same speed at the same angle with the normal. It is in contact with the wall for 2.0 ms. What is the average force exerted by the ball on the wall?

Picture the Problem The figure shows the handball just before and immediately after its collision with the wall. Choose a coordinate system in which the positive x direction is to the right. The wall changes the momentum of the ball by exerting a force on it during the ball's collision with it. The reaction to this force is the force the ball exerts on the wall. Because these action and reaction forces are equal in magnitude, we can find the average force exerted on the ball by finding the change in momentum of the ball.



Using Newton's 3rd law, relate the average force exerted by the ball on the wall to the average force exerted by the wall on the ball:

$$\vec{F}_{\text{av on wall}} = -\vec{F}_{\text{av on ball}}$$

and

$$F_{\text{av on wall}} = F_{\text{av on ball}} \qquad (1)$$

Relate the average force exerted by the wall on the ball to its change in momentum:

$$\vec{F}_{\text{av on ball}} = \frac{\Delta\vec{p}}{\Delta t} = \frac{m\Delta\vec{v}}{\Delta t}$$

Express $\Delta\vec{v}$ in terms of its components:

$$\Delta\vec{v} = \Delta\vec{v}_x + \Delta\vec{v}_y$$

or, because

$\Delta\vec{\mathbf{v}}_y = v_{\mathrm{f},y}\hat{j} - v_{\mathrm{i},y}\hat{j}$ and $\boldsymbol{v}_{\mathrm{f},y} = \boldsymbol{v}_{\mathrm{i},y}$.

$$\Delta\vec{v} = \Delta\vec{v}_x$$

Express $\Delta\vec{v}_x$ for the ball:

$$\Delta\vec{v}_x = v_{f,x}\hat{i} - v_{i,x}\hat{i}$$

or, because $v_{i,x} = v\cos\theta$ and $v_{f,x} = -v\cos\theta$,

$$\Delta\vec{v}_x = -v\cos\theta\,\hat{i} - v\cos\theta\,\hat{i} = -2v\cos\theta\,\hat{i}$$

Substituting in the expression for $\vec{F}_{\text{av on ball}}$ yields:

$$\vec{F}_{\text{av on ball}} = \frac{m\Delta\vec{v}}{\Delta t} = -\frac{2mv\cos\theta}{\Delta t}\hat{i}$$

The magnitude of $\vec{F}_{\text{av on ball}}$ is:

$$F_{\text{av on ball}} = \frac{2mv\cos\theta}{\Delta t}$$

Substitute numerical values and evaluate $F_{\text{av on ball}}$:

$$F_{\text{av on ball}} = \frac{2(0.060\,\text{kg})(5.0\,\text{m/s})\cos 40°}{2.0\,\text{ms}} = 0.23\,\text{kN}$$

Substitute in equation (1) to obtain:

$$F_{\text{av on wall}} = \boxed{0.23\,\text{kN}}$$

61 •• A proton of mass m is moving with initial speed v_0 directly toward the center of an α particle of mass $4m$, which is initially at rest. Both particles carry positive charge, so they repel each other. (The repulsive forces are sufficient to prevent the two particles from coming into direct contact.) Find the speed v' of the α particle (*a*) when the distance between the two particles is a minimum, and (*b*) later when the two particles are far apart.

Picture the Problem We can find the velocity of the center of mass from the definition of the total momentum of the system. We'll use conservation of energy to find the speeds of the particles when their separation is a minimum and when they are far apart.

(*a*) Noting that when the distance between the two particles is a minimum, both move at the same speed, namely v_{cm}, use the definition of the total momentum of a system to relate the initial momenta to the velocity of the center of mass:

$$\vec{P} = \sum_i m_i\vec{v}_i = M\vec{v}_{cm}$$

or

$$m_p v_{pi} = (m_p + m_\alpha)v_{cm}.$$

Solve for v_{cm} to obtain:

$$v_{cm} = v' = \frac{m_p v_{pi} + m_\alpha v_{\alpha i}}{m_1 + m_2}$$

Additional simplification yields:

$$\boldsymbol{v}_{\text{cm}} = \boldsymbol{v}' = \frac{m\boldsymbol{v}_0 + 0}{\boldsymbol{m} + 4\boldsymbol{m}} = \boxed{0.2\boldsymbol{v}_0}$$

(*b*) Use conservation of linear momentum to obtain one relation for the final velocities:

$$m_{\text{p}}v_0 = m_{\text{p}}v_{\text{pf}} + m_\alpha v_{\alpha\text{f}} \qquad (1)$$

Use conservation of mechanical energy to set the velocity of recession equal to the negative of the velocity of approach:

$$v_{\text{pf}} - v_{\alpha\text{f}} = -\left(v_{\text{pi}} - v_{\alpha\text{i}}\right) = -v_{\text{pi}} \qquad (2)$$

Solve equation (2) for v_{pf}, substitute in equation (1) to eliminate v_{pf}, and solve for $v_{\alpha\text{f}}$:

$$\boldsymbol{v}_{\alpha\text{f}} = \frac{2\boldsymbol{m}_{\text{p}}\boldsymbol{v}_0}{\boldsymbol{m}_{\text{p}} + \boldsymbol{m}_\alpha}$$

Simplifying further yields:

$$\boldsymbol{v}_{\alpha\text{f}} = \frac{2\boldsymbol{m}\boldsymbol{v}_0}{\boldsymbol{m} + 4\boldsymbol{m}} = \boxed{0.4\boldsymbol{v}_0}$$

87 •• [SSM] A puck of mass 5.0 kg moving at 2.0 m/s approaches an identical puck that is stationary on frictionless ice. After the collision, the first puck leaves with a speed v_1 at 30º to the original line of motion; the second puck leaves with speed v_2 at 60º, as in Figure 8-50. (*a*) Calculate v_1 and v_2. (*b*) Was the collision elastic?

Picture the Problem Let the direction of motion of the puck that is moving before the collision be the +*x* direction. Applying conservation of momentum to the collision in both the *x* and *y* directions will lead us to two equations in the unknowns v_1 and v_2 that we can solve simultaneously. We can decide whether the collision was elastic by either calculating the system's kinetic energy before and after the collision or by determining whether the angle between the final velocities is 90°.

(*a*) Use conservation of linear momentum in the *x* direction to obtain:

$$\boldsymbol{p}_{\text{xi}} = \boldsymbol{p}_{\text{xf}}$$

or

$$\boldsymbol{m}\boldsymbol{v} = \boldsymbol{m}\boldsymbol{v}_1\cos 30° + \boldsymbol{m}\boldsymbol{v}_2\cos 60°$$

Simplify further to obtain:

$$\boldsymbol{v} = \boldsymbol{v}_1\cos 30° + \boldsymbol{v}_2\cos 60° \qquad (1)$$

Use conservation of momentum in the *y* direction to obtain a second equation relating the velocities of the

$$\boldsymbol{p}_{\text{yi}} = \boldsymbol{p}_{\text{yf}}$$

or

$$0 = \boldsymbol{m}\boldsymbol{v}_1\sin 30° - \boldsymbol{m}\boldsymbol{v}_2\sin 60°$$

collision participants before and after the collision:

Simplifying further yields: $0 = \boldsymbol{v}_1 \sin 30° - \boldsymbol{v}_2 \sin 60°$ (2)

Solve equations (1) and (2) simultaneously to obtain: $\boldsymbol{v}_1 = \boxed{1.7\,\text{m/s}}$ and $\boldsymbol{v}_2 = \boxed{1.0\,\text{m/s}}$

(*b*) Because the angle between $\vec{\boldsymbol{v}}_1$ and $\vec{\boldsymbol{v}}_2$ is 90°, the collision was elastic.

104 •• Figure 8-54 shows a World War I cannon mounted on a railcar so that it will project a shell at an angle of 30º. With the car initially at rest, the cannon fires a 200-kg projectile at 125 m/s. (All values are for the frame of reference of the track.) Now consider a system composed of a cannon, shell, and railcar, all on the frictionless track. (*a*) Will the total vector momentum of that system be the same just before and just after the shell is fired? Explain your answer. (*b*) If the mass of the railcar plus cannon is 5000 kg, what will be the recoil velocity of the car along the track after the firing? (*c*) The shell is observed to rise to a maximum height of 180 m as it moves through its trajectory. At this point, its speed is 80.0 m/s. On the basis of this information, calculate the amount of thermal energy produced by air friction on the shell on its way from firing to this maximum height.

Picture the Problem We can use conservation of momentum in the horizontal direction to find the recoil velocity of the car along the track after the firing. Because the shell will neither rise as high nor be moving as fast at the top of its trajectory as it would be in the absence of air friction, we can apply the work-energy theorem to find the amount of thermal energy produced by the air friction.

(*a*) No. The vertical reaction force of the rails is an external force and so the momentum of the system will not be conserved.

(*b*) Use conservation of momentum in the horizontal (*x*) direction to obtain:

$$\Delta p_x = 0$$

or

$$mv\cos 30° - Mv_{\text{recoil}} = 0$$

Solving for v_{recoil} yields:

$$v_{\text{recoil}} = \frac{mv\cos 30°}{M}$$

Substitute numerical values and evaluate v_{recoil}:

$$\boldsymbol{v}_{\text{recoil}} = \frac{(200\,\text{kg})(125\,\text{m/s})\cos 30°}{5000\,\text{kg}} = \boxed{4.3\,\text{m/s}}$$

(*c*) Using the work-energy theorem, relate the thermal energy produced by air friction to the change in the energy of the system:

$$W_{\text{ext}} = W_{\text{f}} = \Delta E_{\text{sys}} = \Delta U + \Delta K$$

Substitute for ΔU and ΔK to obtain:

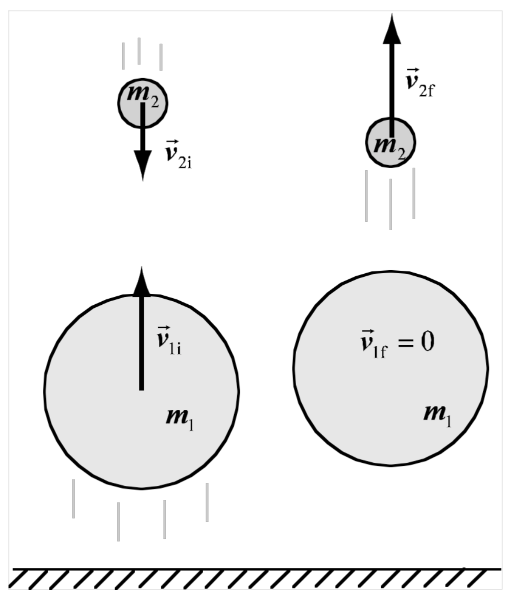
$$\begin{aligned} W_{\text{ext}} &= mgy_{\text{f}} - mgy_{\text{i}} + \tfrac{1}{2}mv_{\text{f}}^2 - \tfrac{1}{2}mv_i^2 \\ &= mg\left(y_{\text{f}} - y_{\text{i}}\right) + \tfrac{1}{2}m\left(v_{\text{f}}^2 - v_i^2\right) \end{aligned}$$

Substitute numerical values and evaluate W_{ext}:

$$\begin{aligned} W_{\text{ext}} &= (200\,\text{kg})\left(9.81\,\text{m/s}^2\right)(180\,\text{m}) + \tfrac{1}{2}(200\,\text{kg})\left[(80.0\,\text{m/s})^2 - (125\,\text{m/s})^2\right] \\ &= \boxed{-569\,\text{kJ}} \end{aligned}$$

106 ••• (*a*) Referring to Problem 105, if we held a third ball above the baseball and basketball, and wanted both the basketball and baseball to stop in mid-air, what should the ratio of the mass of the top ball to the mass of the baseball be? (*b*) If the speed of the top ball is *v* just before the collision, what is its speed just after the collision?

Picture the Problem In Problem 105 only two balls are dropped. They collide head on, each moving at speed *v*, and the collision is elastic. In this problem, as it did in Problem 105, the solution involves using the conservation of momentum equation $m_1v_{1\text{f}} + m_2v_{2\text{f}} = m_1v_{1\text{i}} + m_2v_{2\text{i}}$ and the elastic collision equation $v_{1\text{f}} - v_{2\text{f}} = v_{2\text{i}} - v_{1\text{i}}$ where the numeral 1 refers to the baseball, and the numeral 2 to the top ball. The diagram shows the balls just before and just after their collision. From Problem 105 we know that $v_{1\text{i}} = 2v$ and $v_{2\text{i}} = -v$.



(*a*) Express the final speed $v_{1\text{f}}$ of the baseball as a function of its initial speed $v_{1\text{i}}$ and the initial speed of the top ball $v_{2\text{i}}$ (see Problem 64):

$$v_{1\text{f}} = \frac{m_1 - m_2}{m_1 + m_2}v_{1\text{i}} + \frac{2m_2}{m_1 + m_2}v_{2\text{i}}$$

Substitute for v_{1i} and , v_{2i} to obtain:

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2}(2v) + \frac{2m_2}{m_1 + m_2}(-v)$$

Divide the numerator and denominator of each term by m_2 to introduce the mass ratio of the upper ball to the lower ball:

$$v_{1f} = \frac{\frac{m_1}{m_2} - 1}{\frac{m_1}{m_2} + 1}(2v) + \frac{2}{\frac{m_1}{m_2} + 1}(-v)$$

Set the final speed of the baseball v_{1f} equal to zero and let x represent the mass ratio m_1/m_2 to obtain:

$$0 = \frac{x-1}{x+1}(2v) + \frac{2}{x+1}(-v)$$

Solving for x yields:

$$x = \frac{m_1}{m_2} = \boxed{\tfrac{1}{2}}$$

(b) Apply the second of the two equations in Problem 64 to the collision between the top ball and the baseball:

$$v_{2f} = \frac{2m_1}{m_1 + m_2}v_{1i} + \frac{m_2 - m_1}{m_1 + m_2}v_{2i}$$

Substitute $v_{1i} = 2v$ and $v_{2i} = -v$ to obtain:

$$v_{2f} = \frac{2m_1}{m_1 + m_2}(2v) + \frac{m_2 - m_1}{m_1 + m_2}(-v)$$

In part (a) we showed that $m_2 = 2m_1$. Substitute and simplify to obtain:

$$\boldsymbol{v}_{3f} = \frac{2(2\boldsymbol{m}_1)}{\boldsymbol{m}_1 + 2\boldsymbol{m}_1}(2\boldsymbol{v}) - \frac{2\boldsymbol{m}_1 - \boldsymbol{m}_1}{\boldsymbol{m}_1 + 2\boldsymbol{m}_1}\boldsymbol{v}$$

$$= \boxed{\tfrac{7}{3}\boldsymbol{v}}$$