Physics 2A
Chapter 9 HW Solutions

Chapter 9
Conceptual Question: 2, 4, 8, 13
Problems: 3, 8, 12, 15, 23, 40, 51, 62

Q9.2. **Reason:** We can find the change in momentum of the objects by computing the impulse on them and using the equation $\Delta p = J$. Since they start at rest with zero momentum, we can write $mv_{\text{f}} = p_{\text{f}} = \Delta p = J = F\Delta t$. So the final velocity of either object equals the impulse on the object divided by its mass. For the first object, this will be

$$(v_1)_{\text{f}} = (12\text{ N})(2.0\text{ s})/m = (24\text{ N}\cdot\text{s})/m$$

For the second object, the velocity is given by

$$(v_2)_{\text{f}} = (15\text{ N})(3.0\text{ s})/(2m) = (22.5\text{ N}\cdot\text{s})/m$$

The velocity of the first object is seen to be higher, because no matter what the value of m is, the numerator is greater in the first expression than in the second expression.
Assess: The second object was subject to a greater force exerted for a greater time. But it ended with less velocity because it was more massive. All three factors are important in determining the final speed.

Q9.5. **Reason:** The sum of the momenta of the three pieces must be the zero vector. Since the first piece is traveling east, its momentum will have the form $(p_1, 0)$, where p_1 is a positive number. Since the second piece is traveling north, its momentum will have the form $(0, p_2)$, where p_2 is a positive number. If a third momentum is to be added to these and the result is to be $(0,0)$, then the third momentum must be $(-p_1, -p_2)$. Since its east-west and north-south components are both negative, the momentum of the third piece must point south west and so the velocity must be south west. The answer is D.
Assess: It makes sense that the third piece would need to travel southwest. It needs a western component of momentum to cancel the eastern component of the first piece and it needs a southern component to cancel the northern component of the second piece.

Q9.8. **Reason:** The impulse needed to stop a car without crumple zones will be the same as for a car with crumple zones since the change in momentum is same. The average force needed to stop the car is the impulse divided by the time the car takes to stop. A car designed with crumple zones will take longer to stop than a stiff car, so the force exerted on the car during a collision is smaller for a car with crumple zones.
Assess: See Section 9.2 for a discussion of bridge abutments, which are used for impact-lessening and work on the same principle.

Q9.13. **Reason:** If you do not move backward when passing the basketball it is because the ball-you system is not isolated: There is a net external force on the system to keep you from moving backward that changes the momentum of the system. If the ball-you system *is* isolated (say you are on frictionless ice), then you *do* move backward when you pass the ball.
Assess: If the friction force of the floor on you keeps you from moving backward (relative to the floor), then the law of conservation of momentum doesn't apply because the system isn't isolated. But you could then include the floor, building, and the earth in the system so it (the system) is isolated; then momentum of the system is conserved—and that means the earth does recoil ever so slightly when you pass the basketball.

P9.3. **Prepare:** From Equations 9.5, 9.2, and 9.8, Newton's second law can be profitably rewritten as

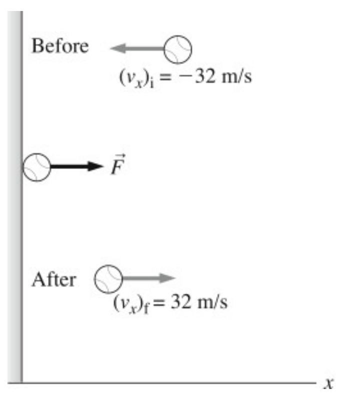
$$\vec{F}_{\text{avg}} = \frac{\Delta \vec{p}}{\Delta t}$$

In fact, this is much closer to what Newton actually wrote than $\vec{F} = m\vec{a}$.
Solve: This allows us to find the force on the snowball. By Newton's third law we know that the snowball exerts a force of equal magnitude on the wall.

$$\vec{F}_{\text{avg}} = \frac{\Delta \vec{p}}{\Delta t} = \frac{m\vec{v}_{\text{f}} - m\vec{v}_{\text{i}}}{\Delta t} = \frac{m(\vec{v}_{\text{f}} - \vec{v}_{\text{i}})}{\Delta t} = \frac{(0.12\text{ kg})(0\text{ m/s} - 7.5\text{ m/s})}{0.15\text{ s}} = -6.0\text{ N}$$

where the negative sign indicates that the force on the snowball is opposite its original momentum. So the force on the wall is also 6.0 N.
Assess: This is not a large force, but the snowball has low mass, a moderate speed, and the collision time is fairly long.

P9.8. **Prepare:** Model the tennis ball as a particle, and its interaction with the wall as a collision. The force increases to F_{max} during the first two ms, stays at F_{max} for two ms, and then decreases to zero during the last two ms. Please refer to Figure P9.8. The graph shows that F_x is positive, so the force acts to the right.



Solve: Using the impulse-momentum theorem $p_{\text{f}x} = p_{\text{i}x} + J_x$,

$$(0.06\text{ kg})(32\text{ m/s}) = (0.06\text{ kg})(-32\text{ m/s}) + \text{area under force graph}$$

Now,

$$\text{area under force curve} = \frac{1}{2}F_{\text{max}}(0.002\text{ s}) + F_{\text{max}}(0.002\text{ s}) + \frac{1}{2}F_{\text{max}}(0.002\text{ s}) = (0.004\text{ s})F_{\text{max}}$$

$$\Rightarrow F_{\text{max}} = \frac{(0.06\text{ kg})(32\text{ m/s}) + (0.06\text{ kg})(32\text{ m/s})}{0.004\text{ s}} = 960\text{ N}$$

P9.12. Prepare: We can use Equations 9.6 and 9.8 to calculate the impulse and Equation 9.2 to calculate the average force.

Solve: **(a)** Consider the ball to be moving along the positive *x*-axis before it is hit. Then $(v_x)_i = +15.0$ m/s. After the collision, the velocity of the ball is $(v_x)_f = -20.0$ m/s. The impulse on the ball is given by Equation 9.8:

$$J_x = (p_x)_f - (p_x)_i = (0.145\text{ kg})(-20.0\text{ m/s}) - (0.145\text{ kg})(15.0\text{ m/s}) = -5.08\text{ kg}\cdot\text{m/s}$$

(b) Given the impulse and duration of the collision, Equation 9.2 gives the average force on the ball.

$$(F_x)_{avg} = \frac{J_x}{\Delta t} = \frac{-5.08\text{ kg}\cdot\text{m/s}}{0.0015\text{ s}} = -3400\text{ N}$$

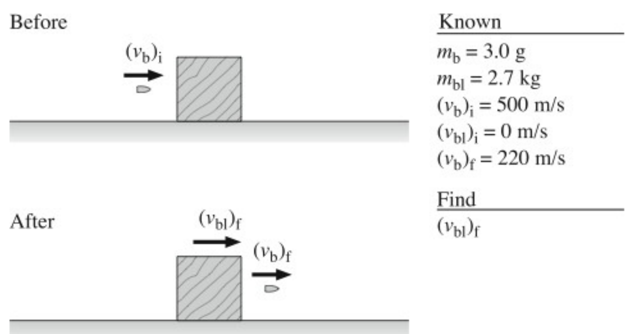
Assess: Note that impulse and momentum are vectors. The impulse and force are directed in the negative *x* direction.

P9.15. Prepare: This is a problem with no external forces so we can use the law of conservation of momentum.

Solve: The total momentum before the bullet hits the block equals the total momentum after the bullet passes through the block so we can write

$$m_b(v_b)_i + m_{bl}(v_{bl})_i = m_b(v_b)_f + m_{bl}(v_{bl})_f \Rightarrow$$
$$(3.0\times10^{-3}\text{ kg})(500\text{ m/s}) + (2.7\text{ kg})(0\text{ m/s}) = (3.0\times10^{-3}\text{ kg})(220\text{ m/s}) + (2.7\text{ kg})(v_{bl})_f.$$

We can solve for the final velocity of the block: $(v_{bl})_f = 0.31$ m/s .



Assess: This is reasonable since the block is about one thousand times more massive than the bullet and its change in speed is about one thousand times less.

P9.23. Prepare: Even though this is an inelastic collision, momentum is still conserved during the short collision if we choose the system to be spitball plus carton. Let SB stand for the spitball, CTN the carton, and BOTH be the combined object after impact (we assume the spitball sticks to the carton). We are given m_{SB} = 0.0030 kg, m_{CTN} = 0.020 kg, and $(v_{BOTHx})_f$ = 0.30 m/s.

Solve:

$$(P_x)_i = (P_x)_f$$
$$(p_{SBx})_i + (p_{CTNx})_i = (p_{BOTHx})_f$$
$$m_{SB}(v_{SBx})_i + m_{CTN}(v_{CTNx})_i = (m_{SB} + m_{CTN})(v_{BOTHx})_f$$

We want to know $(v_{SBx})_i$ so we solve for it. Also recall that $(v_{CTNx})_i = 0$ m/s so the last term in the following numerator drops out.

$$(v_{SBx})_i = \frac{(m_{SB} + m_{CTN})(v_{BOTHx})_f - m_{CTN}(v_{CTNx})_i}{m_{SB}} = \frac{(0.0030\text{ kg} + 0.020\text{ kg})(0.30\text{ m/s})}{0.0030\text{ kg}} = 2.3\text{ m/s}$$

Assess: The answer of 2.3 m/s is certainly within the capability of an expert spitballer.

P9.40. **Prepare:** There are three parts to the motion in this problem. The ball falls to the ground, the ball has a collision with the ground, and finally the ball travels upward under the influence of gravity. The floor exerts a force on the ball that creates an impulse on the ball. The change in momentum of the ball can be calculated with Equation 9.8 once the impulse is known. The velocity of the ball as it leaves the floor can be calculated from the momentum of the ball after the collision with the floor.

Solve: Additional significant figures will be kept in intermediate results. The impulse due to a force is the area under the force-versus-time curve, from Equation 9.1. The curve on the graph is a triangle. Any triangle has an area that is equal to one half the length of the base multiplied by the height of the triangle. The "height" of the triangle is 1000 N and the base has a "length" equal to 4 ms. The impulse is then

$$J_y = \frac{(1000\text{ N})(4\times10^{-3}\text{ s})}{2} = 2\text{ kg}\cdot\text{m/s}$$

The change in momentum of the ball is equal to the impulse, from Equation 9.8. We can find the velocity of the ball as it leaves the floor knowing its initial momentum. The velocity of the ball just before it hits the floor can be calculated with the kinematic equation

$$(v_\text{f})^2 = (v_\text{i})^2 + 2a_y\Delta y$$

The initial velocity of the ball is zero, and the acceleration of the ball is the acceleration due to gravity. Solving for the magnitude of the velocity of the ball just before it hit the ground,

$$v_\text{f} = \sqrt{-2g\Delta y} = \sqrt{-2(9.80\text{ m/s}^2)(-2.0\text{ m})} = 6.26\text{ m/s}$$

The magnitude of the momentum of the ball just before it hits the ground is $mv_\text{f} = (0.2\text{ kg})\,(6.26\text{ m/s}) = 1.25\text{ kg}\cdot\text{m/s}$. This is the *initial* momentum of the ball just before the collision, $(p_y)_\text{i} = -1.25\text{ kg}\cdot\text{m/s}$. A negative sign has been inserted since the momentum is in the downward direction. Using Equation 9.8 to find the momentum of the ball right after the collision,

$$(p_y)_\text{f} = J_y + (p_y)_\text{i} = 2\text{ kg}\cdot\text{m/s}+(-1.25\text{ kg}\cdot\text{m/s}) = 0.75\text{ kg}\cdot\text{m/s}$$

We can now find the velocity of the ball right after it bounces up from the floor,

$$(v_y)_\text{f} = \frac{(p_y)_\text{f}}{m} = 3.75\text{ m/s}$$

Using this velocity as the initial velocity for the upward part of the motion and using the same kinematics equation as above, we find the ball rebounds to a height of

$$\Delta y = \frac{-(v_y)_\text{i}^2}{2a_y} = \frac{-(3.75\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = 0.717\text{ m}$$

Assess: This is a very special floor.

P9.54. **Prepare:** We arbitrarily pick the direction the linebacker was running as the positive *x*-direction since he was mentioned first. If, after we solve the conservation of momentum equation for v_f, the answer is positive, then we know the linebacker ends up moving forward; if v_f is negative, then the quarterback ends up moving forward.

We will use subscripts l for linebacker and q for quarterback.

Known

$m_\text{l} = 110\text{ Kg}$

$m_\text{q} = 82\text{ Kg}$

$(v_{\text{l}x}) = 2.0\text{ m/s}$

$(v_{\text{q}x})_\text{i} = -3.0\text{ m/s}$

Find

v_f

We employ the conservation of momentum. Since the collision is inelastic (the linebacker grabs and holds onto the quarterback) the final momentum will be $P_\text{f} = (m_\text{l} + m_\text{q})v_\text{f}$, where v_f is the answer we seek.

Solve:

$$\vec{P}_f = \vec{P}_i$$

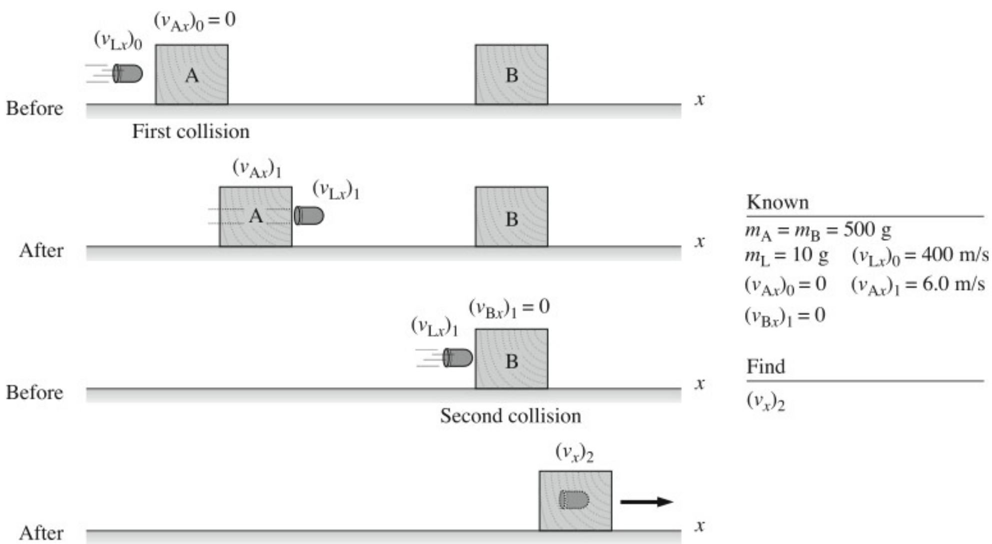
$$(m_l + m_q)v_f = m_l(v_{lx})_i\, m_q(v_{qx})_i$$

$$v_f = \frac{m_l(v_{lx})_i + m_q(v_{qx})_i}{m_l + m_q} = \frac{(110\text{ kg})(2.0\text{ m/s}) + (82\text{ kg})(-3.0\text{ m/s})}{110\text{ kg} + 82\text{ kg}} = -0.14\text{ m/s}$$

The answer is negative; this indicates that the quarterback ends up moving forward after the hit. (The linebacker gets knocked backward.)

Assess: If all we want to know is the sign of the answer then we do not really need to compute or divide by the denominator—the total mass will certainly be positive and will not affect the sign of the answer. So we could have done a simple mental calculation of the numerator ($82 \times 3 > 110 \times 2$) to figure out which football players "wins."

P9.62. Prepare: Model the two blocks (A and B) and the bullet (L) as particles. This is a two-part problem. First, we have a collision between the bullet and the first block (A). Momentum is conserved since no external force acts on the system (bullet + block A). The second part of the problem involves a perfectly inelastic collision between the bullet and block B. Momentum is again conserved for this system (bullet + block B).



Solve: For the first collision the equation $(p_x)_f = (p_x)_i$ is

$$m_L(v_{Lx})_1 + m_A(v_{Ax})_1 = m_L(v_{Lx})_0 + m_A(v_{Ax})_0$$

$$\Rightarrow (0.01\text{ kg})(v_{Lx})_1 + (0.500\text{ kg})(6\text{ m/s}) = (0.01\text{ kg})(400\text{ m/s}) + 0\text{ kg m/s} \Rightarrow (v_{Lx})_1 = 100\text{ m/s}$$

The bullet emerges from the first block at 100 m/s. For the second collision the equation $(p_x)_f = (p_x)_i$ is

$$(m_L + m_B)(v_x)_2 = m_L(v_{Lx})_1 \Rightarrow (0.01\text{ kg} + 0.5\text{ kg})(v_x)_2 = (0.01\text{ kg})(100\text{ m/s}) \Rightarrow (v_x)_2 = 2.0\text{ m/s}$$

Assess: This problem invloves repeated application of the law of conservation of momentum. Also note that the actual value of 2 m for the separation between the blocks is not necessary for our calculations.