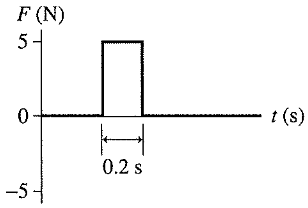
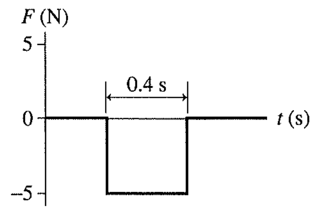
9 Momentum

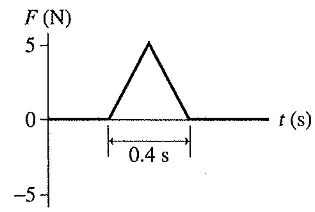
9.1 Impulse

9.2 Momentum and the Impulse-Momentum Theorem

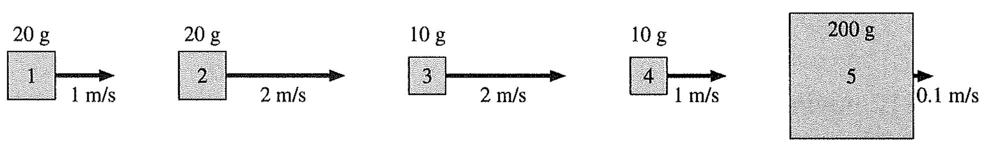
1. What impulse is delivered by each of these forces?

a. 

b. 

c. 

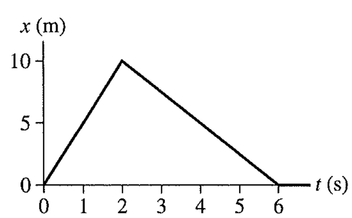
2. Rank in order, from largest to smallest, the momenta $(p_x)_1$ to $(p_x)_5$.

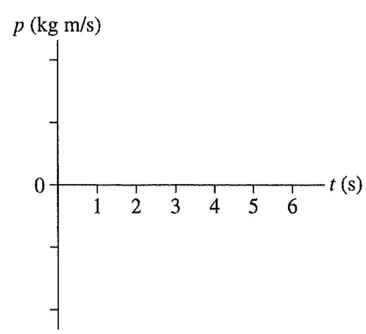


Order:

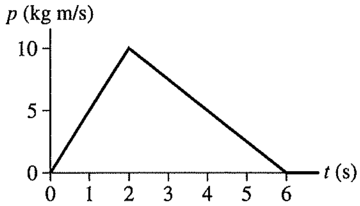
Explanation:

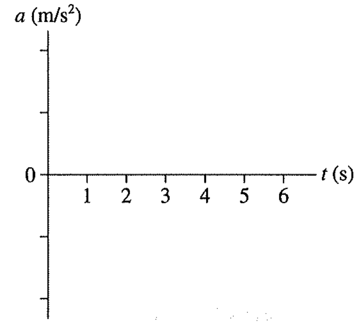
3. The position-versus-time graph is shown for a 500 g object. Draw the corresponding momentum-versus-time graph. Include an appropriate vertical scale.





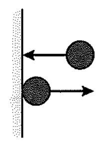
4. The momentum-versus-time graph is shown for a 500 g object. Draw the corresponding acceleration-versus-time graph. Include an appropriate vertical scale.





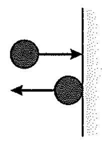
5. In each of the following, where a rubber ball bounces with no loss of speed, is the change in momentum Δp positive (+), negative (–), or zero (0)? Explain.

a.



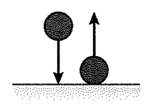
$\Delta p_x =$ ____

b.



$\Delta p_x =$ ____

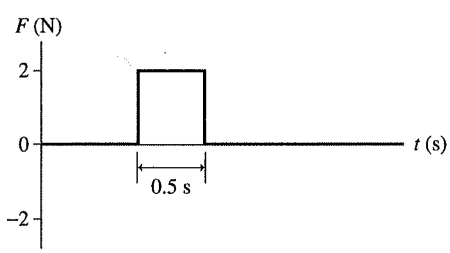
c.



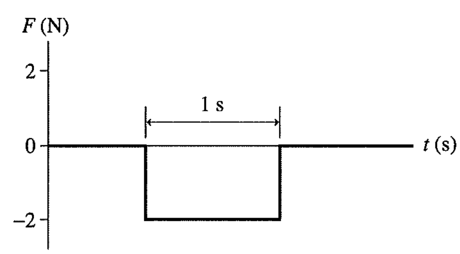
$\Delta p_y =$ ____

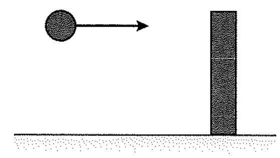
6. A 2 kg object is moving to the right with a speed of 1 m/s when it experiences an impulse due to the force shown in the graph. What is the object's speed and direction after the impulse?

a.



b.





7. A carnival game requires you to knock over a wood post by throwing a ball at it. You're offered a very bouncy rubber ball and a very sticky clay ball of equal mass. Assume that you can throw them with equal speed and equal accuracy. You only get one throw.

   a. Which ball will you choose? Why?

   b. Let's think about the situation more carefully. Both balls have the same initial momentum $(p_x)_i$ just before hitting the post. The clay ball sticks, the rubber ball bounces off with essentially no loss of speed. What is the final momentum of each ball?

   Clay ball: $(p_x)_f =$ ____________ Rubber ball: $(p_x)_f =$ ____________
   Hint: Momentum has a sign. Did you take the sign into account?

   c. What is the *change* in the momentum of each ball?

   Clay ball: $\Delta p_x =$ ____________ Rubber ball: $\Delta p_x =$ ____________

   d. Which ball experiences a larger impulse during the collision? Explain.

   e. From Newton's third law, the impulse that the ball exerts on the post is equal in magnitude, although opposite in direction, to the impulse that the post exerts on the ball. Which ball exerts the larger impulse on the post?

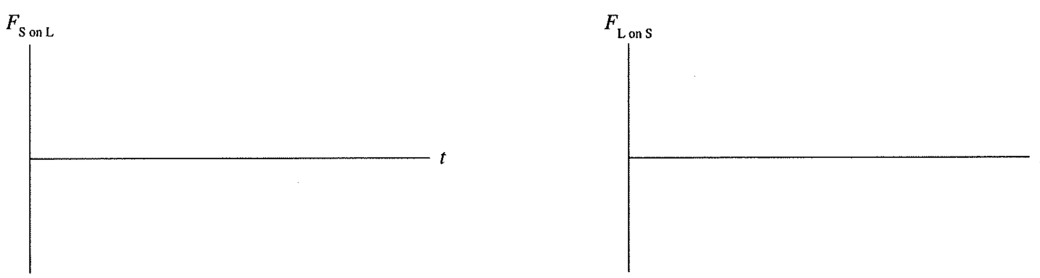
   f. Don't change your answer to part a, but are you still happy with that answer? If not, how would you change your answer? Why?

8. A small, light ball S and a large, heavy ball L move toward each other, collide, and bounce apart.

a. Compare the force that S exerts on L to the force that L exerts on S. That is, is $F_{\text{S on L}}$ larger, smaller, or equal to $F_{\text{L on S}}$? Explain. (Hint: One of Newton's laws is especially relevant.)

b. Compare the time interval during which S experiences a force to the time interval during which L experiences a force. Are they equal, or is one longer than the other?

c. Sketch a graph showing a *plausible* $F_{\text{S on L}}$ as a function of time and another graph showing a plausible $F_{\text{L on S}}$ as a function of time. Be sure to think about the *sign* of each force.



d. Compare the impulse delivered to S to the impulse delivered to L. Are they equal, or is one larger than the other?

e. Compare the momentum change of S to the momentum change of L.

f. Compare the velocity change of S to the velocity change of L.

9.3 Solving Impulse and Momentum Problems

Exercises 9–11: Prepare a before-and-after visual overview for these problems, but *do not* solve them.

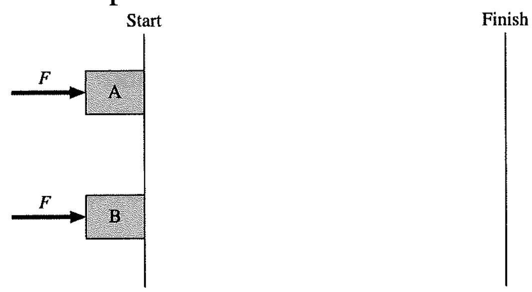
- Draw pictures of "before" and "after."
- Establish a coordinate system.
- Define symbols relevant to the problem.
- List known information, *and* identify the desired unknown.

9. A 50 kg archer, standing on frictionless ice, shoots a 100 g arrow at a speed of 100 m/s. What is the recoil speed of the archer?

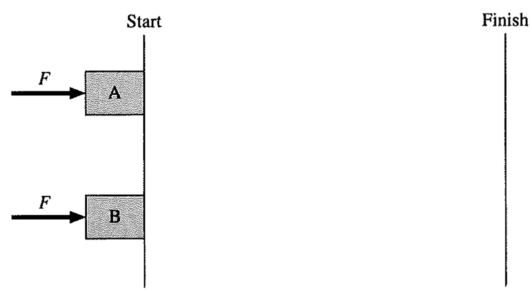
10. The parking brake on a 2000 kg Cadillac has failed, and it is rolling slowly, at 1 mph, toward a group of small innocent children. As you see the situation, you realize there is just time for you to drive your 1000 kg Volkswagen head-on into the Cadillac and thus save the children. With what speed should you impact the Cadillac to bring it to a halt?

11. Dan is gliding on his skateboard at 4 m/s. He suddenly jumps backward off the skateboard, kicking the skateboard forward at 8 m/s. How fast is Dan going as his feet hit the ground? Dan's mass is 50 kg and the skateboard's mass is 5 kg.

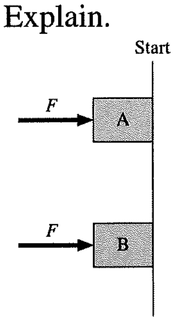
12. Blocks A and B, both initially at rest, are pushed to the right continuously by identical constant forces. Block B is more massive than Block A. Which block crosses the finish line with more momentum? Or do they finish with equal momenta? Explain.



13. Blocks A and B, of equal mass, are pushed to the right continuously by identical constant forces. Block B starts from rest, but Block A is already moving to the right as it crosses the starting line. Which block undergoes a larger *change* in momentum before crossing the finish line? Or are they the same? Explain.



14. Blocks A and B are pushed to the right continuously by identical constant forces for exactly 1.0 s, starting from rest. Block B is more massive than Block A. After 1.0 s, which block has more momentum? Or do they have equal momenta? Explain.



9.4 Conservation of Momentum

15. As you release a ball, it falls—gaining speed and momentum. Is momentum conserved?
    a. Answer this question from the perspective of choosing the ball alone as the system.

    b. Answer this question from the perspective of choosing ball + earth as the system.

16. Two particles collide, one of which was initially moving and the other initially at rest.
    a. Is it possible for *both* particles to be at rest after the collision? Give an example in which this happens, or explain why it can't happen.

    b. Is it possible for *one* particle to be at rest after the collision? Give an example in which this happens, or explain why it can't happen.

17. A tennis ball traveling to the left at speed v_{Bi} is hit by a tennis racket moving to the right
PSS at speed v_{Ri}. Although the racket is swung in a circular arc, its forward motion during the
9.1 collision with the ball is so small that we can consider it to be moving in a straight line. Further, we can invoke the *impulse approximation* to neglect the steady force of the arm on the racket during the brief duration of its collision with the ball. Afterward, the ball is returned to the right at speed v_{Bf}. What is the racket's speed after it hits the ball? The masses of the ball and racket are m_B and m_R, respectively.

a. Begin by drawing a before-and-after visual overview, as described in Tactics Box 9.1. You can assume that the racket continues in the forward direction but at a reduced speed.

b. Define the system. That is, what object or objects should be inside the system so that it is an *isolated system* whose momentum is conserved?

c. Write an expression for $(P_x)_i$, the total momentum of the system before the collision. Your expression should be written using the quantities given in the problem statement. Notice, however, that you're given *speeds*, but momentum is defined in terms of *velocities*. Based on your coordinate system and the directions of motion, you may need to give a negative momentum to one or more objects.

d. Now write an expression for $(P_x)_f$, the total momentum of the system after the collision.

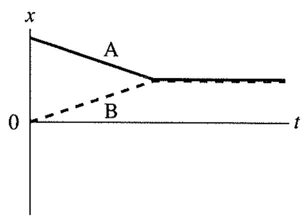
e. If you chose the system correctly, its momentum is conserved. So equate your expressions for the initial and final total momentum, and then solve for what you want to find.

9.5 Inelastic Collisions

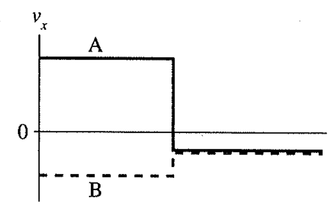
18. Determine whether each of the following graphs represents an inelastic collision between Object A (solid line) and Object B (dashed line). The objects in an inelastic collision must stick together, *and* the collision must conserve momentum. Part of your explanation should consider the relative masses of A and B.

Note that part a is a position-versus-time graph, but parts b–d are velocity-versus-time graphs.

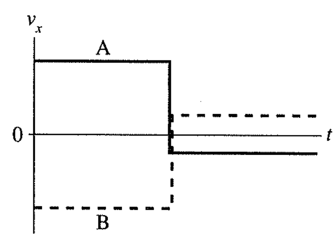
a.



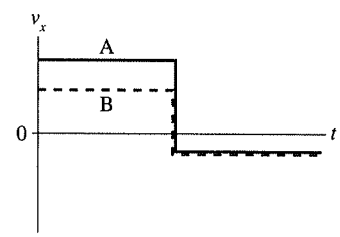
b.



c.

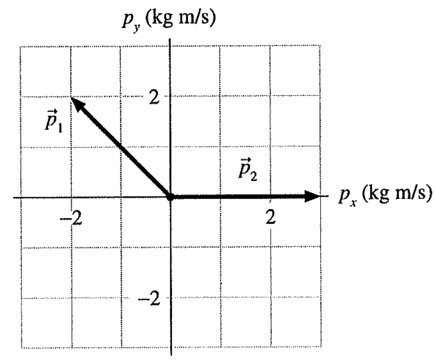


d.

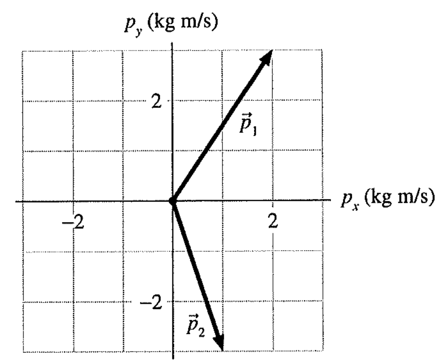


9.6 Momentum and Collisions in Two Dimensions

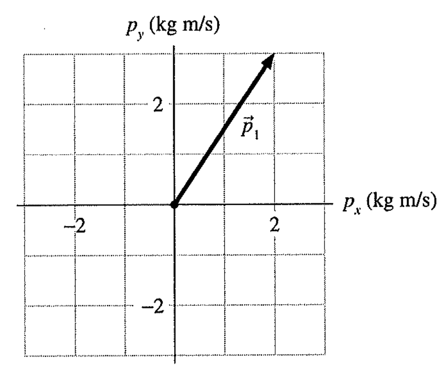
19. An object initially at rest explodes into three fragments. The momentum vectors of two of the fragments are shown. Draw the momentum vector $\vec{p}_3$ of the third fragment.



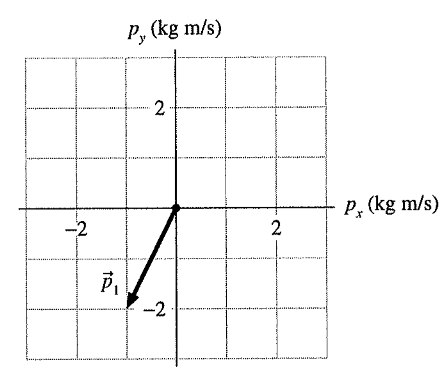
20. An object initially at rest explodes into three fragments. The momentum vectors of two of the fragments are shown. Draw the momentum vector $\vec{p}_3$ of the third fragment.



21. A 500 g ball traveling to the right at 4.0 m/s collides with and bounces off another ball. The figure shows the momentum vector $\vec{p}_1$ of one ball after the collision. Draw the momentum vector $\vec{p}_2$ of the second ball.

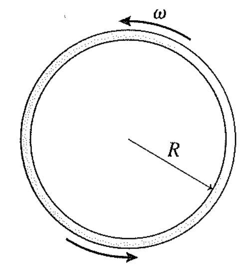


22. A 500 g ball traveling to the right at 4.0 m/s collides with and bounces off another ball. The figure shows the momentum vector $\vec{p}_1$ of one ball after the collision. Draw the momentum vector $\vec{p}_2$ of the other ball.



9.7 Angular Momentum

23. An isolated hoop of mass M and radius R is rotating with an angular speed of 60 rpm about its axis.



   a. What would be its angular speed if its mass suddenly doubled without changing its radius? Explain.

   b. What would be its angular speed if its radius suddenly doubled without changing its mass? Explain.

24. A solid circular disk and a circular hoop (like a bicycle wheel) both have mass M and radius R. If both are rotating with the same angular velocity ω, which has the larger angular momentum? Or are they equal? Explain.

You Write the Problem!

Exercises 25–28: You are given the equation that is used to solve a problem. For each of these:

a. Write a *realistic* physics problem for which this is the correct equation. Look at worked examples and end-of-chapter problems in the textbook to see what realistic physics problems are like. Be sure that the problem you write, and the answer you ask for, is consistent with the information given in the equation.
b. Draw a before-and-after visual overview for your problem.
c. Finish the solution of the problem.

25. $(0.10\text{ kg})(40\text{ m/s}) - (0.10\text{ kg})(-30\text{ m/s}) = \frac{1}{2}(1400\text{ N})\,\Delta t$

26. $(600\text{ g})(4.0\text{ m/s}) = (400\text{ g})(3.0\text{ m/s}) + (200\text{ g})(v_{2x})_i$

27. $(3000\text{ kg})(v_x)_f = (2000\text{ kg})(5.0\text{ m/s}) + (1000\text{ kg})(-4.0\text{ m/s})$

28. $(50\text{ g})(v_{1x})_f + (100\text{ g})(7.5\text{ m/s}) = (150\text{ g})(1.0\text{ m/s})$