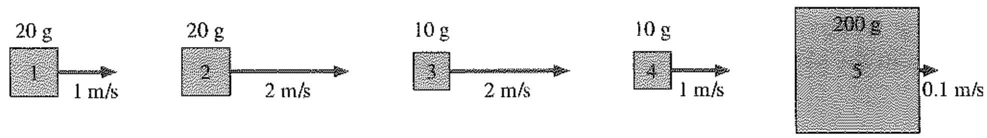
9 Impulse and Momentum

9.1 Momentum and Impulse

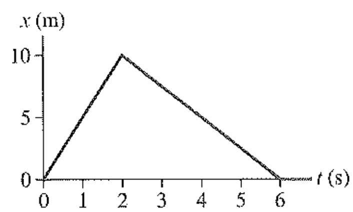
9.2 Solving Impulse and Momentum Problems

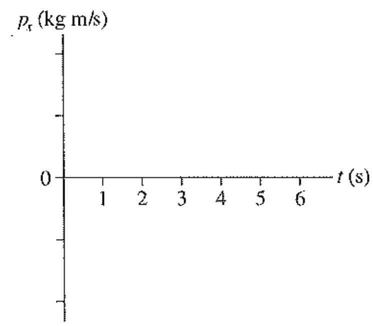
1. Rank in order, from largest to smallest, the momenta $(p_x)_1$ to $(p_x)_5$.



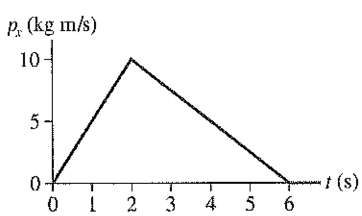
Order:

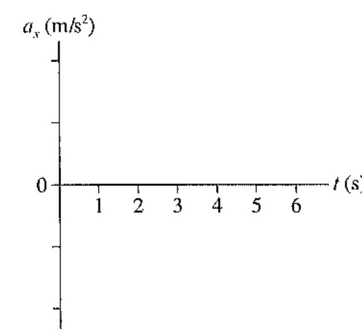
2. The position-versus-time graph is shown for a 500 g object. Draw the corresponding momentum-versus-time graph. Supply an appropriate scale on the vertical axis.





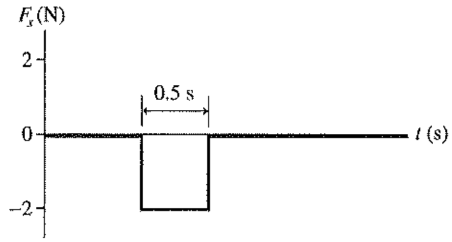
3. The momentum-versus-time graph is shown for a 500 g object. Draw the corresponding acceleration-versus-time graph. Supply an appropriate scale on the vertical axis.



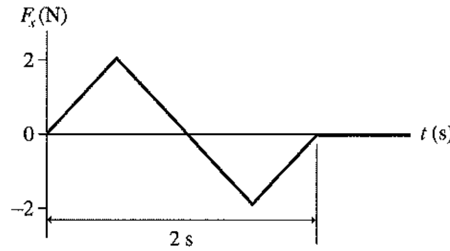


4. A 2 kg object is moving to the right with a speed of 1 m/s when it experiences an impulse due to the force shown in the graph. What is the object's speed and direction after the impulse?

a.

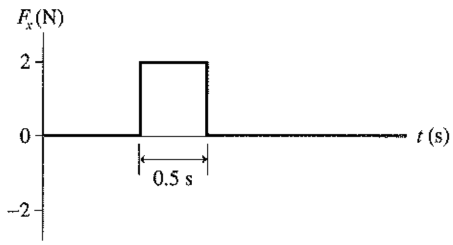


b.

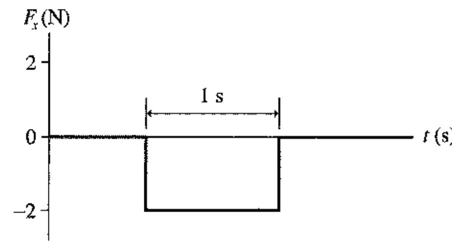


5. A 2 kg object is moving to the left with a speed of 1 m/s when it experiences an impulse due to the force shown in the graph. What is the object's speed and direction after the impulse?

a.



b.



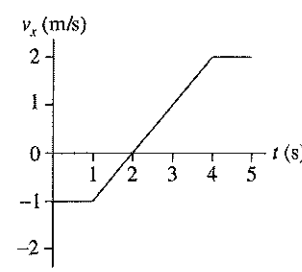
6. A 2 kg object has the velocity graph shown.

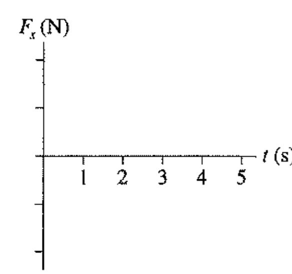
a. What is the object's initial momentum? ____________

b. What is the object's final momentum? ____________

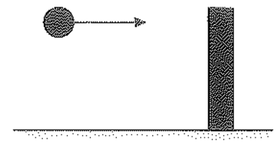
c. What impulse does the object experience? ____________

d. Draw the graph showing the force on the object.





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_{ix} just before hitting the post. The clay ball sticks, the rubber ball bounces off with essentially no loss of speed. In terms of p_{ix}, what is the final momentum of each ball?

Clay ball: $p_{fx} =$ ______ Rubber ball: $p_{fx} =$ ______

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 falling rubber ball bounces on the floor.

a. Use the language of force, acceleration, and action/reaction to describe what happens.

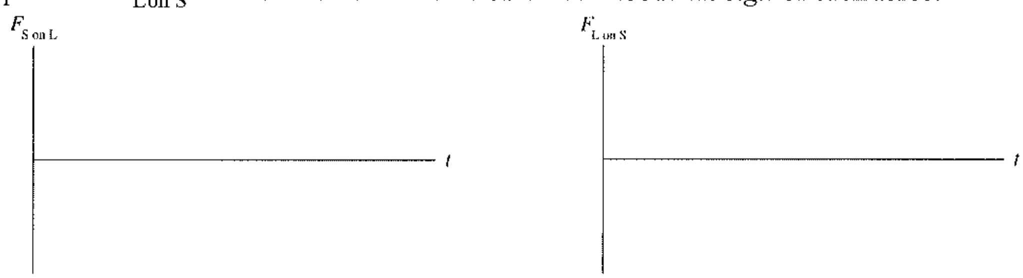
b. Use the language of impulse and momentum to describe what happens.

9. 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 during the collision 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.

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 think about the *sign* of each force.



d. Compare the impulse delivered to S to the impulse delivered to L. Explain.

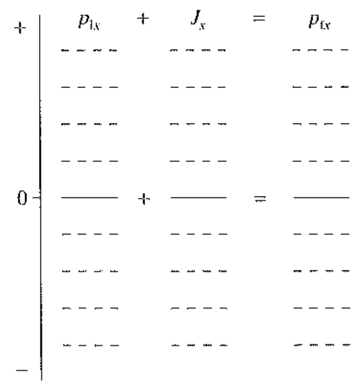
e. Compare the momentum change of S to the momentum change of L.

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

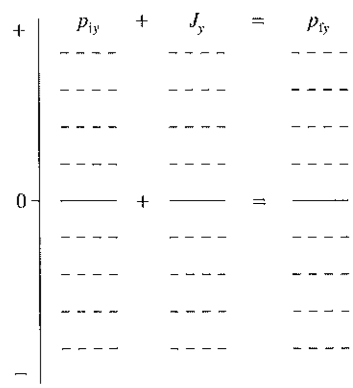
g. What is the change in the *sum* of the momenta of the two balls? Is it positive, negative, or zero?

Exercises 10–12: Draw a momentum bar chart to show the momenta and impulse for the situation described.

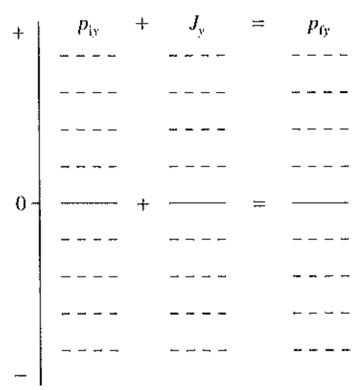
10. A compressed spring shoots a ball to the right. The ball was initially at rest.



11. A rubber ball is tossed straight up and bounces off the ceiling. Consider only the collision with the ceiling.



12. A clay ball is tossed straight up and sticks to the ceiling. Consider only the collision with the ceiling.



9.3 Conservation of Momentum

13. A golf club continues forward after hitting the golf ball. Is momentum conserved in the collision? Explain, making sure you are careful to identify the "system."

14. 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.

15. 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.

16. A tennis ball traveling to the left at speed v_{Bi} is hit by a tennis racket moving to the right at speed v_{Ri}.
PSS 9.1 Although the racket is swung in a circular arc, its forward motion during the 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 pictorial representation 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_{ix}, 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_{fx}, 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.

9.4 Inelastic Collisions

9.5 Explosions

Exercises 17–19: Prepare a pictorial representation for these problems, but *do not* solve them.

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

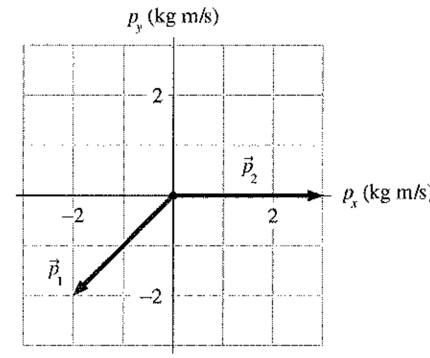
17. A 50 kg archer, standing on frictionless ice, shoots a 100 g arrow at a speed of 100 m/s. What is the recoil speed of the archer?

18. 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 to save the children. With what speed should you impact the Cadillac to bring it to a halt?

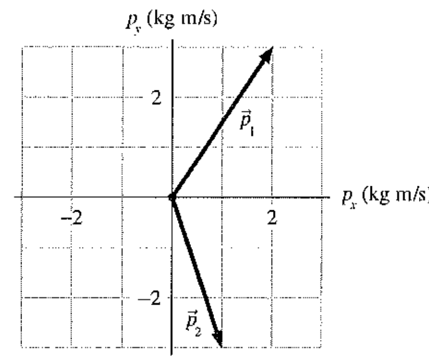
19. Dan is gliding on his skateboard at 4 m/s. He suddenly jumps backward off the skateboard, kicking the skateboard forward at 8 m/s. How fast is Dan going as his feet hit the ground? Dan's mass is 50 kg and the skateboard's mass is 5 kg.

9.6 Momentum in Two Dimensions

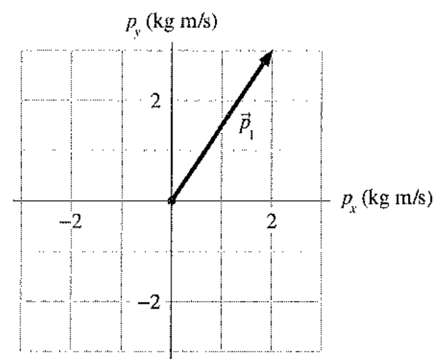
20. An object initially at rest explodes into three fragments. The momentum vectors of two of the fragments are shown. Draw the momentum vector $\vec{p}_3$ of the third fragment.



21. 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.



22. A 500 g ball traveling to the right at 8.0 m/s collides with and bounces off another ball. The figure shows the momentum vector $\vec{p}_1$ of the first ball after the collision. Draw the momentum vector $\vec{p}_2$ of the second ball.



23. 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 the first ball after the collision. Draw the momentum vector $\vec{p}_2$ of the second ball.