

## KEY TERMS

**conservation of linear momentum:** If the net external force on a system is zero, the total linear momentum of the system does not change.

**conserved:** This term is used in physics to mean that a number associated with a physical property does not change; it is invariant.

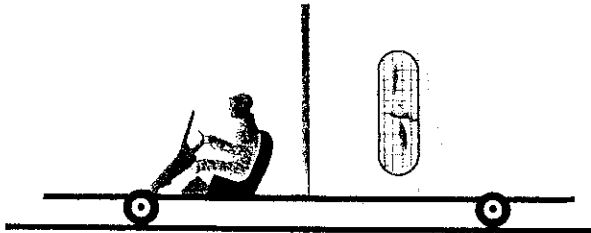
**impulse:** The product of the force and the time during which it acts,  $F\Delta t$ . This vector quantity is equal to the change in momentum.

**linear momentum:** A vector quantity equal to the product of an object's mass and its velocity,  $\mathbf{p} = m\mathbf{v}$ .

## CONCEPTUAL QUESTIONS

- Two identical carts with identical speeds collide head-on and stick together. Sydney argues, "Momentum for this system is conserved because the momentum of the first cart cancels the momentum of the second cart to give zero." Toby responds, "No, momentum is conserved because it's zero both before and after the collision." Which student do you agree with, and why?
- A 2-kilogram cart moving at 6 meters per second hits a stationary 2-kilogram cart. The two move off together at 3 meters per second. Lee contends, "Momentum is conserved in this collision because momentum of the system has the same value before and after the collision." Jackie counters, "The momentum of the system before the collision is 12 kilogram-meters per second, not zero, so momentum is not conserved." Which student do you agree with, and why?
- Why are supertankers so hard to stop? To turn?
- Which has the greater momentum, a cement truck parked at the lot or a child on a skateboard moving slowly down the street? Why?
- How does the padding (or air pockets) in the soles of running shoes reduce the forces on your legs? Explain your answer in terms of impulse and momentum.
- How does padding dashboards in automobiles make them safer? Explain your answer in terms of impulse and momentum.
- An astronaut training at the Craters of the Moon in Idaho jumps off a platform in full space gear and hits the surface at 5 meters per second. If later, on the Moon, the astronaut jumps from the landing vehicle and hits the surface at the same speed, will the impulse be larger, smaller, or the same as that on Earth? Why?
- Why is skiing into a wall of deep powder less hazardous to your health than skiing into a wall of bricks? Assume in both cases that you have the same initial speed and come to a complete stop. Explain your answer in terms of impulse and momentum.
- Assume that a friend jumps from the roof of a garage and lands on the ground. How will the impulses the ground exerts on your friend compare if the landing is on grass or on concrete?
- Why does an egg break when it is dropped onto the kitchen tile floor but not when it lands on the living room carpet?
- A 2-kilogram sack of flour falls off the counter and lands on the floor. Just before hitting the floor, the sack has a speed of 4 meters per second. What impulse (magnitude and direction) does the floor exert on the sack?
- A 2-kilogram rubber ball falls off the counter and lands on the floor. Just before hitting the floor, the ball has a speed of 4 meters per second. If the ball bounces, is the magnitude of the impulse the floor exerts on the ball less than, equal to, or greater than 8 kilograms-meters per second? Why?
- Greg and Jeff are walking down the sidewalk when identical flowerpots fall out of a window above. One flowerpot lands on Greg's head and does not bounce while the other lands on Jeff's head and bounces back up. Which of the flowerpots experiences the greater impulse? Assuming that the collision time is the same for both cases, who ends up with the worse headache? Explain.
- Two balls are dropped on the floor from the same height. The balls are made of different types of rubber so that one bounces back to nearly the same height while the other does not bounce at all. Assuming both balls have the same mass, which of the balls experiences the greater impulse in colliding with the floor? Why?
- Explain why the 12-ounce boxing gloves used in amateur fights hurt the boxer being struck less than the 6-ounce ones used in professional fights.
- You kick a soccer ball 15 meters without hurting your foot much. You then pump the ball up until it is really hard (the extra air does not significantly change the ball's mass) and again kick it 15 meters. This time it hurts a lot. Using the concept of impulse, explain why it hurts more in the second case.
- Two people are playing catch with a ball. Describe the momentum changes that occur for the ball, the people, and Earth. Is momentum conserved at all times?
- Describe the momentum changes that occur when you dribble a basketball.

19. Which produces the larger change in momentum: a force of 3 newtons acting for 3 seconds or a force of 4 newtons acting for 2 seconds? Explain.
20. Which produces the larger impulse: a force of 6 newtons acting for 3 seconds or a force of 4 newtons acting for 5 seconds? Explain.
21. How can you explain the recoil that occurs when a rifle is fired?
- \*22. How might you design a rifle that does not recoil?
23. Young Bill loves to fly model rockets. In his current project, however, he worries that once the rocket leaves the launch pad it will have nothing left to push on. To fix this, Bill fastens to the rocket, directly below its engine, a permanent launch pad (actually, an aluminum pie plate) that will travel with the rocket. Explain why Bill will be sorely disappointed with the results of his careful modifications.
24. A student who recently studied the law of conservation of linear momentum decides to propel a go-cart by having a fan blow on a board as shown in the figure. This idea won't work very well. Why not?



25. While a ball is falling toward the floor it is continually speeding up and therefore increasing its momentum. Why is this not a violation of the law of conservation of linear momentum?
26. A cue ball hits a stationary eight ball on a pool table. For which of the following systems is there a change in momentum during the collision? Explain why.
- The cue ball
  - The eight ball
  - Both balls
27. Two identical objects moving at the same speed collide with each other as shown in the figure. If the two objects stick together after the collision, will they be moving to the left, to the right, or not at all? Justify your answer using the concept of linear momentum.



28. An object of mass  $m$  and an object of mass  $3m$ , both moving at the same speed, collide with each other as shown in the figure. If the two objects stick together after the collision, will they be moving to the left, to the right, or not at all? Justify your answer using the concept of linear momentum.



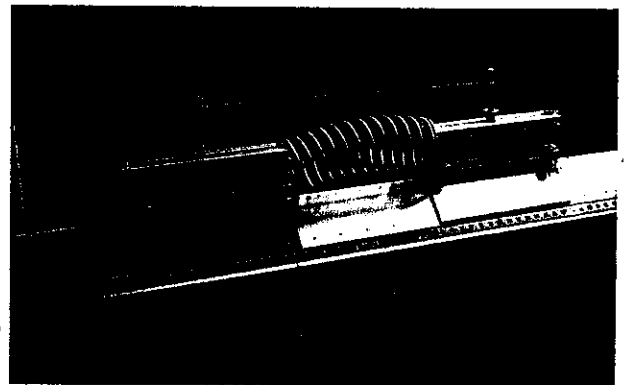
29. An object of mass  $m$  and an object of mass  $3m$  collide with each other as shown in the figure. The lighter object is initially moving twice as fast as the heavier one. If the two objects stick together after the collision, will they be moving to the left, to the right, or not at all? Justify your answer using the concept of linear momentum.



30. Two identical objects, one moving twice as fast as the other, collide with each other as shown in the figure. If the two objects stick together after the collision, will they be moving to the left, to the right, or not at all? Justify your answer using the concept of linear momentum.



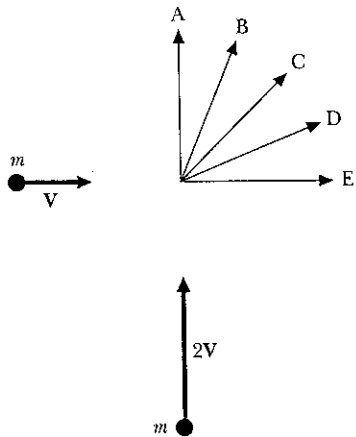
31. Your teacher runs across the front of the classroom with a momentum of 250 kilogram-meters per second and foolishly jumps onto a giant skateboard. The skateboard is initially at rest and has a mass equal to your teacher's. If you ignore friction with the floor, what is the total momentum of your teacher and the skateboard before and after the landing?
32. A friend is standing on a giant skateboard that is initially at rest. If you ignore frictional effects with the floor, what is the momentum of the skateboard if your friend walks to the right with a momentum of 150 kilogram-meters per second? What is the momentum of the skateboard-person system?
33. The figure shows two air-track gliders held together with a string. A spring is tightly compressed between the gliders and is released by burning the string. The mass of the glider on the left is twice that of the glider on the right, and they are initially at rest. What is the total momentum of both gliders after the release?



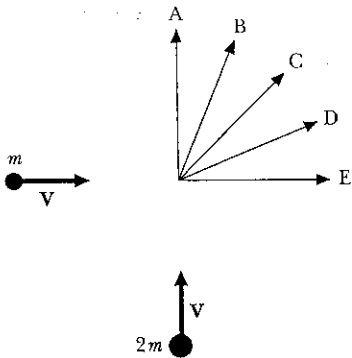
David Rogers

34. If the glider on the right in Question 33 has a speed of 2 meters per second after the release, how fast will the glider on the left be moving?
35. Sometimes a star "dies" in an enormous explosion known as a supernova. What happens to the total momentum of such a star?

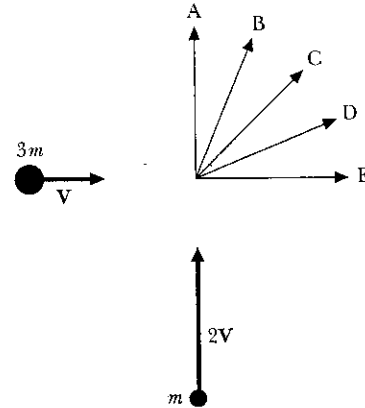
- \*36. During a Fourth of July celebration, a rocket is launched from the ground and explodes at the top of its arc. If we ignore air resistance, what happens to the total momentum of all of the rocket's fragments?
37. Two identical objects, one moving north and the other moving east, collide and stick together. If the northbound object is initially moving twice as fast as the eastbound object, which of the indicated paths represents the most likely final motion of the pair? Justify your answer using the concept of linear momentum.



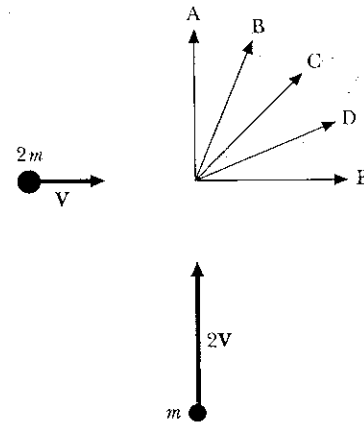
38. Two objects with the same speed, one moving north and the other moving east, collide and stick together. If the northbound object has twice the mass of the eastbound object, which of the indicated paths represents the most likely final motion of the pair? Justify your answer using the concept of linear momentum.



39. Two objects, one moving north and the other moving east, collide and stick together. If the eastbound object has three times the mass and is initially moving half as fast as the northbound object, which of the indicated paths represents the most likely final motion of the pair? Justify your answer using the concept of linear momentum.



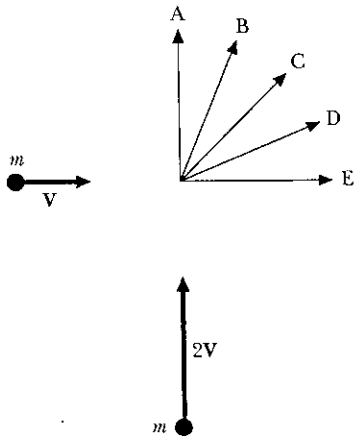
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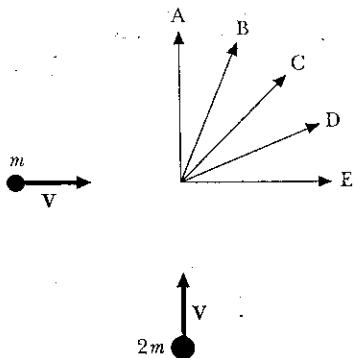
### EXERCISES

- What is the momentum of a 1200-kg sports car traveling down the road at a speed of 30 m/s?
- Calculate the approximate momentum of a world-class sprinter.
- How fast would you have to throw a baseball ( $m = 145$  g) to give it the same momentum as a 10-g bullet traveling at 900 m/s?
- You have a mass of 60 kg. How fast (in mph) would you have to run to have the same momentum as an 18-wheeler ( $m = 24,000$  kg) rolling along at 1 mph?
- What average net force is needed to accelerate a 1500-kg car to a speed of 30 m/s in a time of 8 s?
- It takes about 30 s for a jet plane to go from rest to the takeoff speed of 100 mph (44.7 m/s). What is the average

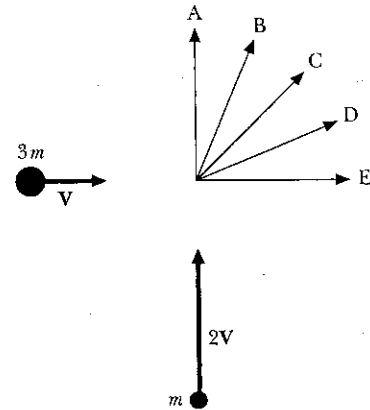
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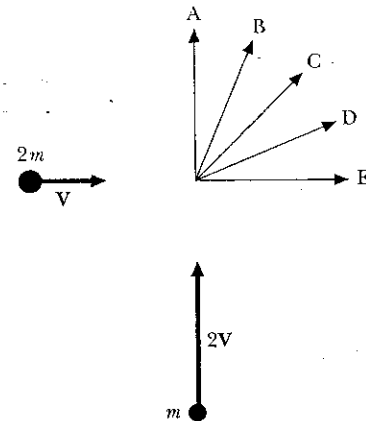
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- What average net force is needed to accelerate a 1500-kg car to a speed of 30 m/s in a time of 8 s?
- It takes about 30 s for a jet plane to go from rest to the takeoff speed of 100 mph (44.7 m/s). What is the average

horizontal force that the seat exerts on the back of a 60-kg passenger during takeoff?

7. What impulse is needed to stop a 1400-kg car traveling at 25 m/s?
8. A soft rubber ball ( $m = 0.5$  kg) is falling vertically at 6 m/s just before it hits the ground and stops. What is the impulse acting on the ball? If the ball had bounced instead, would the impulse be less than, equal to, or greater than what you calculated?
9. A 1500-kg car has a speed of 30 m/s. If it takes 8 s to stop the car, what is the impulse and the average force acting on the car?
10. A coach is hitting pop flies to the outfielders. If the baseball ( $m = 145$  g) stays in contact with the bat for 0.04 s and leaves the bat with a speed of 50 m/s, what is the average force acting on the ball?
11. A very hard rubber ball ( $m = 0.6$  kg) is falling vertically at 6 m/s just before it bounces on the floor. The ball rebounds back at essentially the same speed. If the collision with the floor lasts 0.04 s, what is the average force exerted by the floor on the ball?
12. A tennis ball ( $m = 0.2$  kg) is thrown at a brick wall. It is traveling horizontally at 16 m/s just before hitting the wall and rebounds from the wall at 8 m/s, still traveling horizontally. The ball is in contact with the wall for 0.04 s. What is the magnitude of the average force of the wall on the ball?
13. A father ( $m = 80$  kg) and son ( $m = 40$  kg) are standing facing each other on a frozen pond. The son pushes on the father and finds himself moving backward at 3 m/s after they have separated. How fast will the father be moving?
14. A woman with a mass of 50 kg runs at a speed of 6 m/s and jumps onto a giant skateboard with a mass of 30 kg. What is the combined speed of the woman and the skateboard?
15. A 3-kg ball traveling to the right with a speed of 4 m/s collides with a 4-kg ball traveling to the left with a speed of 3 m/s. What is the total momentum of the two balls before and after the collision?
16. A 4-kg ball traveling to the right with a speed of 4 m/s collides with a 5-kg ball traveling to the left with a speed of 2 m/s. What is the total momentum of the two balls before they collide? After they collide?
17. A 1200-kg car traveling north at 14 m/s is rear-ended by a 2000-kg truck traveling at 25 m/s. What is the total momentum before and after the collision?
18. If the truck and car in Exercise 17 lock bumpers and stick together, what is their speed immediately after the collision?
19. Two identical boxcars ( $m = 18,537$  kg) are traveling along the same track but in opposite directions. Both boxcars have a speed of 5 m/s. If the cars collide and couple together, what will be the final speed of the pair?
20. A boxcar traveling at 10 m/s approaches a string of three identical boxcars sitting stationary on the track. The moving boxcar collides and links with the stationary cars, and the four move off together along the track. What is the final speed of the four cars immediately after the collision? (You may take the mass of each boxcar to be 18,537 kg.)

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