$$v_{1y} = v_{1y}' + v_{2y}'$$
$$0 = -1.36 \text{ m/s} \sin \phi + 1.10 \text{ m/s} \sin \theta$$
$$\sin \phi = \frac{1.10 \text{ m/s} \sin \theta}{1.36 \text{ m/s}}$$
$$\sin \phi = \frac{1.10 \text{ m/s} \sin 40.0°}{1.36 \text{ m/s}}$$
$$\phi = 31.3°$$

Applying conservation of momentum to the *x*-components:

$$v_{1x} = v_{1x}' + v_{2x}'$$
$$= 1.36 \text{ m/s} \cos \phi + 1.10 \text{ m/s} \cos \theta$$
$$= 1.36 \text{ m/s} \cos 31.3° + 1.10 \text{ m/s} \cos 40.0°$$
$$v_{1x} = 2.00 \text{ m/s}$$

The initial speed of the moving marble is 2.00 m/s.

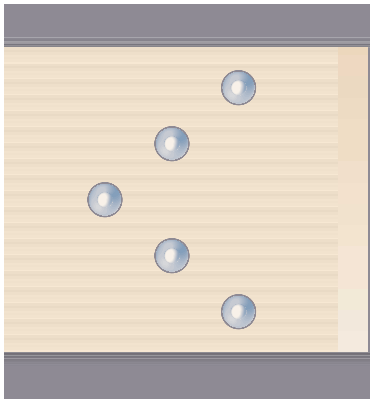

Figure 4
A 5-pin bowling setup is much easier to analyze than a 10-pin setup! (for question 1)

Practice

Understanding Concepts

1. Bowling involves numerous collisions that are essentially two-dimensional. Copy the 5-pin setup in **Figure 4** and complete the diagram to show where a bowling ball could be aimed to cause a "strike" (i.e., a hit in which all the pins are knocked down).
2. A 52-kg student is standing on a 26-kg cart that is free to move in any direction. Initially, the cart is moving with a velocity of 1.2 m/s [S] relative to the floor. The student then walks on the cart and has a net velocity of 1.0 m/s [W] relative to the floor.
   (a) Use a vector scale diagram to determine the approximate final velocity of the cart.
   (b) Use components to determine the approximate final velocity of the cart.
3. Two automobiles collide at an intersection. One car of mass 1.4×10^3 kg is travelling at 45 km/h [S]; the other car of mass 1.3×10^3 kg is travelling at 39 km/h [E]. If the cars have a completely inelastic collision, what is their velocity just after the collision?
4. Two balls of equal mass *m* undergo a collision. One ball is initially stationary. After the collision, the velocities of the balls make angles of 31.1° and 48.9° relative to the original direction of motion of the moving ball.
   (a) Draw a diagram showing the initial and final situations. If you are uncertain about the final directions of motion, remember that momentum is conserved.
   (b) If the initial speed of the moving ball is 2.25 m/s, what are the speeds of the balls after the collision?
   (c) Repeat (b) using a vector scale diagram.
   (d) Is this collision elastic? Justify your answer.
5. A nucleus, initially at rest, decays radioactively, leaving a residual nucleus. In the process, it emits two particles horizontally: an electron with momentum 9.0×10^{-21} kg·m/s [E] and a neutrino with momentum 4.8×10^{-21} kg·m/s [S].
   (a) In what direction does the residual nucleus move?
   (b) What is the magnitude of its momentum?
   (c) If the mass of the residual nucleus is 3.6×10^{-25} kg, what is its recoil velocity?

Answers

2. 4.1 m/s [61° S of E]
3. 3.0×10^1 km/h [51° S of E]
4. (b) 1.18 m/s at 48.9°; 1.72 m/s at 31.1°
   (d) no
5. (a) 28° N of W
   (b) 1.0×10^{-20} kg·m/s
   (c) 2.8×10^4 m/s [28° N of W]

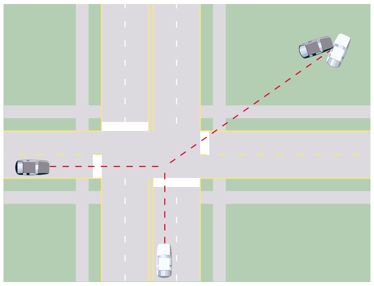

Figure 5
For question 6

Applying Inquiry Skills

6. The police report of an accident between two identical cars at an icy intersection contains the diagram shown in **Figure 5**.
   (a) Which car was travelling faster at the moment of impact? How can you tell?
   (b) What measurements could be made directly on the diagram to help an investigator determine the details of the collision?

Making Connections

7. Choose a sport or recreational activity in which participants wear protective equipment.
   (a) Describe the design and function of the protective equipment.
   (b) Based on the scientific concepts and principles you have studied thus far, explain how the equipment accomplishes its intended functions.
   (c) Using the Internet or other appropriate publications, research your chosen protective equipment. Use what you discover to enhance your answer in (b).

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SUMMARY Conservation of Momentum in Two Dimensions

- Collisions in two dimensions are analyzed using the same principles as collisions in one dimension: conservation of momentum for all collisions for which the net force on the system is zero, and both conservation of momentum and conservation of kinetic energy if the collision is elastic.

Section 5.4 Questions

Understanding Concepts

1. **Figure 6** shows an arrangement of billiard balls, all of equal mass. The balls travel in straight lines and do not spin. Draw a similar, but larger, diagram in your notebook and show the approximate direction that ball 1 must travel to get ball 3 into the end pocket if
   (a) ball 1 collides with ball 2 (in a combination shot)
   (b) ball 1 undergoes a single reflection off the side of the table and then collides with ball 3
2. A neutron of mass 1.7×10^{-27} kg, travelling at 2.7 km/s, hits a stationary lithium nucleus of mass 1.2×10^{-26} kg. After the collision, the velocity of the lithium nucleus is 0.40 km/s at 54° to the original direction of motion of the neutron. If the speed of the neutron after the collision is 2.5 km/s, in what direction is the neutron now travelling?
3. Two ice skaters undergo a collision, after which their arms are intertwined and they have a common velocity of 0.85 m/s [27° S of E]. Before the collision, one skater of mass 71 kg had a velocity of 2.3 m/s [12° N of E], while the other skater had a velocity of 1.9 m/s [52° S of W]. What is the mass of the second skater?

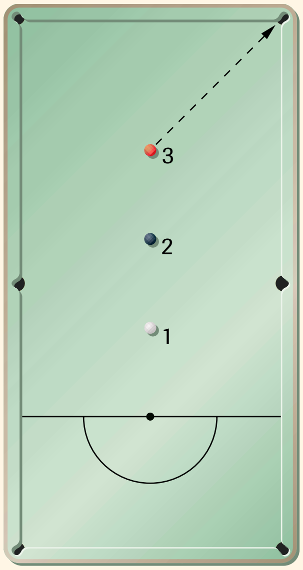

Figure 6
For question 1

4. A steel ball of mass 0.50 kg, moving with a velocity of 2.0 m/s [E], strikes a second ball of mass 0.30 kg, initially at rest. The collision is a glancing one, causing the moving ball to have a velocity of 1.5 m/s [30° N of E] after the collision. Determine the velocity of the second ball after the collision.

Applying Inquiry Skills

5. **Figure 7** shows the results of a collision between two pucks on a nearly frictionless air table. The mass of puck A is 0.32 kg, and the dots were produced by a sparking device every 0.50 s.

(a) Trace the diagram onto a separate piece of paper and determine the mass of puck B. (*Hint:* Determine which equation applies, and then draw the vectors on your diagram.)
(b) Determine the amount of kinetic energy lost in the collision.
(c) Name the type of collision that occurred.
(d) Identify the most likely sources of error in determining the mass of puck B.

Making Connections

6. Today's consumers are well aware that safety features are important in automobiles. For an automobile of your choice, analyze the design, the operation of the vehicle in a collision or other emergency, and the economic and social costs and benefits of its safety features. Use the following questions as a guideline:

(a) What social and economic issues do you think are important in automobile safety, from an individual point of view, as well as society's point of view?
(b) For the automobile you have chosen to analyze, what safety features do you think are essential?
(c) What safety features are lacking that you think would be beneficial to the driver and passengers?
(d) Considering your answers in (a), (b), and (c), perform a cost-benefit analysis of developing safety devices in automobiles. Write concluding remarks.

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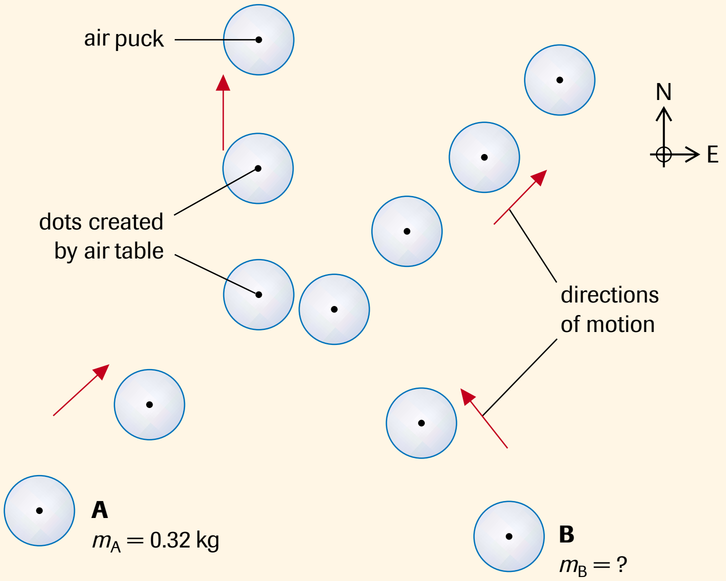

Figure 7
For question 5