$\vec{p}_E = \langle 1.97, -1.93, 0\rangle$ kg · m/s
$\vec{p}_F = \langle 1.68, -3.04, 0\rangle$ kg · m/s
(a) Calculate the change in the ball's momentum between each pair of adjacent locations. **(b)** On a copy of the diagram, draw arrows representing each $\Delta\vec{p}$ you calculated in part (a). **(c)** Between which two locations is the magnitude of the change in momentum greatest?

Section 1.9

•P57 What is the velocity of a 3 kg object when its momentum is $\langle 60, 150, -30\rangle$ kg · m/s?

•P58 A 1500 kg car located at $\langle 300, 0, 0\rangle$ m has a momentum of $\langle 45000, 0, 0\rangle$ kg · m/s. What is its location 10 s later?

••P59 An ice hockey puck of mass 170 g enters the goal with a momentum of $\langle 0, 0, -6.3\rangle$ kg · m/s, crossing the goal line at location $\langle 0, 0, -26\rangle$ m relative to an origin in the center of the rink. The puck had been hit by a player 0.4 s before reaching the goal. What was the location of the puck when it was hit by the player, assuming negligible friction between the puck and the ice? (Note that the ice surface lies in the xz plane.)

••P60 A space probe of mass 400 kg drifts past location $\langle 0, 3\times10^4, -6\times10^4\rangle$ m with momentum $\langle 6\times10^3, 0, -3.6\times10^3\rangle$ kg · m/s. Assuming the momentum of the probe does not change, what will be its position 2 minutes later?

Section 1.10

•P61 A proton in an accelerator attains a speed of $0.88c$. What is the magnitude of the momentum of the proton?

•P62 An electron with a speed of $0.95c$ is emitted by a supernova, where c is the speed of light. What is the magnitude of the momentum of this electron?

•P63 A "cosmic-ray" proton hits the upper atmosphere with a speed $0.9999c$, where c is the speed of light. What is the magnitude of the momentum of this proton? Note that $|\vec{v}|/c = 0.9999$; you don't actually need to calculate the speed $|\vec{v}|$.

•P64 A proton in a particle accelerator is traveling at a speed of $0.99c$. (Masses of particles are given on the inside back cover of this textbook.) **(a)** If you use the approximate nonrelativistic equation for the magnitude of momentum of the proton, what answer do you get? **(b)** What is the magnitude of the correct relativistic momentum of the proton? **(c)** The approximate value (the answer to part a) is significantly too low. What is the ratio of magnitudes you calculated (correct/approximate)?

•P65 When the speed of a particle is close to the speed of light, the factor γ, the ratio of the correct relativistic momentum $\gamma m\vec{v}$ to the approximate nonrelativistic momentum $m\vec{v}$, is quite large. Such speeds are attained in particle accelerators, and at these speeds the approximate nonrelativistic equation for momentum is a very poor approximation. Calculate γ for the case where $|\vec{v}|/c = 0.9996$.

•P66 An electron travels at speed $|\vec{v}| = 0.996c$, where $c = 3\times10^8$ m/s is the speed of light. The electron travels in the direction given by the unit vector $\hat{v} = \langle 0.655, -0.492, -0.573\rangle$. The mass of an electron is 9×10^{-31} kg. **(a)** What is the value of γ? You can simplify the calculation if you notice that $(|\vec{v}|/c)^2 = (0.996)^2$. **(b)** What is the speed of the electron? **(c)** What is the magnitude of the electron's momentum? **(d)** What is the vector momentum of the electron? Remember that any vector can be "factored" into its magnitude times its unit vector, so that $\vec{v} = |\vec{v}|\hat{v}$.

•P67 If $|\vec{p}|/m$ is $0.85c$, what is $|\vec{v}|$ in terms of c?

COMPUTATIONAL PROBLEMS

These problems are intended to introduce you to using a computer to model matter, interactions, and motion in 3D. You do not need to know how to program; you will learn what you need to know by doing these problems. In later chapters you will build on these small calculations to build models of physical systems.

To install the free 3D programming environment VPython, go to http://vpython.org and (carefully) follow the instructions for your operating system (Windows, MacOS, or Linux). Note the instructions given there on how to zoom and rotate the "camera" when viewing a 3D scene you have created.

More detailed and extended versions of some of these computational modeling problems may be found in the lab activities included in the *Matter & Interactions 4th Edition* resources for instructors.

•P68 Watch the first introductory VPython video, *VPython Instructional Videos 1: 3D Objects,* at vpython.org/video01.html and complete the challenge activity at the end of the video.

•P69 **(a)** Write a VPython program that creates eight spheres, each placed at one corner of a cube centered on the origin. The length of a side of the cube should be 6 units, and the radius of each sphere should be 0.5. Use at least two different colors for the spheres. **(b)** Add to the program an arrow whose tail is at one corner of the cube and whose tip is at the corner diagonally opposite. Figure 1.62 shows the display from one possible solution to this problem.

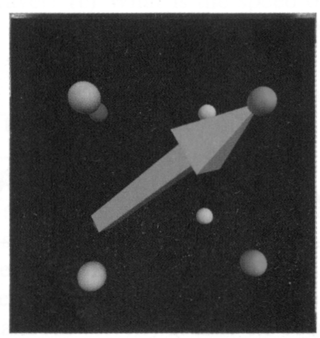

Figure 1.62

•P70 Write a VPython program that represents the x, y, and z axes by three cylinders of different colors. The display from one possible solution is shown in Figure 1.63.