4 minutes gradually slows to a stop. Make a sketch like the figures in Section 1.2, marking dots for the position along the road every minute.

Q10 A spaceship far from all other objects uses its thrusters to attain a speed of 1×10^4 m/s. The crew then shuts off the power. According to Newton's first law, what will happen to the motion of the spaceship from then on?

Q11 Which of the following are vectors? **(a)** $\vec{r}/2$ **(b)** $|\vec{r}|/2$ **(c)** $\langle r_x, r_y, r_z\rangle$ **(d)** $5 \cdot \vec{r}$

PROBLEMS

The difficulty of a problem is represented by the number of dots preceding the problem number.

Section 1.4

•P12 Figure 1.55 shows several arrows representing vectors in the xy plane. **(a)** Which vectors have magnitudes equal to the magnitude of $\vec{a}$? **(b)** Which vectors are equal to $\vec{a}$?

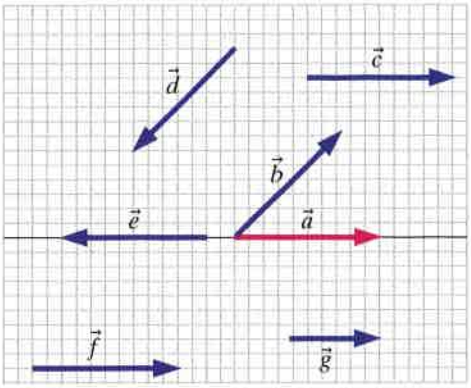

Figure 1.55

•P13 What is the magnitude of the vector $\vec{v}$, where $\vec{v} = \langle 8 \times 10^6, 0, -2 \times 10^7\rangle$ m/s?

•P14 In Figure 1.56 three vectors are represented by arrows in the xy plane. Each square in the grid represents one meter. For each vector, write out the components of the vector, and calculate the magnitude of the vector.

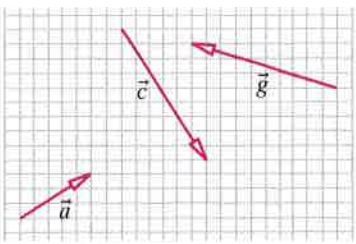

Figure 1.56

•P15 The following questions refer to the vectors depicted by arrows in Figure 1.57. **(a)** What are the components of the vector $\vec{a}$? (Note that since the vector lies in the xy plane, its z component is zero.) **(b)** What are the components of the vector $\vec{b}$? **(c)** Is this statement true or false? $\vec{a} = \vec{b}$ **(d)** What are the components of the vector $\vec{c}$? **(e)** Is this statement true or false? $\vec{c} = -\vec{a}$ **(f)** What are the components of the vector $\vec{d}$? **(g)** Is this statement true or false? $\vec{d} = -\vec{c}$

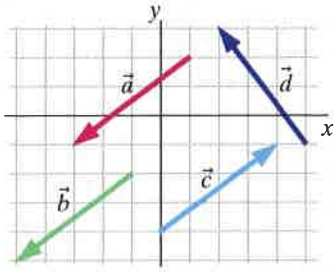

Figure 1.57

•P16 On a piece of graph paper, draw arrows representing the following vectors. Make sure the tip and tail of each arrow you draw are clearly distinguishable. **(a)** Placing the tail of the vector at $\langle 5,2,0\rangle$, draw an arrow representing the vector $\vec{p} = \langle -7,3,0\rangle$. Label it $\vec{p}$. **(b)** Placing the tail of the vector at $\langle -5,8,0\rangle$, draw an arrow representing the vector $-\vec{p}$. Label it $-\vec{p}$.

•P17 What is the result of multiplying the vector $\vec{a}$ by the scalar f, where $\vec{a} = \langle 0.02, -1.7, 30.0\rangle$ and $f = 2.0$?

•P18 **(a)** In Figure 1.58, what are the components of the vector $\vec{d}$? **(b)** If $\vec{e} = -\vec{d}$, what are the components of $\vec{e}$? **(c)** If the tail of vector $\vec{d}$ were moved to location $\langle -5,-2,4\rangle$ m, where would the tip of the vector be located? **(d)** If the tail of vector $-\vec{d}$ were placed at location $\langle -1,-1,-1\rangle$ m, where would the tip of the vector be located?

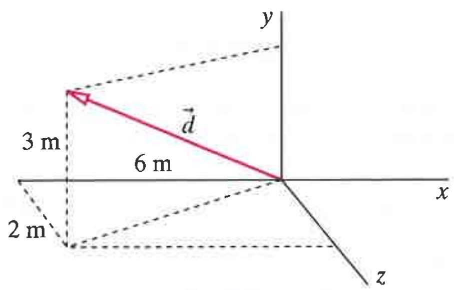

Figure 1.58

•P19 What is the unit vector in the direction of $\langle 2,2,2\rangle$? What is the unit vector in the direction of $\langle 3,3,3\rangle$?

•P20 **(a)** On a piece of graph paper, draw the vector $\vec{f} = \langle -2,4,0\rangle$, putting the tail of the vector at $\langle -3,0,0\rangle$. Label the vector $\vec{f}$. **(b)** Calculate the vector $2\vec{f}$, and draw this vector on the graph, putting its tail at $\langle -3,-3,0\rangle$, so you can compare it to the original vector. Label the vector $2\vec{f}$. **(c)** How does the magnitude of $2\vec{f}$ compare to the magnitude of $\vec{f}$? **(d)** How does the direction of $2\vec{f}$ compare to the direction of $\vec{f}$? **(e)** Calculate the vector $\vec{f}/2$, and draw this vector on the graph, putting its tail at $\langle -3,-6,0\rangle$, so you can compare it to the other vectors. Label the vector $\vec{f}/2$. **(f)** How does the magnitude of $\vec{f}/2$ compare to the magnitude of $\vec{f}$? **(g)** How does the direction of $\vec{f}/2$ compare to the direction of $\vec{f}$? **(h)** Does multiplying a vector by a scalar change the magnitude of the vector? **(i)** The vector $a(\vec{f})$ has a magnitude three times as great as that of $\vec{f}$, and its direction is opposite to the direction of $\vec{f}$. What is the value of the scalar factor a?

•P21 Write the vector $\vec{a} = \langle 400, 200, -100\rangle$ m/s^2 as the product $|\vec{a}|\cdot\hat{a}$.

•P22 **(a)** On a piece of graph paper, draw the vector $\vec{g} = \langle 4,7,0\rangle$ m. Put the tail of the vector at the origin. **(b)** Calculate the magnitude of $\vec{g}$. **(c)** Calculate $\hat{g}$, the unit vector pointing in the direction of $\vec{g}$. **(d)** On the graph, draw $\hat{g}$. Put the tail of the vector at $\langle 1,0,0\rangle$ m so you can compare $\hat{g}$ and $\vec{g}$. **(e)** Calculate the product of the magnitude $|\vec{g}|$ times the unit vector $\hat{g}$, $(|\vec{g}|)(\hat{g})$.

•P23 A proton is located at $\langle 3\times 10^{-10}, -3\times 10^{-10}, 8\times 10^{-10}\rangle$ m. **(a)** What is $\vec{r}$, the vector from the origin to the location of the proton? **(b)** What is $|\vec{r}|$? **(c)** What is $\hat{r}$, the unit vector in the direction of $\vec{r}$?

•P24 In Figure 1.59, the vector $\vec{r}_1$ points to the location of object 1 and $\vec{r}_2$ points to the location of object 2. Both vectors lie in the xy plane. **(a)** Calculate the position of object 2 relative to object 1, as a relative position vector. **(b)** Calculate the position of object 1 relative to object 2, as a relative position vector.

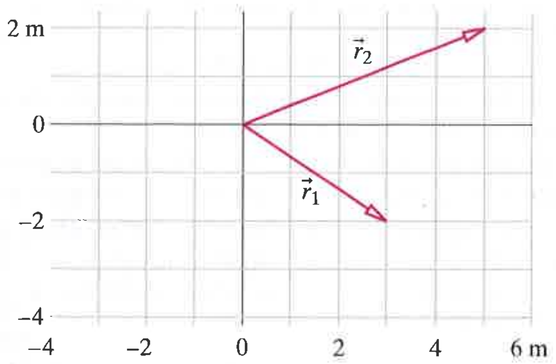

Figure 1.59

•P25 **(a)** What is the vector whose tail is at $\langle 9.5,7,0\rangle$ m and whose head is at $\langle 4,-13,0\rangle$ m? **(b)** What is the magnitude of this vector?

•P26 A man is standing on the roof of a building with his head at the position $\langle 12,30,13\rangle$ m. He sees the top of a tree, which is at the position $\langle -25,35,43\rangle$ m. **(a)** What is the relative position vector that points from the man's head to the top of the tree? **(b)** What is the distance from the man's head to the top of the tree?

•P27 A star is located at $\langle 6\times 10^{10}, 8\times 10^{10}, 6\times 10^{10}\rangle$ m. A planet is located at $\langle -4\times 10^{10}, -9\times 10^{10}, 6\times 10^{10}\rangle$ m. **(a)** What is the vector pointing from the star to the planet? **(b)** What is the vector pointing from the planet to the star?

•P28 A planet is located at $\langle -1\times 10^{10}, 8\times 10^{10}, -3\times 10^{10}\rangle$. A star is located at $\langle 6\times 10^{10}, -5\times 10^{10}, 1\times 10^{10}\rangle$. **(a)** What is $\vec{r}$, the vector from the star to the planet? **(b)** What is the magnitude of $\vec{r}$? **(c)** What is $\hat{r}$, the unit vector (vector with magnitude 1) in the direction of $\vec{r}$?

•P29 A proton is located at $\langle x_p, y_p, z_p\rangle$. An electron is located at $\langle x_e, y_e, z_e\rangle$. What is the vector pointing from the electron to the proton? What is the vector pointing from the proton to the electron?

••P30 A cube is 3 cm on a side, with one corner at the origin. What is the unit vector pointing from the origin to the diagonally opposite corner at location $\langle 3,3,3\rangle$ cm? What is the angle from this diagonal to one of the adjacent edges of the cube?

Section 1.6

•P31 A "slow" neutron produced in a nuclear reactor travels from location $\langle 0.2,-0.05,0.1\rangle$ m to location $\langle -0.202, 0.054, 0.098\rangle$ m in 2 microseconds ($1\mu s = 1\times 10^{-6}$ s). **(a)** What is the average velocity of the neutron? **(b)** What is the average speed of the neutron?

•P32 The position of a baseball relative to home plate changes from $\langle 15,8,-3\rangle$ m to $\langle 20,6,-1\rangle$ m in 0.1 s. As a vector, write the average velocity of the baseball during this time interval.

•P33 You jog at a steady speed of 2 m/s. You start from the location $\langle 0,0,0\rangle$ and for the first 200 s your direction is given by the unit vector $\langle 1,0,0\rangle$. Next you jog for 300 s in the direction given by the unit vector $\langle \cos 45°, 0, \cos 45°\rangle$. Finally you jog for 150 s in the direction given by the unit vector $\langle \cos 60°, 0, \cos 30°\rangle$. **(a)** Now what is your position? **(b)** What was your average velocity?

•P34 The position of a golf ball relative to the tee changes from $\langle 50,20,30\rangle$ m to $\langle 53,18,31\rangle$ m in 0.1 second. As a vector, write the velocity of the golf ball during this short time interval.

•P35 The crew of a stationary spacecraft observe an asteroid whose mass is 4×10^{17} kg. Taking the location of the spacecraft as the origin, the asteroid is observed to be at location $\langle -3\times 10^3, -4\times 10^3, 8\times 10^3\rangle$ m at a time 18.4 s after lunchtime. At a time 21.4 s after lunchtime, the asteroid is observed to be at location $\langle -1.4\times 10^3, -6.2\times 10^3, 9.7\times 10^3\rangle$ m. Assuming that the velocity of the asteroid does not change during this time interval, calculate the vector velocity $\vec{v}$ of the asteroid.

••P36 A spacecraft traveling at a velocity of $\langle -20,-90,40\rangle$ m/s is observed to be at a location $\langle 200,300,-500\rangle$ m relative to an origin located on a nearby asteroid. At a later time the spacecraft is at location $\langle -380,-2310,660\rangle$ m. **(a)** How long did it take the spacecraft to travel between these locations? **(b)** How far did the spacecraft travel? **(c)** What is the speed of the spacecraft? **(d)** What is the unit vector in the direction of the spacecraft's velocity?

••P37 Here are the positions at three different times for a bee in flight (a bee's top speed is about 7 m/s).

Time	6.3 s	6.8 s	7.3 s
Position	$\langle -3.5, 9.4, 0\rangle$ m	$\langle -1.3, 6.2, 0\rangle$ m	$\langle 0.5, 1.7, 0\rangle$ m

(a) Between 6.3 s and 6.8 s, what was the bee's average velocity? Be careful with signs. **(b)** Between 6.3 s and 7.3 s, what was the bee's average velocity? Be careful with signs. **(c)** Of the two average velocities you calculated, which is the best estimate of the bee's instantaneous velocity at time 6.3 s? **(d)** Using the best information available, what was the displacement of the bee during the time interval from 6.3 s to 6.33 s?

Section 1.7

•P38 At time $t_1 = 12$ s, a car is located at $\langle 84,78,24\rangle$ m and has velocity $\langle 4,0,-3\rangle$ m/s. At time $t_2 = 18$ s, what is the position of the car? (The velocity is constant in magnitude and direction during this time interval.)

•P39 An electron passes location $\langle 0.02, 0.04, -0.06\rangle$ m, and $2\,\mu$s later is detected at location $\langle 0.02, 1.84, -0.86\rangle$ m (1 microsecond is 1×10^{-6} s). **(a)** What is the average velocity of the electron? **(b)** If the electron continues to travel at this average velocity, where will it be in another $5\,\mu$s?

•P40 After World War II the U.S. Air Force carried out experiments on the amount of acceleration a human can survive. These experiments, led by John Stapp, were the first to use crash dummies as well as human subjects, especially Stapp himself, who became an effective advocate for automobile safety belts. In one of the experiments Stapp rode a rocket sled that decelerated from 140 m/s (about 310 mi/h) to 70 m/s in just 0.6 s. **(a)** What was the absolute value of the (negative) average acceleration? **(b)** The acceleration of a falling object if air resistance is negligible is 9.8 m/s/s, called "one g." What was the absolute value of the average acceleration in g's? (Stapp eventually survived a test at 46 g's!)

••P41 At a certain instant a ball passes location $\langle 7, 21, -17\rangle$ m. In the next 3 s, the ball's average velocity is $\langle -11, 42, 11\rangle$ m/s. At the end of this 3 s time interval, what is the height y of the ball?

••P42 You throw a ball. Assume that the origin is on the ground, with the $+y$ axis pointing upward. Just after the ball leaves your hand its position is $\langle 0.06, 1.03, 0\rangle$ m. The average velocity of the ball over the next 0.7 s is $\langle 17, 4, 6\rangle$ m/s. At time 0.7 s after the ball leaves your hand, what is the height of the ball above the ground?

••P43 Figure 1.60 shows the trajectory of a ball traveling through the air, affected by both gravity and air resistance. Here are the positions of the ball at several successive times:

Location	t(s)	Position (m)
A	0.0	$\langle 0,0,0\rangle$
B	1.0	$\langle 22.3, 26.1, 0\rangle$
C	2.0	$\langle 40.1, 38.1, 0\rangle$

(a) What is the average velocity of the ball as it travels between location A and location B? **(b)** If the ball continued to travel at the same average velocity during the next second, where would it be at the end of that second? (That is, where would it be at time $t=2$ s?) **(c)** How does your prediction from part (b) compare to the actual position of the ball at $t=2$ s (location C)? If the predicted and observed locations of the ball are different, explain why.

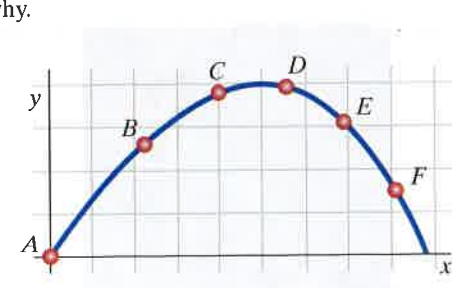

Figure 1.60

••P44 At 6 s after 3:00, a butterfly is observed leaving a flower whose location is $\langle 6, -3, 10\rangle$ m relative to an origin on top of a nearby tree. The butterfly flies until 10 s after 3:00, when it alights on a different flower whose location is $\langle 6.8, -4.2, 11.2\rangle$ m relative to the same origin. What was the location of the butterfly at a time 8.5 s after 3:00? What assumption did you have to make in calculating this location?

Section 1.8

•P45 A baseball has a mass of 0.155 kg. A professional pitcher throws a baseball 90 mi/h, which is 40 m/s. What is the magnitude of the momentum of the pitched baseball?

•P46 A hockey puck with a mass of 0.4 kg has a velocity of $\langle 38, 0, -27\rangle$ m/s. What is the magnitude of its momentum, $|\vec{p}|$?

•P47 What is the magnitude (in kg·m/s) of the momentum of a 1000 kg airplane traveling at a speed of 500 mi/h? (Note that you need to convert speed to meters per second.)

•P48 A baseball has a mass of about 155 g. What is the magnitude of the momentum of a baseball thrown at a speed of 100 miles per hour? (Note that you need to convert mass to kilograms and speed to meters per second. See the inside back cover of the textbook for conversion factors.)

•P49 If a particle has momentum $\vec{p} = \langle 4, -5, 2\rangle$ kg·m/s, what is the magnitude $|\vec{p}|$ of its momentum?

•P50 An object with mass 1.6 kg has momentum $\langle 0, 0, 4\rangle$ kg·m/s. **(a)** What is the magnitude of the momentum? **(b)** What is the unit vector corresponding to the momentum? **(c)** What is the speed of the object?

•P51 A tennis ball of mass m traveling with velocity $\langle v_x, 0, 0\rangle$ hits a wall and rebounds with velocity $\langle -v_x, 0, 0\rangle$. **(a)** What was the change in momentum of the tennis ball? **(b)** What was the change in the magnitude of the momentum of the tennis ball?

•P52 A basketball has a mass of 570 g. Heading straight downward, in the $-y$ direction, it hits the floor with a speed of 5 m/s and rebounds straight up with nearly the same speed. What was the momentum change $\Delta\vec{p}$?

••P53 A basketball has a mass of 570 g. Moving to the right and heading downward at an angle of 30° to the vertical, it hits the floor with a speed of 5 m/s and bounces up with nearly the same speed, again moving to the right at an angle of 30° to the vertical. What was the momentum change $\Delta\vec{p}$?

•P54 The first stage of the giant Saturn V rocket reached a speed of 2300 m/s at 170 s after liftoff. **(a)** What was the average acceleration in m/s/s? **(b)** The acceleration of a falling object if air resistance is negligible is 9.8 m/s/s, called "one g." What was the average acceleration in g's?

••P55 A 50 kg child is riding on a carousel (merry-go-round) at a constant speed of 5 m/s. What is the magnitude of the change in the child's momentum $|\Delta\vec{p}|$ in going all the way around (360°)? In going halfway around (180°)? It is very helpful to draw a diagram, and to do the vector subtraction graphically.

••P56 Figure 1.61 shows a portion of the trajectory of a ball traveling through the air. Arrows indicate its momentum at several locations.

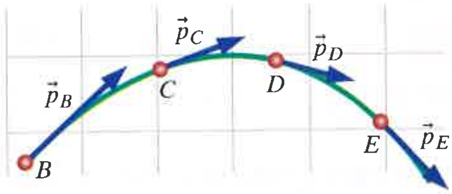

Figure 1.61

At various locations, the ball's momentum is:
$\vec{p}_B = \langle 3.03, 2.83, 0\rangle$ kg·m/s
$\vec{p}_C = \langle 2.55, 0.97, 0\rangle$ kg·m/s
$\vec{p}_D = \langle 2.24, -0.57, 0\rangle$ kg·m/s

$\vec{p}_E = \langle 1.97, -1.93, 0 \rangle$ 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.

Figure 1.63

•**P71** Write a VPython program that represents the x, y, and z axes by three boxes (rectangular solids) of different colors. The display from one possible solution is shown in Figure 1.64.

Figure 1.64

•**P72** Watch the second introductory VPython video, *VPython Instructional Videos 2: Variable Assignment*, at vpython.org/video02.html and complete the challenge activity at the end of the video.

•**P73** Based on Problem P72, write a program that shows an arrow pointing from one small box to another in such a way that when you change only the position of the first box, making no other changes, the arrow and the other box move too, so that the two boxes remain linked by the arrow.

•**P74** Watch the third introductory VPython video, *VPython Instructional Videos 3: Beginning Loops*, at vpython.org/video03.html and complete the challenge activity at the end of the video.

••**P75** **(a)** Write a VPython program that uses three while loops to create a display in which each of the axes (x, y, z) is represented by a linear array of boxes, with spaces between the boxes. Figure 1.65 shows a possible example. **(b)** (Optional) Rewrite your program to produce the same display using only one while loop.

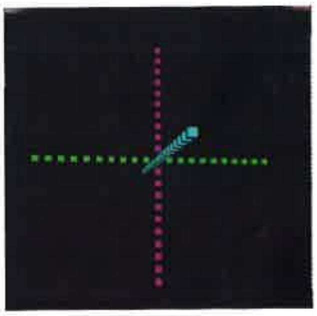

Figure 1.65

••**P76** Write a VPython program that creates three circles of spheres: one in the xy plane, one in the yz plane, and one in the xz plane. Each ring should be centered on the origin. Use either three while loops or one while loop. A possible solution is shown in Figure 1.66.

Figure 1.66

•**P77** Watch the fourth introductory VPython video, *VPython Instructional Videos 4: Loops and Animation*, at vpython.org/video04.html and complete the challenge activity at the end of the video.

••**P78** Consider the VPython program shown below. **(a)** An important skill is being able to read and understand an existing program, in order to be able to make useful modifications. *Before running the program*, study the program carefully line by line, then answer the following questions: (1) What is the initial velocity of the particle? (2) Is the particle initially located in front of the box or behind it? (3) In which line of code is the position of the particle updated? (4) What is the value of the time step Δt? (5) Will the particle bounce off of the red box, or travel through it? **(b)** Now run the program, and see if your answers were correct. **(c)** Modify the program to start the particle from an initial position on the $+x$ axis, to the right of and in front of the red box. Give the particle a velocity that will make it travel to the left, along the x axis, passing in front of the box.

```
from visual import *
box(pos=vector(0,0,-1),
    size=(5,5,0.5),
    color=color.red,
    opacity = 0.4)
particle = sphere(pos=vector(-5,0,-5),
                  radius=0.3,
                  color=color.cyan,
                  make_trail = True)
v = vector(0.5,0,0.5)
delta_t = 0.05
t = 0
while t < 20:
    rate(100)
    particle.pos = particle.pos + v * delta_t
    t = t + delta_t
```

•••**P79** Modify the program shown above to make the particle bounce off the red box instead of passing through it. On the Help menu available in IDLE (the VPython editor), choose "Python docs" or search the web for "Python if" to find out how to use an `if` statement. You may also find it helpful to look at the example program `bounce2.py`, included in the examples installed with VPython.