```
      // ball displayed in 3D as a planar ellipse of size (dx,dy,dz)
      ball.setSizeXYZ(1, 1, 1);
      frame.addElement(ball);
      Element box = new ElementBox();
      box.setXYZ(0, 0, 0);
      box.setSizeXYZ(4, 4, 1);
      box.getStyle().setFillColor(Color.RED);
      // divide sides of box into smaller rectangles
      box.getStyle().setResolution(new Resolution(5, 5, 2));
      frame.addElement(box);
      frame.setMessage("time = "+ControlUtils.f2(time));
   }

   protected void doStep() {
      time += 0.1;
      double z = ball.getZ()+vz*dt-4.9*dt*dt;
      vz -= 9.8*dt;
      if((vz<0)&&(z<1)) {
         vz = -vz;
      }
      ball.setZ(z);
      frame.setMessage("time = "+ControlUtils.f2(time));
   }

   public static void main(String[] args) {
      SimulationControl.createApp(new Ball3DApp());
   }
}
```

Note that the 3D drawing API is similar to the 2D drawing API described in Section 3.3. The `setPreferredMinMax` method, for example, has a variant that accepts up to six double parameters. You can set the size and location of objects in three dimensions before or after they are added to the frame.

Although the `Display3DFrame` is designed for three-dimensional visualizations, it can also show two-dimensional projections. For example, we can project onto the y-z plane by invoking

```
frame.setDisplayMode(VisualizationHints.DISPLAY_PLANAR_YZ);
```

Projections onto various planes are available at runtime using the frame's menu. The full capabilities of Open Source Physics 3D are discussed in the *Open Source Physics: A User's Guide with Examples*.

We will require only a small subset of the methods of the Open Source Physics 3D framework to create the three-dimensional visualizations in this book and will introduce the necessary objects as needed. Readers may wish to run the demonstration programs in the ch03 directory to obtain an overview of its drawing capabilities.

Of particular interest to baseball fans is the curve of balls in flight due to their rotation. This force was first investigated in 1850 by G. Magnus, and the curvature of the trajectories of spinning objects is now known as the *Magnus effect* (see Figure 3.5). It can be explained qualitatively by observing that the speed of the ball's surface relative to the air is different on opposite edges of the ball. If the drag force has the form $F_{\text{drag}} \sim v^2$, then the unbalanced force due to the difference in the velocity on opposite sides of the ball due to its rotation is

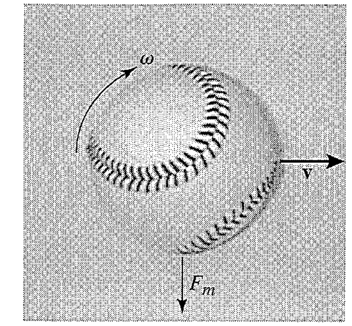

Figure 3.5 The Magnus force on a spinning ball pushes a ball with topspin down.

given by

$$F_{\text{magnus}} \sim v\Delta v. \tag{3.22}$$

We can express the velocity difference in terms of the ball's angular velocity and radius and write

$$F_{\text{magnus}} \sim vr\omega. \tag{3.23}$$

The direction of the Magnus force is perpendicular to both the velocity and the rotation axis. For example, if we observe a ball moving to the right and rotating clockwise (that is, with topspin), then the velocity of the ball's surface relative to the air at the top, $v + \omega r$, is higher than the velocity at the bottom, $v - \omega r$. Because the larger velocity will produce a larger force, the Magnus effect will contribute a force in the downward direction. These considerations suggest that the Magnus force can be expressed as a vector product:

$$F_{\text{magnus}}/m = C_M(\boldsymbol{\omega} \times \mathbf{v}), \tag{3.24}$$

where m is the mass of the ball. The constant C_M depends on the radius of the ball, the viscosity of air, and other factors such as the orientation of the stitching. We will assume that the ball is rotating fast enough so that it can be modeled using an average value. (If the ball does not rotate, the pitcher has thrown a knuckleball.) The total force on the baseball is given by

$$\mathbf{F}/m = \mathbf{g} - C_D|\mathbf{v}|\mathbf{v} + C_M(\boldsymbol{\omega} \times \mathbf{v}). \tag{3.25}$$

Equation (3.25) leads to the following rates for the velocity components:

$$\frac{dv_x}{dt} = -C_D v v_x + C_M(\omega_y v_z - \omega_z v_y) \tag{3.26a}$$

$$\frac{dv_y}{dt} = -C_D v v_y + C_M(\omega_z v_x - \omega_x v_z) \tag{3.26b}$$

$$\frac{dv_z}{dt} = -C_D v v_z + C_M(\omega_x v_y - \omega_y v_x) - g, \tag{3.26c}$$