```
      String data = res.getString();
      // split string on newline character
      String[] lines = data.split("\n");
      // extract x-y data from every line
      for(int i = 0, n = lines.length;i<n;i++) {
         if(lines[i].trim().startsWith("//")) {
            // skip comment lines
            continue;
         }
         // split on any white space
         String[] numbers = lines[i].trim().split("\\s");
         System.out.print("t = "+numbers[0]);
         System.out.println("  y = "+numbers[1]);
      }
   }
}
```

Problem 3.8 The fall of a coffee filter

(a) Use the empirical data in Table 3.1 for the height $y(t)$ of the coffee filter shown in Figure 3.2 to determine the velocity $v(t)$ using the central difference approximation given by

$$v(t) \approx \frac{y(t+\Delta t) - y(t-\Delta t)}{2\Delta t} \quad \text{(central difference approximation).} \tag{3.14}$$

Show that if we write the acceleration as $a(t) \approx [v(t+\Delta t) - v(t)]/\Delta t$ and use the backward difference approximation for the velocity,

$$v(t) \approx \frac{y(t) - y(t-\Delta t)}{\Delta t} \quad \text{(backward difference approximation),} \tag{3.15}$$

we can express the acceleration as

$$a(t) \approx \frac{y(t+\Delta t) - 2y(t) + y(t-\Delta t)}{(\Delta t)^2}. \tag{3.16}$$

Use (3.16) to determine the acceleration.

(b) Determine the terminal velocity from the data given in Table 3.1. This determination is difficult, in part because the terminal velocity has not been reached during the time that the fall of the coffee filter was observed. Use your approximate results for $v(t)$ and $a(t)$ to plot a as a function of v and, if possible, determine the nature of the velocity dependence of a. Discuss the accuracy of your results for the acceleration.

(c) Choose one of the numerical algorithms that we have discussed and write a class that encapsulates this algorithm for the motion of a particle with quadratic drag resistance.

(d) Choose the terminal velocity as an input parameter and take as your first guess for the terminal velocity the value you found in part (b). Make sure that your computed results for the height of the particle do not depend on Δt to the necessary accuracy. Compare your plot of the computed values of $y(t)$ for different choices of the terminal velocity with the empirical values of $y(t)$ in Table 3.1.

Table 3.1 Results for the vertical fall of a coffee filter. Note that the initial time is not zero. The time difference is ≈ 0.0247. This data is also available in the `falling.txt` file in the ch03 package.

t (s)	Height (m)	t (s)	Height (m)	t (s)	Height (m)
0.2055	0.4188	0.4280	0.3609	0.6498	0.2497
0.2302	0.4164	0.4526	0.3505	0.6744	0.2337
0.2550	0.4128	0.4773	0.3400	0.6990	0.2175
0.2797	0.4082	0.5020	0.3297	0.7236	0.2008
0.3045	0.4026	0.5266	0.3181	0.7482	0.1846
0.3292	0.3958	0.5513	0.3051	0.7728	0.1696
0.3539	0.3878	0.5759	0.2913	0.7974	0.1566
0.3786	0.3802	0.6005	0.2788	0.8220	0.1393
0.4033	0.3708	0.6252	0.2667	0.8466	0.1263

(e) Repeat parts (c) and (d) assuming linear drag resistance. What are the qualitative differences between the two computed forms of $y(t)$ for the same terminal velocity?

(f) Visually determine which form of the drag force yields the best overall fit to the data. If the fit is not perfect, what is your criteria for which fit is better? Is it better to match your results to the experimental data at early times or at later times? Or did you adopt another criterion? What can you conclude about the velocity dependence of the drag resistance on a coffee filter? ■

Problem 3.9 Effect of air resistance on the ascent and descent of a pebble

(a) Verify the claim made in Section 3.7 that the effects of air resistance on a falling pebble can be appreciable. Compute the speed at which a pebble reaches the ground if it is dropped from rest at a height of 50 m. Compare this speed to that of a freely falling object under the same conditions. Assume that the drag force is proportional to v^2 and that the terminal velocity is 30 m/s.

(b) Suppose a pebble is thrown vertically upward with an initial velocity v_0. In the absence of air resistance, we know that the maximum height reached by the pebble is $v_0^2/2g$, its velocity upon return to the Earth equals v_0, the time of ascent equals the time of descent, and the total time in the air is $2v_0/g$. Before doing a simulation, give a simple qualitative explanation of how you think these quantities will be affected by air resistance. In particular, how will the time of ascent compare with the time of descent?

(c) Do a simulation to determine if your qualitative answers in part (b) are correct. Assume that the drag force is proportional to v^2. Choose the coordinate system shown in Figure 3.1 with y positive upward. What is the net force for $v > 0$ and $v < 0$? We can characterize the magnitude of the drag force by a terminal velocity even if the motion of the pebble is upward and the pebble never attains this velocity. Choose the terminal velocity $v_t = 30$ m/s, corresponding to a drag coefficient of $C_2 \approx 0.01089$. It is a good idea to choose an initial velocity that allows the pebble