

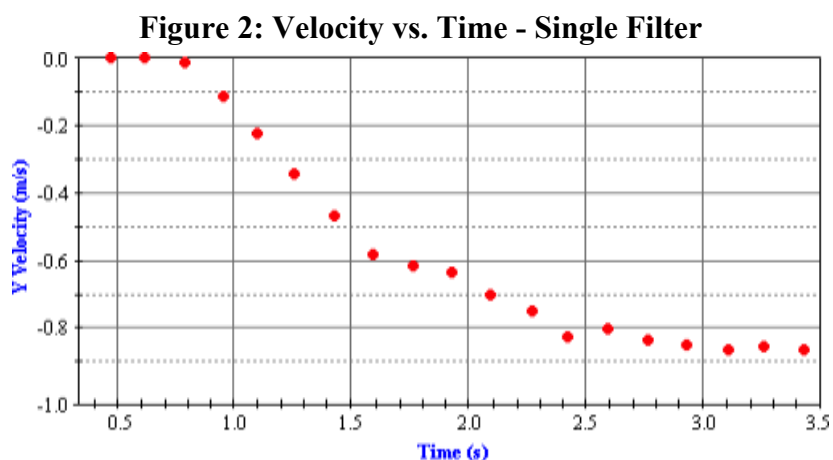
Coffee Filter Lab

As objects fall, they increase their speed due to the downward pull of gravity. Air resistance counteracts gravity's pull by resisting the downward motion of the object. The amount of air resistance depends upon a variety of factors, most noticeably, the object's speed. As objects move faster, they encounter more air resistance. When the amount of upward air resistance force is equal to the downward gravity force, the object encounters a balance of forces and is said to have reached a **terminal velocity**. The terminal velocity value is the final, constant velocity value achieved by the falling object.

A group of physics students are investigating the terminal velocity values obtained by falling coffee filters. They videotape the falling filters and use *video analysis software* to analyze the motion. The video is imported into the software program and the filter's position in each consecutive frame is clicked on (see **Figure 1**). The software uses the position coordinates to generate a plot of the vertical velocity as a function of time. **Figure 2**



shows the velocity versus time graph that resulted from the analysis of the motion of a single filter.

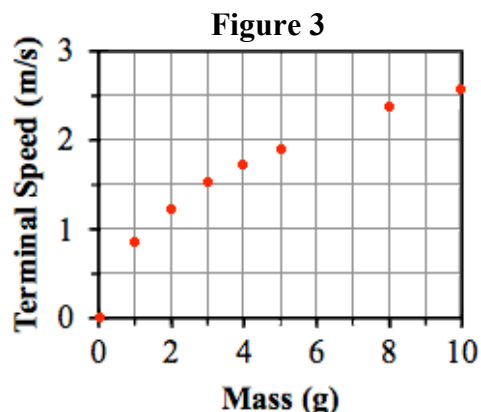


The lab group then investigated the effect of mass on the motion of the falling filters. They stacked varying numbers of pleated coffee filters tightly together and analyzed the motion of the stacks of filters. They determined the terminal

velocity of the stacks of filters. The students also measured the mass of the filters to determine their weight and used the value to determine the amount of air resistance encountered by the filters. The results of several trials are shown in **Table 1**. The terminal speed (i.e., velocity) as a function of mass is shown in **Figure 3**.

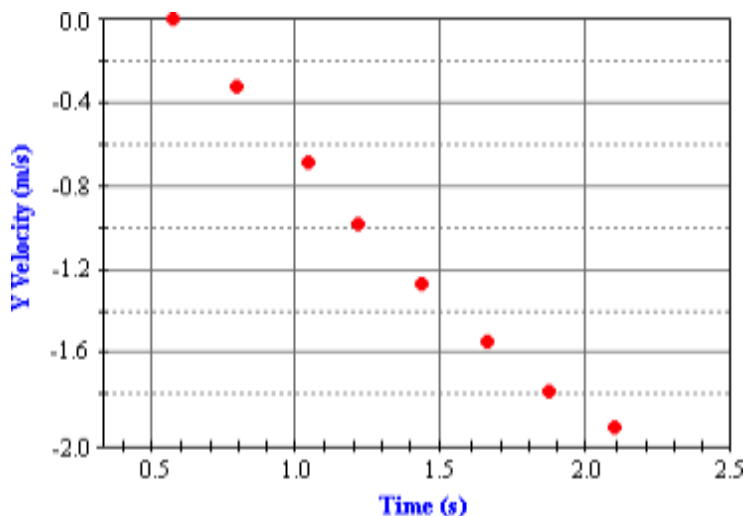
Table 1

Trial	# of Filters	Mass (g)	v_{terminal} (m/s)	Resistance (N)
1	1	0.99	0.87	0.0097
2	2	1.99	1.24	0.0195
3	3	3.01	1.52	0.0295
4	4	4.00	1.75	0.0392
5	5	5.00	1.90	0.0490
6	8	7.99	2.41	0.0783
7	10	10.01	2.55	0.0981



Questions:

1. At which of the listed times does the single coffee filter stop gaining speed and reach a terminal velocity?
 - a. 0.8 seconds
 - b. 1.6 seconds
 - c. 2.5 seconds
 - d. 3.5 seconds
2. When the students dropped eight filters, the video analysis provided a velocity-time graph that looked like the graph below. As seen, the stack of eight filters hit the ground after 2.0 seconds.



- Why were the students bothered by this graph?
- a. The time was much shorter than the other times.
 - b. The time was much longer than the other times.
 - c. A terminal velocity was not reached during the fall.
 - d. The slope of the line was too steep.
3. How does the downward force of gravity compare to the upward air resistance force at the 1.5 second mark in **Figure 2**?
 - a. The force of air resistance is weaker than the force of gravity.
 - b. The force of air resistance is stronger than the force of gravity.
 - c. The force of air resistance is of equal strength as the force of gravity.
 - d. There is no force of air resistance at this point; there is only a force of gravity.
 4. How does the downward force of gravity compare to the upward air resistance force at the 3.4 second mark in **Figure 2**?
 - a. The force of air resistance is weaker than the force of gravity.
 - b. The force of air resistance is stronger than the force of gravity.
 - c. The force of air resistance is of equal strength as the force of gravity.
 - d. There is no force of air resistance at this point; there is only a force of gravity.

5. What would be an estimate of the terminal speed of a stack of six coffee filters?
 - a. 2.10 m/s
 - b. 2.41 m/s
 - c. 5.22 m/s
 - d. 7.99 m/s

6. Having performed this lab, a student suggests that the terminal velocity of a 2.5-gram penny would be 1.38 m/s. Which one of the following statements is incorrectly assumed by the student when making this comment?
 - a. The penny will fall with a flat orientation instead of a sideways orientation.
 - b. Despite their greater density, copper still reaches a terminal velocity value.
 - c. The mass of an object is the only variable that affects the terminal velocity.
 - d. The weight of 2.5 grams of copper (penny) equals that of 2.5 grams of paper (filter).

7. What final speed will be reached by a stack of three coffee filters if dropped from a very tall building?
 - a. 0.0295 m/s
 - b. 1.52 m/s
 - c. 2.61 m/s
 - d. 3.01 m/s

8. Which one of the following is an independent variable in this experiment?
 - a. The number of filters
 - b. The terminal velocity
 - c. Force of air resistance
 - d. Time required to reach terminal velocity

9. Which of the following conclusions is **NOT** supported by the data in **Table 1**?
 - a. More massive objects reach a higher terminal speed than less massive objects.
 - b. The amount of air resistance encountered by an object increases as the mass increases.
 - c. A more massive object will encounter a greater amount of air resistance during its fall.
 - d. The time required to reach terminal velocity increases as the mass of the object increases.

10. Which one of the following graphs represents the relationship between the force of air resistance and the terminal velocity?
 - a. Graph A
 - b. Graph B
 - c. Graph C
 - d. Graph D

