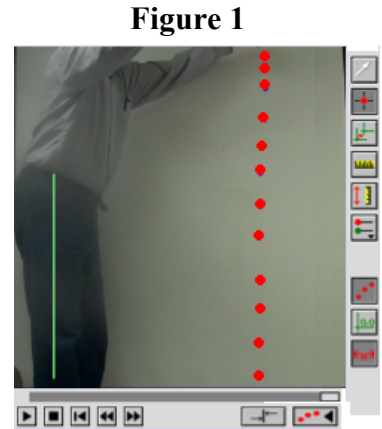


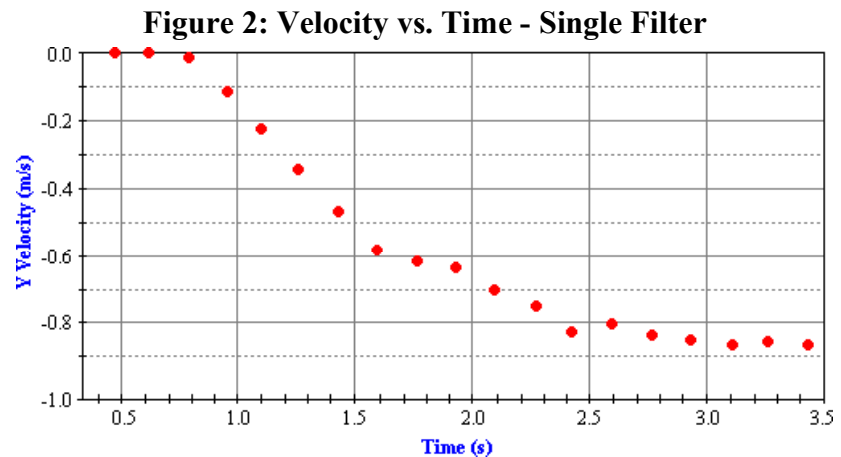
## Coffee Filter Lab

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.

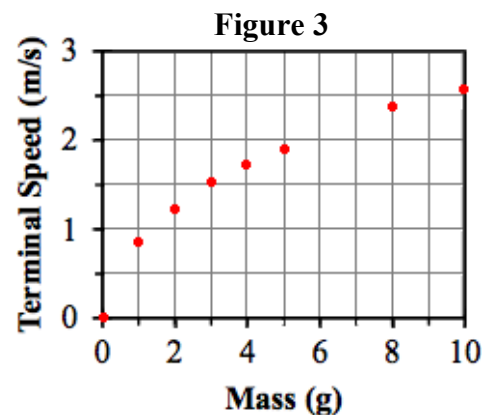


The lab group then investigated the effect of mass on the motion of the falling filters. They stacked varying numbers of pleated coffee filters tightly together and analyzed the motion of the stacks of filters. They determined the terminal

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**.

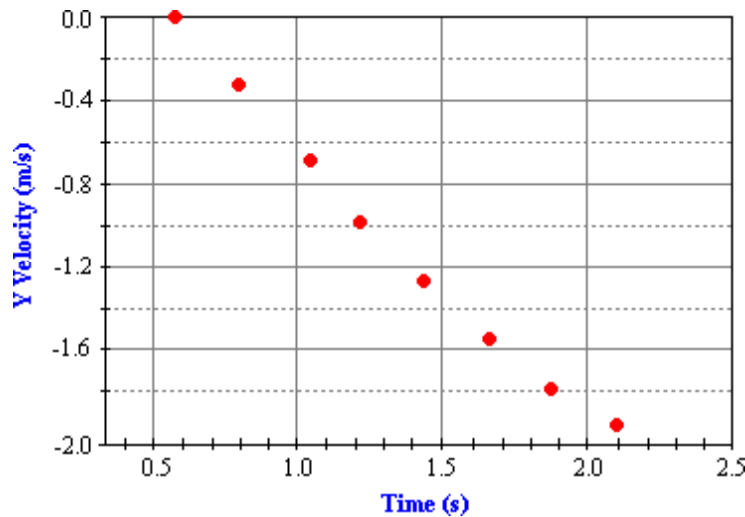
**Table 1**

Trial	# of Filters	Mass (g)	$v_{\text{terminal}}$ (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. How was the terminal velocity determined from the video analysis software?
  - a. The terminal velocity was the slope of the line on the graph.
  - b. The terminal velocity was the velocity value at the point the line leveled off.
  - c. The terminal velocity was the mean (average) velocity as found from the graph.
  - d. The terminal velocity was the median of the velocity values found on the graph.
2. What must happen in order for a falling object to reach a terminal velocity?
  - a. The force of gravity must increase until it is equal to the force of air resistance.
  - b. The force of gravity must decrease until it is equal to the force of air resistance.
  - c. The force of air resistance must increase until it is equal to the force of gravity.
  - d. The force of air resistance must decrease until it is equal to the force of gravity.
3. 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. This occurred before the filters reached a terminal velocity.



- Which alteration in procedure would allow the students to determine the terminal velocity of the stack of eight filters?
- a. Drop the filters from the second floor and capture video of their fall.
  - b. Blow air upward from a fan below the filters to create more air resistance.
  - c. Extrapolate the line on the graph so that it curves and flattens out to a terminal velocity.
  - d. Throw the filters sideways so there is more time to fall and capture the motion on video.
4. 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).

5. Which one of the following statements implies the correct cause-to-effect relationship?
  - a. Decreasing the amount of air resistance reduces the mass of an object.
  - b. Changing the amount of air resistance serves to decrease the object's weight.
  - c. As the value of the terminal velocity is decreased, the number of filters decreases.
  - d. Increasing the number of filters increases the upper limit on the amount of air resistance.
  
6. Which of the following conclusions is supported by the data presented in **Table 1**?
  - a. Heavier objects fall faster than lighter objects.
  - b. All objects fall at the same rate in a vacuum chamber.
  - c. A more massive object will take a longer time to reach a terminal velocity.
  - d. Terminal velocity is reached when the force of gravity is equal to air resistance.

### Answers and Explanations:

1. **Answer:** B

**Explanation:** Terminal velocity occurs when the velocity of the falling filters has become constant. When the filters achieve this terminal velocity, the line on the velocity graph will have leveled off to a constant value.

2. **Answer:** C

**Explanation:** The first paragraph of the passage states that "when the 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 first paragraph also states "as objects move faster, they encounter more air resistance." So one can reason that the gravity force is a constant value on the falling filters and it is the air resistance force that is increasing. It increases because of the gain in speed; the increasing continues until the upward force of air resistance equals the downward force of gravity.

3. **Answer:** A

**Explanation:** The filters hit the ground before they achieved a constant, terminal velocity value. If they could have continued to fall, the air resistance would have increased as the speed increased and terminal velocity would eventually be reached. One way to *fix this problem* would be drop the filters from a higher initial height so that they have a longer time to fall. They would then reach a terminal velocity.

4. **Answer:** C

**Explanation:** The statement made here assumes that one can interpolate the terminal velocity of a 2.5 gram penny by finding a value in **Table 1** between the trial 2 (two filters) and trial 3 (three filters). This is based on the fact that the mass of a 2.5 gram penny is equal to the mass of 2.5 coffee filters. A penny may have the same mass as 2.5 filters but there are more variables that affect the terminal velocity than the mass. The person making the statement is assuming that mass is the only factor that matters. Another factor that plays a role is the *profile area* of the falling object.

5. **Answer:** D

**Explanation:** As an object falls, air resistance will increase until it is equal to the force of gravity. The force of gravity is determined by the number of filters that are dropped. And so it reasons that "increasing the number of filters increases the upper limit on the amount of air resistance" that the filters can experience.

6. **Answer:** A

**Explanation:** A more massive object is a heavier object. By inspecting either **Table 1** or from **Figure 3**, one observes that objects of greater mass (heavier) have a greater terminal velocity. As such, heavier objects fall faster than lighter ones.