Names: Amy Chang, Akaash Kolluri, Ray Tang, Jonathan Xu, Alex Zhang

Night Lab 3 – Coffee Filter Lab Design

AP Physics C – Mechanics

Objective: I can determine the relation of velocity on resistive forces for a falling coffee filter by describing the velocity, acceleration, and position for falling coffee filters in relation to time.

Pre-lab Questions

1. Why are coffee filters perhaps ideal for studying air resistance? List properties of them that may be ideal.
   Coffee filters have small mass but large surface area, and thus are more affected by air resistance. Also, we can stack coffee filters to change the mass without changing the shape or size of the object being dropped, so the air resistance factor would be similar, while the force of acceleration due to gravity would be greater.
2. Is it feasible to measure the force and velocity of a coffee filter in the lab directly and determine the relationship *F(v)* from this (for example, using a sensor to measure a contact force)? Justify your answer.
   No, since the power of the force of a falling coffee filter cannot be properly measured without measuring the force on impact. With just a normal sensor, there is no way to measure a force even while knowing the velocity, so it is not possible to derive F(v).
3. Derive expressions for the terminal velocities of two objects: one under the influence of a linear drag force and the other under the influence of a quadratic drag force. Assume both objects are falling from rest.
   Linear:
   $mg - bv_t = ma = 0$ (At terminal velocity, $a = 0$)
   $mg = bv_t$
   $v_t = \frac{mg}{b}$

   Quadratic:
   $mg - bv_t^2 = ma = 0$
   $mg = bv_t^2$
   $v_t = \sqrt{\frac{mg}{b}}$

Materials

__✓__Coffee filters   _____Meter stick   _____Stopwatch   ___✓__Motion detector

____Force sensor   _____Hanging masses   _____Sharpie markers   ___✓__Other (balance)

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Procedure

Figure 1. A schematic of the experimental setup.

1. Gather 7 coffee filters (constant object), a motion sensor, a balance, and the proper lab software (PASCO Capstone). The number of coffee filters which make up the falling objects is varied, the motion sensor helps to measure the velocity of the filters, the balance beam measures the mass of the coffee filters, and the lab software provides visual data for the motion sensor. Drop height remains constant.
2. Using the balance, first mass the 7 coffee filters, then repeatedly remove one and mass until all test cases have been massed.
3. Drop the coffee filters directly above the motion detector and record the information using the lab software. We would be analyzing the position vs. time graph using the lab software and motion detector.
4. In the lab software, note the slope of the line of best fit on the data points that represent the falling coffee filters.
    a. The slope of the line of best fit for those data points is the terminal velocity, and by collecting the terminal velocity as a result of mass, we can compare the two and note the relation between them with a power regression.
5. Remove a coffee filter and repeat steps 3-4 until data for all test cases have been recorded.

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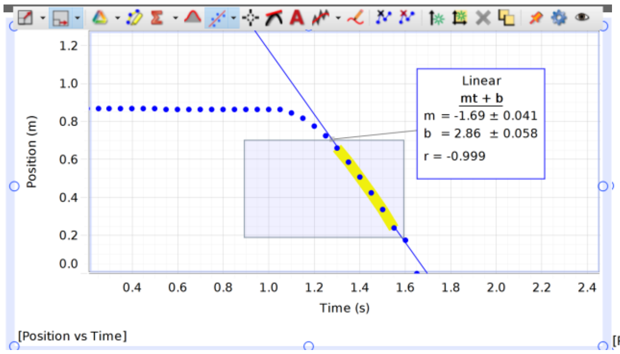
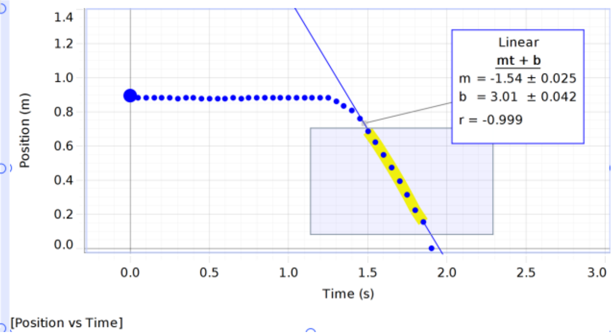
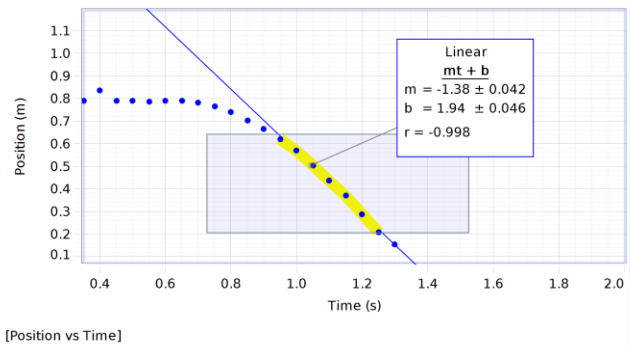
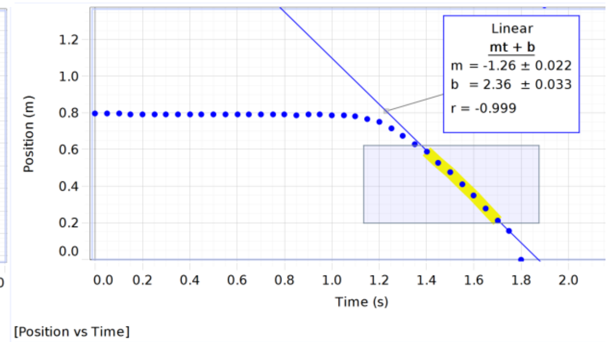
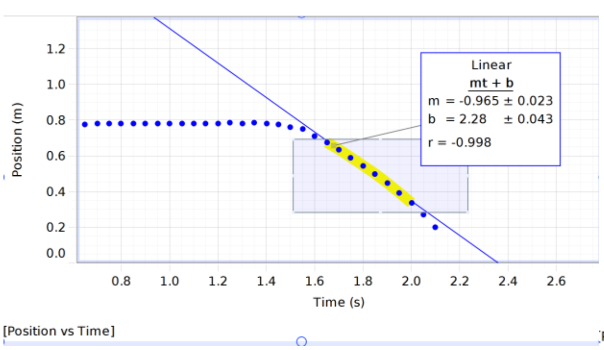
Data











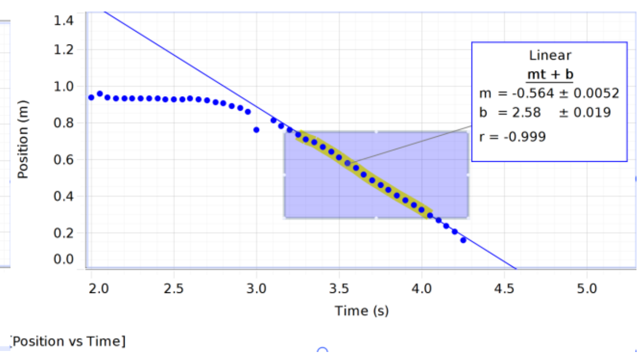


Table 1. A table recording the terminal velocity of falling coffee filters with respect to the mass and number of coffee filters being measured.

Number of Coffee Filters	Mass (g)	Terminal Velocity (m/s)
7	6.30	-1.69
6	5.40	-1.54
5	4.50	-1.38
4	3.60	-1.26
3	2.70	-0.965
1	0.90	-0.564

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Results and Discussion

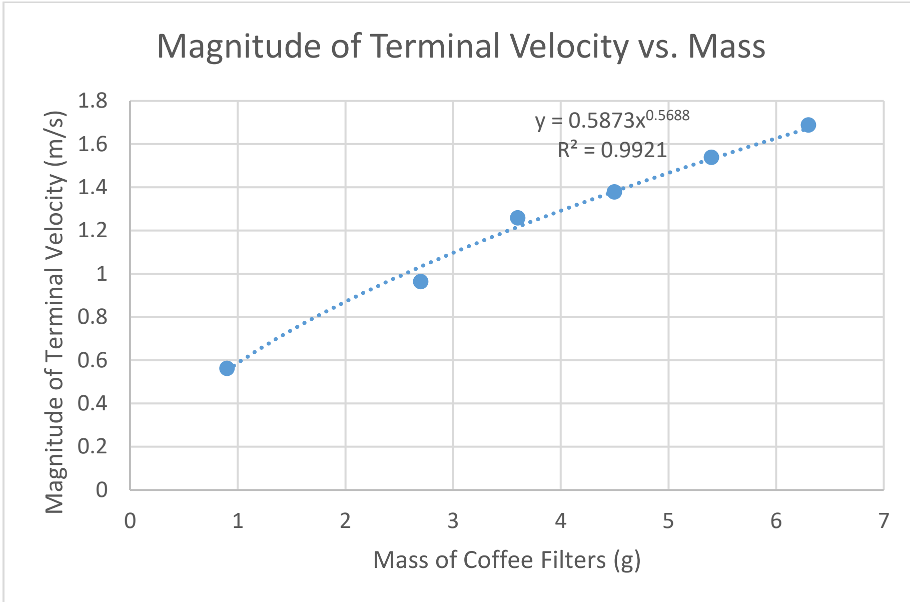

Figure 2. A power regression of the magnitude of terminal velocity vs. mass of the coffee filters

Table 2: A table recording the terminal velocity squared of falling coffee filters with respect to the mass and number of coffee filters being measured. This provides linearized data for Figure 3.

Number of Coffee Filters	Mass (g)	Terminal Velocity ^ 2 $\left(\frac{m}{s}\right)^2$
7	6.30	2.8561
6	5.40	2.3716
5	4.50	1.9044
4	3.60	1.5876
3	2.70	0.9312
1	0.90	0.3181

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Linearized Graph

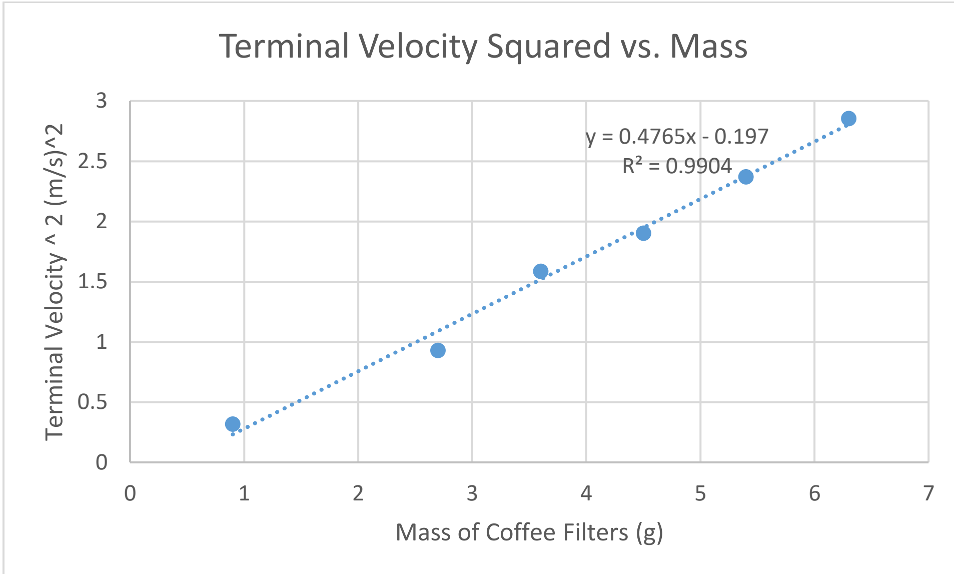

Figure 3. A linearized graph of Figure 2 representing terminal velocity squared vs mass

The graph of the original data points, represented in Figure 2, show that the terminal velocity and mass of the coffee filters are not linearly proportional, thus telling us that we must linearize the graph to determine the trend of the resistive force acting on the coffee filters as they fall. After linearizing our data by squaring terminal velocity, the graph represented in Figure 3 tells us that the coffee filter moves in quadratic motion since the terminal velocity of the coffee filters is proportional to the square root of the mass of the coffee filters. With this, we can conclude that the coffee filters are under the influence of quadratic drag force. These results support what we have learned and what might have been expected because coffee filters reach their terminal velocity quite quickly, suggesting that it is influenced by quadratic air resistance.

A potential source of error in this experiment would be dropping the coffee filter at an angle, such that the object does not fall straight down onto the motion detector. This would cause the trajectory of the coffee filters to change as dropping the coffee filter at an angle also changes the way that air resistance affects its motion. This can be minimized by running multiple trials and dropping the coffee filters multiple times. Another potential source of error is weighing the coffee filters as they are very light – the scale could have been slightly inaccurate and not completely balanced. This error could be minimized by doing multiple weighing or by using an electronic balance.

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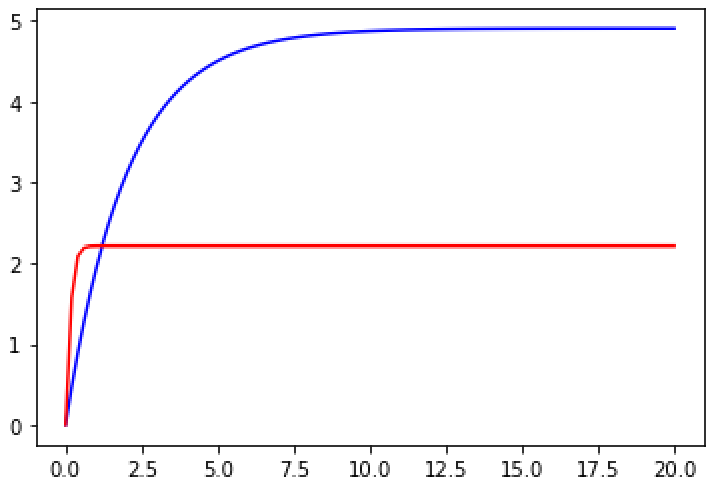
Post-Lab Questions

1. The result for this lab might be a bit surprising to you. So let us go ahead and analyze the other cases as well. List three objects (or types of objects) that would experience each type of air resistance (3 for linear, 3 for quadratic). You may need to do some research for this.
   Linear: Millikan oil droplets, molecules, microbes
   Quadratic: parachute, coffee filter, paper
2. Sketch graphs for the velocity as a function of time for both the linear and quadratic air resistance cases. Which velocity rises and then levels off faster? Given the types of objects you listed, does this make sense? Justify your answer.



Blue line: linear air resistance
Red line: quadratic air resistance

In the quadratic air resistance case, the velocity rises and levels off faster. This makes sense, as objects affected by quadratic air resistance would have less resistance when their velocity is slow, but as their velocity speeds up, the magnitude of air resistance increases quadratically, meaning the velocity of such objects would level off and then reach their terminal velocity faster. For the given objects, all of them reach their terminal velocity quite fast, as they accelerate quickly at first but then are all slowed down. For the linear air resistance objects, they might not even reach their terminal velocity, as their overall size and shape are much smaller than the quadratic objects, meaning they have much less contact with the air and thus are affected by a smaller portion of air resistance.