Physics 120 **Winter 2026**

Lab 3: A Study of Air Resistance

Name: ______________________

Lab Partner(s): ______________________

Honor Code Statement: I affirm that I have carried out my academic endeavors with full academic honesty. ____

Introduction

In lab 2, we made measurements of the motion of a projectile ignoring its interaction with the air. We know, though, that the force of air resistance can be significant, as a sheet of paper falls more slowly than a metal ball. In this lab, you will experimentally determine the strength of the force of air resistance. One interesting (and useful) consequence of air resistance is the concept of **terminal speed**. As a body falls, at some point, it stops accelerating and falls at a constant speed – this is called the object's terminal speed.

Procedure

Part 1: General Observations

1. Take a flat-bottom coffee filter, stand on the table top, hold the coffee filter as high up as you can, right-side up, as it would be in a coffee maker. Let go of the coffee filter, letting it drop to the floor, and watch. Does it reach terminal speed? Explain why or why not. If it does, how quickly does it reach terminal speed?

2. Now drop a pack of 4 coffee filters. Does the pack reach terminal speed? Explain why or why not.

3. Drop one coffee filter and pack of 4 at the same time. Do they reach the ground at the same time? Do they reach the same terminal speed? Explain.

4. Considering the answer to #3, what must the magnitude of the force of air resistance equal in both cases. (There is a measurement that you'll need to make to complete the calculation.)

5. Are the magnitudes of the air resistance forces the same?

6. The very instant after you let go of the coffee filter, when its speed is zero, what is the force of air resistance?

7. Considering the answer to #6, does the force of air resistance depend on the body's speed? Explain why it does or why it does not.

8. Why might the strengths of air resistance forces in the two cases be different? What parameter(s) differ in the two cases that could have an effect on the force of air resistance? *Hint: Consider your own experience with air resistance. Imagine sticking your hand out of the window in a moving car and consider when the force on your hand is larger?*

Part 2: The Experiment

1. Select a single coffee filter and measure its mass.

   $m_1 =$

2. Select a pack of 4 filters and a pack of 8 filters. Measure the masses of the 4 and 8 pack and from the measurements determine the mass of a single filter.

   $m_4 =$ $\rightarrow m_1 =$

   $m_8 =$ $\rightarrow m_1 =$

3. From the results of #2, what is the uncertainty in the mass Δm of a filter?

   $\Delta m_1 =$

4. Start by dropping the single filter from the ceiling to the floor and measure the time it takes to fall from 2 meters to the ground. Repeat this step 5 times and average the results.

   $t_1 =$

5. Stack 2 coffee filters (one inside the other), and repeat the drop process (taking five measurements) to get an average drop time for the stack.

   $t_2 =$

6. Do the same for stacks of 4 and 8 filters.

   $t_4 =$

   $t_8 =$

Analysis:
The goal is to determine, empirically, how the force of air resistance depends on the velocity of the falling object. Since most laws of physics involve power laws, we start with the assumption that the air force goes as

$$F_{air} = (some\ numbers) \times v^p$$

where p is the "power" index of the speed in the drag force of air resistance equation. The goal in this lab is to determine the value of p. If the air force is in fact a power law relationship, then a plot of $\log F$ versus $\log v$ should be a linear relationship.

$$\log F_{air} = \log(some\ numbers) + p \log v$$

Note that this is the equation of a straight line: $y = mx + b$, where the slope (m) equals the power index (p) of the velocity and b is the y-intercept. So, if the force of air resistance is indeed a power-law, the plot of $\log F_{air}$ versus $\log v$ should be a straight line ***and*** the slope of that straight line equals the power index of the velocity.

1. Using Excel, calculate a value of F_{air} for each run and then for each value of F_{air} calculate $\log F_{air}$.
2. Determine the terminal velocity of each of the stacks of coffee filters suing the times of fall and then calculate $\log v$.
3. Construct a plot of $\log F_{air}$ versus $\log v$.
4. Do the data fit a straight line? If so, what is the relationship between F_{air} and v? Is it indeed a power law.
5. From your graph of $\log F_{air}$ versus $\log v$, if the data do follow a linear relationship from, fit the data with a straight line and determine the slope and intercept of the line.
6. Perform a linear regression on the data of $\log F_{air}$ versus $\log v$ and determine *the uncertainty* in the slope and y-intercept. In the new chart that appears, the slope, *y*-intercept, and their uncertainties are the four numbers in the lower left corner.
7. What is your expression for the air force (including uncertainties).
8. What are some limitations on the air force expression that you acquired?
9. The air force expression is found to obey

$$F_{air} = \frac{1}{2} C \rho A v^2$$

where ρ is the density of air, taken to be $\rho = 1.3 \frac{kg}{m^3}$, A is the cross-sectional area of the object presented to the air, and C is a constant called the drag coefficient. Determine the cross-sectional area A of a coffee filter along with its uncertainty. Hint: To determine the uncertainty in the area, you will need to derive a formula. Derive the formula below and show the calculation of the uncertainty.

10. Using the equation given in question 9 and the results from the fit from the plot of $\log F_{air}$ versus $\log v$, determine the drag coefficient C of a coffee filter, with its units. Show your calculation below.

$C =$

11. How reasonable of a value is the value for the drag coefficient you obtained? Does this value of or expression for drag coefficient work for any or all objects dropped in the presence of air? Explain why or why not.