Lab 5: Air Resistance

**Equipment:** Vernier computer interface, microgram scale, 8 basket-style coffee filters, Vernier Motion Detector, Computers, Logger Pro

In this experiment, you will measure terminal velocity as a function of mass for falling coffee filters and use the data to choose between two models for the drag force. Coffee filters were chosen because they are light enough to reach terminal velocity in a short distance.

Please work in groups of 2-3. Each lab partner should be responsible for one of the three Excel plots: one linear fit to velocity (Analysis step 1), one fit to velocity squared (Analysis step 2), and one fit to another functional relationship (Analysis step 4).

**Introduction**

When you solve physics problems involving free fall, often you are told to ignore air resistance and to assume the acceleration is constant and unending. In the real world, because of air resistance, objects do not fall indefinitely with constant acceleration. One way to see this is by comparing the fall of a baseball and a sheet of paper when dropped from the same height. The baseball is still accelerating when it hits the floor. Air has a much greater effect on the motion of the paper than it does on the motion of the baseball. The paper does not accelerate very long before air resistance reduces the acceleration so that it moves at an almost constant velocity. When an object is falling with a constant velocity, we prefer to use the term *terminal velocity*, or $v_T$. The paper reaches terminal velocity very quickly, but on a short drop to the floor, the baseball does not.

Air resistance is sometimes referred to as a *drag force*. Experiments have been done with a variety of objects falling in air. These experiments sometimes show that the drag force is proportional to the velocity and sometimes that the drag force is proportional to the square of the velocity. In either case, the direction of the drag force is opposite to the direction of motion. Mathematically, the drag force can be described using $F_{drag} = -bv$ or $F_{drag} = -cv^2$. The constants $b$ and $c$ are called the *drag coefficients* that depend on the size and shape of the object.

When falling, there are two forces acting on an object: the weight, $mg$, and air resistance, $-bv$ or $-cv^2$. At terminal velocity, the downward force is equal to the upward force, so $mg = -bv$ or $mg = -cv^2$, depending on whether the drag force follows the first or second relationship. In either case, since $g$ and $b$ or $c$ are constants, the terminal velocity is affected by the mass of the object. Taking out the constants, this means that either the terminal velocity is proportional to the mass, or the terminal velocity squared is proportional to the mass. So, if we plot mass versus $v_T$ or $v_T^2$, we can determine which relationship is more appropriate.
Procedure
1. Connect the Motion Detector to the DIG/SONIC 1 channel of the interface.

2. Support the Motion Detector about 2 m above the floor, pointing down, as shown in Figure 1. Open the Logger Pro file “Air Resistance” from the Physics 20 folder.

3. Weigh the mass of the coffee filter with the microgram scale in the cabinet. Record it in a data table in Excel (see formatting of table below).

4. Place a coffee filter about 0.25 m under the Motion Detector.

5. Click “collect” to begin data collection. When the Motion Detector begins to click, release the coffee filter directly below the Motion Detector so that it falls toward the floor. Move your hand out of the beam of the Motion Detector as quickly as possible so that only the motion of the filter is recorded on the graph. The coffee filter should fall with constant terminal speed.

6. If the motion of the filter was too erratic to get a smooth graph, repeat the measurement. With practice, the filter will fall almost straight down with little sideways motion.

7. The velocity of the coffee filter can be determined from the slope of the Logger Pro position vs. time graph. At the start of the graph, there should be a region of increasing slope (increasing velocity), where the coffee filter is reaching terminal velocity, and then it should become linear. Do a linear fit of the linear portion of the x-t plot when the coffee filter is falling with constant terminal velocity. **ONLY FIT THE LINEAR PORTION OF THE GRAPH.**

8. Record the slope in the data table (a velocity in m/s). Copy and paste a sample plot of one of your Logger Pro fits into your lab report.

9. Repeat Steps 4 – 8 for two, three, four, and five coffee filters – keep adding as many as you can for which they fall with terminal velocity.
**Data Table Setup**

<table>
<thead>
<tr>
<th>Number of filters</th>
<th>Mass of Filter(s) (kg)</th>
<th>Terminal Velocity $v_T$ (m/s)</th>
<th>(Terminal Velocity)$^2$ $v_T^2$ $(m^2/s^2)$</th>
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**Analysis**

1. During terminal velocity, the drag force is equal to the weight $(mg)$ of the filter. Plot terminal velocity drag force (weight) vs. $v_T$ and do a linear fit, displaying the equation of the trendline and the R-squared value. Label axes and the plot as usual. Include this plot in your lab report.

2. Square the terminal velocity and put the values in the table. Plot drag force (weight) vs. $(v_T)^2$ and do a linear fit, displaying the equation of the trendline and the R-squared value. Label axes and the plot as usual. Include this plot in your lab report.

3. From your graphs, which proportionality ($-bv$ or $-cv^2$) is a better model for the drag force? That is, which graph is closer to a straight line that goes through the origin? Which gives the best R-squared value? Find the drag coefficients ($b$ and $c$) for each fit.

4. Plot drag force (weight) vs. $v_T$ again and try another fit: log, exponential, etc. Do the same analysis as above and copy and paste the plot into your lab report.

5. Write a summary. How does the drag force depend on terminal velocity? Justify your answer with your experimental data and results. Discuss sources of error and how you would improve the lab.