The Air Resistance Force

This lab is based on an activity from the *Matter and Interactions* instructor resources.

1 Experiment

Read all of Section 1 *before* starting the experiment. As is explained in the textbook, there is an approximate, empirical expression for the air resistance force of the form

$$\vec{F}_{\text{air}} \approx -\frac{1}{2}C\rho A v^2 \hat{v}$$

where ρ is the air density (about 1.3×10^{-3} kg/m^3), A is the cross-sectional area of the object, and C is the "drag coefficient" which is typically in the range $0.3 \leq C \leq 1.0$, with larger values for blunter objects.

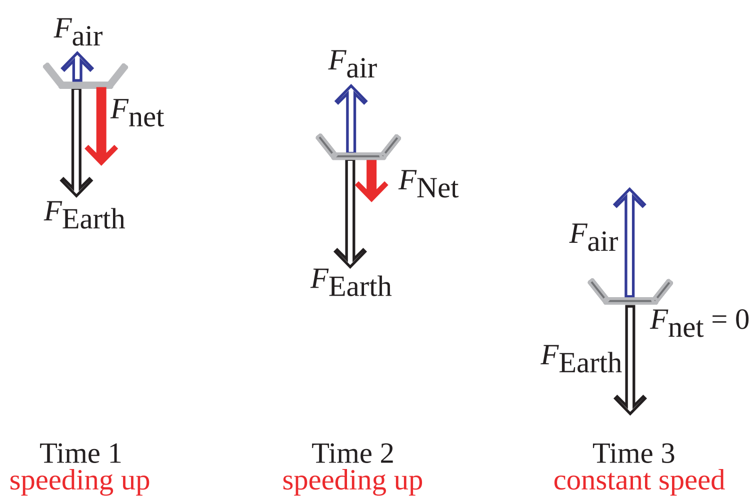
In this experiment you will learn how the exponent "2" in the v^2 term can be experimentally established, and how to determine the drag coefficient C for a particular object.

- You will measure the speed of several moving objects of different mass but the same shape
  - The objects will be stacks of 1, 2, or 3 flat-bottomed coffee filters
- You will determine the magnitude of $\vec{F}_{\text{air}}$, the air resistance force on each object
- You will graph $\left|\vec{F}_{\text{air}}\right|$ versus v in Excel
- You will fit the data in the Excel graph to a power-law curve to find the value of the exponent n in the equation

$$\left|\vec{F}_{\text{air}}\right| = \text{constant} \times v^n$$

1.1 Terminal speed

- First, a question for you: initially, the speed of a falling coffee filter continually increases. Why will the speed become constant? The diagrams below provide a hint.



1.2 Measuring terminal speed

Record all measurements and calculated values in a table in Excel.

⇒ Drop the object (1, 2, or 3 filters) from a high location – near the ceiling in the lab, or from the top of stairs if available.
⇒ To make sure terminal speed has been reached, time only a late portion of the object's fall.
⇒ Repeat each measurement 4 times and average the times, to get better measurements. Record your measurements of speed and air resistance force in Excel, with the speed in column 1 and the force in column 2. Note that at terminal speed $\left|\vec{F}_{\text{air}}\right| = \left|\vec{F}_{\text{Earth}}\right| = mg$, the weight of the filter(s).
⇒ Do this (4 measurements) for each object (12 measurements in all).

1.3 Determining the dependence on speed

⇒ Graph $\left|\vec{F}_{\text{air}}\right|$ versus v in Excel:

- Select the two columns of data (speed and mass).
- Click "Insert", then "Scatter". Choose a graph with no connecting lines.

⇒ Add a "trendline" to the graph:

- Right click on one of the data points and select "Add Trendline".
- Choose "Power" and "Display Equation on Chart", then click "Close". Choosing "Power" means you expect the data to have the form of a "power law", $y = cx^n$.
- This will display the equation of the power law curve that best fits your data. You can drag the equation to reposition it in the graph.

The trendline equation gives you the exponent n in the equation $\left|\vec{F}_{\text{air}}\right| = mg = \text{constant} \times v^n$. What do you find for n? Note that $n = 1.874$ may be indistinguishable from 2, given the relatively low precision of your timing data.

1.4 Determining the drag coefficient C

⇒ Use your experimental data to determine the drag coefficient (bluntness) C of your coffee filters.

I hope you will use the rest of the lab time as a group to work on your computational projects!