# 3.2: Activities

## Equipment

- coffee filters
- two-meter stick
- timing device

## The General Idea

This lab consists of two separate parts. The first involves testing a proposed mathematical model of the motion of an object in free-fall while experiencing air resistance, and the second is an examination of the effect of the object's mass on its free-fall velocity after it has been falling awhile.

### Part 1

It is well-known that an object dropped from rest near the Earth's surface with negligible air resistance will fall a distance as a function of time given by this equation:

$$y=\frac{1}{2}gt^2 \tag{3.2.1}$$

This lab is all about motion in the presence of air resistance that is *not* negligible. Some things are intuitively clear about what happens when air resistance plays a role. First, there is a force (called "drag") that acts in the opposite direction of the motion of the object relative to the air. And second, in the case of a falling object, this force opposes the gravity force, which causes the object to accelerate at a rate *less than* $g$.

Given that we know that the acceleration of a falling object is less than $g$, it leads us to consider the possibility that the correct equation to describe distance fallen as a function of time when air resistance is present looks like:

$$y=\frac{1}{2}kt^2, \tag{3.2.2}$$

where $k$ is a constant that is less than $g$, which depends upon the details of the falling object (e.g. feathers have lower $k$ values than stones).

We can check this experimentally by dropping an object to the ground from many different heights and measuring the time elapsed in each case, to see if this functional dependence applies. As with the previous lab, you are not required to fit a line to the data; you only need to determine *if* the data does seem to form a line. Again, you are encouraged to use the online graphing calculator to plot your points.

### Part 2

As the falling object speeds up, the drag force increases, and when it gets large enough that it happens to equal the gravity force, then the net force (and therefore the acceleration) will be zero. An object falling through the air with no acceleration maintains a constant velocity (commonly referred to as "terminal velocity"). We know from experience that different objects have different terminal velocities, and the main factor that comes to mind is mass. If we hold all other factors fixed and just change the mass, we can determine whether the drag force (for terminal velocity) is roughly proportional to $v$ or $v^2$.

## Some Things to Think About

Though it might seem straightforward, there is a lot going on in this experiment, and a lot to think about, both in terms of physics and experimental methods. Here are some pointers to help you on your way...

### Part 1

- As with any experiment, we don't want to change any variables that we aren't testing. The coffee filters you are working with have very specific aerodynamic qualities, namely: how wide they spread, and whether their pleats remain intact. As you are taking data, be very gentle with these (and make repairs to it as needed) to keep the aerodynamic variables held as constant as possible.
- With the video/timer method of taking data described in the Background Material, you will find that your measurements of time-of-fall are pretty consistent. Knowing this makes for a nice time-saver. Normally you would want to do several runs at a

single height, take mean of the time measurements, compute the standard deviation, etc.  But to save time, it is easier to do just *two* runs at the same height.  If they come out very close to each other (within a couple hundredths of a second), take the average and move on to another height (no need for uncertainty analysis in this lab).  If they are very different, do a third run and throw out the rogue measurement.

- To get a good sense of the $y$-vs-$t$ curve, you will need a wide range of values. You should do at least 5 different heights, with two of them quite short (less than $50cm$, and two of them quite high (more than $150cm$).
- We get a "free" data point.  In a time of zero seconds, the object falls zero meters.  So the origin can be used as a data point – and the most reliable one at that!
- As this is an experiment to prove/disprove a functional dependence, we need to do this graphically. You may want to review the Background Material for Lab #2 as a reminder of the danger of drawing a conclusion about the function that defines a curved graph, and how to avoid this pitfall.
- As always, a data table with measured and important computed quantities is essential.

**Part 2**

- If you wish to approximate the terminal velocity of the object from the data in part 1, do you need the entire graph of data points to do this, or can you do so more simply?  It may help to think about how velocity (and particularly terminal velocity) can be extracted from the $y$-vs-$t$ graph.
- We have discussed two possibilities for the relationship between the drag force and terminal velocity. Hypothesize one of them. Test your speculation by changing the mass of the falling object from part 1, and take the minimum number of measurements you'll need.  It's best not to make a significant increase in the mass (no more than double the original), or the object may not actually reach its terminal velocity.
- Be careful that changing the mass doesn't also change some other factor that plays a role in air resistance – we must only change one variable at a time!

## Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page.  You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important.  You should also feel free to get feedback from your lab TA whenever you find that your group requires clarification or is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*.  These reports are not to be written outside the lab setting.