3746

Air Resistance

Vernier Data-Collection Activity

INTRODUCTION

When you solve physics problems involving free fall, often you are told to ignore air resistance and to assume the acceleration is constant. 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 describe it with 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 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 yields either

$$v_T \mu m \text{ or } v_T^2 \mu m$$

If we plot mass versus v_T or v_T^2, we can determine which relationship is more appropriate.

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

OBJECTIVES

In this experiment, you will

- Observe the effect of air resistance on falling coffee filters.
- Determine how air resistance and mass affect the terminal velocity of a falling object.
- Choose between two competing force models for the air resistance on falling coffee filters.

MATERIALS

- TI-83 Plus or TI-84 Plus graphing calculator
- EasyData application
- CBR 2
- 5 basket-style coffee filters

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PRELIMINARY QUESTIONS

1. Hold a single coffee filter in your hand. Release it and watch it fall to the ground. Next, nest two filters and release them. Did two filters fall faster, slower, or at the same rate as one filter? What kind of mathematical relationship do you predict will exist between the velocity of fall and the number of filters?
2. If there were no air resistance, how would the rate of fall of a coffee filter compare to the rate of fall of a baseball?
3. Sketch your prediction of a graph of the velocity vs. time for one falling coffee filter.
4. When the filter reaches terminal velocity, what is the net force acting upon it?

PROCEDURE

1.

Connect the CBR 2.

a. Open the pivoting head of the CBR 2.
b. Set the sensitivity switch to Normal.
c. Turn on the calculator. Connect the CBR 2 to the calculator.

2.

Set up EasyData for data collection.

a. Start the EasyData application, if it is not already running.
b. Select (File) from the Main screen, and then select **New** to reset the application.

3.

Support the CBR 2 about 2 m above the floor, pointing down, as shown in Figure 1.

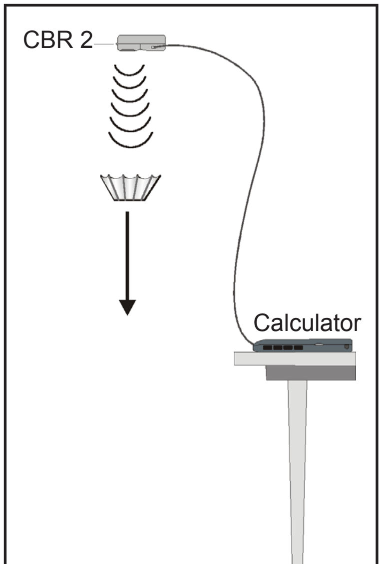

Figure 1

4.

Place a coffee filter in the palm of your hand and hold it about 0.5 m under the Motion Detector. Do not hold the filter closer than 0.4 m.

5.

Select (Start) to begin data collection. Release the coffee filter directly below the CBR 2 so that it falls toward the floor. Move your hand out of the beam of the CBR 2 as quickly as possible so that only the motion of the filter is recorded on the graph.

6.

View your distance graph.

a. When data collection is complete, a graph of distance vs. time will be displayed.

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

c. Repeat data collection as necessary. To do this, select Main, then Start, then OK to overwrite the latest data and begin data collection.

7.

The velocity of the coffe filter can be determined from the slope of the distance vs. time graph. At the start of the graph, there should be a region of increasing slope (increasing velocity), and then the plot should be linear. Since the slope of this line is velocity, the linear portion indicates that the filter was falling with a constant or terminal velocity (v_T) during that time. To fit a line to the linear region, you first need to select that portion of your data.

a. Select Anlyz, then **Select Region…**, then OK.

b. Using the cursor keys, move the cursor to the left edge of the linear region corresponding to the filter in motion at constant speed and select OK.

c. Move the cursor to the right edge of the linear region, and select OK. You should now see only the linear region.

8.

Fit a straight line to the region you just selected.

a. Select Anlyz, and then select Linear Fit.

b. Record the slope in the data table (a velocity in m/s).

c. Select OK to see the fit with your data, then select Main to return to the Main screen.

9.

Repeat Steps 4–8 for two, three, four, and five coffee filters. (Optionally extend to six, seven and eight filters, but be sure to use sufficient fall distance so that a clear velocity can be measured.) Note: After selecting Start, select OK to overwrite the previous data and begin data collection.

DATA TABLE

Number of filters)	Terminal Velocity V_T(m/s)	(Terminal Velocity)^2 V_T^2(m ^{2}/s ^{2})
1		
2		
3		
4		
5		

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ANALYSIS

1.

To help choose between the two models for the drag force, plot terminal velocity v_T vs. number of filters (mass) and v_T^2 *vs*. number of filters. Scale the axis so the origin (0,0) is shown.

2.

During terminal velocity the drag force is equal to the weight (*mg*) of the filter. If the drag force is proportional to velocity, then v_T µ *m*. Or, if the drag force is proportional to the square of velocity, then v_T^2 µ *m*. From your graphs, which proportionality is consistent with your data; that is, which graph is closer to a straight line that *goes through the origin?*

3.

From the choice of proportionalities in the previous step, which of the drag force relationships (– *bv or* – cv^2) appears to model the real data better? Notice that you are choosing between two different descriptions of air resistance—one or both may not correspond to what you observed.

4.

How does the time of fall relate to the weight (*mg)* of the coffee filters (drag force)? If one filter falls in time, t, how long would it take four filters to fall, assuming the filters are always moving at terminal velocity?

EXTENSIONS

1.

Make a small parachute and use the CBR 2 to analyze the air resistance and terminal velocity as the weight suspended from the chute increases.

2.

Draw a free body diagram of a falling coffee filter. There are only two forces acting on the filter. Once the terminal velocity vT has been reached, the acceleration is zero, so the net force, SF = ma = 0, must also be zero

$$\sum F = -mg + bv_{\mathrm{T}} = 0 \quad \text{or} \quad \sum F = -mg + cv_{\mathrm{T}}^2 = 0$$

depending on which drag force model you use. Given this, sketch plots for the terminal velocity (*y* axis) as a function of filter weight for each model (*x* axis). (Hint: Solve for v_T first.)