Name: _____ Date: _____

Student Exploration: Free-Fall Laboratory

Vocabulary: acceleration, air resistance, free fall, instantaneous velocity, terminal velocity, velocity, vacuum

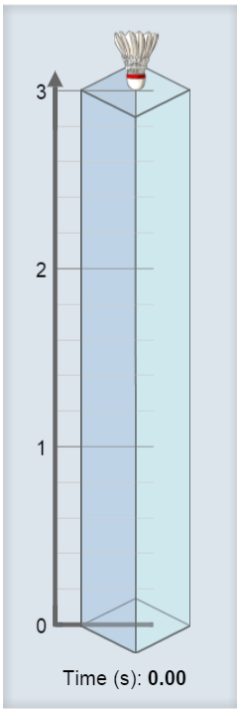
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. Suppose you dropped a feather and a hammer at the same time. Which object would hit the ground first? _____

2. Imagine repeating the experiment in an airless tube, or **vacuum**. Would this change the result? If so, how? _____

Gizmo Warm-up

The *Free-Fall Laboratory* Gizmo™ allows you to measure the motion of an object in **free fall**. On the CONTROLS pane check that the **Shuttlecock** is selected, the **Initial height** is **3 meters**, and the **Atmosphere** is **Air**.



1. Click **Play** ( ) to release the shuttlecock. How long does it take to fall to the bottom? _____

2. Select the GRAPH tab. The box labeled ***h* (m)** should be checked, displaying a graph of height vs. time. What does this graph show?

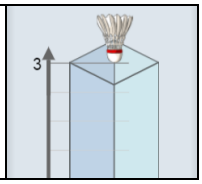
   _____

3. Turn on the ***v* (m/s)** box to see a graph of **velocity** vs. time. Velocity is the speed and direction of the object. Velocity is also referred to as **instantaneous velocity**. Because the shuttlecock is falling downward, its velocity is negative.

   Does the velocity stay constant as the object drops? _____

4. Turn on the ***a* (m/s/s)** box to see a graph of **acceleration** vs. time. Acceleration is the rate at which the velocity changes over time. What does this graph show?

   _____

Activity A: **Falling objects**	Get the Gizmo ready: • Click **Reset** ( ). • Select the CONTROLS tab.	

Question: What factors affect how quickly an object falls?

1. Observe: Drop each item through **Air** from a height of **3 meters**. Record how long it takes to fall below. For the tennis ball, try to click **Pause** ( ) when it hits the ground.

Shuttlecock	Cotton ball	Tennis ball	Rock	Pebble

2. Form a hypothesis: Why do some objects fall faster than others? _____

_____

3. Predict: A vacuum has no air. How do you think the results will change if the objects fall through a vacuum?

_____

4. Experiment: On the **Atmosphere** menu, select **None**. Drop each item again, and record the results below.

Shuttlecock	Cotton ball	Tennis ball	Rock	Pebble

5. Analyze: What happened when objects fell through a vacuum? _____

_____

6. Draw conclusions: Objects falling through air are slowed by the force of **air resistance**. Which objects were slowed the most by air resistance? Why do you think this is so?

_____

_____

_____

(Activity A continued on next page)

Activity A (continued from previous page)

7. Calculate: Select the **Shuttlecock.** Check that the **Initial height** is **3 meters** and the **Atmosphere** is **None**. Click **Play** and wait for the Shuttlecock to fall. Select the BAR CHART tab and turn on **Show numerical values**.

   A. How long did it take the shuttlecock to fall to the bottom? _____

   B. What was the acceleration of the shuttlecock during its fall? _____

   C. What was the velocity of the shuttlecock when it hit the bottom? _____

      (Note: This is an example of instantaneous velocity.)

   D. What is the mathematical relationship between these three values? _____

      _____

8. Make a rule: If the acceleration is constant and the starting velocity is zero, what is the relationship between the acceleration of a falling body (*a*), the time it takes to fall (*t*), and its instantaneous velocity when it hits the ground (*v*)?

   _____

   Express your answer as an equation relating *v*, *a*, and *t*: $v =$

9. Test: Click **Reset**. On the CONTROLS tab, set the **Initial height** to **12 meters**. Click **Play**.

   A. How long did it take for the shuttlecock to fall 12 meters? _____

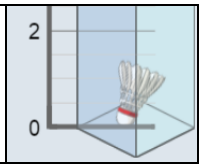
   B. Assuming the acceleration is still -9.81 m/s^2, what is the instantaneous velocity of the shuttlecock when it hits the ground? Show your work below.

      $v =$ _____

   C. Select the BAR CHART tab. What is the final velocity of the shuttlecock? _____

   D. Does this agree with your calculated value? _____

      _____

Activity B: **Terminal velocity**	Get the Gizmo ready: • Click **Reset**. • Set the **Initial height** to **12 meters**. • Set the **Atmosphere** to **Air**.	

Question: How does air resistance affect falling objects?

1. Observe: Select the **Shuttlecock**. Choose the BAR CHART tab, and click **Play**. What do you notice about the velocity and acceleration of the shuttlecock?

   _____

   _____

   When objects fall through air for a long time, they will eventually stop accelerating. Their velocity at this point is called **terminal velocity**.

2. Form hypothesis: How will an object's size and mass affect its terminal velocity?

   _____

3. Experiment: Click **Reset**. On the CONTROLS tab, select **Manual settings**. Set the **height** to 100 meters and the air density (***ρ***) to 1.3 kg/m^3, close to actual air density at sea level.

   For each combination of **mass** and **radius** in the charts below, find the terminal velocity ($v_{terminal}$) of the object. Use the BAR CHART tab to find the terminal velocity. (Hint: Turn on **Show numerical values**.)

Mass	Radius	$v_{terminal}$
1.0 g	3.0 cm	
10.0 g	3.0 cm	
50.0 g	3.0 cm	

Mass	Radius	$v_{terminal}$
10.0 g	2.0 cm	
10.0 g	5.0 cm	
10.0 g	10.0 cm	

4. Analyze: Your data show how mass and radius affect terminal velocity.

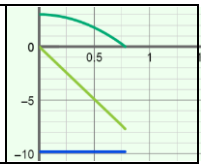
   A. What was the effect of increasing mass? _____

   B. What was the effect of increasing radius? _____

5. Apply: If you wanted to use a device to slow your fall, what properties should it have?

   _____

   _____

Activity C: **Acceleration, distance, and time**	Get the Gizmo ready: • Click **Reset**. • Select **Common objects**. • Set the **Atmosphere** to **None**.	

Question: How long does it take an object to fall from a given height?

1. Observe: Select the **Rock**, and set the **Initial height** to **3 meters**. Choose the GRAPH tab, and click **Play** to drop the rock through a vacuum. Turn on all three graphs.

   A. What is the shape of the graph of velocity vs. time? _____

   B. What is the shape of the graph of acceleration vs. time? _____

2. Analyze: Select the TABLE tab and look at the ***v* (m/s)** column.

   A. The starting velocity was 0 m/s, and the final velocity was -7.68 m/s. Based on this, what was the *average* velocity of the rock? _____

   B. In general, how do you find the average velocity of any object falling in a vacuum? (Assume you know the final velocity.) _____

3. Calculate: Distance, average velocity, and time are related by the equation, $d = v_{average} \bullet t$

   A. How much time did it take the rock to fall? _____

   B. What is the product of the average velocity and time? _____

   C. Does this equal the distance that the rock fell? _____

4. Calculate: The acceleration of any object due to Earth's gravity is -9.81 m/s^2. For every second an object falls, its velocity changes by 9.81 meters per second. For several different times on the table, multiply the time by the acceleration.

   A. What do you notice? _____

   B. If you know the acceleration and time, how can you calculate the final velocity?

   _____

   C. Challenge: If you know the acceleration and time, how can you calculate the *average* velocity? _____

(Activity C continued on next page)

Activity C (continued from previous page)

5. Make a rule: So far you have figured out two rules that relate time, acceleration, average velocity, and distance. Review these rules now.

   A. How do you find average velocity ($v_{average}$) from acceleration (a) and time (t)?

   _____

   B. How do you find distance (d) from average velocity ($v_{average}$) and time (t)?

   _____

   C. Now put the two equations together. Substitute your result in equation A for the ($v_{average}$) term in equation B. Your final equation should only have d, a, and t terms.

   _____

6. Apply: Use your rule to solve the following problems. Check your answers with the Gizmo. Assume that each fall takes place in a vacuum with an acceleration of -9.81 m/s^2.

   A. A rock falls for 1.43 seconds. How far did it fall? _____

   B. How long will it take for a rock to fall 12 meters? _____

   C. A rock falls for 4 seconds. How far did it fall? _____

   D. A rock falls for 3 seconds. What was its velocity when it hit the ground? _____

   E. How long will it take for a rock to fall 50 meters? _____