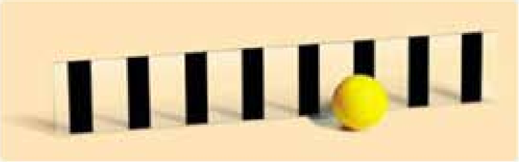

Gravity Lab

P4-1380

BACKGROUND:

Gravity Lab uses three different measurement techniques, with increasing sophistication, to measure a value frequently used in physics, the acceleration due to gravity. Students measure the acceleration of a falling object using a stopwatch, a photogate, and a motion sensor, and compare the results of each.

KIT CONTENTS:

Picket Fence
Rubber Ball

ALSO UTILIZES:

Workshop Stand (P4-1900)
Timer and Photogates (P4-1450)
Timer/Stopwatch (52-3200)
Meter Stick (P1-7072)
Measuring Tape (01-3985)
Calculator (08-0700)

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Physics Workshop
Gravity Labs

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PO Box 2750 ANN ARBOR, MI 48106 WWW.ARBORSCI.COM 800-367-6695

Name: ______________________________

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Gravity Lab:
Measuring *g* with Photogates

Objective: To find the acceleration of an object in freefall.

Materials: Timer, 2 Photogates, Workshop Stand or Ring Stand, Ruler, Calculator, small object such as a pad of "Post-it" notes.

Background: This experiment will use a timer and photogates to measure an important quantity, the acceleration of an object in freefall. This is also known as the acceleration due to gravity or *g*. The acceleration due to gravity is nearly the same at all points on the earth's surface, 9.8 m/s^2. You will compare your result to this accepted value.

The velocity of an object will be measured at two different moments in time. The time interval between these two measurements (Δt) reveal how quickly the change in velocity (Δv) occurred. The acceleration (a) therefore can be calculated using

$$a = \frac{\Delta v}{\Delta t}$$

Procedure:

1. Mount two photogates to the workshop stand so that the photogates are about 15cm apart. Make sure that the stand is situated in a way that allows an object to be dropped vertically through them.
2. Connect the top most photogate to the timer input port "A" and the lower photogate to input port "B"

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3. Change the mode of the timer so that it is in "Interval" mode and activate both photogates. The photogate status LED on the timer should glow green for photogates A and B.
4. Measure the length in meters, (Δx) of a small object (pad of "Post-it" notes with the sticky end down to reduce air resistance, etc…) and drop it so it falls freely through both photogates. You will want to position the small object just above the top photogate when dropping it. Δx = ____________ meters

5. Record the time between both photogates Δt_{ab} = ____________ seconds

6. Calculate the velocity of the object at photogate A. The time (Δt_{a}) that the small object blocked photogate A is displayed by the timer. The velocity can now be calculated by:

   $Va = \frac{\Delta x}{\Delta ta}$ V_a = ____________ m/s (velocity of small object at photogate A)

7. Calculate the velocity of the object at photogate B. The time (Δt_{b}) that the small object blocked photogate B is displayed by the timer. The velocity can now be calculated by:

   $Vb = \frac{\Delta x}{\Delta tb}$ V_b = ____________ m/s (velocity of small object at photogate B)

8. The acceleration for the small falling object can now be found from the change in velocity at Photogates A and B and the time Δt_{ab} from above.

   $A = \frac{\Delta V}{\Delta T} = \frac{Vb - Va}{\Delta Tab}$ = ____________ m/s^2

9. The accepted value for the acceleration due to gravity is 9.8 m/s^2. How does your experimental value compare to the accepted value? Calculate the percent difference.

$$\%difference = \frac{\exp erimental\_value - accepted\_value}{accepted\_value} * 100\%$$

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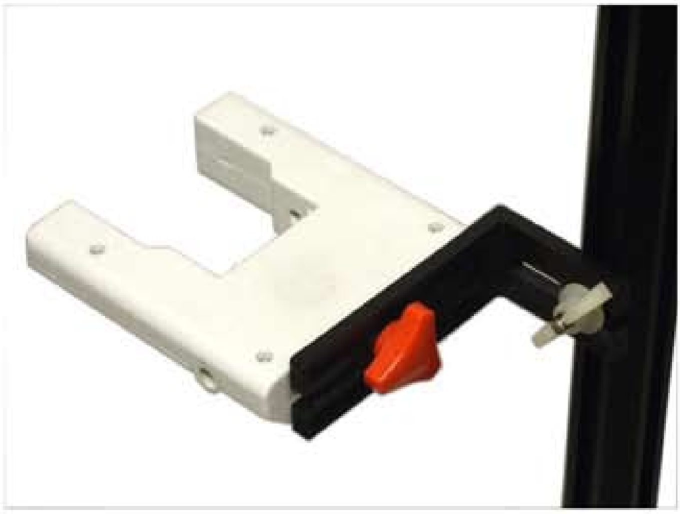
Gravity Lab:
Measuring *g* with Photogate and Picket Fence



Objective: To find the acceleration of an object in freefall.

Materials: Picket Fence, Timer, Photogate, Workshop Stand or Ring Stand, Ruler, Calculator.

Background: This experiment will use a timer and photogate along with a picket fence to measure an important quantity, the acceleration of an object in freefall. This is also known as the acceleration due to gravity or *g*. The acceleration due to gravity is nearly the same at all points on the earth's surface, 9.8 m/s^2. You will compare your result to this accepted value.

The "picket fence" has been used since photogates were developed to measure acceleration. The black picket fence stripes briefly block the photogate given a series of readings for the time that the photogate was blocked. These time giving intervals are directly related to the velocity of the moving picket fence.

$$V = \frac{\Delta x}{\Delta t} = \frac{width\_of\_picket}{time\_photogate\_blocked}$$

Procedure:

1. Mount a photogate to the workshop stand so that the picket fence can be dropped vertically through it.
2. Connect the photogate to the timer input port "A", change the mode of the timer so that it is in "Interval" mode and activate photogate A. The photogate status LED on the timer should glow green for photogate A.
3. Measure the narrow width (∆x) of one of the black picket stripes, then drop the fence so if falls freely through the photogate. **For best results, drop the picket fence from a height that positions the bottom end of the picket fence just above the height of the photogate.**

Name: ______________________________

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4. From the timer obtain the recorded times of each of the last 10 black picket fence stripes as it passes through the photogate (t_a). Remember that the most recent time (picket 10) is displayed while the previous nine will be found in memory. Fill these times in the table below.
5. Calculate the velocity v_a at each stripe and enter it in the table.

Δx = _______m (stripe width) $\quad Va = \dfrac{\Delta x}{\Delta ta}$ m/s

Last 10 Pickets	Time Δt_a (s)	Velocity v_a (m/s)	Avg Velocity v_{avg} (m/s)	Time Between $\Delta t_{between}$ (s)	Acceleration (m/s^2)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

6. Assuming that the speed is changing very smoothly (with constant acceleration) we can find the average velocity between any two speed measurements by: $V_{avg} = (V1+V2)/2$. Calculate the average speed between each two adjacent picket fence stripes and record them in the table. The first calculation will involve pickets 1 and 2, the next 2 and 3, etc…
7. The distance traveled between any two measurements is 0.04 meters because this is the distance between the leading edge of one stripe and the next. Fill in the table with "time between" measurements by using the formula: distance=V_{avg} * time. We can solve for the time between the two velocity measurements to get:

$$\Delta T_{between} = \frac{.04m}{V_{avg}}$$

8. The acceleration can be found by using the calculated velocity at adjacent picket fence stripes. The first calculation will subtract V_a for picket 2 from V_a for picket 1. The next calculation will use V_a for picket 3 minus V_a for picket 2. Fill in the table with your calculated value for the acceleration between each pair of measurements using:

$$A = \frac{\Delta V}{\Delta T_{between}} \qquad \text{for pickets 1 and 2} \quad A = \frac{\Delta V}{\Delta T_{between}} = \frac{V_{picket2} - V_{picket1}}{\Delta T_{between}}$$

9. The acceleration of each strip should be the same because they are all moving as part of the same object. Find the average acceleration.
A_{avg} = ___________

10. The accepted value for the acceleration due to gravity is 9.8 m/s^2. How does your experimental value compare to the accepted value? Calculate the percent difference.

$$\%difference = \frac{\exp erimental\_value - accepted\_value}{accepted\_value} * 100\%$$

11. Compare the accuracy of this measurement method to the method from lab #1.

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12. Describe some probable sources of error in this experiment. When possible, explain whether the error would cause the value for acceleration to be too high or too low.

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13. How would the measured velocities change if you increased the height above the photogate from which the picket fence was dropped from?

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Name: ______________________________

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14. How would the acceleration change?

____

____

15. Run the experiment described in question 16 and find out if your predictions are correct.

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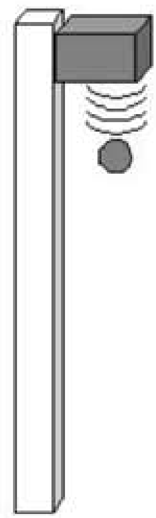
Gravity Lab:
Measuring *g* with a Motion Sensor

Objective: To find the acceleration of an object in freefall.



Materials: Yellow Ball, Motion Sensor and software, Workshop Stand or Ring Stand, Measuring Tape, Computer.

Background: This experiment will use a motion sensor (**Go-Motion** P4-2400) to measure an important quantity, the acceleration of an object in freefall. This is also known as the acceleration due to gravity or *g*. The acceleration due to gravity is nearly the same at all points on the earth's surface, 9.8 m/s^2. You will compare your result to this accepted value.

Helpful Notes: Motion sensors are very sensitive to objects in their nearby environment. For best results, do this experiment in as wide open of a space as possible. Objects that are nearby may be picked up by the motion detector causing inaccurate data or limiting the range of the motion detector. Set the sampling rate on your motion detector as high as possible. A minimum of 20 samples per second are needed to accurately track an object falling due to gravity.

Procedure:

1. Mount the motion sensor at least 1.5m above the floor, so that it points straight down.
2. Program the timer to record distance data for about 20 seconds and display the results as a line graph. Be sure to set the sampling period for as many samples as possible per second.
3. Hold the ball about 10cm below the motion sensor. Start the program and drop the ball, taking care to keep your hand out of the measurement path.
4. Pick up the ball and repeat the experiment several times, until the 20 seconds is up.

Name: ______________________________
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5. Inspect the resulting graph and choose one trial that has smooth, uninterrupted results. Select and display only that block of data.
6. Use the motion sensors included software to create graphs of velocity and acceleration vs. time for that block of data.
7. Inspect the values for acceleration during the trial.
8. Select the part of the Acceleration graph that appears to be approximately constant (this will be after the release and before impact). Using the software's tools, calculate the average value of acceleration for this selected period. Record the average acceleration __________(m/s^2).

9. Print a copy of the graph for each group member. Attach the graph to this worksheet.
10. The accepted value for the acceleration due to gravity is 9.8 m/s^2. How does your experimental value compare to the accepted value? Calculate the percent difference.

$$\%difference = \frac{\exp erimental\_value - accepted\_value}{accepted\_value} * 100\%$$

11. Compare the accuracy of this measurement method to the methods used in the previous two labs.

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12. Describe some probable sources of error in this experiment. When possible, explain whether the error would cause the value for acceleration to be too high or too low.

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Gravity Lab:
Curriculum Guide & Answer key

Introduction: The Gravity Lab can help teach topics in both physical science and physics classes. Students use three different measurement techniques, with increasing sophistication, to measure a value frequently used in physics, the acceleration due to gravity. Students measure the acceleration of a falling object using a stopwatch, a photogate, and a motion sensor, and compare the results of each. For the best learning experience, at least one of the advanced measuring systems (photogate or motion sensor) should be used.

Activity Titles

1. Measuring g with Photogates
2. Measuring g with Photogate and Picket Fence
3. Measuring g with a Motion Sensor

Gravity Curriculum	**Grade Level**	
Content	**8-9**	**10-12, college**
Scientific Methods	1	1,2,3
Displacement, Velocity, Acceleration	1	1,2,3

Notes on Gravity Activities

Lab #1: Measuring g with Photogates

Key Concepts:

Before doing lab 1, illustrate the difficulty in trying to time the free fall of an object with a stop watch. Since a photogate can measure times to a much greater precision, respectable values for the initial and final velocities of a falling object can be obtained and used to calculate acceleration.

Prerequisites:

Students need to be familiar with the acceleration equation ($a = (v_f - v_i)/t$). Knowledge in using a timer and photogates to measure velocity is also necessary.

Considerations:

When dropping the post-it-notes, or any rectangular object, rotation may occur while falling causing the object to not pass through the photogate in a vertical orientation. This could result in a source of error. Also be sure to orient the bound end of the pad of paper downward so that increased air resistance does not become a factor.

Lab #2: Measuring g with Photogates and Picket Fence

Key Concepts:

In lab #1, it was shown how effective a timer and photogate are in calculating the acceleration due to gravity of a free falling object. We now take this a step further by adding a picket fence to the procedure.

Prerequisites:

Students need to be familiar with the acceleration equation ($a = (v_f - v_i)/t$). Knowledge in using a timer and photogates to measure velocity is also necessary.

Considerations:

When dropping the picket fence, be as consistent as possible with your starting position. Also, try to drop the picket fence in a manner that it does not rotate or strike the side of the photogate.

Lab #3: Measuring g with a Motion Sensor

Key Concepts:

It will now be demonstrated how valuable a motion sensor can be in graphing and calculating the acceleration of a free falling object.

Prerequisites:

Students need to be familiar with how to set up and operate a **Go-Motion Sensor** (p4-2400).

Considerations:

When dropping the ball, be as consistent as possible with your starting position. Also, try to drop the ball in a manner that it travels directly vertical with the motion sensor.

Motion sensors are very sensitive to objects in their nearby environment. For best results, do this experiment in as wide open of a space as possible. Objects that are nearby may be picked up by the motion detector causing inaccurate data ("noisy" graph) or limiting the range of the motion detector.

Set the sampling rate on your motion detector as high as possible. A minimum of 20 samples per second are needed to accurately track an object falling due to gravity.

Gravity Lab:
Measuring *g* with Photogates (Answer Key)

Objective: To find the acceleration of an object in freefall.

Materials: Timer, 2 Photogates, Workshop Stand or Ring Stand, Ruler, Calculator, small object such as a pad of "Post-it" notes.

Background: This experiment will use a timer and photogates to measure an important quantity, the acceleration of an object in freefall. This is also

> Note: Numerical answers given here are sample answers. Student results may vary, but ultimate conclusions should be the same. Coach students on how to interpret results as being "close enough" to be equal.

different moments in time. The time interval between these two measurements (Δt) reveal how quickly the change in velocity (Δv) occurred. The acceleration (a) therefore can be calculated using

$$a = \frac{\Delta v}{\Delta t}$$

Procedure:

1. Mount two photogates to the workshop stand so that the photogates are about 15cm apart. Make sure that the stand is situated in a way that allows an object to be dropped vertically through them.
2. Connect the top most photogate to the timer input port "A" and the lower photogate to input port "B"

3. Change the mode of the timer so that it is in "Interval" mode and activate both photogates. The photogate status LED on the timer should glow green for photogates A and B.
4. Measure the length in meters, (Δx) of a small object (pad of 'Post-it" notes with the sticky end down to reduce air resistance, etc...) and drop it so it falls freely through both photogates. You will want to position the small object just above the top photogate when dropping it. Δx = $\boxed{\Delta x = 0.076m}$

5. Record the time between both photogates Δt_{ab} = $\boxed{0.1223s}$

6. Calculate the velocity of the object at photogate A. The time (Δt_a) that the small object blocked photogate A is displayed by the timer. The velocity can now be calculated by:

$$Va = \frac{\Delta x}{\Delta ta} = \frac{0.076m}{0.0669s} = 1.136m/s$$ V_a = $\boxed{1.136 \text{ m/s}}$ bject at photogate A)

7. Calculate the velocity of the object at photogate B. The time (Δt_b) that the small object blocked photogate B is displayed by the timer. The velocity can now be calculated by:

$$Vb = \frac{\Delta x}{\Delta tb} = \frac{0.076m}{0.0363s} = 2.094m/s$$ V_b = $\boxed{2.094 \text{ m/s}}$ bbject at photogate B)

8. The acceleration for the small falling object can now be found from the change in velocity at Photogates A and B and the time Δt_{ab} from above.

$$A = \frac{\Delta V}{\Delta T} = \frac{Vb - Va}{\Delta Tab} = \frac{2.094m/s - 1.136m/s}{0.1223s} = \boxed{8.53 \text{ m/s}^2}$$ m/s^2

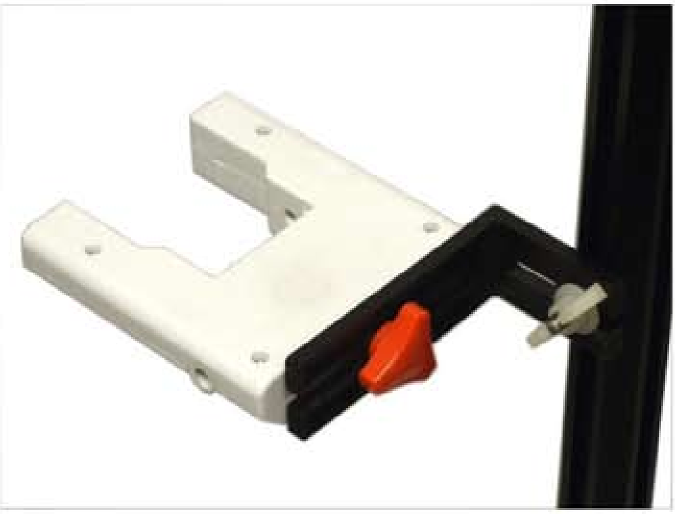
9. The accepted value for the acceleration due to gravity is 9.8 m/s^2. How does your experimental value compare to the accepted value? Calculate the percent difference.

$$\%difference = \frac{experimental\_value - accepted\_value}{accepted\_value} * 100\%$$

$$= \frac{8.53m/s^2 - 9.81m/s^2}{9.81m/s^2} * 100\% = 12.96\% \quad difference$$

Gravity Lab:
Measuring *g* with Photogate and Picket Fence (Answer Key)

Objective: To find the acceleration of an object in freefall.



Materials: Picket Fence, Timer, Photogate, Workshop Stand or Ring Stand, Ruler, Calculator.

Background: This experiment will use a timer and photogate along with a picket fence to measure an important quantity, the acceleration of an object in freefall. This is also known as the acceleration due ... ly the same at all poi ... your result to this acc ...

The ... developed to measure acc ... e photogate given a series of readings for the time that the photogate was blocked. These time giving intervals are directly related to the velocity of the moving picket fence.

> Note: Numerical answers given here are sample answers. Student results may vary, but ultimate conclusions should be the same. Coach students on how to interpret results as being "close enough" to be equal.

$$V = \frac{\Delta x}{\Delta t} = \frac{width\_of\_picket}{time\_photogate\_blocked}$$

Procedure:

1. Mount a photogate to the workshop stand so that the picket fence can be dropped vertically through it.
2. Connect the photogate to the timer input port "A", change the mode of the timer so that it is in "Interval" mode and activate photogate A. The photogate status LED on the timer should glow green for photogate A.
3. Measure the narrow width (Δx) of one of the black picket stripes, then drop the fence so if falls freely through the photogate. **For best results, drop the picket fence from a height that positions the bottom end of the picket fence just above the height of the photogate.**

4. From the timer obtain the recorded times of each of the last 10 black picket fence stripes as it passes through the photogate (t_a). Remember that the most recent time (picket 10) is displayed while the previous nine will be found in memory. Fill these times in the table below.
5. Calculate the velocity v_a at each stripe and enter it in the table.

Δx = 20mm = .02m width) $$Va = \frac{\Delta x}{\Delta ta} \text{ m/s}$$

Last 10 Pickets	Time Δt_a (s)	Velocity v_a (m/s)	Avg Velocity v_{avg} (m/s)	Time Between $\Delta t_{between}$ (s)	Acceleration (m/s^2)
1	0.0138	1.45	1.57	0.0255	9.02
2	0.0119	1.68	1.78	0.0225	8.44
3	0.0107	1.87	1.96	0.0204	8.33
4	0.0098	2.04	2.12	0.0189	8.47
5	0.0091	2.2	2.28	0.0175	8.57
6	0.0085	2.35	2.43	0.0165	9.09
7	0.008	2.5	2.59	0.0154	11.04
8	0.0075	2.67	2.75	0.0145	10.34
9	0.0071	2.82	2.91	0.0137	12.41
10	0.0067	2.99			

6. Assuming that the speed is changing very smoothly (with constant acceleration) we can find the average velocity between any two speed measurements by: $V_{avg} = (V1+V2)/2$. Calculate the average speed between each two adjacent picket fence stripes and record them in the table. The first calculation will involve pickets 1 and 2, the next 2 and 3, etc...
7. The distance traveled between any two measurements is 0.04 meters because this is the distance between the leading edge of one stripe and the next. Fill in the table with "time between" measurements by using the formula: distance=V_{avg} * time. We can solve for the time between the two velocity measurements to get:

$$\Delta T_{between} = \frac{.04m}{V_{avg}}$$

8. The acceleration can be found by using the calculated velocity at adjacent picket fence stripes. The first calculation will subtract V_a for picket 2 from V_a for picket 1. The next calculation will use V_a for picket 3 minus V_a for picket 2. Fill in the table with your calculated value for the acceleration between each pair of measurements using:

$A = \frac{\Delta V}{\Delta T_{between}}$ for pickets 1 and 2 $A = \frac{\Delta V}{\Delta T_{between}} = \frac{V_{picket2} - V_{picket1}}{\Delta T_{between}}$

9. The acceleration of each strip should be the same because they are all moving as part of the same object. Find the average acceleration.
A_{avg} = 9.52m/s^2

10. The accepted value for the acceleration due to gravity is 9.8 m/s2. How does your experimental value compare to the accepted value? Calculate the percent difference.

$$\%difference = \frac{\exp erimental\_value - accepted\_value}{accepted\_value} * 100\% = \frac{9.52 - 9.8}{9.8} \times 100 = 2.86\%$$

11. Compare the accuracy of this measurement method to the methods from lab #1.

This method is much more accurate.

12. Describe some probable sources of error in this experiment. When possible, explain whether the error would cause the value for acceleration to be too high or too low.

Air resistance would cause it to slow.

13. How would the measured velocities change if you increased the height above the photogate from which the picket fence was dropped from?

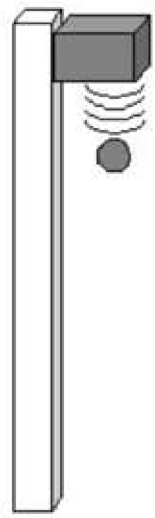
Every velocity would be higher.

14. How would the acceleration change?

The acceleration would not change.

15. Run the experiment described in question 13 and find out if your predictions are correct.

Gravity Lab:
Measuring *g* with a Motion Sensor (Answer Key)



Objective: To find the acceleration of an object in freefall.

Materials: Yellow Ball, Motion Sensor and software, Workshop Stand or Ring Stand, Measuring Tape, Computer.

Background: This experiment will use a motion sensor (**Go-Motion** P4-2400) to measure an
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the s
You

Note: Numerical answers given here are sample answers. Student results may vary, but ultimate conclusions should be the same. Coach students on how to interpret results as being "close enough" to be equal.

Helpful Notes: Motion sensors are very sensitive to objects in their nearby environment. For best results, do this experiment in as wide open of a space as possible. Objects that are nearby may be picked up by the motion detector causing inaccurate data or limiting the range of the motion detector. Set the sampling rate on your motion detector as high as possible. A minimum of 20 samples per second are needed to accurately track an object falling due to gravity.

Procedure:

1. Mount the motion sensor at least 1.5m above the floor, so that it points straight down.
2. Program the timer to record distance data for about 20 seconds and display the results as a line graph. Be sure to set the sampling period for as many samples as possible per second.
3. Hold the ball about 10cm below the motion sensor. Start the program and drop the ball, taking care to keep your hand out of the measurement path.

4. Pick up the ball and repeat the experiment several times, until the 20 seconds is up.
5. Inspect the resulting graph and choose one trial that has smooth, uninterrupted results. Select and display only that block of data.
6. Use the motion sensors included software to create graphs of velocity and acceleration vs. time for that block of data.
7. Inspect the values for acceleration during the trial.
8. Select the part of the Acceleration graph that appears to be approximately constant (this will be after the release and before impact). Using the software's tools, calculate the average value of acceleration for this selected period. Record the average acceleration $9.378 m/s^2$

9. Print a copy of the graph for each group member. Attach the graph to this worksheet.

10. The accepted value for the acceleration due to gravity is 9.8 m/s2. How does your experimental value compare to the accepted value? Calculate the percent difference.

$$\%difference = \frac{experimental\_value - accepted\_value}{accepted\_value} * 100\%$$

$$= \frac{9.378 m/s^2 - 9.81 m/s^2}{9.81 m/s^2} * 100\% = 4.4\% \quad difference$$

11. Compare the accuracy of this measurement method to the methods used in the previous two labs.

It is more accurate than the method of lab #1 but not quite as accurate as the method of lab #2. This may vary depending on the sampling rate of your motion sensor.

12. Describe some probable sources of error in this experiment. When possible, explain whether the error would cause the value for acceleration to be too high or too low.

Air resistance would cause it to slow. Other objects in the path of the ultrasound wave sent out by the motion detector could give inaccurate data. Other sources of inaccurate data: Not dropping the ball in a straight line below the sensor, having your hand in the way, other ultrasound waves in the same frequency range.

