Introduction to Kinematics (Constant Velocity and Acceleration)

Your Name _____

Partners' Names _____

_____

TA's signature allowing you to take the quiz or leave _____

Obtained reasonable experimental results?	yes ☐
Answered questions?	yes ☐
Cleaned your table?	yes ☐

Introduction

To trace motion of an object, we have to know how it moves with respect to time. Namely, it is expected to record the change of motion in terms of elapsed time. The motion of an object can be described by the displacement, velocity, and acceleration. Each of them has a dimension [L], $[L][T^{-1}]$, and $[L][T^{-2}]$, respectively; namely, each unit has to be m, m/s, and m/s^2.

Displacement indicates the direction and distance from the initial and the final points. Velocity is the change of a displacement in a certain time interval. Acceleration is a change of velocity in certain time. Thus, a constant acceleration creates a constant increase of the velocity and a constant velocity creates a constant change of the displacement. This can be found in daily life experiences such as traveling with a car.

On the other hand, the most common constant acceleration in nature is known as gravitational acceleration. Objects on the Earth fall toward the center of the Earth with an acceleration, 9.81 m/s^2. This depicts that a falling object obtains velocity, 9.81 m/s, each second. The procedure of the experiment to obtain gravitational acceleration is following: Under a constant acceleration, the average velocity, $\bar{v}$, is (final velocity + initial velocity) divided by 2. That is:

$$\bar{v} = \frac{v_f + v_i}{2}$$

Making the initial velocity zero, we obtain the average velocity as only final velocity divided by 2. Another expression of the average velocity is distance (or height) divided by time:

$$\bar{v} = \frac{h}{t}$$

From these equations, the average velocity is eliminated and we have:

$$\frac{v_f}{2} = \frac{h}{t}$$

Thus, the final velocity can be solved as

$$v_f = \frac{2h}{t}$$

Therefore, the acceleration reaching the final velocity is the final velocity divided by the time, $\frac{v_f}{t}$; namely,

$$a = \frac{2h}{t^2}$$

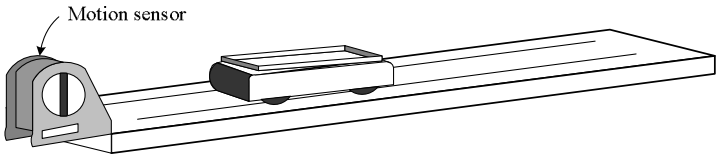
The acceleration, a, from the free-fall experiment is supposed to be the gravitational acceleration, g, 9.81 m/s^2.

Objectives:

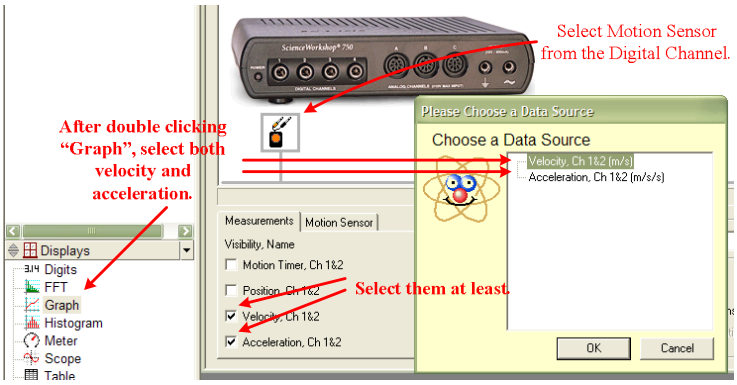
- To learn qualitative description of motion (constant velocity and acceleration)
- To verify the gravitational acceleration as 9.81 m/s^2 (constant falling acceleration)

Procedure:

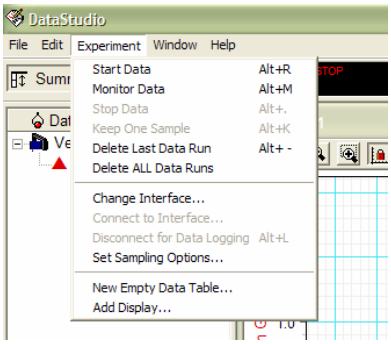
① Set up the following experimentation as shown:



② Start up DataStudio and select the motion sensor. **[Click a channel, A or B, in the interface of the picture only ONCE although there are two connections.]** Open two graphs of velocity vs. time and acceleration vs. time.



③ Mimic a situation when you get on a highway to reach 70 mi/h with the miniature set up. Attach a string to the cart if needed and pull it by imagining the situation. (Let's say, accelerate uniformly from rest to 0.5 m/s in this case.) Then, obtain two graphs with the DataStudio.

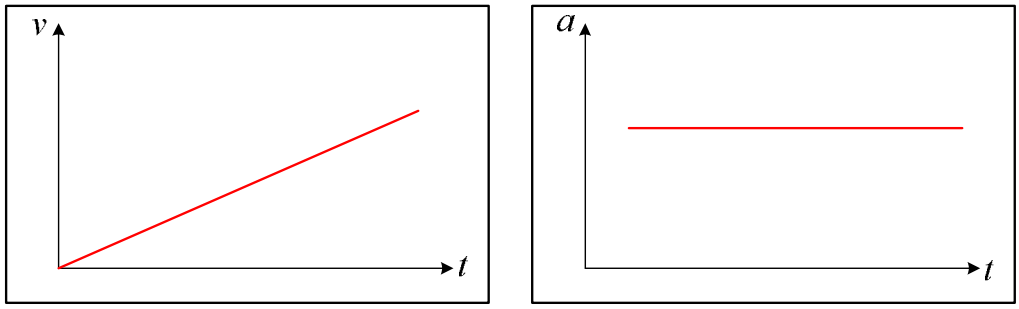


④ When you want to delete the previous data, go to "Experiment" and select either "Delete Last Data Run" or "Delete ALL Data Runs" as shown.

Make sure:

The graphs likely give you the following result. Try to obtain the expected results. <u>Also, let everyone try this experiment.</u>

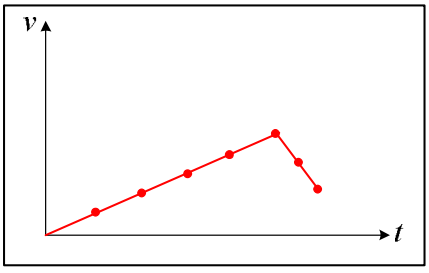
Theoretical Expectation



Conceptual note:

The above picture illustrates an ideal case and you would most likely obtain the following graph: Does it make sense? Explain what happened to the velocity after reaching the peak.

An example of actual data

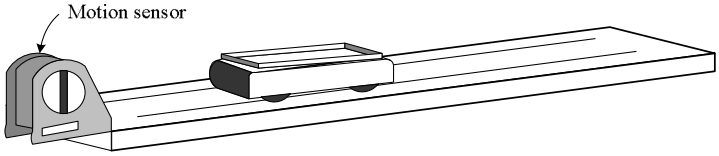


Print this out!
Check with your instructor to see if you obtained the proper graphs with DataStudio. One best graph is enough to share with other partners. [Do NOT modify any data. Use every data point if it physically makes sense.]

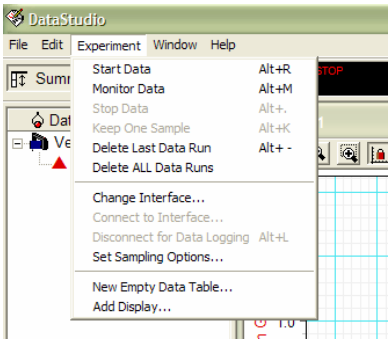
What is acceleration? How do the velocity and acceleration change with respect to time? What is the meaning of constant acceleration according to the graph?

2. A constant velocity

Procedure:
① Use the same set up as previously.



③ Mimic a situation when you have to drive at 70 mi/h constantly (no acceleration, not to be caught by police) with the miniature set up. Attach a string to the cart if needed and pull it by imagining the situation. Then, obtain two graphs with the DataStudio.



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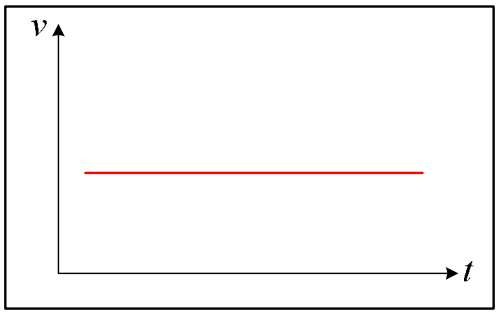
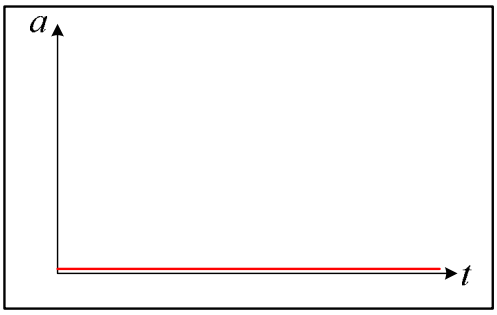
Make sure:
The graphs likely give you the following result. Try to obtain the expected results. Also, let everyone try this experiment.

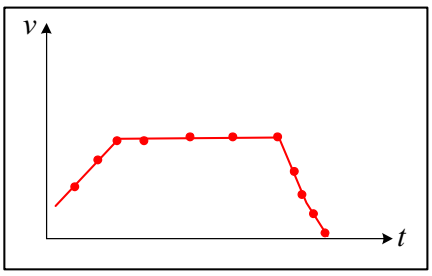
Theoretical Expectation





Conceptual note:
The above picture illustrates an ideal case and you would most likely obtain the following graph: Does it make sense? Explain what happened to the velocity before and after reaching the plateau.

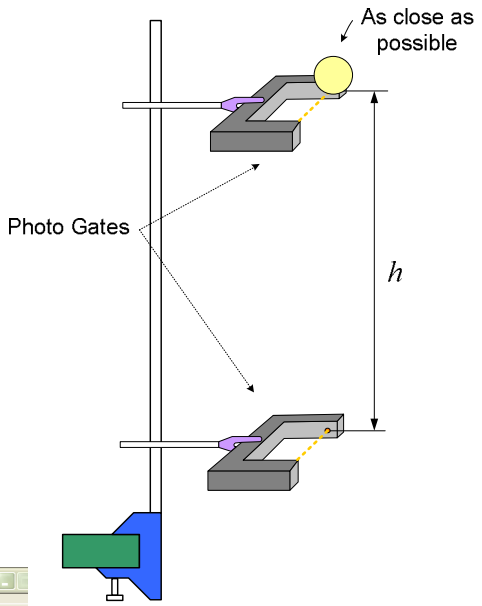
An example of actual data



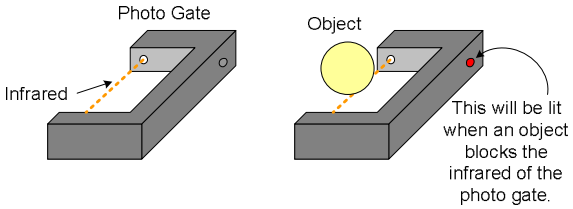
Print this out!
Check with your instructor to see if you obtained the proper graphs with DataStudio. One best graph is enough to share with other partners. [Do NOT modify any data. Use every data point if it physically makes sense.]

❶What is the relationship between velocity and acceleration? ❷How do you describe these two graphs? ❸How do you instruct your friends how to make a constant speed with a cart?

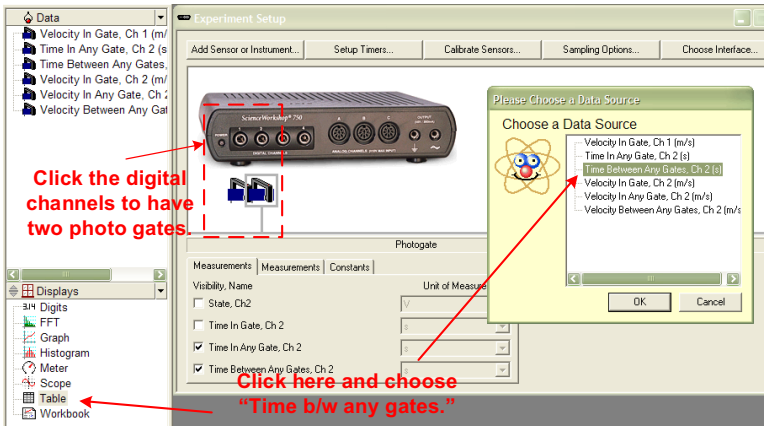
3. Gravitational acceleration g:



Procedure:
① Set up the pieces of equipment as shown in the figure:
The photo gate works as follows:

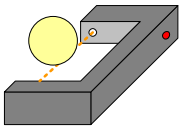


② Start up DataStudio. Click the digital channels 1 to select the photo gate. Do the same for the digital channel 2. Click the "table" for the display. Then, the data source has to be "Time Between Any Gates" as shown below:

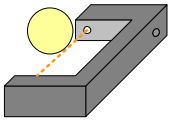


③ Measure the fall distance, *h*, with a meter stick, which is between two photo gates (between infrared beams).

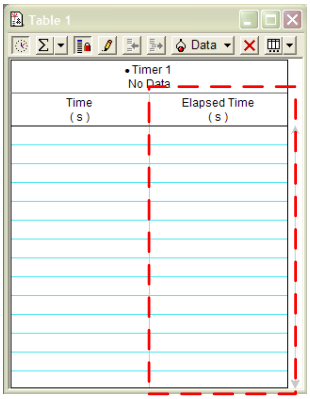
④ The fall time is obtained from the photo gate. The initial place to drop must be <u>as close to the photo gate as possible</u> because the initial velocity is assumed as zero. **This is very important to obtain an accurate result.** The tips are following:



Make the object interrupt the infrared and the light will be turned on.



Just lift the object right above the beam. After making sure the light turned off, tell your partners to click start.



⑤ The elapsed time is what you record in the data table as shown:

⑥ According to the introduction of this lab, we can assume that the acceleration is constant. Using the average velocities, we have the final velocity as $v_f = \frac{2h}{t}$.

Therefore, the acceleration reaching the final velocity is $a = \frac{2h}{t^2}$. The acceleration, a, has to be the gravitational acceleration, g, 9.81 m/s^2.

Do not get confused with *a* and *g*. The *a* is the acceleration measured by the experiment, which is supposed to be close to the constant falling acceleration, *g*, gravitational acceleration.

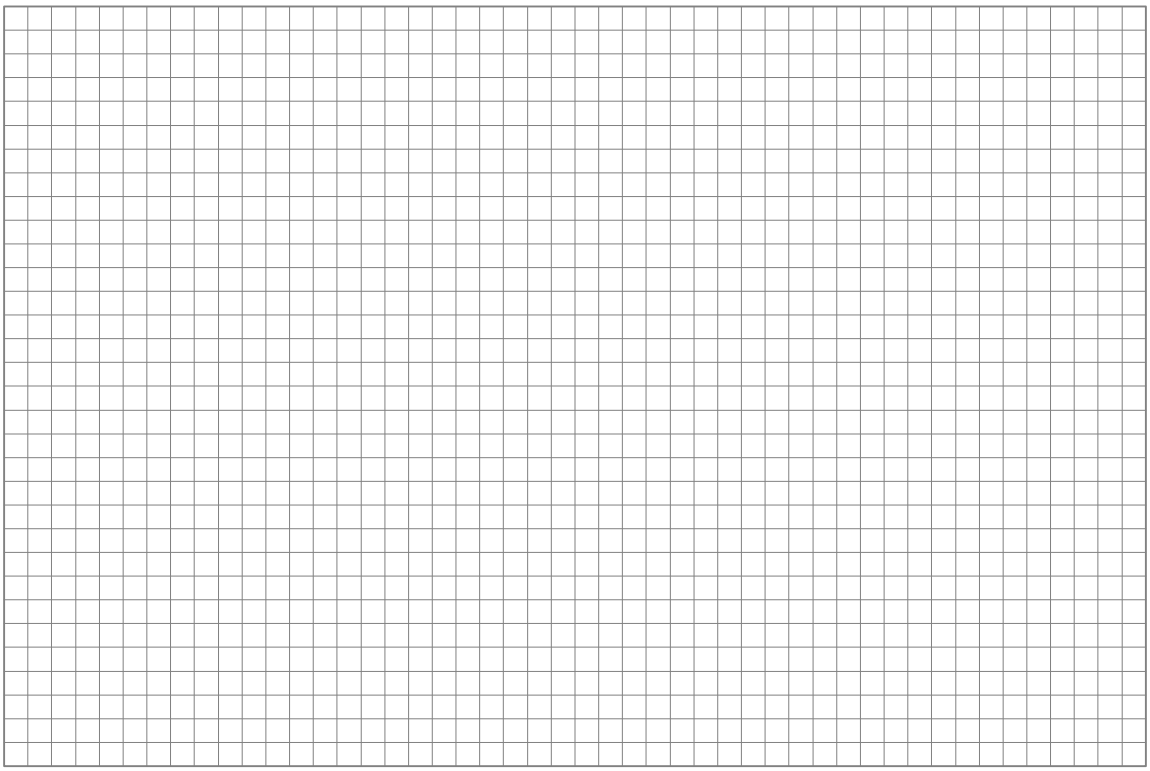
Hints:
If you obtained the acceleration greater than 9.81 m/s^2, you would likely make an initial velocity by releasing the object higher than it should have been. If you obtained it less than the accepted value, the object would block the photo gate before dropping.

1	**2**	**3**	**4**	**5**	**6**
Fall distance, h (m)	Fall time, t (by photo gate) Take "Elapsed Times."	The final velocity at the distance (Columns **1** ÷ **2**) × 2 *	$\frac{t^2}{2}$ (Use the value in column **2**.)	The acceleration $a = \frac{2h}{t^2}$	% Error $\frac{\lvert\text{Column } \mathbf{5} - 9.81\rvert}{9.81} \times 100\ \%$
0.700					
0.800					
0.900					
1.000					
1.100					

* $\bar{v} = (v_i + v_f)/2$; thus, $v_f = 2\bar{v}$ since v_i is zero.

Question: How does the error depend on the fall distance? (The more distance, the more % error, or opposite? Discuss the reasons.) How do you describe your experiment in terms of the data distribution? (See section 6 in the first lab.)

➢ Plot a graph using columns **2** and **1**. (Note that falling distance, h, is in y-axis and time is in x-axis.)



Questions:

- According to column **3** above, is it a uniformly accelerated, or a non-uniformly accelerated motion?

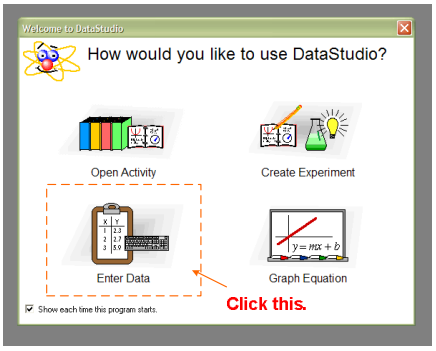
- Are the results of the acceleration close to the accepted values by referring to the column 5? What are the possible causes of errors?

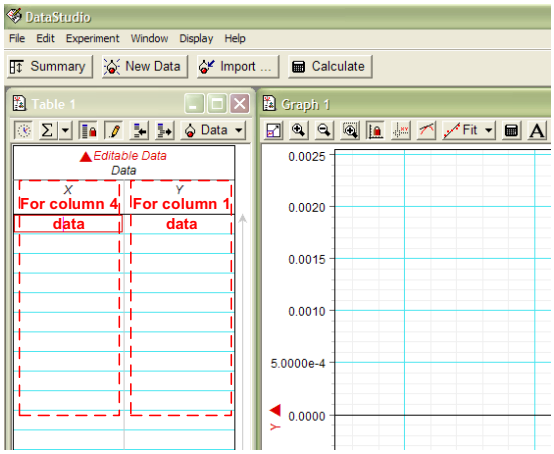
- From the above graph, how does the falling distance vary with time? Is it linearly proportional?

➢ **The theory of the following analysis:**

The acceleration formula is given as $a = \frac{2h}{t^2}$. Solving for *h*, we have $h = a\frac{t^2}{2}$. Compare it with a line equation, $y = bx$. The values, $\frac{t^2}{2}$, and h correspond to *x* and *y* axes, respectively. Therefore, plotting a graph using columns **4** and **1** gives you the slope, which is the acceleration, a. You obtain it with the linear fit line program in DataStudio. The slope is supposed to be the gravitational acceleration, g = 9.81 m/s^2. [**Note: The data shown below are only for the explanation purpose. Please do not compare your results with these.**]

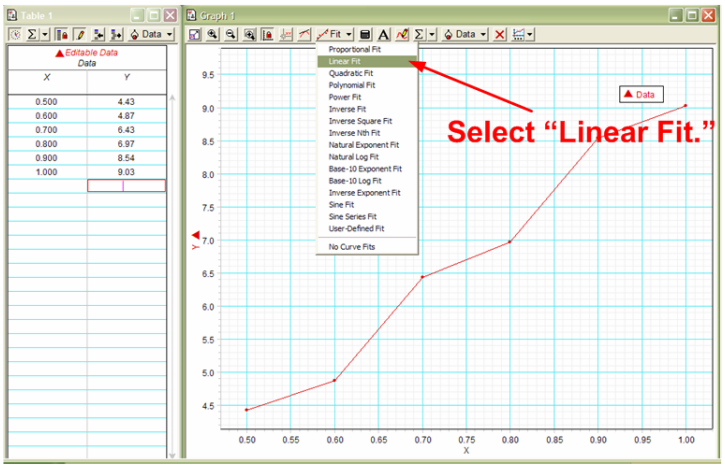
① Restart DataStudio to have opening screen. Click "Enter Data." ⇨

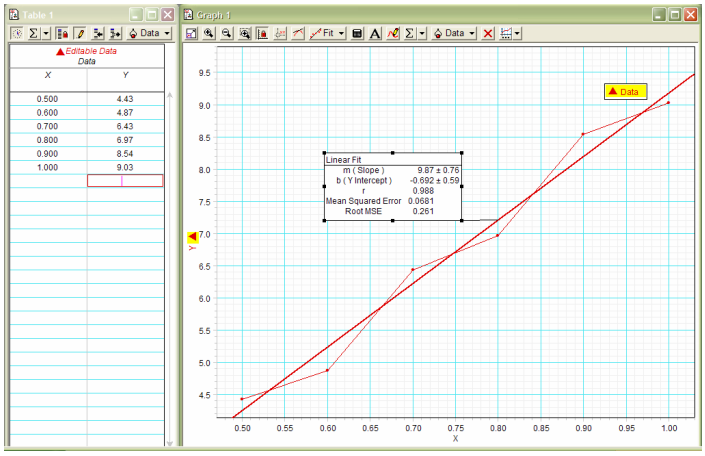




⇦ ② Type the data in the data columns as indicated.

③ Click "Fit" in the panel, then select "Linear Fit." ⇨





⇦ ④ The linear fit line and its information will be displayed as shown. [The data used in the figure are fictitious!]

Question:

From the slope of the linear fit line, how well does your result agree with the expected value (9.81 m/s^2) also in terms of the uncertainty? [What is (are) the advantage(s) of this "averaging" method?]