Galileo / Free Fall Experiments

Galileo Galilei had strong **beliefs** about physics, which have perhaps had a more profound influence on us than the actual discoveries he made.

Galileo had faith that there are fundamental laws of physics, which are very simple. Unlike some philosophers who sought understanding through increasingly detailed descriptions of physical experience, for Galileo, the trick was to figure out **what we can ignore** in order that the simple rules could be shown. When Galileo did experiments, he tried to accomplish these two goals:

1. To design an experiment so that the variable of interest could be **observed almost directly** (by controlling many other variables).
2. To extrapolate his observations out to **limiting situations** that might not actually be attainable experimentally.

The question that Galileo sought to answer in his apocryphal "Leaning Tower of Pisa" experiment[1] of dropping two objects was **whether heavier (more massive) objects fall in the same way as lighter objects or not**.

First it would be good to explore what is meant by "falling in the same way". The total distance an object moves divided by the time it takes is its **average speed**. But is the instantaneous speed of a falling object the same from moment to moment, or is it changing throughout the fall? What do you think?

In particular, from your life experience of dropping objects: If you "drop" an object… is it moving faster at the beginning of the fall or at the end of the fall? Or at a constant speed throughout the experiment? Justify your answer.

[1] The tale of Galileo dropping objects off the Leaning Tower of Pisa is apparently a scientific folk tale, which may have never happened. Galileo *did* come up with a very elegant *thought experiment*, to refute Aristotle's claim that heavier objects dropped faster than lighter ones. See tinyurl.com/dropstuff.

Sketch a graph of your **best guess** of the speed of the object (y-axis) versus time (on the x-axis) for a falling object.

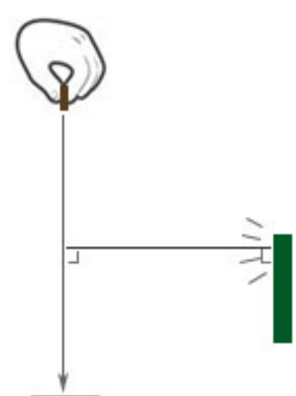
You'll drop a lightweight object and a heavier object and compare how they fall, and measure some things about how they fall

We'll use your iPads to take videos of the falling objects and "Logger Pro" (video analysis software) to explore some aspects of how the speed is changing when an object falls, and eventually bring this back to the question of mass and falling.

Getting good data (videos): We came up with some guideline in class before lab 1 to get good data from videos: 1.) Have some 'ruler' in the video: an object of known length. You may use a meter stick from SC 008. 2.) As much as possible, all parts of the path of a moving object, as well as all parts of the ruler object should be the same distance away from the video camera.

Here are a few more guidelines,

- The more light you have, the less blurred the object will be, and the easier it will be to mark each position on an individual video frame. Make your videos outside if possible. But if weather keeps you inside, make sure the windows in the lab are wide open. Also put some cardboard on the floor to protect it from the impact of the heavier object!
- To avoid having to think about dropping **and** rotation, hold an object like a brick close to its short side, and let it hang down below your hand before releasing it. It shouldn't rotate as it drops.
- The object with a known length, the 'ruler', should be as close to the falling object as possible, and just as far from the iPad as the object itself. All points on the ruler should be about the same distance from your iPad. It can be horizontal (need not be vertical): So a common thing to do is to lay down a meter stick and drop the object so that it lands close to the middle of the meter stick.
- Position the iPad parallel to the line of fall of the object, and about halfway between the point you drop it and the ground (see diagram at right).



Can you come up with a ridiculous position for the camera where you violate the last suggestion and make a movie in which it appears that the falling object does not move across the screen at all??

Pick one light object (100 g or less) and one heavy object (1000 g=1 kg or greater). Weigh your light object, and your heavy object and the balances in SC 008 and record their weights (or rather masses) below. Convert grams to kilograms. Say what light object you've chosen and what heavy object.

m_{light}= m_{heavy}=

What is it? *What is it?*

Calculate how much heavier the heavy object is than the light object. That is, calculate:

m_{heavy} / m_{light} =

Make 4 movies: 2 of dropping the light object, and 2 of dropping the brick (or another heavy object). Drop each object from at least 2 meters above the ground: Release it from above your head.

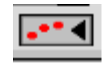
Make your movies available to the GC lab computers: There are two possible approaches to make the movies you've taken into files you can access on the GC lab computers:

1. E-mail each movie from your iPad to yourself. When you're on a GC lab computer you can check your e-mail and download the movie attachment.
2. Instead, you can put the movies on your Google Drive on the iPad. When you're on a GC lab computer you can open up Google Drive and then download the movie.

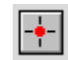
Open your video in "Logger Pro" on one of the GC lab computers: Log in to one of the computers in SC 008 and download your videos onto the desktop.

Open up "Logger Pro" from the Start menu. You'll see cells, like in a spreadsheet and some other things. Choose "Insert | Movie" and select one of the movie files on your desktop.

You'll see the first frame of the movie with controls at the bottom (try them out) which let you play/stop/rewind the movie, and advance or reverse the movie by one frame at a time. (One frame of the movie is 1/30 of a second, so Logger Pro uses this to figure out the time when it makes graphs.)



Mark up your movie for analysis: On the right bottom side of the movie frame, press the button that looks like this to enable video analysis.



To the right of the movie frame, you'll see several buttons. This one is the "Add Point" button.

Advance until you're at the point in the movie just after you release the falling object. Click this "Add Point" button, and then click a point on the falling object to mark it with a dot on the movie.

Each time you click to add a point, the movie is advanced by one frame, so you can click on the position of the object in the next frame, and keep going. Before long, you've marked the "trajectory" of the falling object, and the computer knows the on-screen position and time of each blue dot.

You put a meter stick, or some other object of known length in the scene, which you can use to figure out distances in the scene. Use this "Set Scale" button to mark your object and tell Logger Pro how big it is: After you click it, you'll move the cross hair on the screen to one end of your "meter stick" object. Hold the mouse button down and drag it to the other end. A green line will show up, and a menu asks you how long the object that you've marked is in real life.

can grab the yellow dot that's a little ways from the origin, and rotate the coordinate axes until the points are running along one of the axes.

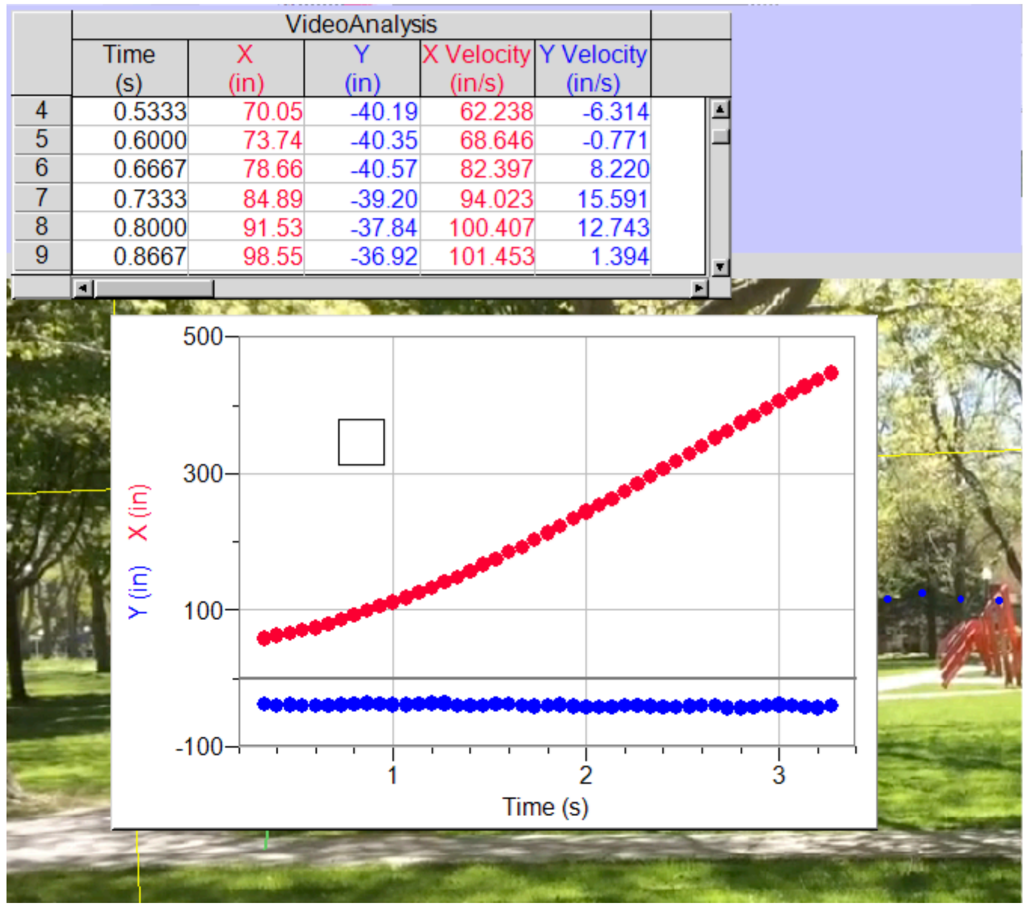
Finally, use this "Set Origin" button. After you click it, move the pointer to the first point that you marked on the movie and click the mouse button to set the "origin" of your coordinate system. Make sure the points you marked are running along the *x*-axis (or the *y*-axis): You can grab the yellow dot that's a little ways from the origin, and rotate the coordinate axes until the points are running along one of the axes (in case you had your iPad not exactly straight up and down).

Display distance and velocity graphs: You'll see areas on the screen that contain a graph, and another area that contains data.

One of those data sets (X or Y) has the data you want (the vertical position) and the other is the horizontal position (Which we don't care about: mostly you're seeing the jitter in how you mark the object).

If you click in the picture where it says "Y (in) X (in)" you can select the data you want.

(Hopefully your data will come in marked in meters instead of inches.)



VideoAnalysis

	Time (s)	X (in)	Y (in)	X Velocity (in/s)	Y Velocity (in/s)
4	0.5333	70.05	-40.19	62.238	-6.314
5	0.6000	73.74	-40.35	68.646	-0.771
6	0.6667	78.66	-40.57	82.397	8.220
7	0.7333	84.89	-39.20	94.023	15.591
8	0.8000	91.53	-37.84	100.407	12.743
9	0.8667	98.55	-36.92	101.453	1.394

If I had wanted to see a velocity vs time graph, I would have selected one of the Velocitygraphs instead.

Speed or acceleration: You probably positioned things such that the y-distance is going towards more negative values as time goes along (the positive direction is "up"). The *slope* of a line on the distance graph is the **velocity**, *v*:

$$v=\Delta y/\Delta t$$

The slope, *v*, can be either positive or negative. But the "**speed**" is the absolute value of the velocity, and so by convention it's always a positive number. It's the absolute value of velocity. it's always a positive number.

You can also make velocity graphs. The average rate of change of the velocity is the same as the average slope of of that velocity vs time graph. Call this average "*a*" which on this graph is

$$a=\Delta v/\Delta t$$

This is how fast the velocity is changing, and is called the **acceleration**.

If, for example, you measured distances in meters, then velocity will be in units of m/sec, and time will be in seconds. So the units of acceleraton would be (m/sec)/sec which is also written as m/sec^2

Do this full analysis of one of your four movie datasets: For **one** of your four data sets, answer all of the following questions.

Display the **speed (velocity) vs time graph** for one of your objects. How does it look the same and/or different from what you guessed?

Now, on your **distance vs time** graph, select the range of your data (drag a rectangle with the mouse) during which your object was falling (not bouncing, and after it was released). and use the "Analyze | Curve Fit" menu to try fitting various equations (of increasing complexity) to your data. Your lab assistant can help you with this part. Which is the *simplest* equation that fits this graph well, as judged by eye?

Now select your **velocity vs time** graph… Which is the simplest equation that fits this graph?

You should have found that **one** of the these graphs is approximately *linear*.

A straight line graph means that the slope is pretty much constant…so is it the velocity or the acceleration which is **constant** for a falling object? (Check this with your lab assistant before going on to the next part).

Of the two graphs you looked at, one should be more nearly linear. When you do "Analyze | Linear Fit", the slope (see note[2] below) will be calculated for you, and the straight line is shown on the graph. Write down the slope that Logger Pro found (be **sure** to include units…)

m_{fit}=

Check this quickly against an estimate that you make for that average by taking the values for first and last data point and using the "rise over run" formula.Look at the first value and time for the graph, and the last value and time, and calculate the slope from those two points. Show your work below by including the printout of the graph and your markings on that, used to estimate the slope. Is your "eyeball" estimate close to the value Logger Pro gave you from the computer fit?

$m_{estimated}$=

Save the marked up movie, together with data and last graph you made. It will be a .cmbl file. Save this one on your M: drive or Google Drive. That will be one of the files you hand in on Moodle. (You may hand in just one file per lab group).

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[2] *m* is the symbol used for the slope of a line: You have probably seen the equation for a line written as a function of *x*, as $y(x)=m*x+b$, where *x* is the independent variable (on the horizontal axis). But on our graphs the horizontal axis is always time *t*, so we'll write: $y(t)=m*t+b$.

You likely have found that the **acceleration** is very nearly constant for a falling body, but the velocity was changing with time.

But is the acceleration of the ball and of the brick the same? Now you should go ahead and **fit the velocity graphs for each of your four trials and report the results below**. (You do not need to answer all the questions above for each of the remaining three trials. Just find the acceleration values each one by fitting in Logger Pro.) The units should be meters/sec/sec=meters/(seconds*seconds) which can also be written m/s^2.

Measured accelerations (convert to m/sec/sec if necessary)

Light object	Heavy object

We'll graph everyone's data to try to get at the question of whether these values are close "enough" or not, so as to decide what to say about whether mass matters or not.

If, you found, for the sake of argument, that the accelerations of both are the same, write shortly why that should result in equal dropping times for two objects, dropped at the same time, from the same height.

On Moodle you'll hand in your marked-up-in-Notability file (this one), and the .cmbl file for one of your movies that you saved above. Just one person in each group can hand this in, but include both your names somewhere in what you hand in.