Name: ________________________________ Date:__________________
Lab Instructor:_________________________ Lab Section:____________

PRELAB CC105 LAB 1: Experimenting with Gravity

Due at the BEGINNING of lab section and worth 10% of your lab grade.

1. On a plot of velocity (y-axis variable) versus time (x-axis variable), what would the Aristotelian view of a stone dropped to the earth look like? Sketch your answer.

2. Write a formula for Galileo's quantitative description of the relationship between distance and time. Define all of your symbols and variables.

3. Write a mathematical formula that expresses Newton's law of universal gravitation in terms of variables. Define all of your symbols and variables.

4. Rewrite the formula, $P = 2\pi\sqrt{L/g}$ and solve for g (i.e., isolate g on one side of the equation).

CC105 LAB 1: Experimenting with Gravity

Background

If you were asked the simple question,

"why do all dropped objects fall to the earth,"

the obvious answer would be,

"because of the force of gravity."

But what is gravity? Is it really the tendency for objects to fall to the earth at a constant acceleration? What causes gravity? Although early observers also noted this phenomenon, it was not until the publication of Newton's *Philosophiae Naturalis Principia Mathematica,* or *Principia,* in 1687 that the theory of gravity was formally proposed and described. Before Newton's work there were other theories to explain why objects fall to the earth.

Aristotle

Aristotle (384 BCE – 322 BCE) observed the behavior of falling objects and derived a theory based on his observations. According to Aristotle, all matter was made of four elements, earth, water, air, and fire (Figure 1), and elements tend to go towards their elemental source. Thus, a heavy stone (earth matter) will tend to fall to the earth, whereas fire will rise towards the realm of fire, which exists above air.

In Aristotle's view, heavier objects fall faster to the earth than lighter objects because of their greater relative composition of the earth element. Aristotle also proposed that after a brief initial period of acceleration, the speed of the fall of any object would be constant. Aristotle's ideas are appealing because they are based on common sense and correspond to what we observe. We have all seen a leaf fluttering through the air, compared to the fast descent of a heavy stone.

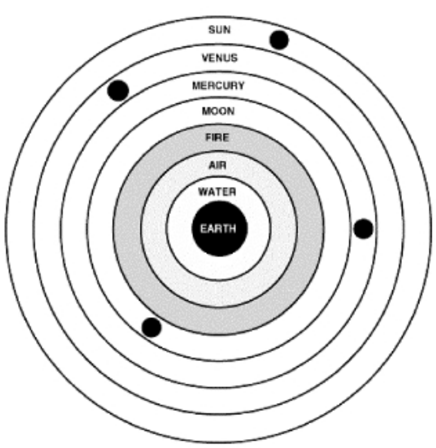

Figure 1. Aristotle's view of the elements and the cosmos.

Galileo
Galileo Galilei (1564-1642) revisited Aristotle's ideas with strict empiricism. Galileo stressed the importance of physical observation as the basis for the formation of logical arguments. Galileo asked,

"How do objects fall to the earth?"

And he devised carefully controlled experiments to investigate his question. Because modern clocks had not yet been invented, timing the free-fall of an object was especially difficult. Galileo slowed the process down by rolling balls down an inclined plane with carefully spaced bumps. When the ball rolled over a bump, it made a noise, which he could use to time the descent.

Galileo made 3 critical conclusions from his experiments. These were:

- Objects of varying weights fall to the earth at the same rate.

- When objects fall from rest, they fall more and more quickly the longer they have been falling (i.e., they accelerate).

- The distance an object falls through is proportional to the square of the time elapsed during the fall.

Galileo's well-designed experiments and measurements enabled him to give a mathematical or quantitative description of his results. This is indeed the basis for the modern scientific method.

Newton
Sir Isaac Newton (1643-1727) was born just after Galileo died. He was a mathematician and theoretician. Using the theories and observations advanced by philosophers, astronomers, and physicists before him, he was able to come up with a formal theory of gravitation, which unified previously unrelated phenomena.

Newton, following Galileo's description of falling bodies, wondered why the moon does not fall to the earth. What Newton realized is that the moon is falling towards the earth, but that it keeps missing the earth. Imagine that you are standing in a skyscraper on earth and you throw a stone horizontally off the top. That stone will arc down and eventually hit the earth. If you throw another stone harder, it will arc and hit the earth farther away. Hypothetically, if you throw it hard enough, the stone will arc all the way around the earth. Like the stone, the moon is falling towards the earth, but because it is far away and moving quickly, and the earth is curved, the moon never hits the earth. This is the definition of being in "orbit." Newton posited that if the moon is subject to gravity, then the rest of the solar system must be too. To suggest that the heavens were subject to the same physical laws as the earth was a revolutionary idea. Newton proposed that gravity is a force that acts on all bodies. His law of universal gravitation states that:

All bodies attract all other bodies, and the strength of the attraction is proportional to the masses of the two bodies and inversely proportional to the square of the distance between the bodies.

Einstein

Thus according to Newton, all masses are subject to the force of gravity; all masses attract each other. However, Newton was not able to describe a mechanism for this force. All other known forces had mechanisms: the wind causes movement of the air, which then forces the movement of a windmill. The notion of an action that acts at a distance and is propagated through an unknown medium was unsettling to Newton and his contemporaries. It was not until 1915, when Albert Einstein (1879-1955) published his theory of general relativity, that a mechanism for the force of gravity was proposed: the curvature of space-time.

Activities

In this lab, you will experimentally calculate a value for the acceleration due to gravity, g. You will do this using 2 different methods:

A) using a spark timer to time a free falling mass, and

B) using a pendulum's period and length.

Experiment A:

First you will use a spark timer to measure a value for acceleration due to gravity. The spark timer will emit a spark once every 1/10 of a second (10 Hertz) or once every 1/60 (60Hz) of a second depending on where you have the switch set. These sparks will be recorded on the special waxed tape running through the timer. Attach a weight of at least 100 grams to the bottom of the wax tape using a paper clip. Measure and record the distance from the bottom of the spark timer to the floor. Cut a piece of tape long enough to reach this distance. Thread the tape through the timer making sure that the shiny side is up. With one hand, hold the tape extended vertically in the direction that it will feed through the timer, while holding the mass with the other hand. Turn on the spark timer and set it to spark at 60 Hz; at this setting, the timer will leave a spark every 0.0167 seconds. When you are ready, release the weight and the tape, allowing the weight to free fall to the ground. When it reaches the ground, turn off the spark timer and remove the wax tape with the spark marks on it. Now you have a record of the fall. **BEWARE**, the timer tape can get stuck leaving a large fuzzy spot. If this occurs, repeat the experiment. The timer may also occasionally skip a mark. If the distance between marks seems abnormally large, correct your time assignments as if there had been another mark (however you will not have a distance for this time). You will have to watch out for these inconsistencies and correct for them if they occur or they will ruin your data.

Data & Analysis:

1. Create a table with 4 columns: spark mark #, time, distance, and velocity, together with their appropriate units.

   In the column labeled spark mark #, just list which mark you are measuring, *eg*, 1,2,3, *etc*. In the "time" column, record the time elapsed since you released the weight. To calculate this, simply multiply the spark mark # by $\frac{1}{60\text{s}}$. Use a ruler to measure the distance from the first spark mark (time 0, distance 0) to each successive mark. Record these distances in your table. Now, using the formula $v = d/t$, calculate the velocity of the weight at each time (each spark mark) and record this in the velocity column. Show at least one example of all of your calculations.

2. Plot a graph of velocity (on the y-axis) versus time (on the x-axis). Make sure your axes are labeled with units. Plot all of your points and draw a best-fit line through the points.

3. How can you calculate acceleration due to gravity (g) from this graph (hint: $g = \Delta v / \Delta t$)?

4. Calculate the percent error between your value for the acceleration due to gravity from question 3 and the actual value (9.8 m/s^2). Remember, the formula for percent error is:

   $$\%\text{error} = (|\text{Observed} - \text{Actual}| / \text{Actual}) * 100\%$$

5. What sources of error are there in your data? Could they account for the percent error seen in question 4?

6. Identify the largest source of error in your data and estimate the uncertainty in that variable.

Experiment B:

Next you will use a simple pendulum to determine a value for the acceleration due to gravity. Simple pendulums have been used for accurate time-keeping since the 17^{th} century. Their motion depends on the acceleration due to gravity. In a simple pendulum, all the mass is concentrated at a single point suspended by a massless cord. Figure 2 shows the parameters of a simple pendulum. A formula can be written to calculate the period of the pendulum. This formula is only accurate when the angle Θ is less than 14º. The actual formula involves sin Θ, which at small angles is approximately equal to Θ (when measured in radians). Therefore, the formula can be simplified to $P = 2\pi\sqrt{L/g}$. Here, P is the period of the pendulum, and L is the length of the cord from the center of the mass to the pivot point. You will use a photogate to measure the period of this simple pendulum. When you release the pendulum and it passes through the photogate, the timer starts. After two more passes through, the photogate timer stops and reads out the period of the pendulum – the time that the pendulum takes to return to its original position.

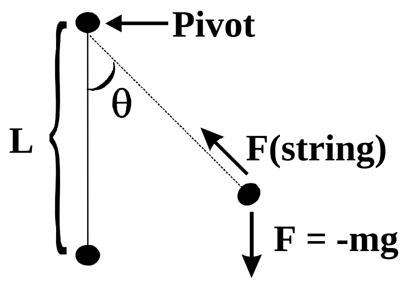

Figure 2: The physical parameters of a simple pendulum.

Data Collection:

- Measure the length of the cord (L), and measure the period (P) by using the photogate.
- Set the photogate to "pend" and the memory setting to "read." Make sure that the pendulum passes through the photogate to give you a reliable reading for P.
- Make sure to start the pendulum at an angle less than or equal to 14º.

7. Devise 2 experiments to determine whether :

A) period (P) is dependent on the length (L) of the pendulum

B) if P is dependent on the mass of the pendulum.

Check your experimental procedure with your lab instructor before proceeding.

Take at least 5 measurements of P for each data set, so that you can compute average values for P. Write a brief description of your experiments. Record and report all of your data and averages in tables.

Data & Analysis:

8. Explain how length and mass affect the period of your pendulum. Do they both affect it in the same way? Why or why not?

9. Using your pairs of data for period (P) and length (L), plot a graph of P^2 vs. L. From the equation $P = 2\pi\sqrt{L/g}$, you see that P vs. L will not be a straight line, because of the square root on the right-hand side. However, if we square both sides, then we have the equation:

$$P^2 = (2\pi)^2 L/g.$$

Therefore, a graph of P^2 vs. L will be a straight line. The slope of the line should then be $(2\pi)^2 / g$. Plot a graph of P^2 vs. L, with P^2 on the vertical (y-axis) and L on the horizontal (x-axis). Fit a best-fit line to your data points.

10. Calculate a value of acceleration due to gravity (g) from the slope of the line on your plot (note: some algebra will be required).

11. Calculate the percent error between your value for the acceleration due to gravity from question 10 and the actual value (9.8 m/s^2).

Synthesis:

12. Does the pendulum give you a more accurate value for g than the spark timer? Why or why not? What sources of error have been added or removed?

13. Using your best experimental value for g, you can now measure the mass of the earth. You know from earlier that Force = ma, or Weight = mg and from Newton, we know that $F=GMm/r^2$ (*all bodies attract all other bodies, and the strength of the attraction is proportional to the masses of the two bodies and inversely proportional to the square of the distance between the bodies*), so therefore, $\mathbf{mg = GMm/r^2}$. Imagine that the masses that are being attracted to each other are a ball and the earth, as in your first experiment. Then m would represent the mass of the ball, and M, the mass of the earth. Given the gravitational constant $G = 6.673 \times 10^{-11}$ Nm^2/kg^2, and the radius of the earth from its center is $r_E = 6378.1$ km, use your best value of g to compute the mass of the earth.

14. Do you need to know the mass of the ball to calculate the mass of the earth? Why or why not?

15. Given the mass of the moon ($m_M = 7.35 \times 10^{22}$ kg) and the radius from the surface to the center of the moon ($r_M = 1738.1$ km), calculate the acceleration due to gravity on the moon.

16. If you weighed yourself on the moon, would you weigh more or less than you do on earth? Why?