NEWTON'S LAWS

PURPOSE: To understand the concepts of Newton's Laws of motion.

APPARATUS: PC, Universal Lab Interface (ULI), force probe, motion detector, spring, masses

Introduction to Newton's Laws: In the late 1600's Isaac Newton formulated the three fundamental laws of motion:

1. Every object continues in its state of rest or of uniform speed in a straight line unless it is compelled to change that state by a net force acting on it.
2. The acceleration of an object is directly proportional to the net force acting on it and is inversely proportional to its mass. The direction of the acceleration is in the direction of the applied net force.
3. When one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

The First Law is not intuitively obvious from everyday experience. Friction, an unseen force, slows things down. Early philosophers, followers of Aristotle, taught that everything naturally tended to slow down and come to rest even without a force. The Second Law is essentially the equation $\vec{F} = m\vec{a}$. Note that it describes the *net* force; there can be more than one force in many instances. Their vector sum is the net force. The Aristotelians got this law wrong too. They assumed that velocity, not acceleration, was proportional to force. The Third Law is that every force (or action) is accompanied by an opposite force: $\vec{F_1} = -\vec{F_2}$ or $\vec{F_1} + \vec{F_2} = 0$. That is, you push on something and you feel an opposite (and equal) force. Note that the First and Second Laws refer to a single object while the Third Law is about two interacting objects. In this experiment we will do several exercises to verify the Second and Third Laws.

Set-up Force Probes:

- Turn on the computer and ULI. (If the computer is logged-on when you arrive, log-out and log-in again.)
- Verify that a force probe is plugged into DIN1 and a motion detector is plugged into PORT2. (For the first two parts of the lab, you will only be using the force probe.)
- Load the computer program `LoggerPro` by double clicking on its icon.

- To set-up `LoggerPro` for Parts A and B of the laboratory, you need to do the following:
  - **Setup** menu, select **Sensor...**.
    - Click on DIN1
    - Select Force-Dual Range 50 (verify that the switch on the force probe is set to 50.)
    - Exit the window (note that there is no need to calibrate).
  - Now **Setup** menu, select **Data Collection...**.
    - Set the sampling speed to 50 Hz.
    - Set the experiment length as necessary.
    - Exit the window.
- You should now be able to collect data that will appear in the accompanying plot and table windows. Be sure to verify that the axes and title are correctly labeled.

Part A: Newton's Third Law

For this part you will work with the adjacent group. Connect the hooks on the force probes together. (If necessary, remove the spring and disconnect each force probe from its overhead bracket.) Note that there may be electrical interference when you connect the two force probes - isolate them electrically using masking tape on the metal hooks. Compare the simultaneous readouts as you gently pull or push against each other as follows:

- Call one group, "A" and the other, "B". Record this on your lab reports.
- Group "A": Set the force probe so that Push is Positive. Group "B": Set the force probe so that Push is Negative. [These can be set from the **Setup** menu, by selecting **Sensor...**, clicking on DIN1, going to the **Details** submenu and clicking on **Reverse Direction**.] This makes the force direction the same for both probes. Zero the force probes [under the **Experiment** menu select **Zero**].
- Set the graph's force scale on both graphs to ± 8 N [click on graph near y-axis, select Manual Scaling and enter values].
- Each group must start taking data at the same instant.
- Start taking data and <u>gently</u> PULL on the two probes. Print copies of the resulting graphs. Label the graphs [click on the title and enter a meaningful name] before you print both graphs. Make one copy for every lab partner!

- Strike the two probes together as in a collision and record force vs. time. First try a light impact and make it stronger until you get a large amplitude. Compare the two computer graphs. Do they verify that $\vec{F}_1 + \vec{F}_2 = 0$? Does it matter whether the collision is fast or slow?
- The quantity $\vec{I} = \int \vec{F} dt$ is called the impulse. Rewrite the third law in terms of impulses instead of forces. Use the integrate tool under the ANALYZE menu to verify that your formulation is experimentally true. Does it matter whether the collision is fast or slow? Do you need to integrate over the time of the entire collision, i.e. does the law apply for just part of the collision?

Part B: Newton's Second Law – Static Equilibrium

Now let's look at Newton's Second Law. If you fix the force probe in a clamp and hang a mass from it, there are two forces acting on the hook of the probe – the weight $\vec{W}$ of the mass acting down and the upward pull $\vec{P}$ of the probe. Since the probe is clamped, there is no acceleration and Newton's second law tells us that $\vec{W} + \vec{P} = 0$. What we call the weight of the mass is the force of gravitational attraction by the earth and is proportional to the mass, $W \propto m$. Or letting the constant of proportionality be g, $W = mg$. We call g the acceleration of gravity. [This is a little confusing since there is no acceleration. What we mean is if the mass were dropped then only W would act on the mass and by the Second Law $W = mg = ma$ or $a = g$. Thus g is the acceleration a body would experience due to the force of gravity if it were allowed to fall freely.] Then substituting into $\vec{W} + \vec{P} = 0$, we find $P = mg$. In this part of today's lab you will use the force probe to measure P using `LoggerPro`. Then, you will exit the program and use `Excel` to plot your data and see whether $P = mg$ as predicted by the Second Law. Finally you will determine g from the slope of a graph of P versus m.

- Attach the force probe to the overhead bracket and hang the spring from it. Zero the force probe. Now, starting with only a small amount of mass measure and record the force (weight) on the probe. Do this for a range of masses up to a total of 150 to 200 g. Be sure to include a mass of zero as one of your data points!
- When you are done taking data, exit `LoggerPro` and start up `Excel` to plot your data.
- Enter the data in column format with the independent variable ("x") values in column A and the dependent variable ("y") in column B.
- Highlight the values to be plotted.
- Double click on the "chart wizard" icon. Choose the XY (scatter) option and answer the questions, being sure to insert appropriate axis labels and title.
- When the plot appears, right click on one of the data points. Choose the option ":add trend line" and choose a linear fit. Under options select Display equation and Display R2.

- A best fit straight line will appear on the graph along with an equation for this line. The R2 is the correlation coefficient; a value of 1.000 is a perfect fit to a line, while 0.000 means the data are random. The closer R2 is to 1, the better the fit.
- The slope of the best fit line is your value for g.

Set-up Force Probes and Motion Detectors:

- Reload `LoggerPro`
- To set-up `LoggerPro` for Part C of the laboratory, you need to do the following:
  - **View** menu, select **Graph Layout** and choose 2 panes.
  - **Setup** menu, select **Sensor...**
    - Click on DIN1
    - Select Force-Dual Range 50
    - Click on PORT2
    - Select Motion Detector
    - Exit the window (again, there is no need to calibrate).
  - Now **Setup** menu, select **Data Collection...**
    - Leave the sampling speed set to 50 Hz.
    - Adjust the experiment length as necessary.
    - Exit the window.
  - You will want Force to be the dependent variable in one plot and acceleration as the dependent variable in other. You may need to define acceleration for the plot, like this:
    - With the appropriate plot window highlighted, go to the **Data** menu, select **New Column**, then **Formula**.
    - On the **Options** submenu, enter a long name, short name, and units for acceleration.
    - On the **Definition** submenu, select the appropriate Function for acceleration, using Distance as the Variable. [Note you may find it useful to define another column, like velocity, first.]
- You should now be able to collect data from both devices that will appear in the accompanying plot and table windows. Be sure to verify that the axes in both plots are correctly labeled and are behaving as expected. [You may need to adjust the number of points in the derivative calculation – look at **Options** under the **Experiment** menu.

Part C: Newton's Second Law – Accelerated Motion

We will now verify Newton's Second Law for a case where the acceleration is not zero – a mass oscillating up and down due to the pull of a spring.

- Attach the spring and hanger to the force probe and add about 150 g of additional mass. Place the motion sensor on the table beneath the weight.
- Set the mass oscillating and record data. Adjust the force, acceleration and time scales so that one complete oscillation is displayed. Qualitatively, does $F = ma$?
- Copy the data for one complete cycle and paste into `Excel`. Prepare a graph of force vs. acceleration and fit the data to a straight line as you did for Part B. What slope do you expect?
- In the remaining time design and carry out experiments to answer questions such as: Does the amplitude of oscillation affect the results? Does the size of the mass affect the results? Does the Aristotelian prediction that velocity is proportional to force hold for an oscillating mass?