

Newton's Laws

Objective

To study Newton's Laws.

Introduction

Newton's laws are

1. If no net force acts on a body, its velocity cannot change; that is, the body cannot accelerate.
2. The net force on a body is equal to the product of the body's mass and its acceleration. That is, $\vec{F}_{net} = M \vec{a}$
3. When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

In this lab you will verify these laws using a motion sensor and a force sensor. The motion sensor operates by transmitting ultrasonic pulses. These sound pulses are reflected off of an object in the path of the motion sensor and travel back to the sensor, similar to the process of echolocation used by bats and other animals. By measuring the difference in time between the ultrasonic pulse left the motion sensor and returned to the sensor after hitting an object in its path, the object's distance from the sensor can be determined. The force sensor has a crystal that measures a voltage proportional to the applied force. You will also use a computer program **DataStudio** for data collection and analysis.

Recall that the position y of a particle moving along a straight line with a constant acceleration a is given by the following equation

$$\vec{y} = \frac{1}{2} \vec{a} t^2 + \vec{v}_0 t + \vec{y}_0$$

where t is time, y_0 and v_0 are the position and velocity at $t = 0$, respectively. Therefore, a quadratic fit of the form

$$y = A x^2 + B x + C$$

is the position versus time graph which will give $A = \frac{1}{2} a$, $B = v_0$, and $C = y_0$. When the acceleration a is zero, the position versus time graph will be a straight line and its slope gives the constant velocity.

Exercise 1 – Newton's first law (Demo: to be done by the instructor)

Figure 1 shows the apparatus you will use for this exercise. An air blower is used to reduce the friction between the glider and the track. The motion sensor is connected to a computer via a computer interface module as shown in Figure 2.

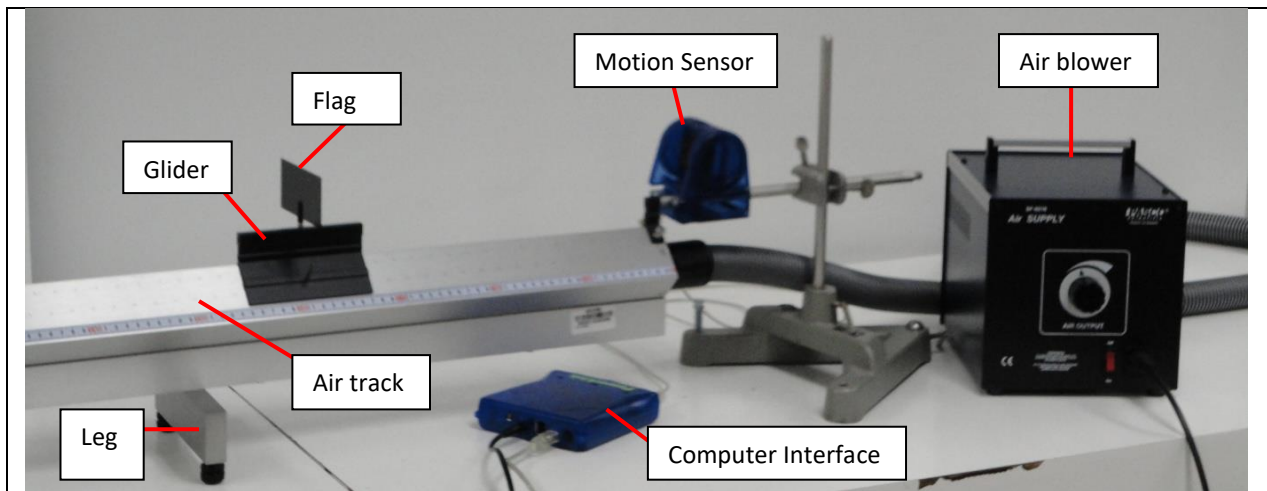


Figure 1

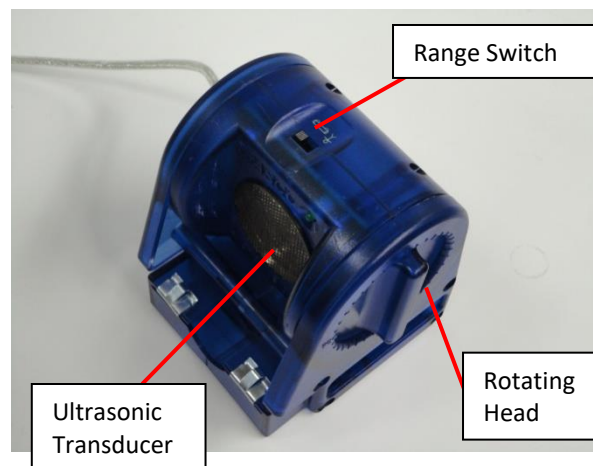



Figure 2

1. Adjust the *Flag* of the *Glider* so it is perpendicular to the linear air track. Make sure the *Motion Sensor* is aligned well so that the *Ultrasonic Transducer* face is in the center of the air track and parallel to the flag of the glider, you can use the *Rotating Head* to adjust the angle of the transducer.
2. Make sure the motion sensor is connected to a computer through the USB interface, and its range switch is set to work with the  (short range) option.
3. Download the file **NewtonEx1.ds** from the link in PHYS101 homepage and save it in the desktop. This file has been preconfigured for optimum experimental parameters such as position and time scales.
4. From the **Start** button, go to **All Program** → **DataStudio** → **English**. This will open **DataStudio**; click on **Open Activity** (see Figure 3). Navigate to the folder desktop and to the file **NewtonEx1.ds**, and open it. This will open the position-time graph as shown in Figure 4.

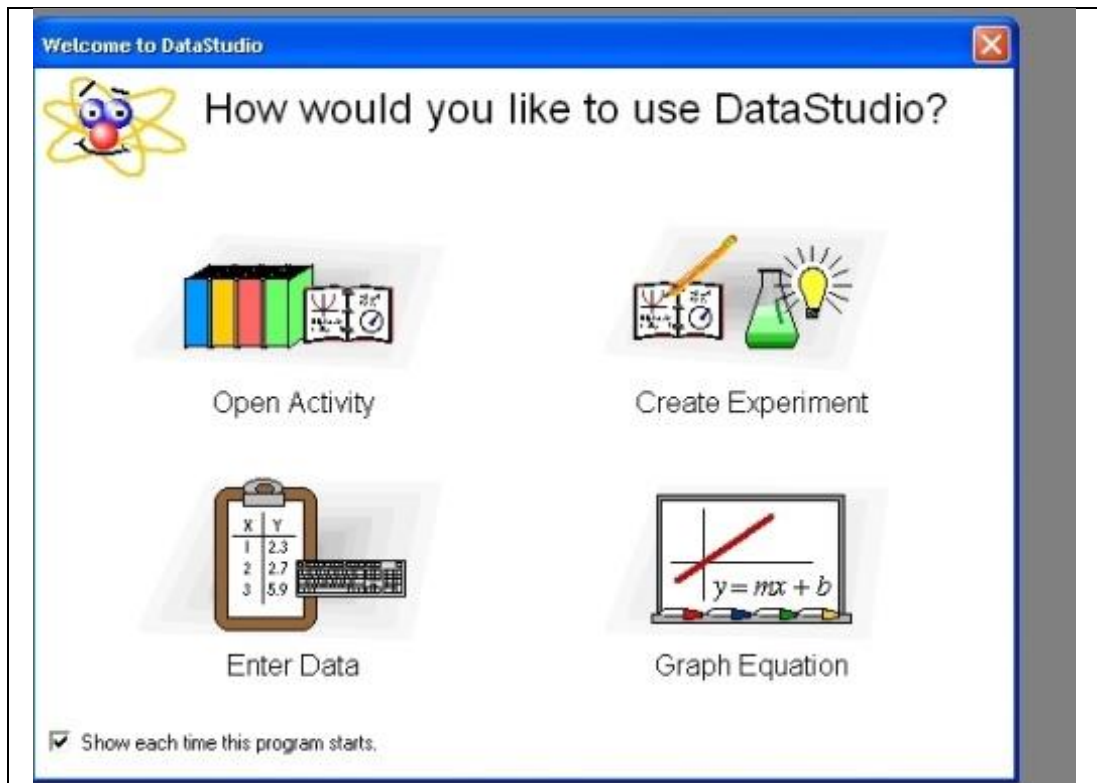


Figure 3

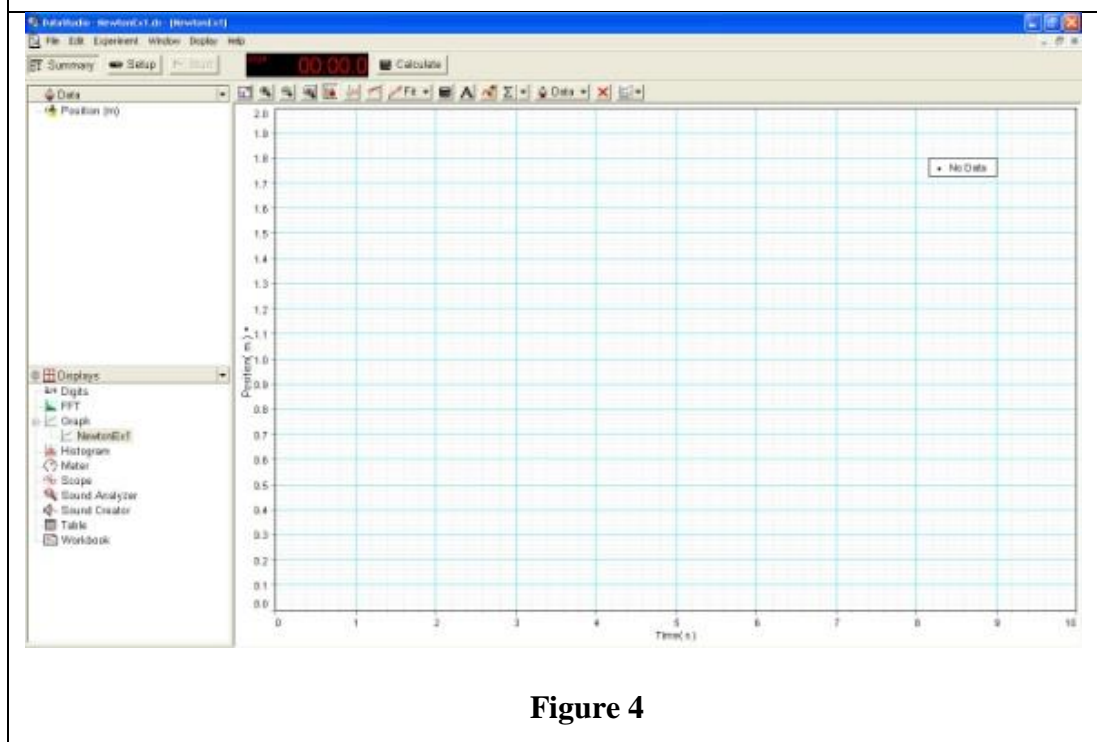


Figure 4

5. Switch on the air blower.
6. Make sure the air track is horizontal. That is, the glider should not move one way or the other while the air blower is on. If not, adjust the leg on the blower side of the air track.

7. Bring the glider closer to the motion sensor. Push the glider away from the sensor while clicking the **start** button at the top left corner in the **DataStudio** program. Click the **stop** button when the glider reaches the end of the air track. Your graph will look like Figure 5.

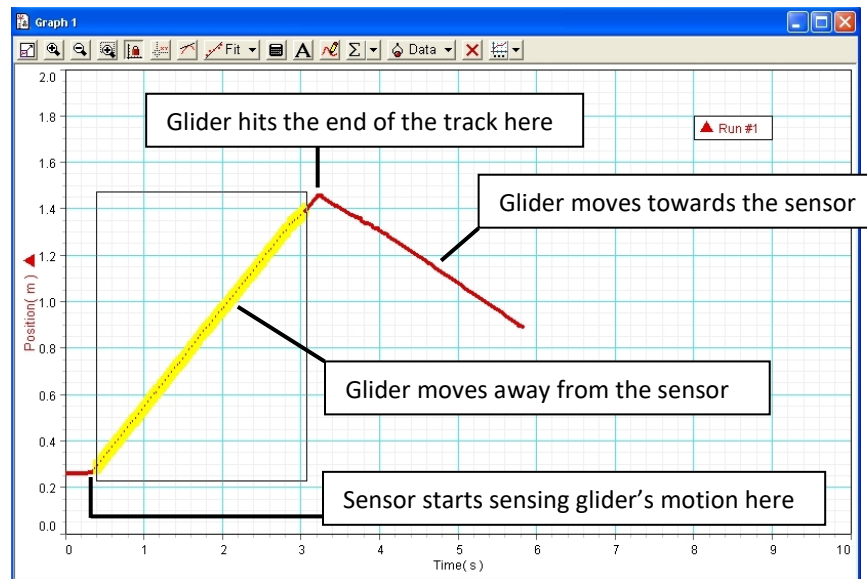


Figure 5

8. If for some reason you want to repeat the experiment, you can delete the data by going to the **Experiment** menu in **DataStudio** and click on **Delete all Data Runs**. Then do step 7 again.
9. Choose the straight line portion of the data corresponding to the glider's motion away from the sensor by pressing the left button of the mouse and drawing a rectangle as shown. Right click in the graph area and choose **Fit** and then select **Linear Fit**. The position versus time graph is a straight line means that the velocity of the object is constant and thus its acceleration is zero. Thus verifying Newton's 1st Law: an object having a given velocity continues to move with the same velocity as long as the net force acting on it is zero.
10. The slope of the linear fit is the velocity of the glider.

Exercise 2 – Newton's second law

In this exercise, you will verify that the acceleration of a body is proportional to the net force on the body when its mass is constant.

Figure 6 shows the photograph of the apparatus you will use for this exercise. The body, glider with attached force sensor and the flag, is pulled by the tension force \vec{T} produced by the hanging mass.

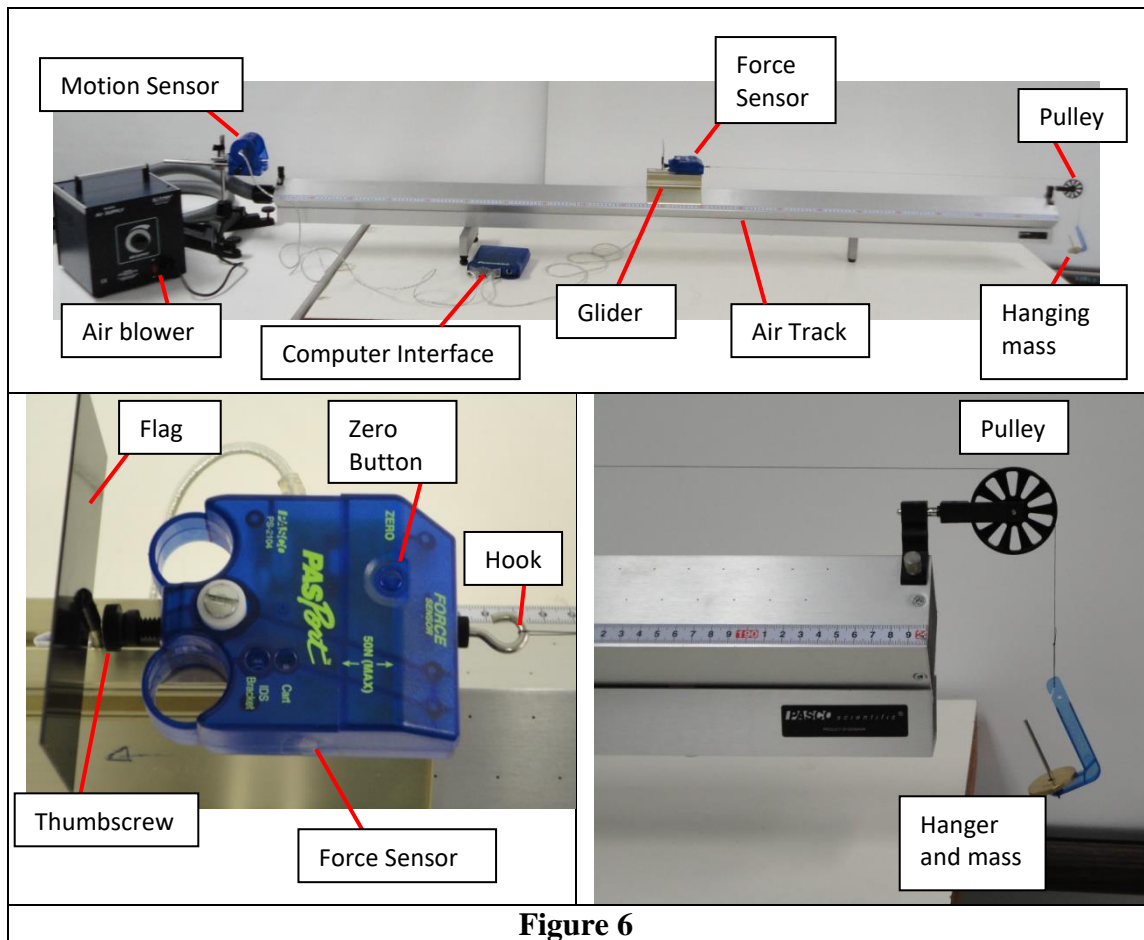


Figure 6

Figure 7 shows all the forces acting on the body.

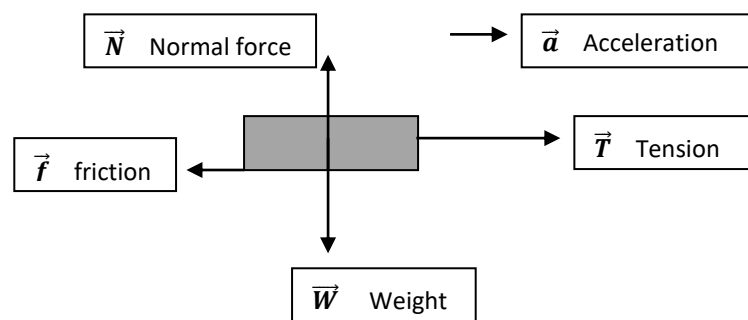


Figure 7

Therefore,

$$\vec{F}_{\text{net}} = \vec{T} + \vec{f} + \vec{N} + \vec{W}$$

Note that the friction between the body and the air track is small compared to the tension and is in opposite direction to the tension. Since the body does not move along the vertical direction, the weight of the body and the normal force on the body balance each other and provide zero net force along the vertical direction. That is,

$$\vec{N} + \vec{W} = \mathbf{0}$$

Therefore, the net force on the body is along the horizontal direction and its magnitude is

$$F_{\text{net}} = T - f$$

Therefore, according to Newton's 2nd law,

$$T - f = M a$$

where M is the mass of the body and a is its acceleration.

Therefore, the net force on the body can be varied by changing the hanging mass. The tension force is measured by the force sensor and the acceleration is determined from the position versus time graph obtained by the motion sensor.

Procedure:

1. Download the file **NewtonEx2.ds** from the link in PHYS101 homepage and save it in the desktop. This file has been preconfigured for optimum experimental parameters such as position, force and time scales. Open **DataStudio** and open this file from within DataStudio.
2. Mount the force sensor on the glider using the thumbscrew of the force sensor. Plug its cable to the USB interface module. You will be prompted to include force sensor in the graph. Click **Yes** button. **Let the cable of the force sensor rest on the table. This step is important, in each experimental run, to minimize the unwanted force exerted by the cable on the glider.**
3. Attach a string to the hook of the force sensor and hang a 40 g mass (total mass of hanger (=5g) and another 35 g masses) from the other end of the string. Make sure the string passes around the pulley and the string attached to the force sensor is parallel to the air track so that the tension force applied is horizontal. **Also make certain that the hook is firmly attached to the force sensor.**
4. Support the hanging mass with your hand so that the string is not pulling on the Force Sensor. Press the zero button on the force sensor to zero the force sensor. **This step is very important prior to each experimental run.**
5. Switch on the air blower.
6. Bring the glider closer to the motion sensor and hold it with your hand.
7. Click the **Start** button in the **DataStudio** program and release the glider. Click the **Stop** button when the glider reaches the end of the air track.
8. Your graphs will look like Figure 8. Choose the data of interest in the position versus time graph by drawing a rectangle with left mouse button. Right click in the graph area and choose **Fit** and then select **quadratic Fit**. Find the acceleration of the body from the fit parameter A . Recall $A = a/2$. **Make sure that the fitted curve exactly coincides with the data that corresponds to the glider's motion away from the motion sensor.** Choose the corresponding data in the force versus time graph again by drawing a rectangle with left mouse button, right click in the graph

area and click **Statistics**. This will show the minimum, maximum, and mean values of Force.

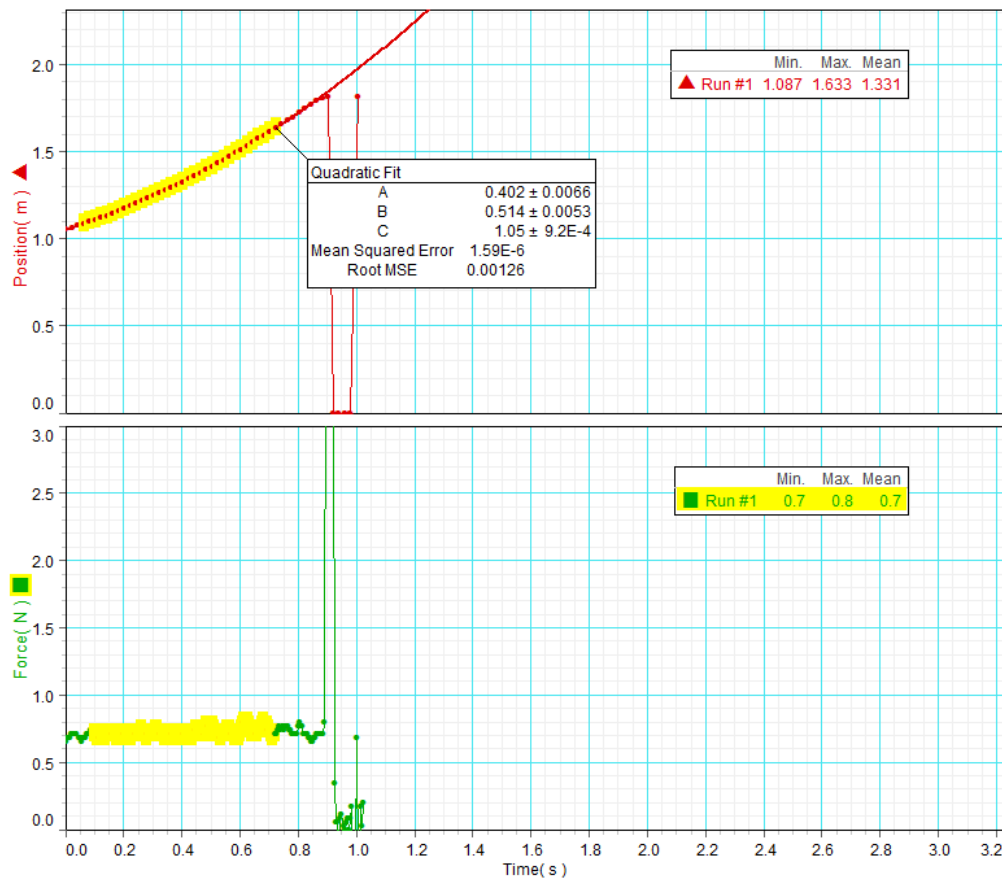


Figure 8

Data:

1. Record the values of hanging mass m , magnitude of mean force T , fit parameter A , and the calculated value of acceleration a in a Table in your report.

Hanging mass (g).	Tension, T (N)	Fit parameter A (m/s^2)	Acceleration $a = 2A$ (m/s^2)

2. Repeat the experiment with the other values of hanging mass:

(Your instructor will assign each group one of the following sets of masses)

a. 60, 80, 100, 120 and 140 g

b. 70, 90, 110, 130 and 150 g

c. 65, 85, 105, 125 and 145 g

- Complete Table 1.

- For each new experimental run, go to *Experiment* menu in **DataStudio** and click on *Delete all Data Runs*.

Data Analysis:

1. Use the data recorded in your table to plot the tension **T** (y-axis) versus acceleration **a** (x-axis).

2. Find the slope and y-intercept by fitting the graph to a straight line. Paste your trendline equation in your report.

3. What does the slope represent?

4. What does the y-intercept represent?

Recall $T - f = M a$, where M is the mass of the (glider + force sensor + flag), not the hanging mass.

5. Estimate the coefficient of kinetic friction between the glider and the air track.

6. Using a triple-beam balance, measure the mass M of the glider with the force sensor and the flag attached. Record the value in your report.

7. Record the percent difference between the slope and the mass of the object M in your report.

8. List some sources of error in this experiment.

9. Can we say that the tension in the string is equal to the weight of the hanging mass? Why?

10. Write a conclusion.

Exercise 3 – Newton's third law (Demo: to be done by the student)

In this exercise, you will confirm that when two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

1. Unplug the motion sensor from the USB interface module and connect another force sensor (FS#2) to it. Now you have two force sensors connected to the interface.

2. Take the force sensor #1 (FS#1) out from the glider by loosening the thumbscrew and place FS#1 on the table next to FS#2.

3. Download the file **NewtonEx3.ds** from the link in PHYS101 homepage and save it in the desktop. This file has been preconfigured for optimum experimental parameters such as force and time scales. Open **DataStudio** and open this file from within DataStudio. This will open the **Force Graph** window and another window **Force Digits** which may be hidden behind the **Force Graph** window. If the **Force Digits** window is hidden, move the **Force graph** window to a side so you can see both the windows.
4. Press the zero button on both the sensors.
5. **Start** the experiment and you will see the data is collected for both sensors. Pull/push the hook of FS#1 to see which line represent it. Do the same with FS#2 to confirm the line due to that sensor. **Stop** the experiment.
6. From the **Experiment** menu choose **Delete all Data Runs**.
7. Take the spring provided to you and connect its one end to the hook of FS#1 and the other end to the hook of FS#2 as shown in Figure 9.



Figure 9

8. Take one force sensor in your hand and ask your partner to hold the other sensor. Start the experiment and pull the spring back and forth and watch the **Force Graph** and **Force Digits** window.
9. Stop the experiment.