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Anything included in this report in RED (with the exception of the equations which are in black) was added by me (Bill) and represents the data obtained when the experiment was run. *Use your own data you collected and perform the calculations for your own data!*

Newton's Laws I

Name:

PES 115 Report

Lab Station: 002

Objective

The purpose of this lab was to recognize, apply, and measure forces applicable to Newton's Second and Third Laws. For Newton's Second Law, the primary objective was to determine how forces, masses, and accelerations are interrelated. For Newton's Third Law, the primary objective was to determine how the direction of accelerating pairs are related to each other.

Data and Calculations

Part I: Newton's 2nd Law

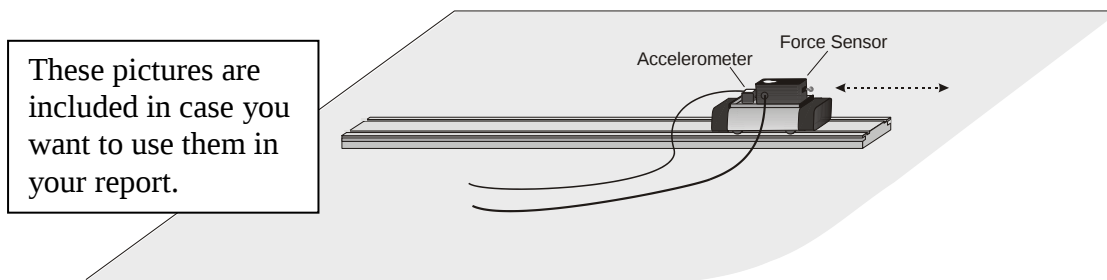


Figure 1: Experimental Set up for testing Newton's 2nd Law.

Mass of cart and sensors (kg)	1.6439 kg
Regression line for force vs. acceleration data	
(force) = (1.659 N/(m/s ²)) (acceleration) - 0.0368 N	
RMSE = 0.0251	

- Note the shape of the force vs. time and acceleration vs. time graphs.

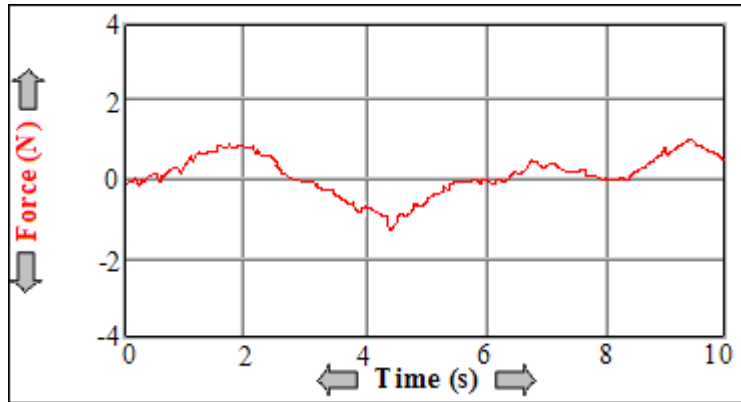


Figure 2: Force versus Time Graph showing Experimentally Collected Data

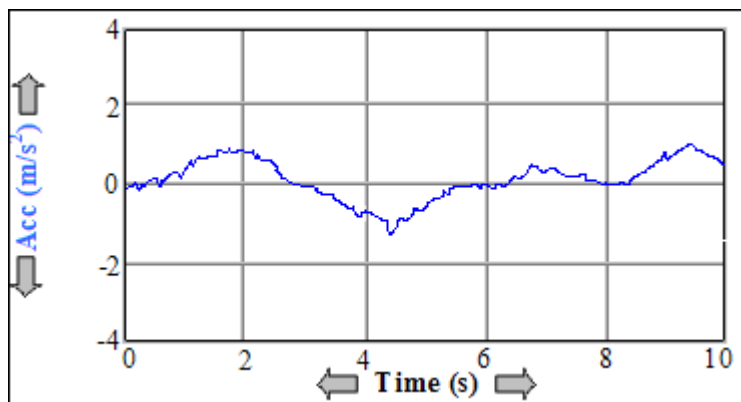


Figure 3: Acceleration versus Time Graph showing Experimentally Collected Data

By examining the two graphs above collected via Logger Pro, it is interesting to note that the patterns are identical for the Force and Acceleration. The maximum magnitudes are not the exact same values, numerically; however, consistently the hills and valleys (maxima and minima) match up 1 for 1. Using the examine tool, we found the maximum height of the first hill for force was 1 Newton and the analogous point for acceleration was 0.7 m/s^2 . This would make sense for a constant mass of 1.5 kg, using Newton's Second Law:

$$F = ma$$

It is interesting to see the roughness associated with the graph. As experience tells us (from lab 2), we know that this is due to “jerk” (since we were manually pushing and pulling on the force sensor hook). If we had a computer driven actuator the lines would have likely been smoother. Likewise, the friction in the wheels and between the wheels and the track probably added to the amount of jerk influenced during the experiment.

- When the force is a maximum, is the acceleration maximum or minimum?

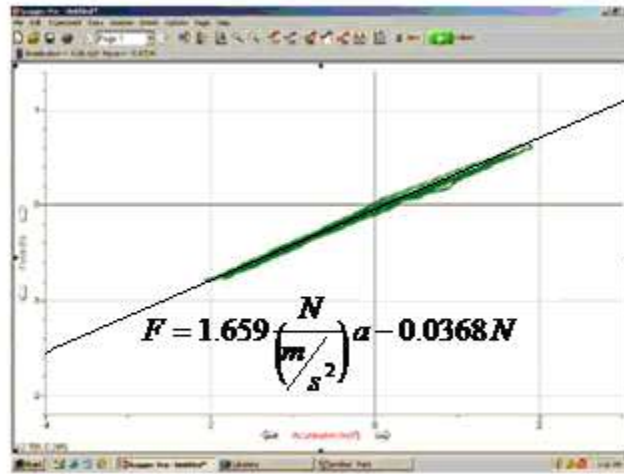


Figure 4: Force versus Acceleration Graph showing Experimentally Collected Data

By examining the graph above (and further reinforced by figures 2 and 3) we can see that there is a definitive positive slope to the data. This means that when force is a maximum, the acceleration is also a maximum. When force is a minimum, the acceleration is also a minimum. Since that mass of the cart is not changing, this means that force and acceleration are directly proportional.

- The graph of force vs. acceleration should appear to be a straight line. Record the equation for the regression line in the data table.

The graph of Force versus Acceleration (see figure 3) is not a perfect straight line (although it should be according to Newton's Second Law). The best fit line was obtained using the logger pro software and was calculated to be:

$$F = 1.659 \left(\frac{N}{m/s^2} \right) a - 0.0368 N$$

It also had a root mean square error of $RMSE = 0.0251$, meaning that 97.5% of the data points fell within one standard deviation of the best fit line.

$$\% \text{ of Points} = (1 - RMSE) \times 100\%$$

$$\% \text{ of Points} = (1 - 0.0251) \times 100\% = 97.5\%$$

The most likely cause of deviation from the straight line was due to cart/track friction (static and kinetic). Friction causes a decrease in the force for an accelerating object.

- Add copies of the graphs.

See figures 2, 3, and 4 above for copies of the graphs collected during the experiment.

Part II: Newton's 3rd Law

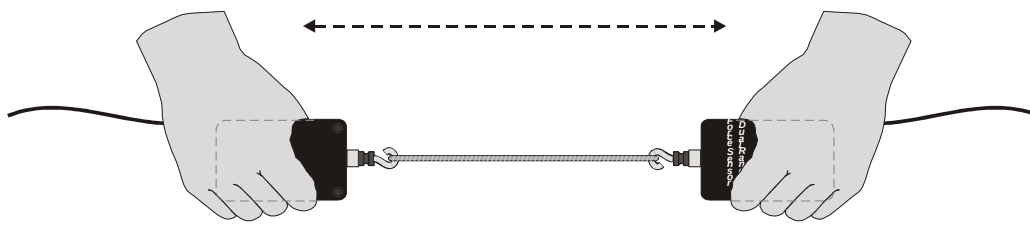


Figure 5: Measuring a force pair with force probes.

- Gently tug on your partner's Force Sensor with your Force Sensor. Print out a plot of your results.

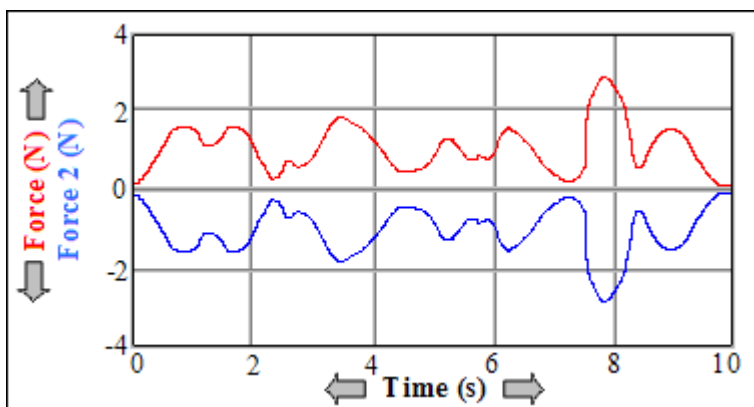


Figure 6: Force versus Time Graph showing Collected Data for Newton's 3rd Law

- Is there any way to pull on your partner's Force Sensor without your partner's Force Sensor pulling back? Try it. Discuss your observations.

There is no way to pull on a second Force Sensor without it producing the results shown in figure 6. We tried setting it on the table and pulling the force sensor. Both sensors always read opposite and equal values whenever friction would catch the sensor not being held. We then tried hanging the second sensor from the first so it was under the influence of gravity. The same result occurred: Equal and opposite force measurements on the sensors.

- Mount one of the force probes to the ring stand by using the hole in the sensor to attach it directly to the ring stand. Print out a plot of your results.

- Repeat using the rubber band instead of the string. Print out a plot of the results.

Additional Questions

Part I: Newton's 2nd Law

- 1.) Compare the graphs of force vs. time and acceleration vs. time for a particular trial. Are the net force on an object and the acceleration of the object directly proportional? Explain.
- 2.) What are the units of the slope of the force vs. acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).

$$\left(\frac{N}{m/s^2} \right)$$

- 3.) For each trial compare the slope of the regression line to the mass being accelerated with a percent error calculation:

$$\%error = \frac{|theoretical\ value - measured\ value|}{theoretical\ value} \times 100\%$$

What does the slope represent? (Your values for the slope may be consistently lower or higher than what you might expect. This is called *systematic error*. Can you figure out what would cause your values to be always lower or higher than expected?)

4.) Write a general equation that relates all three variables: force, mass, and acceleration.

In general, the three variables of force, mass, and acceleration can be simply related by the following equation:

$$F = ma$$

Using the data we collected, it appears that there is some other influence on the determination of the force. Using this logic, the equation above (representative of collected data) should have the following form:

$$F = ma - f_{\mu s}(v)$$

Part II: Newton's 3rd Law

- 1.) Examine your graphs. What can you conclude about the two forces (your pull on your partner and your partner's pull on you)? How are the magnitudes related? How are the signs related?
- 2.) How does the rubber band change the results?
- 3.) The procedure was written so that both force sensors have the same positive directions. What step in the procedure ensured this? Explain.
- 4.) Restate Newton's third law in your own words, not using the words "action," "reaction," or "equal and opposite."

Newton's Third Law basically says: The force exerted by one source object on another target object always creates another force at the target object that pushes back on the source object with the same magnitude. That is to say, things that are not moving try to push back hard enough to not start moving.

5.) Considering the results of Step 10, does the ring stand pull back as you pull on it? Does it matter that the second Force Sensor is not held by a person?

Yes, the ring stand pulls back just as much as we pulled on it. It does not matter that the second force sensor was not being held by a person. Essentially, in this experiment the Earth was holding the other force sensor and Newton's Third Law was still applicable.

Conclusion

You are intelligent scientists. Follow the guidelines provided and write an appropriate conclusion section based on your results and deductive reasoning. See if you can think of any possible causes of error.

**** NOTE:** There are several components of error which could significantly modify the results of this experiment. Some of these are listed below:

- Actual vs Assumed acceleration due to gravity (Altitude, Earth's Oblateness, see prelabs 2 and 3 for examples) [9.76 m/s^2 vs. 9.81 m/s^2]
- Technique
- Friction
- Drag and air resistance
- Snagging and catching
- Calibration
- Sensor limitation parameters
- Computer processor speed and reading registration
- Torque
- Sensor Alignment
- Other ...

A few of the potential errors listed above may be applicable to YOUR experiment.