# Newton's Laws I

**PES 116 Advanced Physics Lab I**

## Purpose of the experiment

- To answer the question "Why do objects move?".
- Explore Newton's $2^{nd}$ Law and see how force, mass, and acceleration relate to each other.
- Explore Newton's $3^{rd}$ Law and see how the direction of the action-reaction pairs relate over time.
- [FYI]

[FYI] The very first bomb dropped by the Allies on Berlin during WWII killed the only elephant in the Berlin Zoo.

# Table of Contents



## Equipment List

**Part I**

- LabPro Interface
- Force Sensor with hook
- Low-g Accelerometer
- Pasco low-friction dynamics cart
- 295 g calibration mass
- Pasco dynamics track
- Level
- Force Sensor cart adapter

**Part II**

- 2 Force Probes with hooks
- Ring stand
- C-clamp

# Background

## Force, Mass, Acceleration and Newton's 1$^{st}$ law

Previously, you have studied *kinematics*, which is the branch of physics that describes *how* objects move. By understanding the quantities of position, velocity and acceleration, you are able to describe an object's motion. Kinematics does not say *why* objects move, just how they move. In this lab, we will look at the branch of physics called *dynamics*. Dynamics relates the cause of motion (forces) to a description of how objects move (acceleration). For dynamics, we will need to discuss three quantities, mass, acceleration and force, in order to answer the question "Why do objects move?".

You should already be familiar with acceleration. If you are not, then a good definition for acceleration is:

> <u>Acceleration:</u> the rate of change with respect to time of an object's velocity. An acceleration would include speeding up, slowing down, or changing direction.

Basically, anything that causes an object to differ from straight line, steady speed motion is an acceleration. Dynamics addresses two other quantities that are related to acceleration. The first is mass:

> <u>Mass:</u> the quantity of matter an object possesses. Mass has the property of inertia, which is the behavior of an object to move in a straight line at a steady speed when left alone. Mass is a resistance to acceleration.

The second is force:

> <u>Force:</u> A push or a pull. An influence that causes objects to accelerate.

Sir Isaac Newton formalized all this into what has been named Newton's 1$^{st}$ Law: *An object at rest will remain at rest and an object in motion will continue in motion with a constant velocity (that is, constant speed in a straight line) unless it experiences a net external force.* With these concepts under our belt, we can discuss the principles of dynamics, called Newton's Laws of Motion.

## Newton's $2^{nd}$ Law

How does a cart change its motion when you push and/or pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart's velocity related to the force you apply? Or does the force just *change* the velocity? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A Force Sensor and an Accelerometer will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart (F), its mass (m), and its acceleration (a) are related. This relationship is Newton's second law of motion: $F = m\ a$.

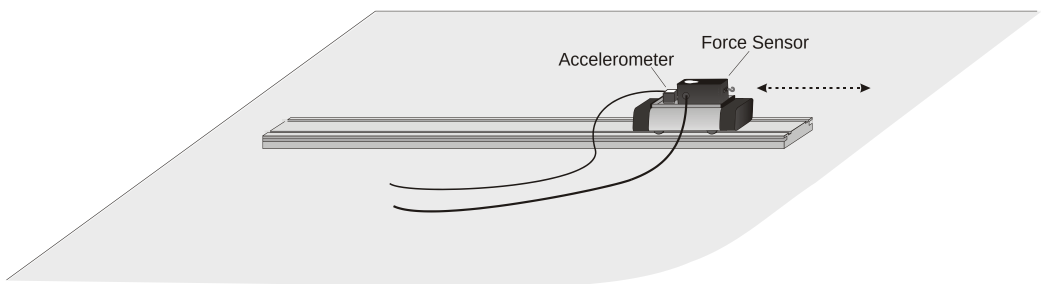



Figure 1: Set up for testing Newton's $2^{nd}$ Law.

## Newton's $3^{rd}$ Law

You may have learned this statement of Newton's third law: "To every action there is an equal and opposite reaction." What does this sentence mean?
Unlike Newton's first two laws of motion, which concern only forces on individual objects, the third law describes an interaction between two bodies. For example, what if you pull on your partner's hand with your hand? To study this interaction, you can use two Force Sensors. As one object (your hand) pushes or pulls on another object (your

partner's hand) the Force Sensors will record those pushes and pulls. They will be related in a very simple way as predicted by Newton's third law.

The *action* referred to in the phrase above is the force applied by your hand, and the *reaction* is the force that is applied by your partner's hand. Together, they are known as a *force pair*. This short experiment will show how the forces are related.

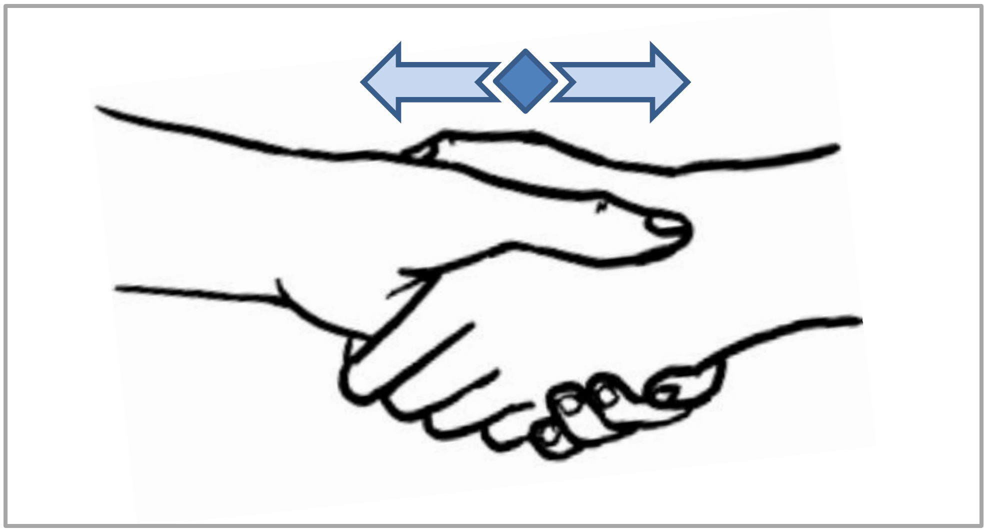


Figure 2: A force pair between lab partners.

Nearly every force encountered in everyday life obeys Newton's 3rd Law. Therefore, nearly all forces are members of a force pair. Given a force, it is very easy to figure out what force is the reaction. To do this, simply switch the ordering of the objects. For example, consider a book sitting on a table. The table exerts an upward force on the book, and we call that "the force of the table on the book". So what is the reaction force? It is simple, just switch the ordering of the objects. The reaction force is "the force of the book on the table". Be careful, because you might be tempted to say the reaction force is the weight of the book. This is incorrect. Why? Because the other object in the weight force pair is the Earth itself! So this force pair is "the weight of the book due to the Earth" and "the weight of the Earth due to the book". Again, simply switch the ordering of the objects. (Yes, the book does pull up on the Earth. So why doesn't the Earth move?)

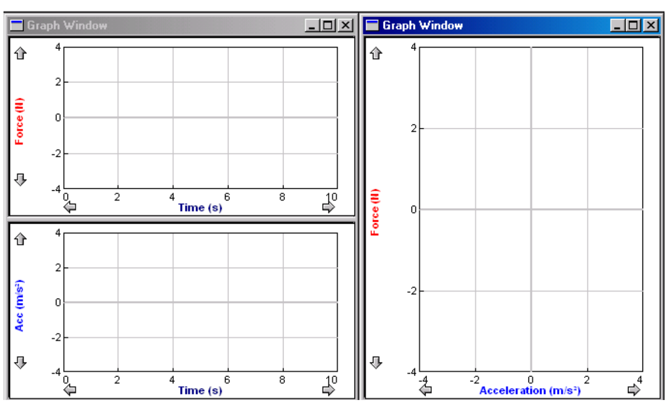
# The Lab

**The goal:** To answer the question "Why do objects move?". Explore Newton's 2nd Law and see how force, mass, and acceleration relate to each other. Explore Newton's 3rd law and see how the direction of the action-reaction pairs relate over time.

# Procedure

## Part I: Newton's 2nd Law

1. Open the file *PES 116//Newtons Laws I/Newtons 2nd Law.cmbl*. Three graphs will appear on the screen, as shown in the figure below:



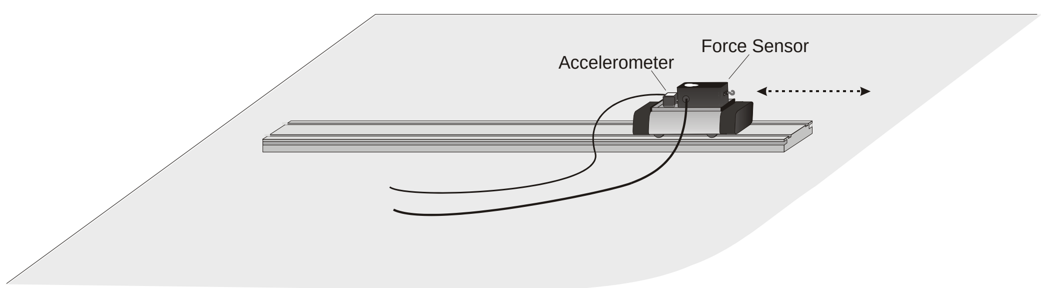

<u>Figure 3:</u> *Logger Pro* graphs for testing Newton's 2nd Law.

2. Check that a Dual-Range Force Sensor is connected to CH 1 and that the Low-g Accelerometer is connected to CH 2 of the LabPro Interface. Set the Force Sensor to the 10 N range by flipping the switch on the sensor.

3. To get the best numerical results in the experiment, you will need to calibrate the force and accelerometer sensors. See the module on *Computer Software* located on the Physics lab webpage.

4. If it is not already attached, attach the Force Sensor to a dynamics cart so you can apply a horizontal force to the hook, directed along the sensitive axis of your Force Sensor. The force sensor will only record the component of the force directed along the sensor, any side-to-side motion will be ignored. Next, attach the Accelerometer so the arrow is horizontal and parallel to the direction that the cart will roll. Orient the arrow so that if you *pull* on the Force Sensor the cart will move in the direction of the arrow.

5. Find the mass of the cart with the Force Sensor, Accelerometer, and <u>two</u> 0.500 kg bar masses on top. The whole system might exceed the limit on the scale available, in which case you will need to measure it in parts. Record the total mass in the data table (see Step 7 below for data table).




<u>Figure 4:</u> Set up for testing Newton's $2^{nd}$ Law.

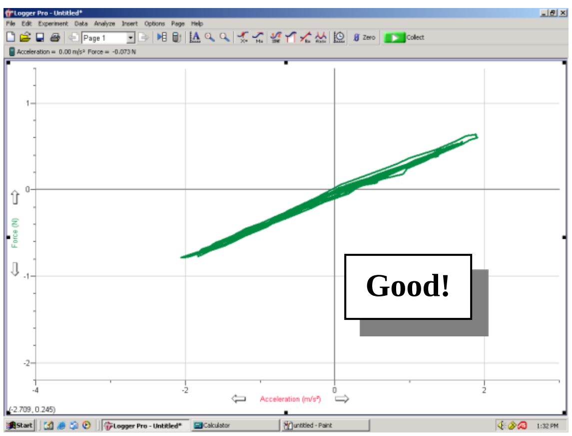
6. Place the cart on the track. Adjust the leveling screw on the end of the track so that the cart doesn't roll by itself and the bubble level reads horizontal. Make sure the cart is not moving and click [Zero], then click [Zero all sensors].

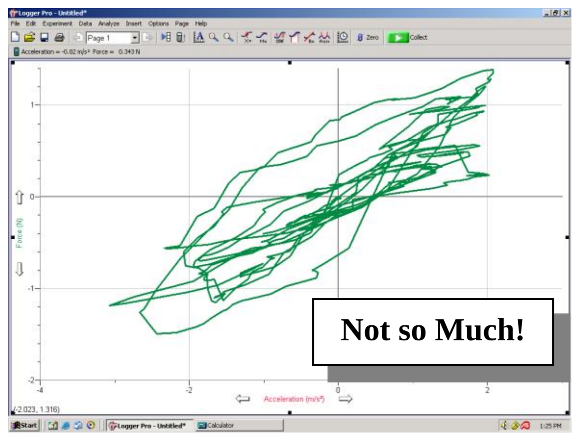
7. Before starting this trial, copy the following data table into your laboratory notebook:

| | |
|---|---|
| Mass of cart and sensors (kg) | |

| Regression line for force *vs*. acceleration data |
|---|
| |

8. You are now ready to collect force and acceleration data. With the two 500 g bar masses on top, grasp the Force Sensor hook. Click Collect and take several seconds to move the cart back and forth smoothly on the track. Vary the motion so that both small and large forces are applied. Make sure that your hand is only touching the hook on the Force Sensor and not the Force Sensor or cart body. Additionally, make sure the sensors' wires do not introduce any additional force. It will take some practice to get a smooth line on the Force *vs*. Acceleration graph as shown below.




9. Note the shape of the force *vs.* time and acceleration *vs.* time graphs. Click the Examine button, , and move the mouse across the force *vs.* time graph. When the force is maximum, is the acceleration maximum or minimum? To turn off Examine mode, click on the Examine button again, .

10. The graph of force *vs.* acceleration should appear to be a straight line. (You may notice that the points don't quite lie on a line. This is due to what is called *hysteresis*. That is, the current value depends somewhat on the previous values.) To fit a straight line to the data, click the graph, then click the Regression Line button, . Record the equation for the regression line in the data table.

11. Print copies of the graphs. Use the "Print" option in the File menu. You might want to add a "Footer" so that you can identify your printout at the printer.

## Part II: Newton's 3rd Law

1. Take a force probe in your hand and apply forces to your lab partners force probe.
2. Assign a positive direction, make sure to note all recorded forces as positive or negative. Fill out the chart below:

| Your Force Probe Setting "*Action Force*" | Lab Partner's Probe Reading: "*Reaction Force*" | |
|---|---|---|
| | Pulling Pair | Pushing Pair |
| 2 N | | |
| 6 N | | |
| 10 N | | |
| 14 N | | |
| 18 N | | |

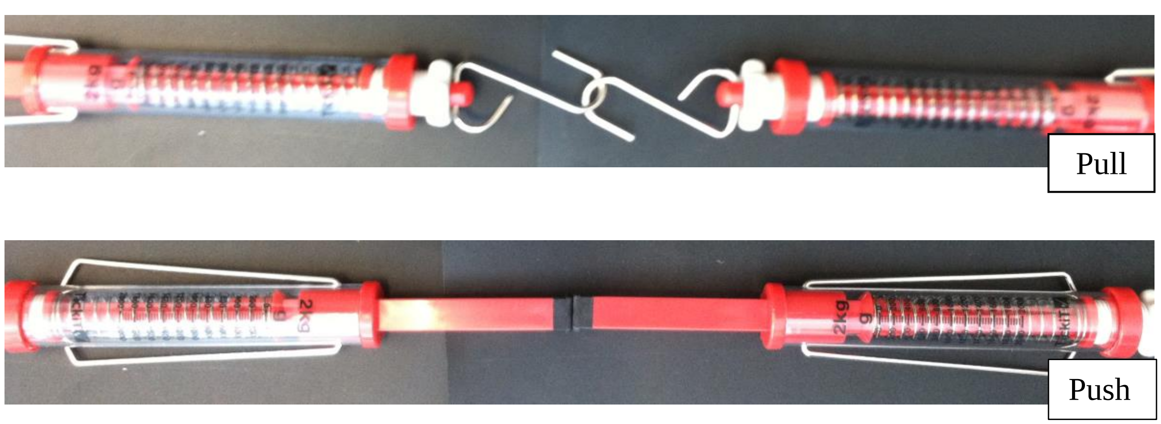



Figure 2: Measuring a force pair with force probes.

3. Is there any way to pull on one probe without the other "pulling back"? Try it. Discuss your observations.

4. Try a different combination; attach a force probe to a clamped a ring stand. Use the other force probe as a pulling force pair. Try various applied forces, not to exceed 18N. Monitor the *reaction* force.

| Your Force Probe Setting "*Action Force*" | Clamped Probe Reading: "*Reaction Force*" Pulling Pair |
|---|---|
| 2 N | |
| 6 N | |
| 10 N | |
| 14 N | |
| 18 N | |

## 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).

3. Compare the slope of the regression line to the measured mass being accelerated with a percent error calculation:

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

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

Part II: Newton's 3rd Law

Lab Partner Pair

- Examine your tables.
    a. What can you conclude about the two forces?

    b. How are the magnitudes related?

    c. How are the signs related?

Clamped Pair

a. Explain your results of the "clamped pair".

b. What object is applying the reaction force?

- Restate Newton's third law in your own words, not using the words "action," "reaction," or "equal and opposite."

- If two forces are equal and opposite, what should the sum of the force pairs be?