PHYS 1P91 Experiment 04

Newton's Laws 1 : Balanced forces

Notes

- Words in blue are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Lab objectives

- Use the iOLab to study Newton's laws and the concept of force.
- Test the correctness of simple free body diagrams of simple systems.
- Use the iOLab to measure tension.

2 Introduction

Before we begin looking in depth at Newton's Laws of *motion*, we should spend some time looking at balanced forces. When all the forces on an object are in balance, no change in the motion of the object occurs. For example, the iOLab sitting at rest on your table experiences the force of gravity pulling it down on the table, and an equal and opposite directed force ("normal force") from the table pushing it up. The two forces cancel each other, and the iOLab remains motionless.

Unbalanced forces leads to a change in the motion, or can allow motion to occur. Any change in motion is known as an acceleration. The amount of acceleration experienced is proportional to the amount of force causing the change in an object's velocity, and inversely proportional to the mass of the object. In this lab, we will start to explore Newton's second law (of motion) $F = ma$.

The iOLab has both a force sensor, and a separate accelerometer sensor. The force sensor is a metal bar with a magnet on the end that can bend when pushed or pulled. The change in the magnetic field is electronically recorded, and we can calibrate it to known forces.

Most cell phones, video game controllers, and fitness watches have microelectromechanical system (MEMS) based accelerometers. These are tiny masses held by thin clip-style springs inside an electronic circuit component, such as in Figure 1. The "proof mass" stays still because of its inertia (Netwon's first law) while the cell phone moves, and the attached fingers change the measured electrical capacitance of the microelectronics. Once calibrated, the motion of the proof mass due to forces causing acceleration can be registered as a electronic signal.

Technically both sensors in the iOLab device move under forces, whether fictional or real, and therefore both measure force, but on different scales. The more robust metal of the force sensor can measure larger forces (up to a few N) than the delicate and microscopic MEMS accelerometer. On the other hand, the electronics of the accelerometer are more sensitive and responsive to smaller forces. Also, there are three MEMS accelerometers in the iOLab, one for each direction x, y, and z, and all are in the same electronic package.

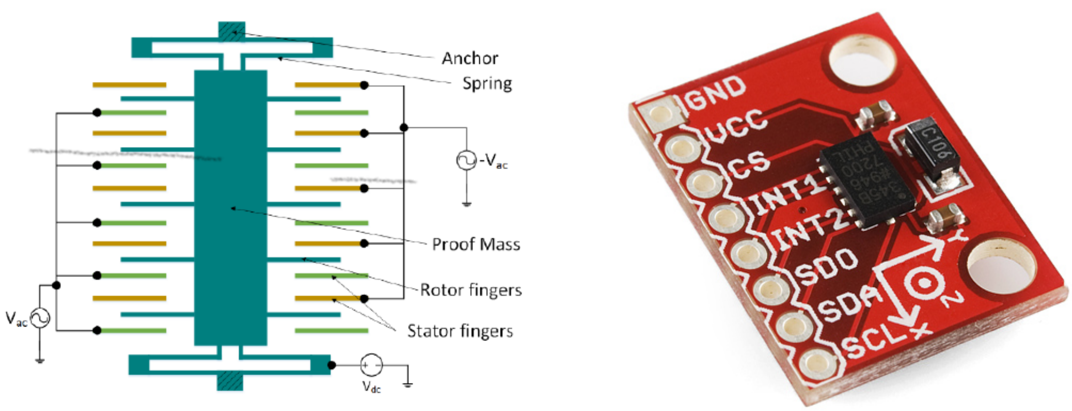

Figure 1: Schematic and picture of MEMS accelerometer. The miniature "proof mass" (green) moves up or down under centrifugal or gravitational forces relative to the fingers, changing the electrical capacitance of the device, which can be measured. There is one of these measuring acceleration along each axis of the iOLab. Image reproduced from CC-BY-SA-4.0.

3 Procedure

This lab includes multiple experimental setups. Double check that you have all the measurements you need before moving on to each new section. This is because you may not be able to return to the exact same set-up you had before. If you later discover you missed a measurement, you will have to start that trial over from scratch.

3.1 Time out for iOLab Online

This lab will require the use of the eye-bolt. Along with the skills you have learned in previous labs you will need to learn how to use iOLab Online's Advanced Features

3.2 Gathering your materials

For this lab you will need your iOLab device with the eye-bolt as well as the string, measuring tape and calibration mass from your accessory kit. This lab will require you to make a ramp. You will need to find a long (30 cm or greater) flat surface as well as a few objects which can be used to prop up the surface to create ramps of various heights (books, *etc.*).

4 Take data

4.1 Calibrating sensors

Like your smartphone, the iOLab acceleromter can measure acceleration in the up *and* down directions, and it is sensitive enough to notice that they are not the same. That difference is due to the force of gravity. This sensitivity is there even if sitting still, as gravity pulls down on the proof mass.

When doing physics problems, we often use the value for the acceleration due to gravity as g =9.8 m/s^2. To make sure the iOLab is recording accurate values, we must first calibrate the accelerometer sensor.

> Connect the iOLab device and open up the Settings menu. Enable a_y =-g, leaving a_x and a_z as zero. Select the 6-point calibration button and follow all of the steps until you have a green checkmark at the end (this sequence actually calibrates three of the sensors in the device).
>
> To verify that the calibration worked, take two sets of accelerometer data (2-3 seconds) with the device sitting in $+y$ and $-y$ directions. If the new data in either direction

averages to ±g, the calibration was successful. If not, repeat the calibration process. Make sure the table is level and that you do not bump it during calibration.

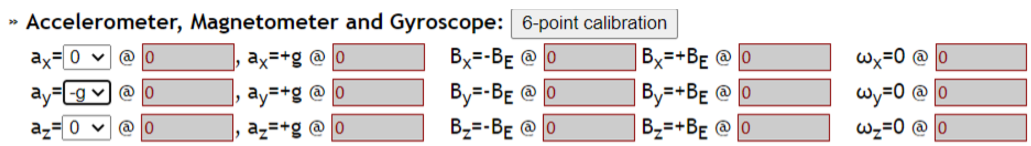

Figure 2: The sensor calibration menu, found under Settings. Since we are looking at motion in the ±y direction for this experiment, enable a_y =-g before you begin calibrating.

4.2 Does acceleration follow the net force?

According to $F = ma$, as the force acting on an object changes, the acceleration should respond in a proportional manner. Since we have two independent sensors, one for force and one for acceleration, we should test that.

Attach the eye-bolt and firmly hold the iOLab device by the eye-bolt, with the $+y$-axis direction facing down. Select both the `ForceGauge` and `Accelerometer` sensors, and while recording a 10-second data run, gently move the iOLab up and down a few centimeters at a time for the duration.

> Important: When using two sensors at the same time, you will only be able to see one sensor's data at a time. Change which sensor you are graphing from the selection menu above the data window.

Please provide in your report two graphs of the data; the first being the force-time graph, the second the y accelerometer-time graph. Do they follow each other? Is it true that $F \propto a$, where $\propto$ means "is proportional to"?

4.3 Calibrating the force sensor

Before taking data in sections 4.4 and 4.5, follow the directions for calibrating the force sensor in the y-axis **down** orientation from Lab 01. Calibration settings are stored in the iOLab Online software, but you may need to repeat calibrations from time to time, especially for something like the force sensor where calibration and orientation are very tightly connected.

4.4 Weigh the iOLab

Experiment reproduciblility of is an important part of the scientific method. Let's re-weigh the iOLab the same way we did it in Lab 01.

A simple free body diagram showing the iOLab being held by it's eye-bolt without moving is in Figure 3. In the figure, because the iOLab is at rest, $F = W$ and $W = mg$ of course. We can use the force sensor to measure F.

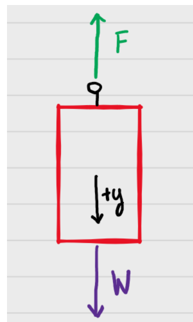

Figure 3: Free body diagram to weigh the iOLab. In this figure, the force holding the iOLab up is equal to its weight: $F = W$.

Place the iOLab on the table, $+y$-axis direction facing down. After a few seconds of collecting force sensor data without touching the iOLab, lift up the iOLab by firmly holding the eye-bolt, and hold it still in the air, and measure $F = W_{\text{iOLab}}$ for a few more seconds.

Provide a graph of the force-time data in your report.

Was the force at the beginning close to $F_0 = 0$, after calibrating it?

What is the weight of the iOLab, W_{iOLab}?

Is the weight of the iOLab similar to the weight measured in Lab 01?

Would the recorded force be different if you held it higher above the table? Would it be different if you looped a rubber band through the eye-bolt and held it that way? In Figure 4, the iOLab is held by a spring which pulls upward. (Assume it's not bouncing up and down.) Try it! Do you get roughly the same measured force?

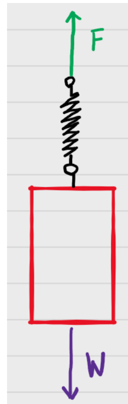

Figure 4: Free body diagram of a spring holding the iOLab. Assume everything is at rest. How does the spring force pulling upwards F compare to W now?

4.5 Systems of forces

Consider the free-body diagram of the iOLab at rest on an inclined plane (a ramp) in Figure 5. The component of gravitational force is parallel to the ramp, and therefore pulling it down the ramp, is balanced by the tension in the string; $T = W_{\parallel}$, where

$$W_{\parallel} = mg\sin\theta. \tag{1}$$

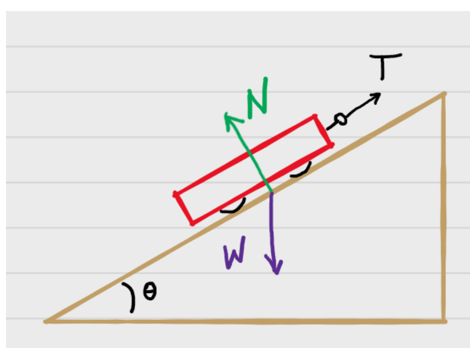

Figure 5: A free-body diagram of the iOLab tethered to a ramp. In order for the iOlab to remain at rest, the components of N, W and T parallel and perpendicular to the ramp must add to zero. To investigate this we will split W into two components; one in the negative direction of T, and the other in the negative direction of N.

Find a solid, flat object that would make a good ramp. Some suggestions are

- a wood board

- a kitchen cutting board
- a shelf detached from a bookcase
- a table, propped up at one end

As long as the ramp remains flat and does not droop or sag under the weight of the iOLab it should work.

Find some objects like books to lift up one end of the ramp. Try four different angles, from small to more than 45° in tilt. Be sure to put something heavy at the base to stop the ramp from sliding as you get to higher angles.

Tie a string to the eye-bolt of the iOLab, and place it wheels-down on the ramp, with the $+y$-axis pointing down the ramp. Secure the string so that the iOLab won't roll down the ramp. Try to keep the string roughly parallel to the ramp, as shown in Figure 5.

> Take a picture of one of your ramps with the iOLab in place, to include in your report.

How do I measure the angle θ? Trigonometry, of course! Make a mark on the edge of the ramp, somewhere above the midpoint. The length of the ramp to the bottom is the hypotenuse of the right triangle shown in Figure 6. To complete the angle, you need to know the height of the mark above the floor.

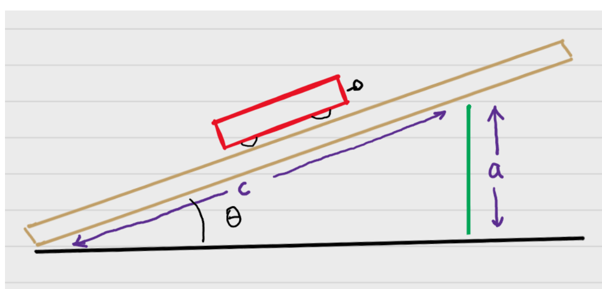

Figure 6: Diagram of how to find the angle of the ramp. The hypotenuse and opposite base of the right angle shown can be measured with the measuring tape.

The next set of measurements requires very short data runs (1-3 seconds is all you need).

> For four different angles, record the tension T in the string from the force sensor (the tension is the average force data). Also provide the measurement lengths a for each trial and the length of the ramp hypotenuse c. Calculate the angle θ and the value of

$\sin\theta$ for each angle.

If you think about it, there are two more data points where you might guess or have already measured the tension; $\theta = 0^\circ$ (horizontal) and $\theta = 90^\circ$ (vertical). Include them as extra data points.

Report the angle in degrees - is your calculator set for degrees or radians?

Although it doesn't look like it, the balanced force equation $T = mg\sin\theta$ is in the form of a straight line, $y = ax + b$ where a is the slope and b is the intercept. (We can't use m as the slope here, because we already used that symbol for the mass.)

What is the independent variable x? In the experiment, we changed the angle of our ramp. so our x variable is $\sin\theta$. What is the dependant varaible y? In the experiment we measured how changing the angle changes the tension T.

Thus if we plot T versus the values of $\sin\theta$, the slope of our line is $a = mg = W$ and the intercept is $b = 0$.

Refresh the iOLab Online software webpage. With the device not connected, you will see the data window is blank. You can use this webpage as graphing software, where you insert your own data. In the empty data window, type in the recorded values of $\sin\theta$ as the x-value, and tension as the y-value for all six data points. You can see a video about how to add your own data for fitting here.

Fit a straight line to the data, using an equation that includes the y-intercept, $y = Ax + B$, and record the values A and B and their uncertainty from the fit in your report.

Was the fit intercept within uncertainty of the theoretical value?

What is the percent difference between the known weight of the iOLab (Section 4.4) and the value from the slope of the line A? Are they within uncertainty?

Include a graph of the fit in your report.

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found on Sakai), include figures, and develop a robust discussion using prompts found throughout the manual.
Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P91@brocku.ca.