Static friction

Learning Goals

By the end of this lab, you should be able to

- Determine the coefficient of maximum static friction of a surface.
- Determine how the coefficient of maximum static friction depends on other parameters.

The Story

In 2014, the seemingly humorous question of why banana peels are so slippery became a serious scientific inquiry for Kiyoshi Mabuchi and his team at Kitasato University in Japan. Inspired by classic slapstick comedy, they conducted experiments to measure the frictional forces between a shoe, banana peel, and the floor.

They discovered that the jelly-like substance between the banana skin and fruit has an exceptionally low friction coefficient. When stepped on, this slippery substance is released, causing the infamous slip.

The team's investigation was more than a comic novelty; it provided valuable insights into lubrication and friction's role in motion. Their creative approach to physics was recognized with the 2014 Ig Nobel Prize. (Note: The Ig Nobel Prize is a satirical award given annually to celebrate unusual or trivial achievements in scientific research that first make people laugh and then make them think, with the ceremony traditionally held at Harvard University's Sanders Theatre.)

The award ceremony celebrated this unique research with humor and intellectual stimulation, reminding the world that science could uncover unexpected truths in even the most trivial questions. The team's work stood as a testament to the potential of curiosity-driven research, showing that even a banana peel can lead to scientific enlightenment.

What is that: Static or Kinetic Friction

Today you will do a very similar experiment as Dr. Mabuchi. Make sure you answer the questions in a clear and concise way as it might lead to an Ig Nobel Prize at some point.

Q1 **Question 1**: Perform an experiment and use *Graphical Analysis* method to determine:

1. The effect of the mass of the block on the maximum pulling force.
2. The coefficient of maximum static friction between a surface of the block and the masonite sheet.

Include in the Lab Work/Lab Participation document:

1. Surface of your choice - name it.
2. FBD of the block on the masonite sheet.
3. Analyze all forces, especially the pulling force applied by the force sensor. What does it represent?
4. A sample of the force applied on the block vs. time graph.
5. An explanation of what each region of the graph shows (static friction region, kinetic friction region, etc).
6. An explanation of how you used the graph to find the maximum pulling force.
7. A raw data table including all trials, average values, and SDOM
8. Maximum pulling force vs mass plot (with proper title, labels, error bars).
9. Graphical Analysis of the graph.
10. An explanation of how you used the graph to find the coefficient of maximum static friction.
11. The value of the coefficient.

Equipment

- wooden block with 4 different surfaces
- weights with different masses
- force sensor
- masonite sheet
- digital balance

First, let's take a look at the wooden block (Fig. 1). The materials covering the sides of the block are: wood, sandpaper, vinyl (the smoothest white side), paper. Use the hook to attach the force sensor. The brass rod can be used to add masses into the block.

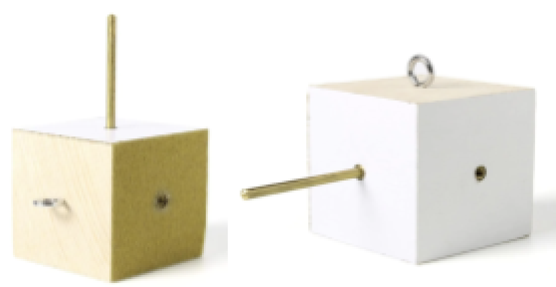


Fig 1: Wooden block with four different surfaces.

What To Do:

- Measure the mass of the wooden block using the digital balance.
- Place it on the masonite sheet. It is a kind of a thin plywood sheet. The sides have a different roughness Choose any side you want and record it in your worksheet.
- Consistency in collecting data is a key to a scientific experiment.
    - o The force sensor has two settings, 10 N and 50 N. Which one should you use?
    - o Discuss with your team about the surface of the block you would like to use (that is the surface touching the masonite sheet). Record it in your worksheet.

- Connect the force sensor to the hook of the wooden block.
- Open Logger Pro and check whether the sensor is detected. If not, unplug the USB port of the LabQuest from the back of the computer and plug it back.
- Before you hook the sensor to the block, zero it by clicking at the "Zero" icon. Make sure you do it every time you start collecting new data. (the sensor should be zeroed ONLY after a file is saved. Zeroing it within a Logger Pro file will crash Logger Pro.)

Pause for a moment. Draw a FBD of the block on the masonite sheet. Analyze all forces and discuss with your group members. What is the actual force that the pulling force represents?

- While keeping the force sensor horizontally (parallel to the surface), *pull it slowly and lightly, while the block is still at rest. That is, pull the force sensor until the block is **about to move, but not moving***. Again here, what is the actual force that the pulling force represents? Is it what you thought?
- Use Logger Pro to record the force applied. You can practice it several times until the graphs on Logger Pro are clear and readable. You can stop pulling the block right after it starts sliding.
- This is how your graph should look; figure 2 shows a sample graph. Analyze different regions of the graph. Locate the area(s) that represent the presence of static friction and kinetic friction.

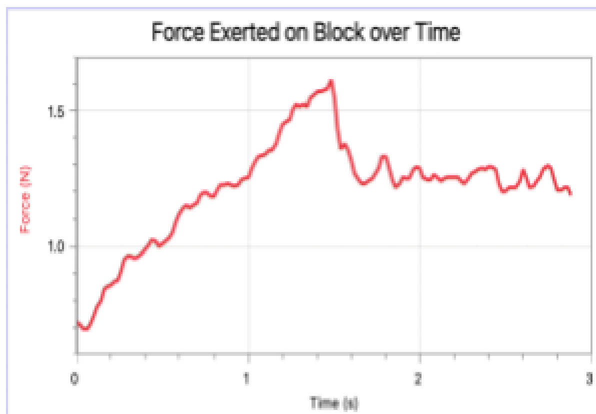


Fig 2: Sample graph

- Locate the maximum pulling force (actually the force that it represents) and find its value. This can be done by highlighting the region where the maximum value is reached and using the "Statistic" feature of Logger Pro to read *the maximum value*.
- Perform as many trials as you think that make the data convincing (3 trials minimum - save them in the same plot (press command and L simultaneously on iMac). Another way to collect several trials - pull, stop, pull, stop, pull, stop,....several times for the entire length of the masonite sheet. Then, choose the best three trials.
- Change the mass of the wooden block by adding more weights.
- Repeat the above procedure to get the maximum pulling force.

You are studying the effect of the mass of the block on the maximum pulling force.

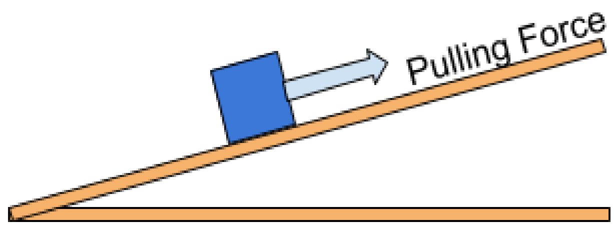
- What are IV, DV, CV? Record the constant variables and the values (if applicable).
- Record and organize the data in a data table.
- Calculate average values and SDOM. The digital balance has an uncertainty of 0.1 g.
- Answer the questions in the green box.

Q2

Question 2: How does *the angle* of the ramp affect the maximum pulling force?

In Q1 you collected data on a horizontal surface. What if there is an angle?

In order to test how the angle affects the outcome, as always, *we have to keep the other variables constant*. We have collected raw data on the relationship between angle and maximum pulling force by using an adjustable metal clamp to set a ramp at various inclines. The mass of the block was recorded to be m = 0.5515 kg, the surface of the ramp was aluminum, and the surface of the block was wooden.



The data sheet can be found in the lab module in Canvas or here.

Include in the Lab Work/Lab Participation document:

1. FBD of the block on the elevated track.
2. Completed Data Table.
3. The plot of maximum pulling force vs angle with proper title, labels, error bars.
4. Graphical Analysis of the graph.
5. Derivation of the equations of the balanced forces (along x- and y- directions) applied on the block placed on an elevated ramp.
6. Simplified force equation using the "small angle approximation".
7. An explanation of how you used the graph to find the coefficient of static friction.

Now let's think about the physics behind this new setup.

- Draw a FBD of the block on the ramp.
- Does the force measured by the force sensor equal the same force as in Q1?
- How would you write the equation of the balanced forces?

You will notice, like many problems you've solved on a ramp, there are now component forces that depend on the angle θ. Likely, your equation has some combination of sin θ and cos θ. Unlike previous experiments, there is no easy algebraic way to combine sin θ and cos θ into a single form or linearize. However, there is one trick we can still do, and it's something that you will encounter later this semester: ***the small angle approximation***.

The small angle approximation, for our purposes, is a helpful mathematical shortcut that holds for relatively small angles (below 17°), with the important rule that ***your angles must be converted to radians***.

The derived equation can then be simplified using the approximations below:

- $\sin\theta \approx \theta$
- $\cos\theta \approx 1$

If you're not convinced, feel free to try some small radian values (≤ 0.3) on a calculator and see how well the approximation holds.

After plotting your data (with your angles in radians):

- What relationship do you see?
- Apply a best fit line
- The equation of the best fit line includes some coefficients. What do the coefficients represent?
- How does the graph equation (and its coefficients) compare to your derived equation?
- Find the coefficient of static friction using the Graphical Analysis method?

Time to Clean Up!

Please clean up your station according to the Station Cleanup! Slideshow found in the lab module.