Coefficient of Static Friction

1 INTRODUCTION

In this laboratory you will design an experiment to measure the coefficient of friction between two surfaces.

2 LEARNING OBJECTIVES

At the conclusion of this activity you should be able to:

- Identify the difference between static and kinetic friction.
- Explain the process used and the details involved with designing your own experiment.
- Collect sensor data from your smartphone to make a measurement.
- Measure the coefficient of static friction between two objects.

3 BACKGROUND

3.1 FRICTIONAL FORCES

Frictional forces occur when two surfaces are in contact with one another. At the atomic scale, friction occurs because of strong inter-molecular forces between the two surfaces. [1]

The simplest model of friction is given by:

$$f = \mu N \tag{3.1}$$

where f is the force of friction, μ is the coefficient of friction, and N is the magnitude of the normal force. Friction is proportional to the normal force exerted by a surface on an object[2].

3.2 MEASURING COEFFICIENT OF FRICTION

When two surfaces are at rest relative to one another they exhibit *static* frictional forces. When two surfaces move with respect to one another the frictional forces are called *kinetic*.

A tricky aspect about static friction is that the force will be just as large as it needs to be to keep the relative motion between the two objects equal to zero (see Figure 3.1). The static frictional force may be anywhere between zero and the maximum static friction force f_s between two surfaces:

$$f_s \le \mu_s N \tag{3.2}$$

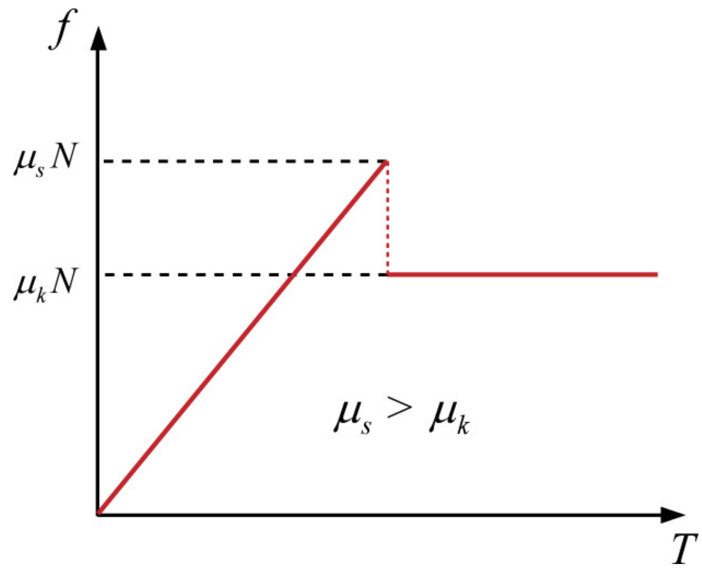

Figure 3.1: A cartoon of the force of friction as a function of tension in a string. You might imagine a simple system of a block at rest on a surface with friction being pulled by a string. At low tensions T, the force of *static* friction are also low (and linearly proportional to tension). At some point, the block begins to move and the frictional force is constant at $f_k = \mu_k N$.

where μ_s is the *coefficient of static friction*. The value of the coefficient of static friction is governed by the chemistry and crystalline structure of the respective materials. Lists of common coefficients of friction can be readily found on the internet [5] [6].

3.3 Coefficient of Static Friction on an Inclined Plane

An expression for the coefficient of static friction can be calculated by considering a block at rest on an inclined plane as shown in Figure 3.2.

3.4 Smart Phone Apps

PhyPhox[4] is the preferred app for collecting acceleration data. Other similar apps exist for accessing sensor data on your smartphone [3].

In the PhyPhox app, it is possible to create your own experiment that collects data from the available sensors on your phone. This is done by pushing the orange "+" icon in the lower right corner of the screen and then selecting the "Add simple experiment" option.

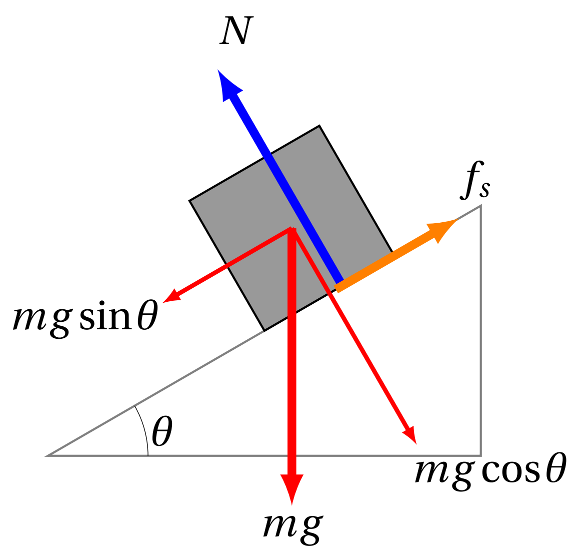

Figure 3.2: A block on an inclined plane is held at rest by static friction. This figure shows the free-body diagram of balanced forces acting on the block.

4 PROCEDURE

Design an experiment to measure the coefficient of friction between two surfaces. This should be a collaborative process between you and your lab group.

Here are a couple of ideas to think about as you design your experiment:

- What system will you use for your experiment? What tools do you have to make this measurement?
- What does the theory predict for the system? How do you plan to test the theory?
- What surface materials will you test? Do you have an expectation of what the result ought to be?
- What aspects of the system will need to be controlled in your experiment?
- What data will you need to collect?
- What steps will you take to build confidence in your result?

5 LAB NOTEBOOK

Your submission will be evaluated using the following rubric:

LAB NOTEBOOK PRACTICES

- Lab Notebook Mechanics (6 points)
  - Relevant information *e.g.*: your name, your lab partner's name, date, *etc.* is present.
  - The notebook is organized and easy to read. Markdown cells are used for narrative text. Code cells are clearly organized and commented.
  - The ZIP file of the notebook is healthy and runs correctly.
- Data Analysis & Plots (6 points)
  - The notebook tells a scientific story; it is an accurate record of the work that you did.
  - The notebook should show evidence of trial and error. Keep a good record of your work – recording mistakes is useful.
  - Record rough data and plots that you used to verify that the analysis was on the right track. Final versions of plots should be well formatted and meet the plotting guidelines for the course.
  - Use models to identify trends that your data exhibit or other apparent relationships between your independent and dependent variables.
- Results and Comparison (6 points)
  - Clearly state the final result(s) of your experiment. Remember to quote your result with units and appropriate significant digits.
  - Final result plots are well formatted and meet the standards described in the Figure Formatting reference.
  - A useful comparison is made to a known/expected value or another similar result.
  - Choose the best available tools for your comparison (*e.g.* plots, pictures, discrepancy, significance of discrepancy, etc).

- Uncertainty and Error Propagation (6 points)
  - Identify the dominant source(s) of error in your experiment.
  - Support your conclusions with appropriate error estimates and error propagation calculations.
- Physical Interpretation (6 points)
  - Throughout the notebook, interpret the data, rough plots, and final results in terms of the underlying physics.
  - What are you able to conclude from your data? Clearly explain how you arrived at your conclusions from your experimental observations.
  - Reflect on how your experiments connects with the physics concepts you are studying.

DEDICATION

This lab is dedicated to the memory of Mark Robbins who passed away in 2020[7]. Mark was a great physicist, mentor, and friend. He did a particularly good job of teaching the introductory sequence of courses to prospective physics majors. One of his diverse physics interests was friction [8][9]. Mark is dearly missed.

REFERENCES

[1] See Chapter 5-3 of Resnick, R., Halliday, D., Krane, K. S. (2002) *Physics, Vol. 1, 5th Edition*. Danvers, MA: John Wiley & Sons, Inc..

[2] HyperPhysics page on friction: `http://hyperphysics.phy-astr.gsu.edu/hbase/frict.html`.

[3] Physics Toolbox website: `https://www.vieyrasoftware.net/`

[4] PhyPhox website: `https://phyphox.org/`

[5] `https://www.engineeringtoolbox.com/friction-coefficients-d_778.html`

[6] `https://en.wikipedia.org/wiki/Friction`

[7] Mark O. Robbins Obituary in the Baltimore Sun.

[8] Mark O. Robbins, Martin H. Müser. "Computer Simulations of Friction, Lubrication and Wear". 1/5/2000; `arXiv:cond-mat/0001056`

[9] M. H. Müser, L. Wenning, M. O. Robbins. "Simple Microscopic Theory of Amontons' Laws for Static Friction". 6/28/2000; `arXiv:cond-mat/0004494`.