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Laboratory 4: Coefficient of Kinetic Friction

Hypothesis: The force of kinetic friction is proportional to the normal force on an object.

Purpose: The purpose of this experiment is to verify the accuracy of the Coulomb model of kinetic friction by observing the motion of an object upon which friction is acting. The coefficient of friction in the model will also be determined from the objects motion. You will further explore the use of linear regression, standard error, confidence intervals.

1   Introduction

Suppose there is an object sliding along a surface. From everyday observation, we know that this object will eventually come to a stop. However, one of Newton's Laws states that an object in motion will stay in motion (or an object at rest will stay at rest) unless the object is acted on by some external force. Therefore, if the object was sliding and eventually stops, we know that some force must have acted on it to stop its initial motion. This force is called friction or more specifically kinetic friction if it acts on an object that is moving.

The mechanism of friction does not allow for a formula for it to be derived from basic principles of physics (it is a complex process involving chemical bonding between the object and surface among other things). Instead, approximations for the friction force have been developed, one of which is Coulomb friction. This model states that the friction force between sliding objects is directly proportional to the normal force acting on the object, with the constant of proportionality referred to as the coefficient of friction, and the force is always directed opposite to the object's motion (see Fig. 1). Stated as an equation, the Coulomb model is as follows:

$$F_f = \mu N \tag{1}$$

where F_f is the friction force, μ is the coefficient of friction, and N is the normal force. This seems reasonable, after all, the harder one pushes down on an object, the larger the normal force, and the harder it is for another person to push the object along. The Coulomb model is the friction model that you will be using during this experiment.

In this experiment, you will be pushing a block along a track. While the block is being pushed, it is acted on by whatever time-varying force your hand provides. If the block stops being pushed, then the only force left acting on it that isn't gravity or the normal force is the friction force, F_f.
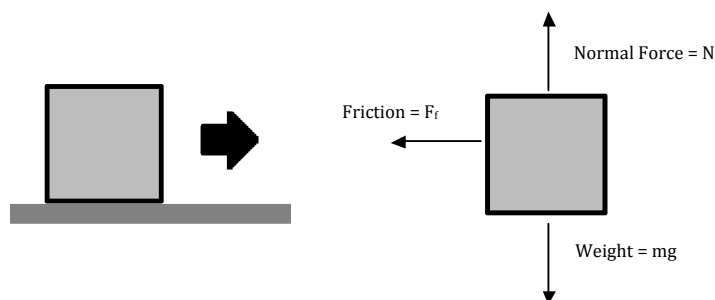
Figure 1: (left): *A block slides to the right across a surface.* **(right):** *A diagram of the forces is shown at right. Note that the friction force points to the left when the object moves to the right.*

And according to Newton's Laws, we have that the sum of all the forces on the object is equal to the object's mass multiplied by its acceleration:

$$\sum F = ma \tag{2}$$

Therefore, combining equations 1 and 2, we have:

$$ma = \mu N \tag{3}$$

In order to balance the forces in the vertical direction, we must have that the normal force is equal to the weight, mg. Substituting into equation 3 and canceling the masses, we have:

$$a = \mu g \tag{4}$$

We now have an equation for the acceleration of the block at any time after it stops being pushed and before it stops moving completely (at which point there is no more kinetic friction, which only applies while the object is moving). Since acceleration is the slope of the velocity versus time graph for this block, if we can obtain the velocity versus time graph, we can obtain the acceleration, and then also the coefficient of kinetic friction. We will use the Pasco motion sensor to obtain a velocity versus time graph.

2   Preparatory Questions

Comment on these questions in your report.

1. A box weighing $10\,\mathrm{N}$ moves along a surface for which the coefficient of friction between the box and surface is 0.5. What is the force of kinetic friction?

2. For the above situation, what would be the acceleration the box would experience if the kinetic friction is the only force acting in its direction of motion?

3. If the box started out moving at $20\,\mathrm{m/s}$, then how long would it take the box to come to a complete stop?

3   Supplies & Equipment

1. Wooden block
2. Motion sensor
3. Aluminum track with leveling screws
4. Computer with DataStudio, sensor interface, Excel
5. Group of 2-4 students
6. Optional: level

4   Suggested Procedure

Setting up the experiment:

1. The motion sensor should be sitting at the end of an aluminum track. There should be a wooden block sitting near the track.

2. Slide the motion sensor onto the end of the track that does not have the leveler. The tab on the bottom front of the sensor should slot into the edge of the track. Push the motion sensor switch to the picture of the cart (or the narrow beam, depending on which type you have). Orient the sensor so that the ultrasonic beam will be projected parallel to the track.

3. Using the screw on the leveler, adjust the track until it is level as you can make it, but dont spend too much time getting it perfectly level.

4. Open Data Studio, select "Create Experiment."

5. Select "Motion Sensor" under the list of sensors. Drag it to the interface box on the right side. When you are over the correct connections they will become highlighted; let go when this happens.

6. Plug the sensor connections (color coded) into the interface as now shown on the screen.

7. Double click on the motion sensor icon that is shown connected to the interface, select the Motion Sensor tab, and set the trigger rate (it may be called the 'sample rate') to 100.

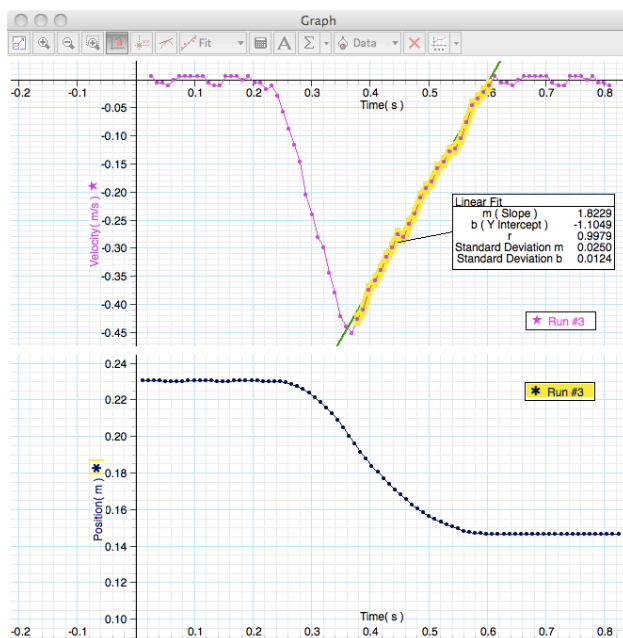8. Set up a plot of velocity and position versus time.

Figure 2: *Example data.*

Measurements

1. The measurement is best performed with at least two people. One person should be at the computer, and the other should be with the wooden block. The computer person should press the Play button to start a measurement, and then the block person should give the block a slight shove. The computer person should press the Play button again when the block has stopped all motion for about one second.

2. The shove should be very light, just enough to make the block move a distance about equal to its own length. You should also keep the block about as far away from the sensor. This keeps it well within the sensor's range. Also, make sure that the block stays aligned parallel to the track throughout its motion (you do not want it to rotate as it moves).

3. It may take a few tries to get a good set of data. An example of a good run of data is shown below in Figure 2. Try to keep your data as close to this as possible, avoiding jagged spikes in the linear portion of the data.

4. After a good run of data is obtained, perform a linear fit on the portion of the data where the block is slowing down, as shown in Figure 2. Make sure not to select the peak or any of the flat portions of the data.

5. The slope and various other data related to the linear fit should now be displayed below the graph. Record the slope in the first column of Table 1 on the Data Sheet.

6. Repeat this process until you have recorded ten slopes. Make sure that each time you push the block, you use the same side of the block (bare or with felt, but not both).

5   Data analysis

1. We have from equation 4 that the slope of the velocity graph, or the acceleration, is equal to the coefficient of kinetic friction multiplied by g, the gravitational constant. Taking this constant to be $9.81\mathrm{m/s}^2$, divide each slope from the first column of Table 1 by 9.81 and record the result (the coefficient of kinetic friction) in the corresponding part of the second column of the table.

2. Calculate the average coefficient of kinetic friction by adding up all the elements of the second column of Table 1 and dividing that by ten. Record this result in the Average space on the Data Sheet.

3. Calculate the standard deviation σ of your measured coefficients. Divide this number by the square root of the number of measurements you made, and the result will be the *standard error of the mean* $\sigma_{\overline{x}} = \sigma/\sqrt{n}$. Record this value in the Standard Error space on the Data Sheet.

4. Finally, multiply the standard error of the mean by 1.96, and record that value in the Error space on the Data Sheet. Assuming a normal distribution, this represents the $\pm 1.96\sigma_{\overline{x}}$ spread about the mean within which you expect to find 95% of measured data. In other words, you have now calculated the 95% confidence interval for the coefficient of kinetic friction. It is 95% likely that the actual value of the coefficient is between the average value plus the error and the average value minus the error.[i] This is the only measure of the accuracy of your data that can be performed, since there is no real accepted value for the coefficient. It is calculated experimentally on a case by case basis in a way very similar to the experiment you just performed. Finish filling out the Data Sheet by filling out the remaining spaces.

Time permitting: Repeat the experiment using a different side of the block (the felt side if you used the bare side or the bare side if you used the felt side.

6   Format of Report

Your report need not be formal, the format is largely up to you. Answer all the questions above, turn in the plots you were asked to make, and your overall conclusions.

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[i]You may recall the short discussion of distributions and error from the first lab.

Table 1: *Data table*

run	slopes	coefficients
average:		
standard deviation:		
standard error:		
error:		

confidence interval =   (average)   ±   (error)

it is 95% likely that the actual coefficient of friction lies within this range.