COEFFICIENT OF FRICTION

Introduction

Friction is the force that resists the sliding of one surface against another. The coefficient of kinetic friction is defined as the ratio of the frictional force to the normal force while the object is sliding,

$$\mu_k = \frac{F_k}{F_n} \tag{1}$$

The coefficient of static friction is defined as the ratio of the maximum frictional force to the normal force before motion,

$$\mu_s = \frac{F_{s,max}}{F_n} \tag{2}$$

In this lab you will explore some of the properties of friction and use different methods to measure the coefficient of friction.

Equipment: Motion sensor, force sensor, mass, string, aluminum track, meter stick, wooden block.

Preliminary questions

Question 1:
According to your textbook, how do μ_k and μ_s usually compare in value? (Which is typically larger?)

Question 2:
How do you expect μ_k to depend on the size of the contact area between the two sliding surfaces?

Question 3:
How do you expect the *coefficient of friction* to depend on the normal force? For example, do you expect μ_k to increase, decrease, or remain constant as the normal force is increased?

Experiment

1. In this part of the experiment you will measure the frictional force between a wooden block and the table by using a force sensor to pull the wooden block on the table. Begin with the large felt side of the block facing down. Place at least 500 g of mass on the block (so that the frictional force is large enough to be more easily measured). Set the sample rate of the force sensor in Data Studio to 50. Attach the force sensor to the block with a string. Zero the force sensor by pressing the tare button on the side of the force sensor before <u>each</u> measurement and while the string is relaxed.

a) Now we are checking your answer to Question 1. Is the maximum force required to start the block moving larger than, smaller than, or the same as the force required to keep it moving at constant speed?

Measure the force as a function of time as you *very* gradually increase the tension in the string, start the block moving, and keep it moving at a constant speed. Repeat this a few times, each time trying to achieve the largest possible force before the block starts sliding.
b) How do your results compare with your answer to Question 1?

2. Now let's check your answer to Question 2. Place the block with the small area felt side down and place the same mass on the block as in part 1 above. Measure the force required to keep the block moving at constant speed and compare with what you got with the large felt side down.
   a) Are your results consistent with your answer to Question 2?

3. Now you want to find the coefficient of kinetic friction μ_k between the wooden block and the aluminum track using Eq. (1) which means to measure the normal force and the friction force for a series of different masses. When pulling horizontally on a level surface, the normal force is the total weight (mg) of the block plus any added mass. To measure the force of friction F_k, use the force sensor.
   a) Draw below a free body diagram for the block while is pulled by the sensor:

   b) Under which physical condition is the value measured by force sensor equal to F_k ?

   Start with the block (large felt surface down) with a mass of 200g on it. (You will also need to determine the mass of the block). Put the motion sensor at one end of the track. On DataStudio have ready the plot of velocity *vs* time and the plot force *vs* time on the same graph. Move the block in the direction away from the motion sensor by pulling it with the force sensor. Looking at both plots, the correct value for F_k should be taken accordantly to your answer to the question above.
   Add a mass to the block and repeat. Do this for five different masses up to about 1 kg (m is the total mass: mass of the block plus the added mass). Include your measurements in the table below

m (kg)	F_n (N)	F_k (N)	$\mu_{k..}$

   c) How do your measurement compare with your answer to Question 3?

Another way to analyze the results in the table is to make a graph of F_k as a function of F_n.
d) What kind of curve would suggest that μ_k is independent of the normal force?

Use Excel to plot F_k as a function of F_n and fit the data to a straight line to determine the slope. Open Excel, on column A insert the value of F_n and on column B insert F_k (Excel plots the first column on the *x*-axis and the second column on the *y*-axis). Using left-click on the mouse, select all your data. Then click the tab *Insert, Scatter, (Scatter with only Markers).* Then right click on one of the point displayed on the graph, *Add Trendline…,* choose *Trend/Regression Type* as *Linear* and mark *Display Equation on chart.* Click *close.* The linear fit equation should appear on the plot, if not try again to follow these steps or ask for help to the TA. You will also have to use Excel for plots on following labs, so take a change to learn how to use it.
e) What is the numerical value of the slope and what does it represent?

Print the Excel graph.
4. Another way to determine the coefficient of kinetic friction is to shove the block along a level surface (aluminum track) and measure the acceleration as it slides to a stop. From Newton's 2nd law we have.

$$F_k = \mu_k F_n = \mu_k mg = ma,$$

or,

$$\mu_k = \frac{a}{g}.$$ (3)

Use this method to measure $\mu_{k..}$ Place the block with added mass on the track 10 cm in front of the motion sensor. Shove the block away from the sensor and measure the velocity as a function of time. Repeat for five different masses. Determine the acceleration a by finding the slope of the curve as it is slowing down. (Be careful in choosing precisely the data points which correspond to the deceleration of the cart).

	m_1	m_2	m_3	m_4	m_5
a					

a) By looking at your data *and* the equation (3), do your results depend on the masses? Explain

b) $a_{average} =$ _____ $\mu_k =$ _____

c) How do your values of μ_k compare with those found in part 3 (the % difference)?

5. A final way to measure friction is to use an inclined plane. Place the block on the track (large felt side down) and very gradually raise one end of the track until the block begins to slide. The coefficient of static friction can be determined using the equation

$$\mu_s = \tan(\theta_s).$$ (4)

where θ_s is the maximum angle of the track such that the block doesn't slide.
Similarly, if the track angle is adjusted so that the block slides down at a constant speed, then

$$\mu_k = \tan(\theta_k).$$ (5)

Without taking specific measurements, determine the relative size of θ_s and θ_k.

You can determine μ_s and μ_k by measuring the elevation of one end of the track and the length of the track and the equation (4) and (5).

$\mu_s =$

$\mu_k =$

a) How do your values of μ_k compare with those found in part **3** and **4** (the % difference)?

Summary Questions

Question 4:
In parts 1-3 of the experiment, you were told to pull the cart at constant speed to measure F_k and μ_k. Why is this important? What effect would it have on your results if the block was speeding up?

Question 5:
Do F_k and μ_k depend on how fast the block moves? How would your results in part 4 help answer this question? Look at Eq. (3). Was the acceleration constant as the block slowed down?