Course and Section________ Names ______________________________

Date____________ ____________________________________

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,

$$\mu_k = \frac{F_k}{F_N} \qquad (1)$$

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

$$\mu_s = \frac{F_{s,max}}{F_N} \qquad (2)$$

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

Equipment

Smart cart, hook, mass set, string, aluminum track, meter stick, wooden block, digital scale.

Preliminary questions

a. How does μ_k and μ_s usually compare in magnitude?

b. How do you expect μ_k to depend on the size of the contact area between the two sliding surfaces?

c. 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 increases?

PART 1 – Static vs Kinetic Friction

Open the file: “**v-t_F-t.cap**” contained in the T:\Capstone folder, which display graphs of the velocity *vs* time and force *vs* time.

Procedure

<u>Tare the force sensor</u>: you want the cart to read a zero force value if no forces are applied. Go to ‘*Hardware Setup’ on left panel.* Click on circle next to ‘*Smart Cart Force Sensor’*. Then click on ‘*zero sensor now*’. Then click ‘ok’.

*Step 1***.** Place the large felt side of the block on the table.

Step 2. Place at least 500 g of mass on the block.

*Step 3***.** Place a hook on cart. Attach the force sensor to the block with a string.

Step 4. Before each measurement, press record.

Step 5. Looking at the force vs time graph as you *very* gradually increase the tension in the string. Try to achieve the largest possible force before the block starts sliding (this may take a few tries).

Step 6. Keep pulling the block and, by looking at the velocity vs time graph, try to make <u>it move at a constant speed</u>,

1. The maximum force required to start the block moving, is larger than, smaller than, or the same as the force required to keep it moving at constant speed?

2. Do your results support your response to the preliminary question *a*?

Step 7. Place the block with the small area felt side down.

Step 8. Place the same mass on the block as in the previous.

Step 9. Measure the force required to keep the block moving at constant speed and compare with what you got with the large felt side down.

3. Are your results consistent with your answer to question *b*?

PART 2 – Friction vs Normal Force

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. Don't forget to tare it.

4. Draw below a free body diagram for the block while is pulled by the hook on the smart cart:

5. Under which kinematic condition is the value measured by force sensor equal to F_k?

6. If you were to increase the tension in the string, by applying an even larger force, how will this affect the kinematic quantities which describe the motion of the block?

Procedure

Step 1. Measure the mass of the block.

Step 2. Start with the large felt surface against the table with a mass of about 200g on it.

Step 3. Move the block by pulling it with the force sensor.

Step 4. Using the plots, extract the value of F_k by looking at the time interval corresponding to motion at constant velocity.

Step 5. Add a mass to the block and repeat.

Step 6. Do this for five different masses up to about 1 kg.

Analysis

Include your measurements in the table below. Here m is the combined mass of the block m_b and additional mass added to it m_a.

m (kg)	F_N (N)	F_k (N)	μ_k

7. If you were to stop pulling the block, how this will affect the kinematic quantities which describe the motion of the block?

8. How do your measurements compare with your answer to the preliminary question *c*?

9. Calculate the mean value of the coefficient of kinetic friction

Mean $\bar{\mu}_k$	

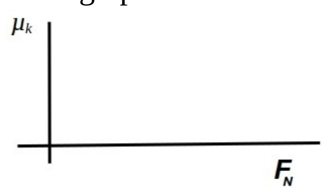
10. Calculate the standard deviation (sample) and the error. You can use the formula below or excel or your calculator or any online resources for example goolge '*Standard Deviation Calculator*'.

$$\sigma_{\mu} = \left[\frac{1}{(N-1)} \sum_{i=1}^{N} d_i^2 \right]^{1/2} = \underline{\qquad} \qquad \sigma_{average} = \frac{\sigma_{\mu}}{\sqrt{N}} = \underline{\qquad}$$

11. Record the final answer for your calculation of the coefficient of kinetic friction.

$$\mu_k = \bar{\mu}_k \pm \sigma_{average} = \underline{\qquad\quad} \pm \underline{\qquad\quad}$$

12. Consider a plot of μ_k *vs* F_N as shown below. Draw the graph that 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.

Plot

Step 1. 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).

Step 2. Using left-click on the mouse, select all your data. Then click the tab *Insert, Scatter, (Scatter with only Markers).*

Step 3. 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.*

Step 4. 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 chance to learn how to use it.

13. What is the numerical value of the slope and what does it represent?

Label your axes in Excel and include an appropriate plot title. Print the Excel graph.

PART 3 – Incline Plane and Forces of Friction.

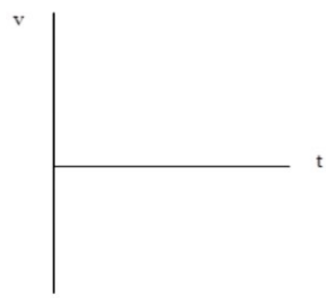
Assume that friction can be neglected. Suppose you shove a cart so that it rolls up an incline plane, and then it comes back down.

14. Draw two free body diagrams: as the cart moves up and as it moves back down. Indicate on the diagrams the net force acting on the cart.

15.

Compare the magnitudes of the net forces. Should they be the same? If not, which one is greater?

16. Sketch the expected position and velocity of the cart as a function of time. Assume the coordinate system has origin located at the bottom of the incline; the *x* axis is parallel to the incline and points upward the incline plane.



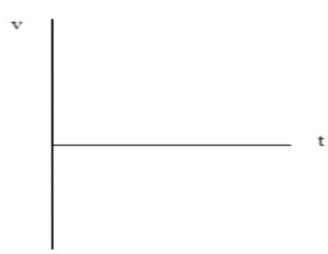
Now assume that friction is present. Suppose you shove a cart so that it rolls up an incline plane, and then it comes back down.

17. Draw two free body diagrams: as the cart moves up and as it moves back down. Indicate on the diagrams also the net force acting on the cart.

18.

Compare the magnitudes of the net forces. Should they be the same? If not, which one is greater?

19. Sketch the expected position and velocity as a function of time.



20. Are your predicted curves the same with and without friction? Explain.

Procedure

Open the file: "**x-t_v-t.cap**" contained in the T:\Capstone folder.

Step 1. Place something under the end of the track to raise it by 2-3 cm.

Step 2. Shove the cart so that it rolls up the incline and comes back down.

Step 3. Record the position and velocity during this time.

Analysis

21. From the velocity *vs* time graph, is the magnitude of the acceleration greater when the cart is moving up or down the incline?

22. How can you tell the two accelerations are different by looking at the position *vs* time graph?

23. Compare these graphs with your earlier predictions with friction.

It can be shown that, in this case, the friction force is given by:

$$F_{FRICTION} = \frac{m}{2}\left|\left(a_{up} - a_{down}\right)\right| \qquad (3)$$

24. Find the accelerations by taking the slope of the velocity versus time curves

a_{up} = ______ a_{down} = ______

25. Calculate the friction force using the above equation (3):

F_k = ______

26. Now raise by a few more centimeters the incline plane, shove the cart again, measure the accelerations and calculate the friction force.

F_k = ______

27. Compare the two numerical values of the frictional forces. Should they be the same?

28. Is there a relation between F_k and the slope of the incline plane?

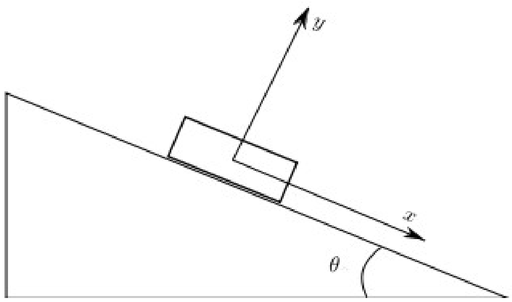
PART 4 - Incline Plane and Coefficients of Friction.

Procedure

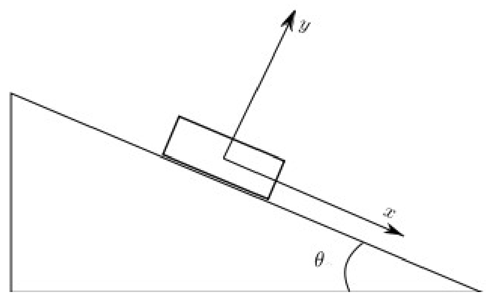
Step 1. Place the block on the track (large felt side down).

Step 2. Very gradually, raise one end of the track until the block begins to slide.

29. Consider the block on the incline plane. At first the block is at rest, if you increase the angle θ the block will start to fall. Draw on the two figures below the free diagrams for the block when it is at rest and when is in motion.



(a) block at rest



(b) block in motion

For the case of static friction $\theta = \theta_s$

30. Write the Newton 2nd law relative to the *x*-axis.

31. Write the Newton 2nd law relative to the *y*-axis

32. Divide the two equations, which expression do you find for μ_s as a function of θ_s?

$$\mu_s =$$

33. Determine the minimum angle θ_s at which the block begins to slide: measure the elevation of one end of the track, the length of the track and use trigonometry.

$$\theta_s = \_\_\_\_\_$$

34. Calculate the coefficient of static frictions μ_s = _____

For the case of kinetic friction a similar calculation can be done if the track angle is adjusted so that the block slides down at a constant speed, in that case we find

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

35. Determine the minimum angle θ_k necessary for the wooden block to slide down the incline: measure the elevation of one end of the track, the length of the track and use trigonometry.

$$\theta_k = \_\_\_\_\_$$

36. Calculate the coefficient of kinetic frictions μ_k = _____

37. How do your values of μ_k compare with those found in PART 1 and PART 2 (the % difference)?

Summary Questions

38. In part 1, 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?

39. Do F_k and μ_k depend on how fast the block moves?

40. Indicate the errors present that had a large effect on the measurements conducted during this lab

Human errors:

Instruments errors:

Others source of errors: