FRICTION

THEORY:

Friction is the resisting force encountered when one tries to slide (static), or does slide (kinetic), one surface over another. This force acts along the tangent (parallel) to the surfaces in contact. The force necessary to overcome friction depends on the nature of the materials in contact, their roughness or smoothness, and on the normal force, but not on the area of contact, within wide limits. Experimentally, the force of friction is found to be directly proportional to the normal force. The constant of proportionality is called the coefficient of friction.

The coefficient of friction is equal to the force of friction divided by the total normal force pressing the surfaces together. Thus $\mathbf{f} = \mu N$ where $\mathbf{f}$ is the magnitude of the force of friction, N is the magnitude of the total normal force, and μ is the coefficient of friction.

A method of checking the above relation is to have one of the surfaces in the form of a horizontal plane, with a pulley fastened at one end. The other surface belongs to a box to which is attached a cord passing over the pulley and carrying weights; these may be varied until the box moves uniformly when given a small push. The normal force magnitude between the two surfaces can be changed by placing weights in the box, and the relation between the coefficient of friction, the force of friction, and the normal force can thus be tested.

Another method of investigating the relation is to experimentally determine the acceleration of a box sliding down an inclined plane. By starting the box from rest and timing a known distance, the acceleration can be calculated. From a free-body diagram, the relationship between the angle of incline, the normal force and the friction force can be determined. The coefficient of friction should be independent of the angle if the box begins to slide without a push. It should also be independent of the mass of the box.

The **limiting angle of repose** is the smallest angle at which a body will just begin to slide down an inclined plane without being pushed to get it started. **The coefficient of static friction is equal to the tangent of the limiting angle of repose**.

When actual sliding is taking place the frictional force acting is slightly lower than the maximum static frictional force that can act just before the body begins to slide. Thus the kinetic coefficient of friction is somewhat lower than the static coefficient of friction. **The coefficient of kinetic friction is equal to the tangent of the angle at which the body slides down the plane at constant speed when given a slight push.**

APPARATUS:

Board with pulley at one end	Balance
Support rod for adjusting angle	Protractor
Wood box with string	Slotted masses
Block of different material or plane with different surface	Hanger

PROCEDURE:

1. Measure and record the mass of the wooden box.

2. Place the board in a horizontal position on the laboratory table with its pulley projecting beyond the edge of the table. Place the cord which is attached to the box over the pulley. Set the box on the board, place 100 g in the box and make sure the string is horizontal. Hang some masses from the cord and slowly increase the hanging mass until it is just sufficient to keep the box sliding slowly with constant speed after it has been started with a small push. Record the hanging mass needed.

3. Repeat Procedure 2 placing masses totaling 200, 400, 600, 800, and 1000 grams successively in the wooden box. Record the hanging mass needed in each case.

4. Now, go back and repeat all measurements in Procedures 2 and 3. Take the average of the values for each sliding load. Record the average in a data table.

5. Place 400 grams in the box. Gradually increase the load on the cord until the box just starts to move, without any initial push. Be careful to place the masses on the hanger gently so as not to jerk the cord. Notice whether this time the box moves with uniform speed or whether it is being accelerated. Record the load needed under

these conditions. Take 4 independent measurements.

6. Adjust the board as an inclined plane at 30 degrees (This angle might change depending on individual conditions. Consult with your instructor.) with the bottom end toward the lab divider. Place a wooden block at the bottom of the plane. Measure a distance of 0.900 meters up the plane and mark it.

7. Place 200 (use two 100 g masses) grams in the box and release the box from rest at the mark you made in the previous step, measuring the time for the box to slide 0.900 m. Repeat this timing for a total of 5 times.

8. Place 300 (use six 50 g masses) grams in the box and repeat the timing measurements 5 times.

9. Change the angle of the board to 2 degrees higher than before and repeat steps 7 and 8.

10. Measure the limiting angle of repose with the wood box with 200 grams in the box. Take 3 independent measurements.

11. Turn the board over to the smooth side and repeat Procedures 6 and 7.

CALCULATIONS:

0. Remember that in the friction formula, $f = \mu N$, f and N are forces, not masses. Thus they must be given in force units, such as newtons. Recall that $w = mg$; given m in kilograms, multiply by 9.80 and you will have its weight in newtons.

1. From the data of Procedures 1-4 calculate and record in a table the coefficient of *kinetic* friction for box on board for each of the averages. The pull of the cord on the box is equal and opposite to the force of friction between the box and the plane. The normal force between the two surfaces, in this case, is equal to the weight of the box plus the weight placed in the box. Then, calculate an average coefficient.

2. From the data of Procedure 5 compute the coefficient of static friction for box on board.

3. From the data of Procedures 6 - 9 for each mass and each angle:
   a. calculate the average time
   b. Calculate the acceleration
   c. Calculate the coefficient of kinetic friction for the box on board
   d. Compare this with the results from Calculation 1 by calculating a percent difference.

4. From the data of Procedure 10 calculate the coefficient of static friction for this material on board and compare the the results of Calculation 2.

5. From the data of Procedure 11 calculate the coefficients of kinetic friction for box on board with the new surface. Compare these coefficients with the kinetic coefficients calculated for the first surface. Comment on whether this makes sense or not.

6. From the data of Procedures 1-4 make a graph using the values of the total normal force as abscissas and the values of the force of friction as ordinates.

7. Calculate the coefficient of kinetic friction from the slope of the best straight line fit of the data points. Compare this with the result from Calculations 1 and 3

QUESTIONS:

1. In this experiment why is it necessary that the body move with uniform velocity in Procedures 2-4?

2. Based on your experiment, does the coefficient of friction depend upon the normal force between the surfaces in contact?

3. How does the coefficient of static friction compare with the coefficient of kinetic friction for the same surfaces, areas, and normal forces? In this context, explain what happened in Procedure 5 once the box started moving.

4. <u>Show the derivation</u> of the relation that exists between the coefficient of static friction and the limiting angle of repose of an object on an inclined plane.

5. Calculate the force needed to pull a mass of 20.0 kilograms at a uniform slow speed up a plane inclined at an angle of 30.0° with the horizontal, if the coefficient of kinetic friction is 0.200.