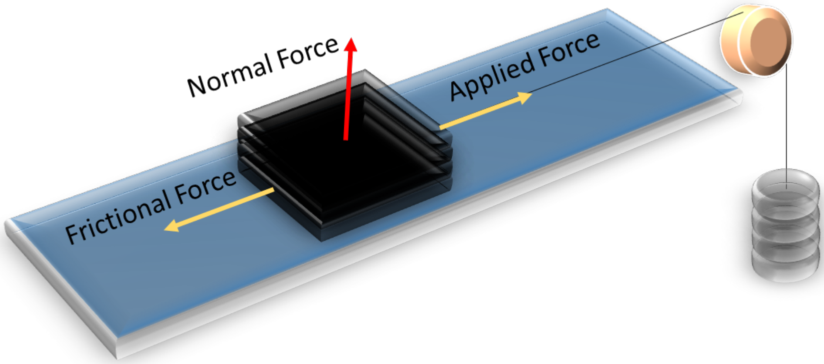

Objectives:
The objectives of this lab are to measure the coefficients of static and kinetic friction between an object and a surface.

Theory:
Friction is the resisting force encountered when one tries to slide or does slide one surface over another. This force acts 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. Experimentally, the force of friction is found to be directly proportional to the normal force. When an object is sliding over a surface, the force of friction is called **kinetic friction** and is given by $F_f = \mu_k n$, where n is the normal or perpendicular force between the surfaces, and μ_k is the constant of proportionality, called the **coefficient of kinetic friction**. If the object is not yet sliding on the surface but there are applied forces on the object and friction is preventing sliding, this type of friction is called **static friction** and is given by $F_f \leq \mu_s n$, where μ_s is called the **coefficient of static friction**. Note the inequality. This equation says that the static frictional force is whatever is needed to prevent sliding ($F_f < \mu_s n$) but cannot be greater than $\mu_s n$. When the resultant forces on the object parallel to the surface become equal to $\mu_s n$, the object is in unstable equilibrium, and sliding will occur if these forces become incrementally larger. When the object begins to slide, kinetic friction takes over.

A method of checking the above kinetic friction relationship 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 block to which is attached a cord passing over the pulley and to a weight hanger carrying weights. These weights may be varied until the block moves uniformly when given a very light push. The normal force magnitude between the two surfaces can be changed by placing additional weight on the block, and the relationship between the coefficient of friction, the force of friction, and the normal force can thus be tested. A variation of this method can be used to find the coefficient of static friction.

Another method of investigating the kinetic friction relationship is to experimentally determine the acceleration of a block sliding down an inclined plane. By starting the block 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 **limiting angle of repose** is the smallest angle at which an object 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 sliding is taking place, the kinetic frictional force acting is slightly lower than the maximum static frictional force that acts just before the object starts to slide. Thus, the coefficient of kinetic friction is always less than the coefficient of static friction between any two surfaces.

<u>Procedure:</u>

General notes for all steps below:

a) Use only the smooth side of the board.
b) Once you begin, do not turn Block 1 over and use its other side.
c) We recommend that when you add the slotted weights to the hanger that you put your hand under the hanger (just touching it), add the weight, and slowly remove your hand. Also, try to keep the weight hanger from swinging.
d) As a courtesy to others (as well as your group), <u>walk very softly</u> on the lab floor. When performing the static friction steps, a very small floor vibration will cause a block to slide prematurely.

On a flat surface

1. Measure and record the mass of the two wooden blocks at your table. The block with the eyelet for the string is Block 1; the other is Block 2.

2. Place the board horizontally on the lab table with the pulley end hanging over the edge of the table. Place Block 1 near the back (opposite side from the pulley) of the board, run the string over the pulley, and put a 50 gram weight hanger on the end of the string. Begin adding weights to the hanger. Add 20 gram weights until the block moves on its own. **Remove all the weights from the hanger, reposition Block1 at the original position, and wait for a while. And add 20 gram weights except for the last 20 gram which made the block start to move on its own. At this time add smaller weights for the last 20 gram until the block just breaks free and moves by itself.** Record the total hanging mass that resulted in unaided motion. Reposition Block 1 and repeat two more times. You will find this to be an inexact process. The value of μ_s may depend on the block's location on the board and even on how long it has been stationary.

3. Repeat Step 2 with Block 2 placed on top of Block 1. But this time, you should start with a 50 gram weight.It may require only a few more grams to move.

4. With the board still lying on the table but with only Block 1 on it, clear the weights from the hanger, add a 10 gram weight, and lightly tap the back of the block. Continue adding weights (decreasing as necessary down to 1 gram) and tapping the block each time

weight is added until it moves at a constant velocity. This may take some patience as the block may move and then stop somewhere along the plane. If it travels as much as 30 cm at a constant speed, consider that trial a success. Repeat two more times and record the required hanging masses to achieve this.

On an inclined surface

5. Adjust the board to create an inclined plane with an angle between 13° and 16° as measured by your angle finder. Be sure to orient the angle finder such that it reads 0° when placed flat on the lab table. Measure a distance of 0.90 m up the plane and mark this location. Somewhere in the range of 13° – 16° the block will travel the 0.9 m in 1.5 to 3 seconds. Adjust the angle to achieve this time range. To hold the board at this angle, use the ring stand apparatus provided. At the foot of the board place a book or other heavy object to keep the plane from sliding forward on the table. Also, make sure that the ring stand support remains at the same point with respect to the board; otherwise, the angle will change.

6. Place Block 1 on the incline plane and release it from rest at the mark you made in the previous step, measuring the time for the block to slide 0.90 m. down the plane. The same person should release the block and start the timer. Stop the timer when the front of the block reaches the end of the board. Repeat this 4 more times and record the time for each trial.

7 Repeat Step 6 after placing Block 2 atop Block 1. If Block 2 will not remain in place, use some tape to hold it.

8. Place Block 1 near the 0.90 meter mark and determine the limiting angle of repose by <u>very slowly</u> increasing the incline angle from 0° until the block slides down the plane with no starting push. Repeat this 4 times and record each angle.

9. Repeat Step 8 after placing Block 2 atop Block 1. Again, use tape if necessary.

<u>Calculations:</u>

1. From the data of Procedure Steps 2 and 3, calculate the average weights of the hanging masses and calculate the coefficient of static friction between the block and the surface for both steps. Using a % difference calculated, determine how the coefficient of static friction from Step 2 compares to that from Step 3?

2. Using the data from Step 4, calculate the average weight of the hanging masses and calculate the coefficient of kinetic friction.

3. Using the data from Steps 5-7:
   a. Calculate the average times for the blocks to slide down the incline for both Step 6 and Step 7.
   b. Using the average times, calculate the acceleration of the blocks in both steps using one of the kinematic equations. Use this acceleration and Newton's 2nd Law of Motion to calculate the values of μ_k for both steps. From these values of μ_k and n, calculate a coefficient of kinetic friction for both steps.

c. Determine the % difference between the coefficient of kinetic friction results from Step 6 and Step 7.
d. Calculate the % different between the coefficient of kinetic friction between Step 4 and Step 6.

4. Find the average limiting angles of repose for both Step 8 and Step 9. Use these average angles to find the coefficients of static friction in both steps.
   a. Compare these values of μ_s by performing a % difference calculation.
   b. Compare the values of μ_s from Step 2 and Step 8 by performing a % difference calculation.

Questions:

1. Based on your results, do the values of μ_k and μ_s depend upon the normal force between the surfaces in contact?

2. How does the coefficient of static friction compare with the coefficient of kinetic friction for the same surface areas and normal forces? In this context, describe the motion of the block(s) in Step 8 or 9 once it started moving.