Experiment #6: Friction

I. About the Experiment

A. Background

Friction is the force that acts against the motion of an object and gradually slows it to a stop. Friction is a result of contact forces at the molecular level; it doesn't occur in a vacuum. But when an object moves through the air it must push the air molecules out of its way. By Newton's second law, the air molecules also push back and create a force to counter motion which we call air resistance.

When objects are pushed into contact, the molecules on their surfaces apply force to each other and create a total force that opposes any sliding motion between them. This friction always acts to oppose any externally applied force.

We are going to investigate how the frictional force is related to the contact force between surfaces. To a first approximation, we will discover that the frictional force is proportional to the contact force. If you know this ratio, called the coefficient of friction, you can calculate the frictional force from the contact force.

B. Theory

Friction is the force between surfaces in contact that opposes any sliding of one versus the other. The force that must be overcome to start a surface moving is called the static frictional force. The force that must be overcome to keep a surface moving is called the kinetic frictional force. In most cases, it takes less force to keep a sliding object in motion than to start it in motion. Both types of frictional force are proportional to the contact force holding the surfaces together.

When an object lies on top of a surface, the contact force is provided by gravity; i.e. the contact force equals the weight of the object. If a sideways force is applied to push the object along a table, there is no initial movement until the sideways force overcomes the force of static friction. When the object is moving, the frictional force still opposes the applied force but the frictional force is now called kinetic friction and is generally less than the force of static friction. That's why it's easier to keep a sliding object in motion than it is to get it moving in the first place.

According to theory, an object in motion is subject to a constant kinetic frictional force which is some fraction of the contact force which is usually the weight of the object. This fraction is the coefficient of kinetic friction μ_k.

The force of static friction is more complicated. When a sideways push is applied to an object resting on a surface, the force of static friction initially matches the applied force. Thus no motion results until the force of static friction is overcome. If the sideways force is increased, the force of static friction will match it until a maximum static frictional force is reached. Beyond that point, the static frictional force cannot match the applied force and the object begins to move. The relative motion between the surfaces tends to reduce the frictional force and so the kinetic frictional force is usually less than the maximum value of the static frictional force.

Like the kinetic frictional force, the maximum value of the static frictional force is dependent on the contact force between the surfaces and thus the weight of the object. So the coefficient of static friction

μ_S is defined as the ratio of the maximum static frictional force to the weight. Figure 1 illustrates the rise of the static frictional force to a maximum and the subsequent drop to the constant kinetic frictional force once the static frictional force is overcome and the object starts moving.

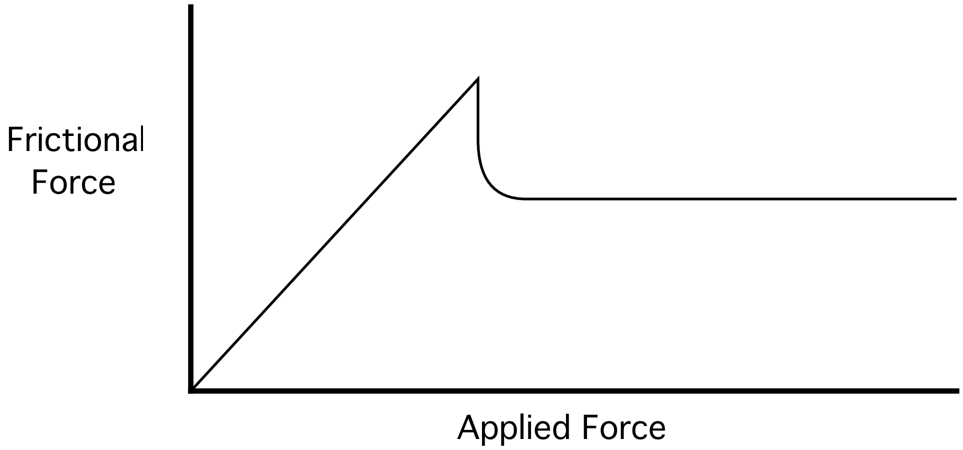

Figure 1

The coefficient of kinetic friction is defined as the ratio of the kinetic frictional force divided by the contact force (usually the weight of the object):

$$\mu_k = F_k / F_{Contact} \qquad \text{Eqn. 1}$$

In this experiment, you will follow a similar procedure to that in the previous experiment. But, instead of using a wheeled cart to minimize the friction, you will use a wooden block resting on the table surface. Measuring the time to accelerate through a given distance will allow you to calculate the acceleration. The actual acceleration will be less than it would be without friction because the force of friction acts as a retarding force. Newton's 2nd Law gives:

$$F_{app} - f_k = m_{Total}a \quad \Rightarrow \quad f_k = F_{app} - m_{Total}a \qquad \text{Eqn. 2}$$

You will find μ_k by direct division.

$$\mu_k = f_k / F_{Contact} \qquad \text{Eqn. 3}$$

Note that μ_S is expressed as a ratio of forces. In our experiment each force will be generated by a weight. The contact force can then be calculated as $F_{Contact} = m_{Block}g$. So Equation 3 can be rewritten as:

$$\mu_k = f_k / m_{Block}\, g \qquad \text{Eqn. 4}$$

II. The Experiment

We will concentrate on the force of kinetic friction to save time. You could also use the same apparatus to determine the coefficient of static friction without the aid of a meter stick and timer. Another interesting way to find the coefficient of static or kinetic friction is to tilt the surface until the object slides. It can be shown that the tangent (rise/run) of the angle of the surface is the coefficient of friction.

But what we will do is to add weights to a hanger and find the resulting acceleration of the system consisting of the block mass and the hanging mass. The force of the hanging weight will be transferred to the object with a string and pulley. as in Figure 2.

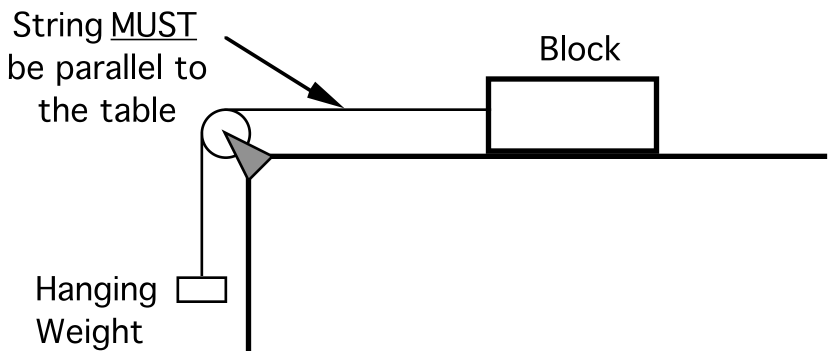

Figure 2

The main difficulty with this experiment is measuring the short times involved. Each run will start with the release of the block and end with the collision of the hanging mass with the floor. This should take between 1 and 2 seconds. Less than 1 second is very hard to measure. More than 2 seconds introduces increased error due to irregularities in the surface and static friction. Since your uncertainty in pressing the timer button is around ±0.05 seconds at best, up to a ±5% experimental error is introduced to start with. This is made worse as our calculation of acceleration involves squaring the measured time which approximately doubles the probable error to ±10%.

III. Procedure

1. Weigh the block (convert to kilograms when you record it below).

   Block mass M_B ________________kilogram______

2. Place the largest wood side of the block down against the table. Hang the string from the block over the pulley and connect the paperclip to the other end of the string. Adjust the pulley height, if needed, to make sure that the string from the block to the pulley is roughly parallel to the table top. If it isn't, part of the tension will lift the block up or jam the block into the table. Either will change the value of μ_k that you get.

3. Measure the distance from the bottom of the hanging mass to the floor when the hanging mass is up as high as possible (i.e. with the top of the paper clip touching the pulley). You should convert this distance to meters.

   Falling distance L _______meter__

4. Add a 50 gram mass to the paper clip/hanger so that the block will slide.

5. Record the time needed for the hanging mass to fall from its maximum height near the pulley to the floor below. Repeat until you have 3 reliable measurements.

   Time for 1st run ______________sec____

   Time for 2nd run ______________sec___

   Time for 3rd run _______________sec___

6. Change the hanging mass to 60 gram and record 3 reliable measurements as in part 5 above.

   Time for 1st run ______________sec____

   Time for 2nd run ______________sec___

   Time for 3rd run _______________sec___

7. Change the hanging mass to 70 gram and record 3 reliable measurements as in part 5 above.

   Time for 1st run ______________sec____

   Time for 2nd run ______________sec___

   Time for 3rd run _______________sec___

IV. Calculations and Analysis

1. Calculate the average run times for parts III.5, 6, and 7.

   Average time for part III.5 runs _______________ sec

   Average time for part III.6 runs _______________ sec

   Average time for part III.7 runs _______________ sec

2. Calculate the average acceleration for each time above. (Note that $a = 2L/t^2$)

   Average acceleration for part III.5 runs _______________ m/s^2

   Average acceleration for part III.6 runs _______________ m/s^2

   Average acceleration for part III.7 runs _______________ m/s^2

3. Calculate the total mass for each set of runs. (Note that $m_{Total} = m_{Block} + m_{Hanging}$).

   Total mass for part III.5 runs _______________ kilogram

   Total mass for part III.6 runs _______________ kilogram

   Total mass for part III.7 runs _______________ kilogram

4. Calculate f_k for each set of runs using Equation 2 ($f_k = F_{app} - m_{Total}a = m_Hg - m_{Total}a$).

   Kinetic frictional force f_k for part III.5 runs _______________ Newton

   Kinetic frictional force f_k for part III.6 runs _______________ Newton

   Kinetic frictional force f_k for part III.7 runs _______________ Newton

5. Convert the kinetic frictional forces above into coefficients of kinetic friction using Eqn 4.

   Coefficient of kinetic frictional force μ_k for part III.5 runs _______________

   Coefficient of kinetic frictional force μ_k for part III.6 runs _______________

   Coefficient of kinetic frictional force μ_k for part III.7 runs _______________

6. Calculate the average value of the coefficient of kinetic friction.

   average value of μ_k _______________

7. Calculate the percent deviation from the average value μk for each set of runs.

   Percent deviation from average μ_k for part III.5 runs ______________________

   Percent deviation from average μ_k for part III.6 runs ______________________

   Percent deviation from average μ_k for part III.7 runs ______________________

V. Questions

1. Does your data indicate that the force of kinetic friction is constant even when the speed of the block changes?
2. From the result in part IV.7. what can you conclude about the accuracy of this experiment?
3. If you rotated the block so that it sat on its smaller side (put the smaller wooden surface against the table), would the force of kinetic friction be increased or decreased? Explain why.
4. Why is it not a good idea to use run times longer than 2 seconds? They could be obtained by reducing the hanging mass and would be measurable with less relative inaccuracy.
5. What is the relationship between μ_s and μ_k? Which is usually larger? Why?
6. Can μ_s or μ_k be greater than 1? Explain what this would mean in real terms.