**Experiment 4**

**Coefficient of Sliding Friction**

In this experiment you study the force $F_{fric}$ that is exerted on a moving object due to friction. When an object slides on a surface of contact, the force of kinetic friction depends upon (1) the nature of the two surfaces in contact and (2) the perpendicular (or normal) force $F_N$ exerted on the object by the surface. Dependence (1) is quantified by the coefficient of kinetic friction $\mu$, which is defined by the equation $\mu = F_{fric}/F_N$. Ideally, the coefficient of kinetic friction only depends on the nature of the surfaces. It does not depend on any other factors, including the relative speed of the surfaces and the surface area of contact. You will determine $\mu$.

You investigate the force of friction by studying objects moving at constant speed. In order to slide an object at constant speed over a surface with which it is in contact, Newton’s 1st Law requires application of a force with a component parallel to the direction of motion which is equal in magnitude but opposite in direction to the force of friction, which opposes the motion.

**Preliminaries.**

**Part a. Horizontal surface.**

If a block is sliding over a horizontal surface, (Figure 1) the total weight of the block is equal in magnitude to the normal force, or $F_N = Mg$, where $M$ is the mass of the block. The force necessary to overcome the friction force and cause the block to move at constant speed is supplied by the tension $F_T$ in a cord that passes over a pulley and holds a weight. $F_T = F_{fric} = mg$.

$$\mu = F_{fric}/F_N = mg/Mg = m/M$$

**Part b. Inclined surface.**

If the surface is tilted to the angle called the angle of repose $\theta_R$, then the block, when started with a slight tap, moves down the plane with a constant speed.

In this case, the normal force is equal in magnitude to the component of the weight of the block perpendicular to the surface of contact, or $F_N = Mg \cos \theta_R$

A definite relationship exists between the angle of repose $\theta_R$ and the coefficient of sliding friction.

$$\mu = \tan \theta_R$$

**Procedure.**

NOTE: The sliding blocks have two types of surfaces: “wood” and “felt”. Use the same surface consistently throughout the experiment.

**Part a. Horizontal surface.**

• Prepare the system as in Figure 1. Increase the hanging mass $m$ until, with a gentle tap, the mass $M$ begins to slide. The hanging mass might be less than a weight holder, which has a mass of 50 g. If so, use a paperclip to attach mass to the string.
Be sure that the cord is horizontal, parallel with the plane. A true constant speed is difficult to attain because \( \mu \) varies as the characteristics of the surface vary along the path. Record the mass values. Determine the uncertainty in the value of \( m \) by adding / subtracting small masses to \( m \) until you can definitely see that the speed of the block is changing.

- Continue the experiment by adding successively heavier masses on top of the block; the mass of the block \( M \) now equals its own mass plus the additional mass stacked on it. Determine the value of the hanging mass \( m \) (and its uncertainty) needed to cause constant speed for each value of block mass \( M \). Repeat for at least five different sliding block masses.

- Place the block on its narrow side with, perhaps, 500 grams stacked on it. Readjust the pulley so that the cord is again parallel to the plane. Find the value of \( m \) necessary to cause the block to slide at constant speed. This will be your test to see if the frictional force has any dependence on the surface area of contact.

**Part b. Inclined surface.**

- Prepare the system as in Figure 2. Increase the angle \( \theta_R \) until, with a gentle tap, the block \( M \) begins to slide. Be sure that the cord is parallel to the plane. A true constant speed is difficult to attain because \( \mu \) varies as the characteristics of the surface vary along the path. Record the value of the angle of repose \( \theta_R \). Determine the uncertainty in the value of \( \theta_R \) by increasing / decreasing the tilt of the track until you can definitely see that the speed of the block is changing.

**Parts a and b.**

- Calculate the normal force \( F_N \) for each measurement made in part a and b.

- Calculate the coefficient of friction \( \mu \) for each measurement made in part a and b.

- Plot your values on a graph of \( \mu \) vs \( F_N \). The simple expectation is that \( \mu \) is a constant. Mark the values from part a with a circle around the points, but mark the single value obtained from the side of the block with an X. Mark the value obtained from the angle of repose by putting a triangle around the point.

**Questions** (Answer clearly and completely).

1. Is the coefficient of friction a constant as the normal force varies or is there any trend apparent? If it is constant, what is its value?

2. Does the area of contact have an effect? How do you know?

3. Is the equation directly above Figure 1 true at any speed? How about if the hanging mass is speeding up as it falls?

4. Derive the relationship between the coefficient of friction and the angle of repose, \( \mu = \tan \theta_R \), by applying Newton’s Laws to the free body diagram of Figure 2.