Friction and Newton's Laws

Introduction

Coefficients of static friction and kinetic friction are determined for a block connected by a string over a pulley to a hanging mass. Static friction is studied by first finding the maximum value the hanging mass can have while the block remains at rest. Kinetic friction is examined by using the Photogate to measure the velocity of the block as it slides along the track. The slope of the velocity vs. time graph gives the acceleration of the system.

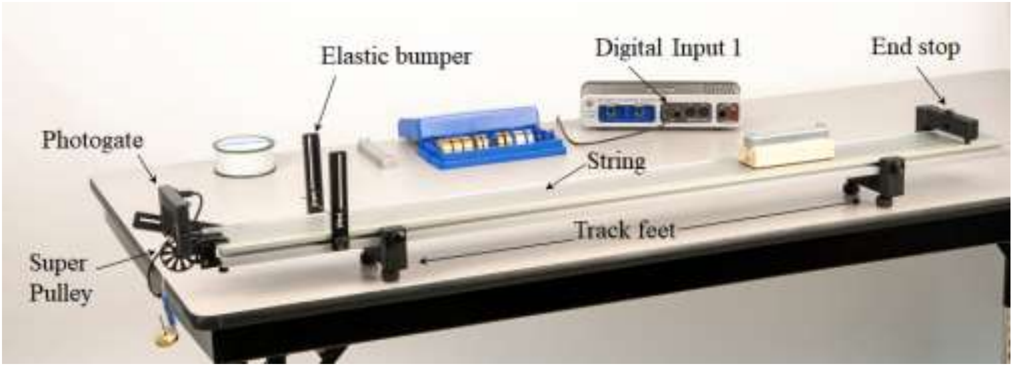

Figure 1: Measuring Coefficients of Friction

Equipment

Qty	Items	Part Number
1	Dynamics Track Feet (Pair)	ME-8972
1	Dynamics Track End Stops (Only 1 needed)	ME-8971
1	Elastic Bumper (Elastic & 3 brackets needed)	ME-8998
1	Photogate	ME-9498A
1	Super Pulley with Clamp (from ME-3420)	ME-9448B
1	1.2m Starter Dyn Track	ME-9493
1	250g Cart Mass (Pair)	ME-6757A
1	Friction Block	ME-9807
1	Mass and Hanger Set	ME-8979
1	String	SE-8050
Required, but not included:		
1	Balance	SE-8723
1	550 Universal Interface	UI-5001
1	PASCO Capstone Software	

Setup

1. Attach the feet to the bottom side of the track, as shown in Figure 1, and level the track.

2. On the top side of the track, attach an end stop at one end, and the elastic bumper (made of two photogate brackets and the elastic band) about 15 cm from the opposite end of the track, as shown in Figure 1.

3. Attach the third photogate bracket at the end near the elastic bumper, cantilevered out over the end of the track, as shown in Figure 2.

   Note that the bracket is put on "reversed" so that it doesn't key into the slot on the side of the track. This allows you to angle the bracket and photogate.

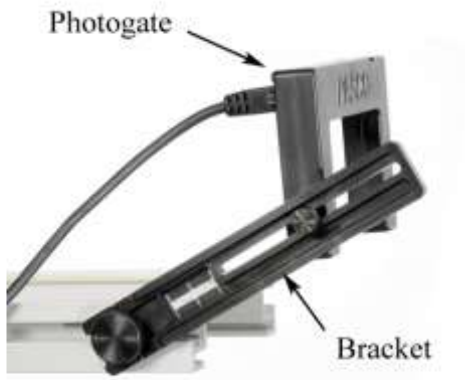

Figure 2: Reversed Bracket

4. Plug the photogate cord into Digital Input #1 of the 550 Universal Interface.

5. Attach the Super Pulley with its clamp at the end of the track with the photogate, so it is under the photogate, as shown in Figure 1.

6. Use the balance to determine and record the combined mass of the friction block and one cart mass, before attaching string. This combination will be the "block" with mass m_2, as shown in Figure 3.

7. Cut a piece of string about 1.2 m long. Tie one end of the string to the friction block. See Figure 3. Place the friction block on the track, felt side down. Place one cart mass on the friction block. Make sure the cart mass is centered on the friction block.

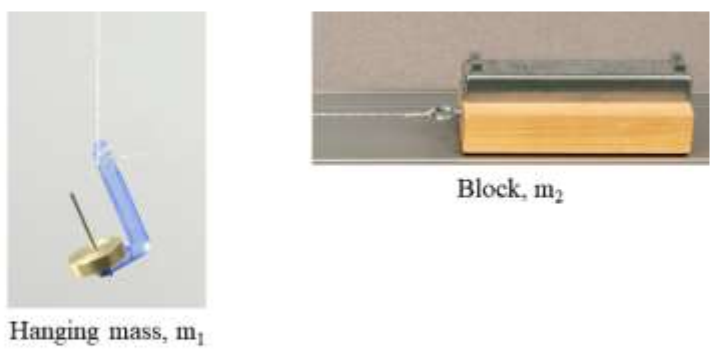

Figure 3: Hanging Mass and Block

8. Pass the other end of the string over the pulley, and then tie it to a mass hanger, as shown in Figure 3. To start, add 50 g to the hanger (5 g), so the total hanging mass is 55 g.

9. When the block reaches the end of the track, you want it to hit the elastic bumper before the hanging mass reaches the floor. Check this, and if necessary, shorten the string.

10. Adjust the pulley height so the string runs parallel to the track, as shown in Figure 3 on the right. Make sure the string does not touch the elastic bumper.

11. Adjust the position of the photogate so that the pulley spokes break the photogate beam. The indicator light on the photogate is on when the beam is blocked by a spoke, and off when the beam passes through between spokes.

12. In Capstone, open Timer Setup in the left toolbar. Choose a pre-configured timer for the photogate in channel 1. Select a photogate with pulley as the type of timer, and select Position and Linear Speed as measurements that will be visible. The spoke arc length is 0.015 m and the spoke angle is 36 degrees.

13. In the lower toolbar, open Recording Conditions. Set a Start condition to be measurement based for Position (in meters) above 0.05. Set a Stop condition to be measurement based for Position (in meters) above 0.40. Later, after you click Record during measurements, these conditions will cause recording to start automatically after the masses have moved 0.05 m, and stop automatically after 0.40 m. You can adjust these conditions later if needed to suit your experiment.

Theory – Kinetic Friction

In Figure 3, assume the hanging mass moves and accelerates downward, and the block slides and accelerates to the left.

The free-body diagrams (see Figure 4) show the forces acting on the hanging mass, m_1, and the block, m_2. The tension, T, is assumed to be constant throughout the string. The kinetic friction force, f, and the normal force, n, are both caused by the track and act on the block.

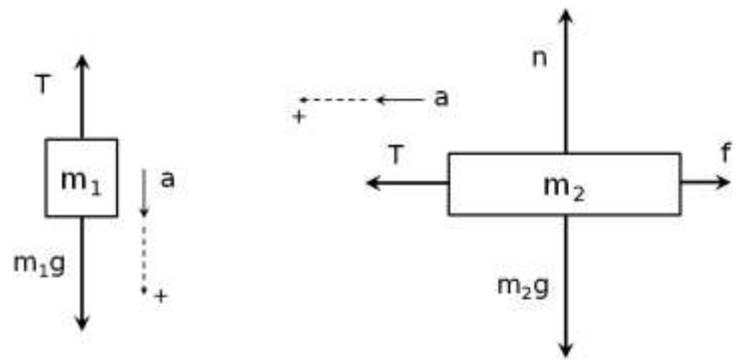

Figure 4: Free-body Diagrams

The sign convention is such that the hanging mass's acceleration, a, is positive downward, and the block's acceleration is positive to the left.

Applying Newton's 2nd Law to m_1 in the vertical direction gives

$$m_1g - T = m_1a \qquad (1)$$

Applying Newton's 2nd Law to m_2 in the horizontal direction gives

$$T - f = m_2a \qquad (2)$$

Since the track is level and the string pulls horizontally on m_2, the vertical forces acting on it cancel out, and so have equal magnitudes:

$$n = m_2g \qquad (3)$$

The kinetic force f is given by

$$f = \mu_k n \qquad (4)$$

where μ_k is the coefficient of kinetic friction.

Theory – Maximum Static Friction

Now assume everything is instead at rest in Figure 3, but the hanging mass, m_1, has just the right value so that the block, m_2, is ***just about to slip***. In other words, if m_1 is increased from this value, then the block will begin to slide and the system will accelerate.

In this situation, the acceleration, a, is zero, and the friction force, f, acting on the block is the maximum static friction force:

$$f = \mu_s n \qquad (5)$$

where μ_s is the coefficient of static friction.

Procedure – Maximum Static Friction

1. With the 50 g you already placed on the mass hanger, you should be able to position the block on the track and not have it slip. However, if you cannot keep it from slipping, decrease the hanging mass.

2. Now increase the hanging mass, m_1, until the block just begins to slide. Fine tune the value of m_1 until you find the maximum value of m_1 that will NOT cause the block to begin to slide.

   Try several times in several different track locations. Try pushing down on the block and releasing as gently as possible. Make sure the hanging mass is not swinging.

   Record only the absolute maximum value of m_1 such that m_2 will not slide. Remember to add the hanger's mass of 5 g to the mass on the hanger to get the total m_1.

3. Calculate the coefficient of static friction μ_s as follows:

   Combine Equations 1 to 3, and Equation 5. Do not use Equation 4 here. Why not?

   Use your maximum value of m_1, and the value of m_2 you measured earlier for the block. Remember that in this situation, the acceleration, a, is zero.

4. What are the units of μ_s? Explain.

5. In most situations, $\mu_s < 1$. Is this the case for your value?

6. Coefficients of friction are always due to an interaction between a pair of surfaces. One surface is felt: What is the other?

Procedure – Kinetic Friction

1. In Capstone, create a graph of Linear Speed vs. Time.

2. In Capstone, create a table. In the first column, create a new user-entered data set called Experimental Acceleration in units of m/s^2. Delete the second column. Turn on statistics, and select the mean and the standard deviation.

3. Pull the block back on the track as far as possible so that the hanging mass is just a few cm below the pulley. Make sure the block can travel at least 0.40 m before hitting the elastic bumper. If it cannot, then adjust the Stop condition in Recording Conditions.

4. Holding the block in place, set the hanging mass to the maximum value of m_1 determined previously.

5. Click on Record. Release the block and give it a small push to get it going. Recording should start automatically after the block has traveled 0.05 m, and stop automatically after 0.40 m. The graph should be approximately linear.

6. On the graph toolbar, turn on the curve fit, and select linear fit. Record the slope in the table of Experimental Acceleration values.

7. Take several runs and record the mean Experimental Acceleration, a, for each.

8. Use Equations 1 and 2 to calculate the frictional force, f.

9. Use equations 3 and 4 to calculate the coefficient of kinetic friction, μ_k.

10. In most situations, $\mu_k < 1$. Is this the case for your value?

11. Generally, $\mu_k < \mu_s$. Is this the case for your results?