

Static & Kinetic Friction



***Produced by the Physics Staff at
Collin County Community College***

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Purpose

The purpose of this activity is to measure frictional force coefficients for an object sliding across a surface. Also, we explore and test the model (theory) of constant frictional coefficients.

Equipment

- 1 Pasco Track
- 1 Rod Clamp
- 1 Large Ringstand
- 1 Slotted Mass Hanger
- 1 Slotted Mass Set
- Lab Balance
- 1 Smart Pulley w/ Clamp
- 1 End Stop
- 1 Friction Block
- Roll of String
- Liquid Household Cleaner

Introduction

If you think of friction at all, you probably consider it to be an energy-wasting nuisance. It converts useful energy into heat and it slows and eventually stops all motion. But the fact is, you could not live without friction. You couldn't walk or drive a car, you couldn't eat with a fork, you couldn't pick up anything unless you could somehow get your hand under it, and even if you could hold a pencil or pen, you couldn't write on paper.

So friction is vitally useful to you. Sure it wastes energy, reduces a machine's efficiency, wears out its moving parts, and creates heat, but it also allows your hands to grip objects and it provides traction between your shoes (or tires) and the ground.

The nature of friction is quite complicated, but its effect is straightforward. In the study of the motion of objects, you treat friction as a force between two adjoining surfaces. Unlike inertia, which resists any changes in an object's motion, the frictional force on an object resists the motion itself. If an object is at rest relative to its environment, friction resists putting it in motion. If the object is made to move anyway, friction resists keeping it in motion.

A frictional force, like all forces, is a vector quantity. Its magnitude depends on (a) the material the two objects or substances are made of, (b) the smoothness of their surfaces, and (c) how tightly they are being pressed together. Its direction is always opposite to (a) the component of the applied vector force that is parallel to the surface if the object is motionless, or (b) the vector velocity of an object if it is moving. In this experiment, you will examine the "laws of friction" between two solid objects in contact, and determine the coefficients of friction between their adjacent surfaces.

YOU WILL LEARN TO:

- 1) Describe how coefficients of friction are determined experimentally,

- 2) Describe whether and how the friction between two solid objects is affected by their relative velocity and acceleration, by their contact surface area, and by the magnitude of the force pressing them together, and
- 3) Explain why the frictional force between an object and the surface it rests on is proportional to the normal (perpendicular) force pressing them together rather than to the object's weight.

Theory

We use the word friction to describe the resisting force that arises when we slide, or attempt to slide, a solid object on a solid surface. In machinery, the adjoining surfaces may slide back and forth in a straight line or may rotate like an axle in a bearing. We use a different word, drag, to describe the resisting force that arises when a solid object moves through a fluid (a liquid or a gas). This is what causes a boat, a raindrop, or a parachutist to have a maximum speed (when the applied force equals the drag force) or what causes a spacecraft re-entering the atmosphere to heat up. In this experiment, you will investigate the friction between a solid object and a solid surface.

The frictional force is always directed parallel to the surface between the objects. Experiments have shown that the magnitude of the frictional force depends on the materials the objects are made of, on how smooth or rough the surfaces in contact are, and on the magnitude of the force pressing the objects together. This “pressing together” force is called the normal force because it is always normal to the surface.

Counter to what you might suppose, the frictional force does not depend on either the area of contact between the objects or the relative speed between them, as long as the speed isn't too great. The relationship between the frictional force and the normal force is expressed by the linear equation:

$$F_f = \mu F_N \qquad \text{Equation 6.1}$$

where the Greek letter μ (mu) is a dimensionless constant of proportionality called the coefficient of friction, F_f is the frictional force, and F_N is the normal force.

Your everyday experience tells you that there are two different kinds of friction. A force of static friction occurs when two objects are at rest relative to each other and you attempt to make one of them slide over the other one. This static frictional force arises to oppose any applied force trying to cause motion along the surface of contact.

The most familiar example of static friction is walking. The friction between the soles of your shoes and the ground prevents your shoe from sliding when you push your foot backward against the ground. The forward reaction force (Newton's third law) of the ground against your foot is the force that causes your body to move forward. If the coefficient of friction between shoe and ground is too low, such as when the ground is covered with ice, your foot does indeed slide when you push backward on the ground, and you don't walk. The magnitude of this frictional force is related to the magnitude of the normal force by the equation:

$$F_f \leq \mu_s F_N$$

Equation 6.2

where μ_s is the coefficient of static friction between the materials of the two surfaces. The meaning of the inequality in this relationship is that the static frictional force is a vector that is equal in magnitude but opposite in direction to the applied force. The frictional force increases as the applied force increases from zero up to a maximum value given by $\mu_s F_N$. If the applied force exceeds this value, then the surfaces begin to move relative to one another.

Another kind of friction occurs when the two surfaces in contact are moving relative to each other. The kinetic frictional force is also characterized by a proportionality constant, this time called the coefficient of kinetic friction. The kinetic frictional force is therefore given by:

$$F_f = \mu_k F_N$$

Equation 6.3

Note that in general $\mu_k < \mu_s$ for any two materials. Table 6.1 below gives approximate values for coefficients of static and kinetic friction between some common materials.

Table 6.1: Coefficients of Friction		
Materials	μ_s	μ_k
Aluminum on Aluminum	1.05	1.40
Glass on Glass	0.94	0.35
Rubber on Concrete (dry)	1.20	0.85
Rubber on Concrete (wet)	0.80	0.60
Steel on Aluminum	0.61	0.47
Steel on Steel (dry)	0.75	0.48
Teflon on Steel	0.04	0.04
Teflon on Teflon	0.04	0.04
Steel on Ice	0.02	0.02
Waxed Wood on Snow	0.05	0.03
Wood on Aluminum	0.30	0.20
Wood on Wood	0.58	0.40

The coefficient of friction between two surfaces is primarily related to their roughness. Even a surface that appears to be smooth can actually look quite rough when examined under a microscope as in Figure 6.1. When you place a flat-bottomed block of wood on a flat aluminum track, the microscopic peaks and valleys in the bottom surface of the block tend to interlock with those in the track below, like two sheets of sandpaper placed face to face. When you attempt to slide the block on the track, the interlocked micro-irregularities of the two surfaces oppose the force that you apply, giving rise to the static frictional force.

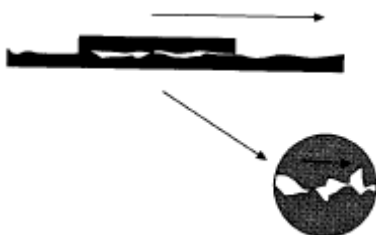


Figure 6.1

Note that as long as at least one micro-peak remains locked in place, the block cannot slide. Thus, to a good approximation, the static frictional force does not depend on the contact area between the surfaces. To free the locked surfaces without breaking off the micro-irregularities, you must raise the block over the bumps, overcoming the force pressing the block against the track. If the track is horizontal, this force is simply equal to the block's weight. However, if the track is inclined at an angle as shown in Figure 6.2, only the component of the block's weight that is perpendicular to the track ($mg \cos \theta$) contributes to the force pressing them together. From Newton's third law, you can see that this normal component of its weight is equal to the normal force.

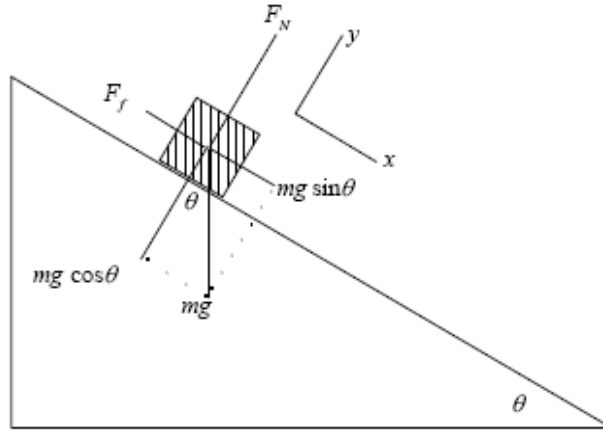


Figure 6.2

Therefore, to avoid confusion, always use the normal force rather than the weight to calculate frictional forces, even when the surface is horizontal and the normal force is equal to the weight.

Figure 6.2 includes a free-body diagram of the forces acting on the block. The block's weight, mg , has been replaced by its two components: $mg \sin \theta$ parallel to the ramp and $mg \cos \theta$ normal to the ramp. If the block is in equilibrium, either at rest or sliding with constant velocity, the net force on the block must equal zero. The only way a vector can be zero is for each component to be zero; so $F_N = mg \cos \theta$ and $F_f = mg \sin \theta$. For the block at rest, F_f is the static frictional force. If the block is sliding with constant velocity, F_f is the kinetic frictional force.

You can solve for the coefficient of static friction. As long as the block is stationary, F_f increases with $mg \sin \theta$ as the ramp is elevated. Maximum static friction occurs when the elevation angle is just great enough to break the static friction and cause the block to slide. So you can write:

$$\mu_s = \frac{F_{f(\max)}}{F_N} = \frac{mg \sin \theta_{(\max)}}{mg \cos \theta_{(\max)}} = \tan \theta_{(\max)} \quad \text{Equation 6.4}$$

Similarly, you can solve for the coefficient of kinetic friction. If the block is sliding at constant velocity, then it is also in equilibrium and:

$$\mu_k = \frac{F_f}{F_N} = \frac{mg \sin \theta}{mg \cos \theta} = \tan \theta \quad \text{Equation 6.5}$$

Using similar methods, you can find the coefficients of friction for a block sliding on a horizontal track. Referring to Figure 6.3, m_1 is the mass of the sliding block and m_2 is the hanging mass. The weight of the hanging mass exerts a tension T on the sliding block which depends on m_1 , m_2 , and the angle θ at which the track is inclined. If m_2 is sufficiently large, m_1 and m_2 will move with an acceleration a . The kinetic frictional coefficient can be calculated from these values (see the prelab, question 4).

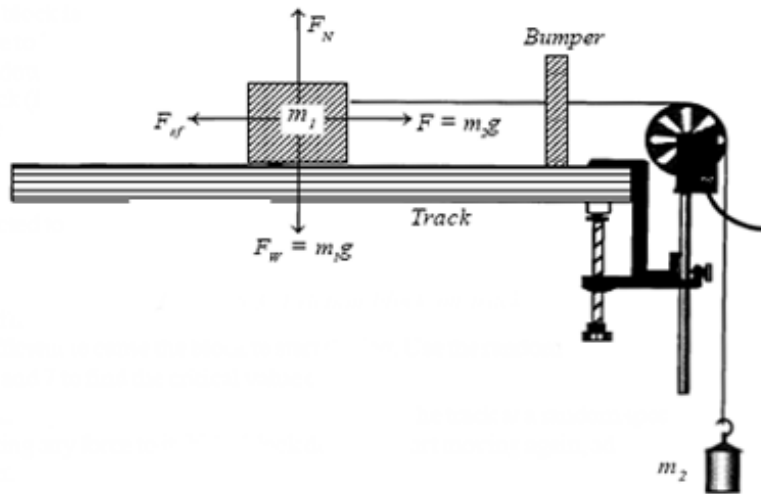


Figure 6.3

Procedure

A. Determination of μ_k and μ_s (equilibrium)

- 1) Use cleaning solution and paper towels to thoroughly clean the track's surface where the block will slide.
- 2) Weigh the wood block and record its mass m_b in Table 6.1.
- 3) Use the rod clamp and ringstand to raise one end of the track such that its surface is at an incline. The angle of inclination can be adjusted by raising and lowering this end of the track.
- 4) Place the block on its *wood* surface at the high end of the track as shown in Figure 6.4.
- 5) Adjust the angle of inclination θ_s so that block just begins to slide *without* an initial push. Try to avoid any sharp bumping or jarring of the block by raising and lowering the track as gently as possible.
- 6) Record this angle θ_s in Table 6.1. Calculate and record μ_s in Table 6.1.
- 7) Place the block on the track, and adjust the angle of inclination θ_k so that, *with an initial push*, the block slides down the track with a constant velocity.
- 8) Record this angle θ_k in Table 6.1. Calculate and record μ_k in Table 6.1.

- 9) Place additional mass m_w on top of the block, and record the new total mass $m_b + m_w$ in Table 6.1. Repeat steps 4-8 and record your results in Table 6.1. Calculate the percent difference between the values of μ_s and μ_k found using different masses.
- 10) Repeat steps 5-10 using the *felt* side of the block. Record your results in Table 6.2.

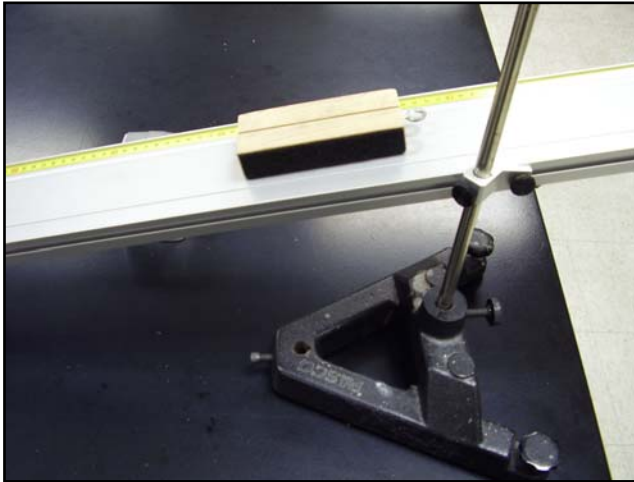


Figure 6.4

B. Determination of μ_k (accelerated motion)

- 1) Place the track flat on the lab table (without leveling feet) with its right end protruding slightly off the edge. Install a bumper a few centimeters from the right end, then clamp the Smart Pulley to that end so that it projects beyond the table's edge.
- 2) Set the block flat on its *wood* surface at the left end of the track. Cut a length of string about 2 m long and tie small loops in both ends. Hook one end of the string to the block, run the string over the pulley, and hook the other end to the mass hanger as in Figure 6.5. Adjust the height of the pulley so the string between it and the block is parallel to the track. Record the mass of the block m_b in Table 6.3.
- 3) Switch on the computer, monitor, and interface. Open Data Studio and select "Create Experiment". In the Experiment Setup window, drag a Smart Pulley sensor to the Interface.
- 4) Open a Graph display window. The graph should show *velocity* vs. *time*.
- 5) Increase the hanging mass m_h so that the block slides on the track *without* an initial push. Record this value of m_h in Table 6.3.
- 6) Pull the block back until the hanging mass is raised almost to the pulley. Press "Start" in Data Studio and then release the block.
- 7) Data Studio will plot the block's velocity vs. time as measured by the Smart Pulley.
- 8) Drag a selection rectangle with the mouse to include only the linear region of the graph. Click the Fit button and select Linear Fit. A linear regression calculation fits the selected data to the linear equation $y = mx + b$, where y is the instantaneous speed of the two-mass system, x is the time, b is the y intercept (the value of speed at $t = 0$), and m is the value of the slope of the highlighted data. Recall that the slope of any velocity-vs-time graph is the average acceleration. If the slope is constant, the block's acceleration must be constant.
- 9) Record the system's acceleration a in Table 6.3 (the acceleration should be positive... a negative acceleration just means the pulley is turned around backwards).

- 10) Use Newton's second law to calculate the force of kinetic friction and the coefficient of kinetic friction for wood on aluminum. Record this value of μ_k in Table 6.3.
- 11) Repeat steps 6-10 with the block on its *edge* to see how a smaller surface area affects the coefficient of kinetic friction. Use the same value of hanging mass that you used earlier so you can compare this run to the run done with the same m_h but larger contact area. Calculate and record the value of μ_k and the percent difference between this value and your first value in Table 6.3.
- 12) Place the block in its original (flat) orientation. Double the weight of the block by placing additional mass m_w on top of the block equal to m_b . Double the hanging mass, then repeat steps 6-10 to see how a larger normal force affects the coefficient of kinetic friction. Calculate and record the value of μ_k and the percent difference between this value and your first value in Table 6.3.
- 13) Repeat steps 5-12 using the *felt* side of the block. Record your result in Table 6.4.
- 14) Close Data Studio and switch off the computer system. Unplug, coil, and secure the sensor cable. Clean the track again with a moist paper towel, then return all your equipment to the lab cart and clean up your lab table area.



Figure 6.5