15 Friction
Slip-Stick

Purpose

To investigate three types of friction and to measure the coefficient of friction for each type.

Required Equipment and Supplies

friction block (foot-long 2 x 4 with an eye hook)
spring scale with maximum capacity greater than the weight of the friction block
set of slotted weights
flat board
meterstick
shoe

Discussion

Friction results when the surfaces of two objects slide or tend to slide over each other. When the objects are in contact, molecules of one surface are attracted to the molecules of the other. Ridges and valleys of one surface settle into the valleys and ridges of the other surface. In sliding, a slip-and-stick sequence occurs as molecules cling and break away from one another.

Air between the surfaces tends to act as a lubricant. The more tightly the surfaces are pressed together, the more air is squeezed out and the greater the attraction between molecules of the two surfaces. So the force of friction between the surfaces depends on the nature and condition of the surfaces, and on how hard the surfaces are pressed together.

Friction also occurs for objects moving through fluids. This friction, known as *fluid friction*, is complex to calculate because it depends on the interaction of the object's surface with the fluid. Air is a fluid, and the motion of a leaf falling to the ground is quite complicated! In this experiment you will be concerned only with the friction between two solid surfaces in contact.

Friction acts in a direction to oppose motion. For a ball moving upward in the air, the friction force is downward. When the ball moves downward, the friction force is upward. For a block sliding along a surface to the right, the friction force is to the left. Friction forces are always *opposite* to the direction of motion.

For a block sliding on a horizontal surface, the force that presses the surfaces together is simply the weight of the block. The ratio of friction force to weight is called the *coefficient of friction* and is symbolized by the Greek letter μ (mu).

$$\mu = \frac{\text{friction force}}{\text{weight}}$$

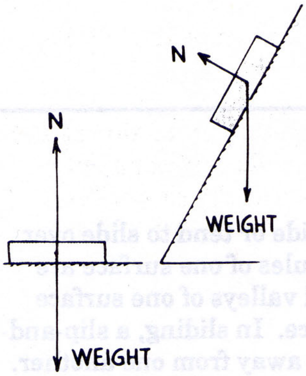
It must be emphasized that this relationship holds true only on a flat surface when the force that presses the surfaces together is only the weight.

The coefficient of friction depends on whether sliding is taking place. When sliding occurs, μ is slightly smaller. (The ridges and valleys are more

SURFACES	μ_s (STATIC)	μ_k (KINETIC)
STEEL ON STEEL, DRY	0.6	0.3
STEEL ON WOOD, DRY	0.4	0.2
STEEL ON ICE	0.1	0.06
WOOD ON WOOD, DRY	0.35	0.15
METAL ON METAL, GREASED	0.15	0.08

Figure 15.1

meshed when the surfaces have time to sink into each other.) When sliding occurs, we speak of the *coefficient of sliding friction* (or coefficient of *kinetic* friction). When friction holds an object at rest, we speak of the coefficient of *static* friction. A partial list of coefficients of both sliding and static friction is shown in Figure 15.1.



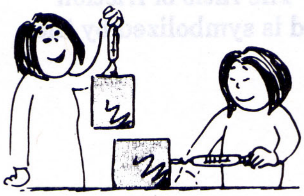
The force that presses surfaces together is the entire weight of the object only when the supporting surface is horizontal. When the object is on an incline, the force pressing the surfaces together is less than the object's weight. The force that presses the surfaces together is perpendicular to the surface and is called the *normal force, N*. (The term *normal* means "perpendicular" in mathematics.) Hence, the force of friction, F_f depends on the coefficient of friction, μ, and the normal force, N:

$$F_f = \mu N$$

For a block on an incline, the normal force is the component of weight that is perpendicular to the surface. For example, an object presses with only half its weight against a 60° incline as compared to against a level supporting surface. So whereas on a level surface N equals the weight of the object, on a 60° incline N equals half the object's weight. The force of friction is therefore half as much on the 60° incline. We will not pursue further trigonometry here and simply say that the normal force, N, equals the weight when the incline is horizontal, and is zero when the incline is vertical because then the surfaces do not press against each other at all.

Part A: Computing the Coefficients of Static and Sliding Friction

Procedure



Step 1. Weigh the friction block by suspending it from the spring scale. Record the weight in Data Table 15.1. Determine the coefficients of static and sliding friction by dragging the friction block horizontally with a spring scale. Be sure to hold the scale horizontally. The static friction force F_f is the force it takes just to get the block moving. The sliding friction force F_f' is the force it takes to keep the block moving at *constant velocity*. Your scale will vibrate around some average value; make the best judgment you can of the values of the static and sliding friction forces. Record your data in Data Table 15.1.

Step 2. Drag the block at different speeds. Note any changes in the sliding friction force.

Data Table 15.1

F_f FORCE TO JUST GET GOING	F_f' DRAG FORCE AT CONSTANT VELOCITY	W WEIGHT OF CART	$\mu_{STATIC} = \frac{F_f}{W}$	$\mu_{SLIDING} = \frac{F_f'}{W}$

1. Does the dragging speed have any effect on the coefficient of sliding friction, $\mu_{sliding}$? Explain.

Step 3. Increase the force pressing the surfaces together by adding slotted masses to the friction block. Record the weight of the block plus added masses in Data Table 15.1. Find both friction forces and coefficients of friction for at least six different weights and record in Data Table 15.1.

Analysis

2. At each weight, how does μ_{static} compare to $\mu_{sliding}$?

3. Does $\mu_{sliding}$ depend on the weight of the friction block? Explain.

4. Tables in physics books rarely list coefficients of friction with more than two significant figures. From your experience, why are more than two significant figures not listed?

5. If you press down upon a sliding block, the force of friction increases but μ does not. Explain.

6. Why are there no units for μ?

Data Table 15.2

CONFIGURATION	F_f FORCE OF FRICTION	W NORMAL FORCE	A AREA OF CONTACT	μ COEFFICIENT OF FRICTION
1				
2				
AVERAGE				

Part B: The Effect of Surface Area on Friction

Procedure

Step 4. Drag a friction block of known weight at a constant speed by means of a horizontal spring scale. Record the friction force and the weight of the block in Data Table 15.2.

Step 5. Repeat Step 4, but use a different side of the block (with a different area). Record the friction force in Data Table 15.2.

Step 6. Compute $\mu_{sliding}$ for both steps and list in Data Table 15.2.

7. Does the area make a difference in the coefficient of friction? Explain.

Going Further

Friction on an Incline

Place an object on an inclined plane and it may or may not slide. If friction is enough to hold it still, then tip the incline at a steeper angle until the object just begins to slide.

The coefficient of friction of a shoe is critical to its function. When will a shoe on an incline start to slip? Study Figure 15.2. To make the geometry clearer, a cube can represent the shoe on the incline, as in Figure 15.3. Triangle B shows the vector components of the shoe's weight. The component perpendicular to the incline is the normal force *N*; it acts to press the surfaces together. This component parallel to the incline and downward tends to produce sliding. This component is equal in magnitude but opposite in direction to the friction force, F_f, when the shoe is in equilibrium. By tilting the incline, we can vary the normal force and the friction force on the shoe.

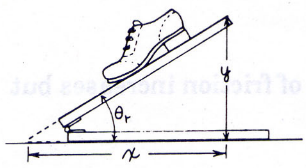


Figure 15.2

At the angle at which the shoe starts to slip (*the angle of repose,* θ_r), the parallel component of the weight of the shoe is just enough that the shoe breaks free. At that angle, the parallel weight component and the friction force are at their maximum. The ratio of this friction force to the normal force gives the coefficient of static friction.

In Figures 15.2 and 15.3, the angle of incline has been set to be the angle of repose, θ_r. With the help of geometry it can be proven that triangles A and B in Figure 15.3 are *similar triangles*—that is, they have the same

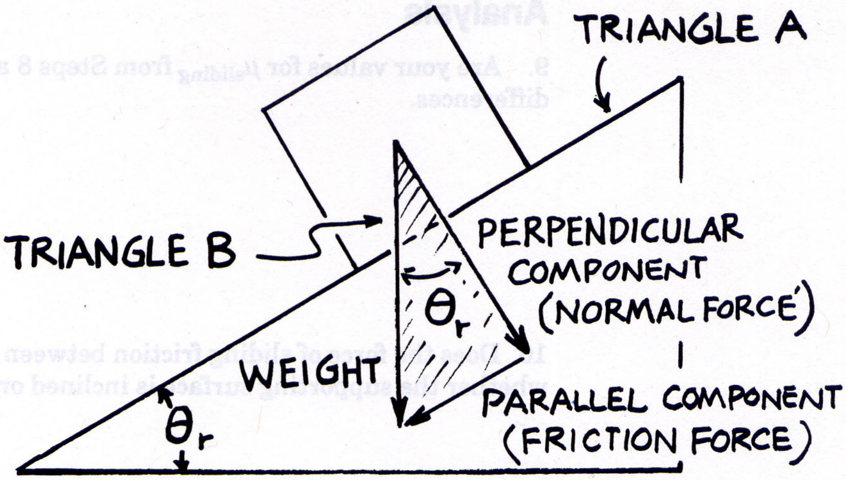
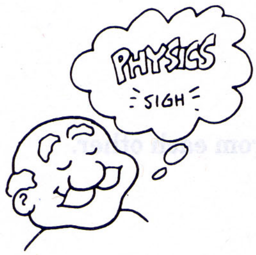


Figure 15.3

angles, and triangle B is a shrunken version of triangle A. The importance of similar triangles is that the ratios of corresponding parts of the two triangles are equal. Thus, the ratio of the parallel weight component to the normal force equals the ratio of the height, y, to the horizontal distance, x. The coefficient of static friction is the ratio of those sides.



$$\mu_{\text{static}} = \frac{F_f}{N} = \frac{y}{x} = \frac{W \sin\theta}{W \cos\theta} = \tan\theta_r$$

So, measuring the coefficient of friction is as simple as finding the tangent of the angle of repose!

Procedure

Step 7. Put a shoe on a board, and slowly tilit the board up until the shoe just begins to slip. Without resorting to a protractor, devise a method to measure the angle of repose, θ_r.

μ_{static} = ________

Step 8. Repeat Step 7, except have a partner tap the board constantly as you approach the angle of repose. Find the coefficient of sliding (kinetic) friction, μ_{sliding}, which equals the tangent of θ_r while the board is being tapped.

μ_{sliding} = ________

8. Did you measure any difference between μ_{static} and μ_{sliding}? How much?

Step 9. With a spring scale, drag your shoe along the same board when it is level. Compute μ_{sliding} by dividing the force of friction (the scale reading) by the weight of the shoe. Compare your result with that of Step 8.

μ_{sliding} = ________

Analysis

9. Are your values for $\mu_{sliding}$ from Steps 8 and 9 equal? Explain any differences.

10. Does the force of sliding friction between two surfaces depend on whether the supporting surface is inclined or horizontal?

11. Does the coefficient of sliding friction between two surfaces depend on whether the supporting surface is inclined or horizontal?

12. Explain why Questions 10 and 11 are different from each other.

Extra for Experts

Describe a method for determining the coefficient of rolling friction for a car. Assume you have large capacity scales available and the weight of the car is listed in the owner's manual.