Friction 7

Whenever a body slides along another body, a resisting force is called into play that is known as the force of friction. This is a very important force and serves many useful purposes—a person could not walk without it, nor could a car propel itself along a highway without the friction between the tires and the road surface. On the other hand, friction is very wasteful; it reduces the efficiency of machines because work must be done to overcome it, and this energy is wasted as heat. The purpose of this experiment is to study the laws of friction and to determine the coefficient of friction between two surfaces.

THEORY

Friction is the resisting force encountered when one surface slides over another; this force acts along the tangent to the surfaces in contact. The force necessary to overcome friction depends on the nature of the materials in contact, their roughness or smoothness, and on the normal force, but not on the area of contact, within wide limits, or the speed of the motion. It is found experimentally that the force of friction is directly proportional to the normal force. The constant of proportionality is called the coefficient of friction.

When the contacting surfaces are actually sliding one over the other, the force of friction is given by

$$F_r = \mu_k N \qquad (7.1)$$

where F_r is the force of friction and is directed parallel to the surfaces and opposite to the direction of motion, N is the normal force, and μ_k the coefficient of friction. The subscript k stands for *kinetic*, meaning that μ_k is the coefficient that applies when the surfaces are moving one with respect to the other. It is therefore more precisely called the coefficient of *kinetic* or *sliding* friction.

A method of checking the proportionality of F_r and N and of determining the proportionality constant μ_k is to have one of the surfaces in the form of a plane placed horizontally with a pulley fastened at one end. The other surface is the bottom face of a block that rests on the plane and to which is attached a cord that passes over the pulley and carries weights. These are varied until the block moves at constant speed after having been started with a slight push. Since there is thus no acceleration, the net force on the block is zero, which means that the frictional force is equal to the tension in the cord. This tension, in turn, is equal to the total weight attached to the end of the cord. The normal force between the two surfaces is equal to the weight of the block and can be increased by placing weights on top of the block. Thus, corresponding values of F_r and N can be found, and plotting them will show whether F_r and N are indeed proportional. The slope of this graph gives μ_k.

When a body lies at rest on a surface and an attempt is made to push it, the pushing force is opposed by a frictional force. As long as the pushing force is not strong enough to start the body moving, the body remains in equilibrium, which means that the frictional force automatically adjusts itself to be equal to the pushing force and thus to just balance it. There is, however, a threshold value of the pushing force beyond which larger values will cause the body to break away and slide. We conclude that in the static case (body at rest) the frictional force automatically adjusts itself to keep the body at rest up to a certain maximum. But if static equilibrium demands a frictional force larger than this maximum, static equilibrium conditions will cease to exist because this force is not available, and the body will start to move. This situation may be expressed in equation form as

$$F_r \leq \mu_s N \qquad \text{or} \qquad F_{r_{max}} = \mu_s N \qquad (7.2)$$

where F_r is the frictional force in the static case, $F_{r_{max}}$ is the maximum value this force can assume, and μ_s is the coefficient of *static* friction. It is found that μ_s is slightly larger than μ_k, which means that a somewhat larger force is needed to break a body away and start it sliding than is needed to keep it sliding at constant speed once it is in motion. This is why a slight push is necessary to get the block started for the measurement of μ_k.

One way of investigating the case of static friction is to observe the so-called *limiting angle of repose,* defined as the maximum angle to which an inclined plane may be tipped before a block placed on the plane just starts to slide. The arrangement is illustrated in Fig. 7.1. The block has weight W whose component $W \cos \theta$ (where θ is the plane angle) is

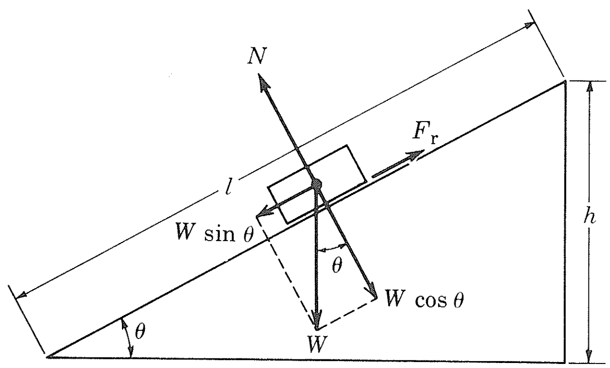

Figure 7.1 *The inclined plane*

perpendicular to the plane and is thus equal to the normal force N. The component $W \sin \theta$ is parallel to the plane and constitutes the force urging the block to slide down the plane. It is opposed by the frictional force F_r, and as long as the block remains at rest, F_r must be equal to $W \sin \theta$. If the plane is tipped up until at some value θ_{max} the block just starts to slide, then $F_{r_{max}} = W \sin \theta_{max}$. But $F_{r_{max}} = \mu_s N = \mu_s W \cos \theta_{max}$. Hence, $W \sin \theta_{max} = \mu_s W \cos \theta_{max}$ or

$$\mu_s = \frac{\sin \theta_{max}}{\cos \theta_{max}} = \tan \theta_{max} \qquad (7.3)$$

Thus, if the plane is gradually tipped up until the block just breaks away and the plane angle is then measured, the coefficient of static friction is just equal to the tangent of this angle. It is interesting to note that W cancelled out in the derivation of Equation 7.3, so that the weight of the block doesn't matter.

APPARATUS

1. Board with pulley at one end
2. Rods, bench clamp, and right-angle clamp for supporting the inclined plane
3. Wood block with a cord attached to it
4. Glass block
5. Set of known weights
6. Weight hanger
7. Triple-beam balance
8. Protractor
9. Lintless dust cloth or paper wipers

PROCEDURE

1. Weigh the wood block and record the weight in newtons.

2. Place the board in a horizontal position on the laboratory table with its pulley projecting beyond the table's edge. Be sure that the surfaces of both the board and the wood block are clean, dry, and free of any dust or grit. Wipe them off if necessary with a clean, dry, lintless cloth or paper wiper. *After this has been done, do not touch these surfaces with your hands*. Handle the block with the cloth or a wiper and set it down *only* on the clean board. Begin the experiment by setting the block on the board with its largest surface in contact with the board's surface. Run the cord attached to the block over the pulley and attach it to the weight hanger. Place some weights on the hanger and slowly increase the load until it is just sufficient to keep the block sliding slowly with constant speed after it has been started with a very small push. Record this load. Don't forget to include the weight of the hanger.

3. Repeat Procedure 2 placing masses of 200, 400, 600, 800, and 1000 g successively on top of the wood block. Record the load needed to produce constant speed in each case.

4. Turn the wood block on its side and repeat Procedure 2 with a mass of 400 g on top of the block. Record the load needed.

5. Again turn the wood block with the largest surface in contact with the plane and place 400 g on top of the block. Gradually increase the load on the hanger until the block just starts to move, without any initial push. Be careful to place the weights on the hanger gently so as not to jerk the cord. Notice whether this time the block moves with uniform speed or whether it is being accelerated. Record the load needed under these conditions. Repeat this procedure twice to obtain three independent measurements of the required load.

6. Set up the board as an inclined plane. Place the wood block on the plane with its largest surface in contact, and gradually tip the plane up until the block just breaks away and starts to slide down. Be very careful to tip the plane slowly and smoothly so as to get a precise value of the angle with the horizontal at which the block just breaks away. This is the limiting angle of repose θ_{max}. Measure it by means of a protractor and record the result obtained in three separate trials. These trials should be independent, meaning that in each case the plane should be returned to the horizontal, the block placed on it, and the plane carefully tipped up until the limiting angle of repose is reached.

7. Repeat Procedure 6 using the glass block. Record the limiting angle of repose obtained in three independent trials.

DATA

Weight of wood block ______

Position of block	Mass placed on the block	Total normal force	Force to keep block moving uniformly
Flat	0 g		
Flat	200 g		
Flat	400 g		
Flat	600 g		
Flat	800 g		
Flat	1000 g		
On side	400 g		

Coefficient of kinetic friction μ_k from graph ______

Coefficient of kinetic friction μ_k from Procedure 4 ______

Total normal force for Procedure 5 ______

Trial	Force to start block moving	μ_s	Deviation
1			
2			
3			
Averages			

Block used	Trial 1			Trial 2			Trial 3			Averages	
	θ_{max}	μ_s	Deviation	θ_{max}	μ_s	Deviation	θ_{max}	μ_s	Deviation	μ_s	Deviation
Wood											
Glass											

Difference between your two values of μ_s ______

Percent error in agreement of the two values of μ_s ______

CALCULATIONS

1. From the data of Procedures 2 and 3, plot a curve using the values of the total normal force as abscissas and the values of the force of friction as ordinates. See if your curve is a straight line and obtain the coefficient of kinetic friction μ_k for wood on wood by finding its slope.

2. Use the data of Procedure 4 to calculate the coefficient of kinetic friction for the case of the wood block sliding on its side. Record your result and see how it compares with the value of μ_k obtained from your graph.

3. From the data of Procedure 5, compute the coefficient of static friction μ_s for wood on wood from each of your three trials. Calculate an average value of μ_s, the deviation for each trial, and the a.d. Record your result on the data sheet.

4. From the data of Procedure 6, calculate μ_s for wood on wood from each of your three trials. Calculate an average value of μ_s, the deviation for each trial, and the a.d. Record your result on the data sheet. Compare this value of μ_s with that obtained in Procedure 5 by finding the difference between the two values and the percent error in their agreement. See whether your two values agree within their limits of error.

5. From the data of Procedure 7, calculate μ_s for glass on wood for each of your three trials and obtain the average value, the deviation for each trial, and the a.d. Record your result on the data sheet.

QUESTIONS

1. Explain in your own words why it is necessary that the block move at constant velocity in Procedures 2–4.

2. (a) How does the coefficient of friction depend upon the normal force between the surfaces in contact? (b) How does it depend upon the area of the surfaces in contact?

3. How does the coefficient of static friction compare with the coefficient of kinetic friction for the same surfaces, areas, and normal forces? In this connection explain what happened in Procedure 5.