EXPERIMENT 3 INCLINED PLANE

DETERMINATION OF THE COEFFICIENT OF FRICTION

Purpose: To determine the static (μ_s) and kinetic (μ_k) coefficients of friction for contacting surfaces using an inclined plane.

Equipments: Ruler, wooden-surfaced block, and fabric-surfaced block.

GENERAL INFORMATION

Force is a measure of an object's interaction with its surroundings. If an object is placed on a table, its surroundings are considered to be the table. When two surfaces are in contact and rub against each other, both objects interact as each other's surroundings. As a result of this interaction, they exert equal and opposite forces on one another. The nature of this force arises from the contact forces caused by the roughness of the interacting surfaces. This force is called the frictional force.

Frictional forces are directly proportional to the roughness of the surfaces of the contacting bodies. They are also proportional to the perpendicular component of the normal forces exerted by the bodies on each other at the contact points (Figure 1). In the most general form, the frictional force is expressed as the product of a proportionality constant and the normal force, given by the equation $f = \mu N$. The proportionality constant μ is referred to as the coefficient of friction for the contacting surfaces. The greater the surface roughness of the bodies in contact, the larger the coefficient of friction for those bodies.

For solid (inelastic, rigid) bodies, the maximum value of the coefficient of friction is 1 , and it is dimensionless. This means that the coefficient of friction between a solid body capable of remaining stationary without sliding on an inclined plane of up to 45 degrees and the surface itself is 1 . It should be noted that for pairs of elastic surfaces in contact, the coefficient of friction can exceed 1. In this experiment, the focus will be on the frictional forces of solid (inelastic) bodies.

Note that although the frictional force is a vector quantity, it is expressed by a scalar equation. As illustrated in Figure 1, the frictional force is the sum of the horizontal components of the normal forces acting at the contact points of the bodies. Similarly, the sum of the vertical components constitutes the normal force vector $\vec{N}$ acting on the body.

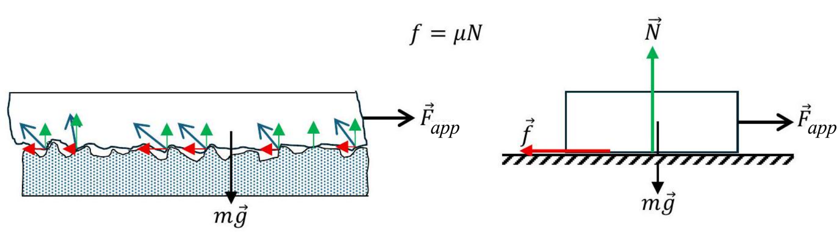


Figure 1

Frictional forces act in the direction opposite to the possible or intended direction of motion of an object. Considering a walking person, the frictional force generated between the sole of the shoe and the ground acts in the opposite direction to the shoe's motion relative to the ground. It may seem contradictory that the frictional force is, at the same time, in the same direction as the person's motion. However, it is the sole of the shoe–not the person–that interacts with the ground. Therefore, this situation does not create a contradiction. If a frictional force opposite to the direction of the person's motion is to be considered, it would correspond to air resistance.

When an object is not in motion but has a tendency to move, frictional force is still present. This means that if an external force is applied to the object but it remains at rest, then, according to Newton's first law, there must be a force acting in the opposite direction with an equal magnitude. This force is known as the static frictional force. The static frictional force exists during the stationary phase, up until the object begins to move. Therefore, the static frictional force can take on multiple values between zero and a maximum value (Figure 2).

Frictional forces also arise when objects move on rough surfaces or through air and liquid environments. In other words, when an object has a relative velocity with respect to its surroundings, the resulting frictional force is called the kinetic friction force. For two solid surfaces in contact, the kinetic friction force has a single, constant value.

As shown in Figure 2, when no horizontal force is applied to an object of mass m resting on a table, no frictional force acts on it (Figure 2-a). When a horizontal force is applied to the object, it still does not move; however, a static friction force f_s equal in magnitude and opposite in direction to the applied force is generated (Figure 2-b). The frictional force is caused by the applied force $\mathrm{F}_{\mathrm{app}}$. When the horizontal force applied to the object is increased to a value that almost initiates motion, the static friction force f_s reaches its maximum value, equal in magnitude and opposite in direction to the applied force. This maximum value is given by $f_s^{\max} = \mu_s N$ (Figure 2-c).

If the horizontal force applied to the object continues to increase, the object will eventually begin to move. In this case, the frictional force acting on the object becomes smaller than the applied force and assumes a constant value given by f$f_k = \mu_k N$. This value is smaller than the maximum static frictional force, ${f_s}^{\max} = \mu_s N$ (Figure 2-d).

$$
\begin{aligned}
f_k &< f_s^{\max} \\
f_k = \mu_k N &< f_s^{\max} = \mu_s N \\
\mu_k N &< \mu_s N \\
\mu_k &< \mu_s \leq 1 \quad \text{should be satisfied.}
\end{aligned}
$$

When an object begins to move from rest, microscopic fractures occur at the points of contact, leading to a reduction in the roughness of the interacting surfaces. As a result, the kinetic friction force becomes smaller than the maximum value of the static friction force. During continued motion, these fractures are less intense than those occurring at the onset

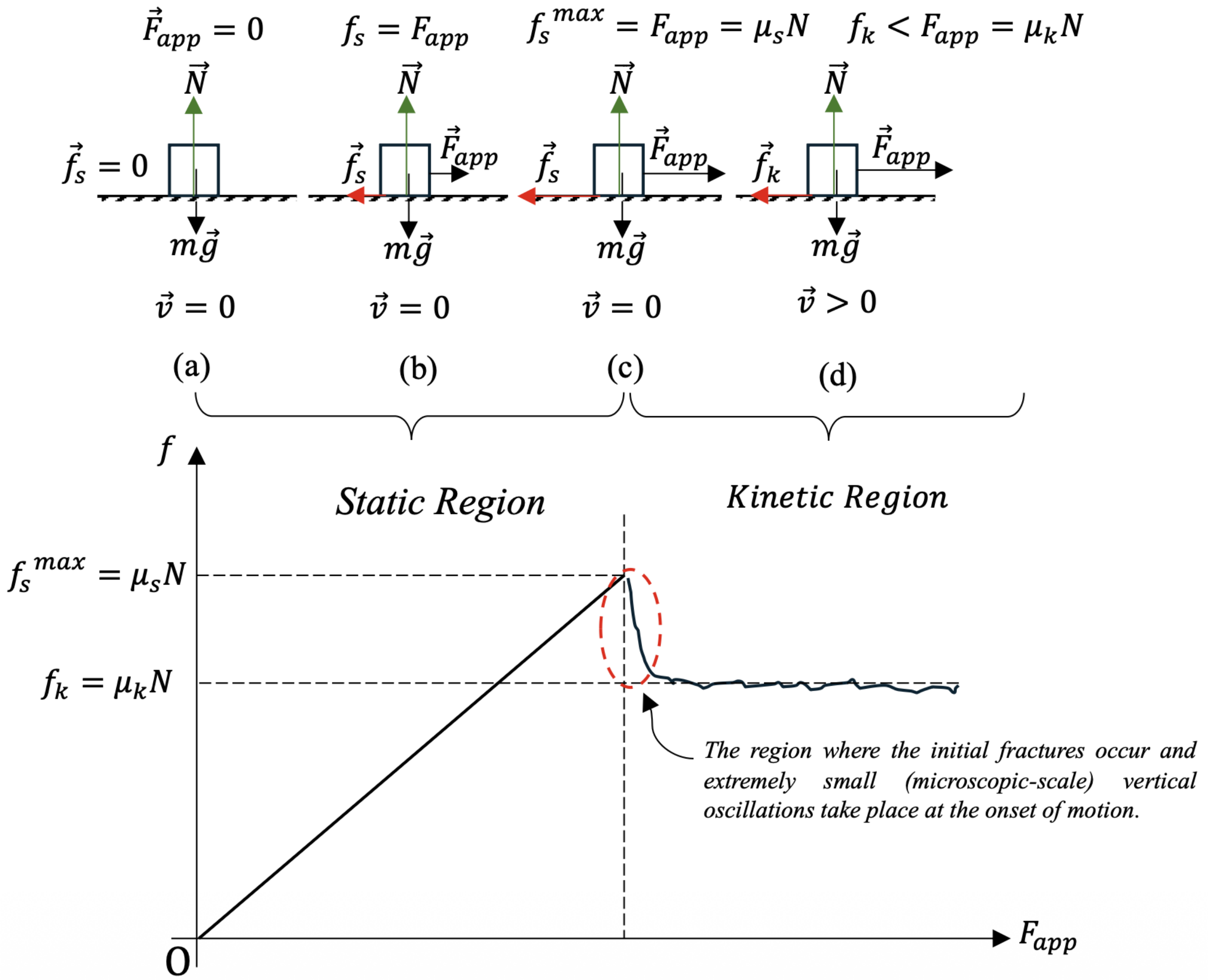


Figure 2

of motion, causing the kinetic friction force to remain approximately constant.

The frictional force between solid bodies can be classified into three types: static friction, kinetic friction, and rolling friction.

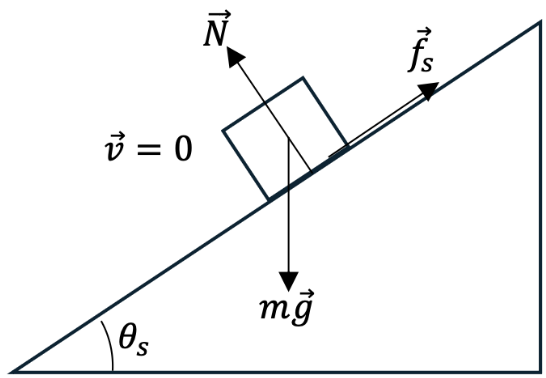
Rolling friction acts on bodies that roll without slipping and is based on static contact. In other words, the relative velocity between the point of contact and the surface is zero. In rolling motion, the direction of the frictional force depends on the point of application of the external force on the body. However, this direction remains consistent with the general definitions of frictional force provided above.

It should be noted that frictional forces also depend on atomic-scale interactions. The definitions of frictional forces given above are considered within a mechanical framework.

EXPERIMENT

Determination of the Coefficient of Static Friction

In this part of the experiment, the coefficient of static friction will be determined for different pairs of surfaces.



$$f_s - mgsin\theta_s = 0$$

$$N - mgcos\theta_s = 0$$

$$f_s = \mu_s N$$

$$\mu_s = tan\theta_s$$

1. Place the wooden block on the inclined plane with its wooden surface facing downward, and gradually increase the inclination angle until the block just begins to move. At this point, the static frictional force acting on the block has reached its maximum value.
2. Record the corresponding angle θ_S from the protractor on the inclined plane in Table 1.
3. Using this angle, calculate the coefficient of static friction with the formula $\mu_s = \tan(\theta_s)$, and record the result in Table 1.
4. Repeat this procedure five times for different regions of the inclined plane.
5. Next, place the same block on the inclined plane with its fabric surface facing downward, and repeat the above steps. Record the obtained values in Table 2.

Table 1: Static friction coefficient between the wooden surface and the inclined plane

Measurement	θ_s	$\mu_s = \tan(\theta_s)$	$\Delta\mu_s = \mu_s - {\mu_s}^{avg}$	${\Delta\mu_s}^2$
1				
2				
3				
4				
5				
${\mu_s}^{avg} =$				
$(\Delta{\mu_s}^{avg})^2 =$				
$\mu_s = {\mu_s}^{avg} \pm (\Delta{\mu_s}^{avg})^2 =$ ...... $\pm$				

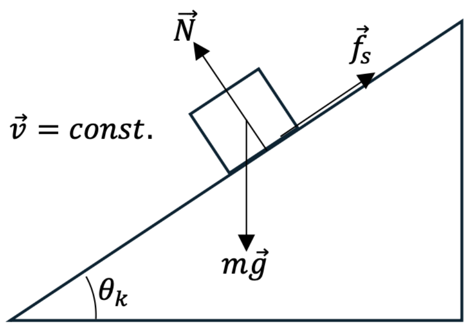
Table 2: Static friction coefficient between the fabric surface and the inclined plane

Measurement	θ_s	$\mu_s = \tan(\theta_s)$	$\Delta\mu_s = \mu_s - {\mu_s}^{\text{avg}}$	${\Delta\mu_s}^2$
1				
2				
3				
4				
5				
${\mu_s}^{\text{avg}} =$				
$(\Delta{\mu_S}^{\text{avg}})^2 =$				
$\mu_s = {\mu_s}^{\text{avg}} \pm (\Delta{\mu_s}^{\text{avg}})^2 =$ ..... $\pm$				

Determination of the Coefficient of Kinetic Friction

In this part of the experiment, the coefficient of kinetic friction will be determined for different surface pairs. This section of the experiment will be conducted in two stages.

I. Finding the coefficient of kinetic friction by moving a block at constant velocity on an inclined plane



$$f_k - mgsin\theta_k = 0$$

$$N - mgcos\theta_k = 0$$

$$f_k = \mu_k N$$

$$\mu_k = tan\theta_k$$

$\theta_k < \theta_s$ **should be satisfied.**

1. Place the wooden block on the inclined plane with its wooden surface in contact with the plane.

2. Gently tap the block with a finger to check whether it moves at a constant speed. Adjust the angle of inclination until the block moves at a uniform (constant) velocity.

3. Once uniform motion is observed, record the corresponding angle θ read from the protractor of the inclined plane in Table 3.

4. Using this angle, calculate the coefficient of kinetic friction from $\mu_k = \tan(\theta_k)$ and record the result in Table 3.

5. Repeat this procedure 10 times.

6. Next, place the same block on the inclined plane with its fabric-covered surface in contact with the plane, and repeat the above steps. Record the obtained values in Table 4.

Table 3: The coefficient of kinetic friction between the wooden surface and the inclined plane

Measurement	θ_k	$\mu_k = \tan(\theta_k)$	$\Delta\mu_k = \mu_k - \mu_k{}^{avg}$	$\Delta\mu_k{}^2$
1				
2				
3				
4				
5				
$\mu_k{}^{avg} =$				
$(\Delta\mu_k{}^{\text{avg}})^2 =$				
$\mu_k = \mu_k{}^{avg} \pm (\Delta\mu_k{}^{avg})^2 =$ ..... $\pm$				

Table 4: The coefficient of kinetic friction between the fabric surface and the inclined plane

Measurement	θ_k	$\mu_k = \tan(\theta_k)$	$\Delta\mu_k = \mu_k - {\mu_k}^{avg}$	${\Delta\mu_k}^2$
1				
2				
3				
4				
5				
${\mu_k}^{avg} =$				
$({\Delta\mu_k}^{\text{avg}})^2 =$				
$\mu_k = {\mu_k}^{avg} \pm ({\Delta\mu_k}^{avg})^2 = \ldots\ldots \pm \ldots\ldots$				

QUESTIONS

1. Why is the coefficient of kinetic friction smaller than the coefficient of static friction for a pair of contacting surfaces?
2. Racing cars and airplanes have wide, smooth (treadless) tires. What could be the reason for this design choice?