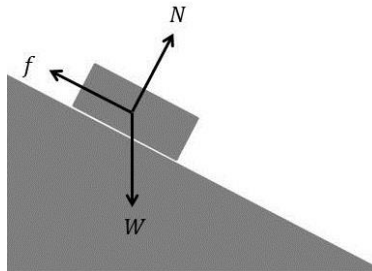


# Inclined Plane and Friction

## INTRODUCTION

When two surfaces are in contact, they push against each other. This pushing force can be broken up into two components: one parallel to the surfaces, and one perpendicular to the surfaces. The component perpendicular to the surfaces is called the normal force,  $\vec{N}$ . The component parallel to the surface is called friction,  $\vec{f}$ . Loosely speaking, friction is the force that resists the lateral motion of two surfaces in contact. If the surfaces are sliding across each other, we call it *kinetic* friction,  $f_k$ . If they are not sliding across each other, we call it *static* friction,  $f_s$ .

In the figure below, a block is at rest on an inclined plane. The net force on the block is zero, so the plane pushes up on the block with a force equal to its weight. However, we break that upward force into a component parallel to the plane (friction) and one perpendicular to the plane (normal force). Friction pushes up the plane and opposes the *impending* motion of the block. (If there was *no* friction it would slide *down* the plane.) Note that the normal force is less than the weight of the block.



## KINETIC FRICTION

If two surfaces are sliding across each other, the strength of the kinetic frictional force depends on the nature (roughness, material, etc.) of the surfaces in contact and the magnitude of the normal force. This force is given by

$$f_k = \mu_k N$$

Here  $\mu_k$  is called the coefficient of kinetic friction and is a dimensionless quantity that characterizes the nature of the surfaces.

## STATIC FRICTION

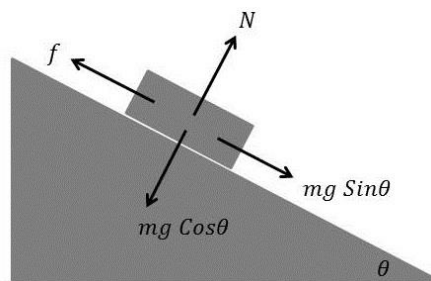
If two surfaces are not sliding across each other, the maximum frictional force that can exist before sliding occurs is given by

$$f_{s_{max}} = \mu_s N$$

Here  $\mu_s$  is called the coefficient of static friction and is a dimensionless quantity that characterizes the nature of the surfaces. The static frictional force can have any value less than or equal to the maximum static frictional force,  $f_s \leq f_{s_{max}}$

## INCLINED PLANE

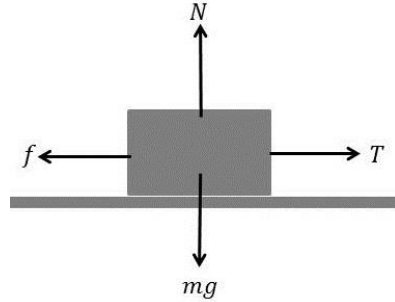
Consider a block at rest on an inclined plane with friction preventing it from sliding down the plane. The figure below demonstrates breaking the block's weight,  $W = mg$ , into two components: one parallel to the plane ( $mg \sin \theta$ ) and one perpendicular to the plane ( $mg \cos \theta$ ). If the block is in equilibrium, then  $N = mg \cos \theta$  and  $f = mg \sin \theta$ .



## PROCEDURE

### PART I: Kinetic Friction

- Position the plane horizontally.
- Use the wooden block, rather than the wheeled cart, and add extra weight on top of it. Now add weight to the hanging pan, until you can set the block moving at a *constant velocity* with a slight push. Your TA can help with determining when the block is moving with constant velocity. Make sure not to add so much weight that the block moves on its own. Below is a proper free body diagram of the cart.



- Record the masses and determine the coefficient of kinetic friction by comparing the tension to the frictional force,  $f_k = \mu_k N$ .  
*Note that when the block is moving with a constant velocity, the acceleration of the block is zero. Therefore, according to the Newton's second law the net force must be equal to zero. Since there are only two forces in the horizontal direction which are opposite to each other, they must be equal in magnitude.*
- Repeat with a different mass on the block.

## PART II: Static Friction

- Using the wooden block, with no attached masses, slowly lift the plane. Record the angle at which the block begins to slide on its own, without pushing.
- Determine the coefficient of static friction by setting the maximum static frictional force,  $f_{s_{max}} = \mu_s N$ , to the component of the block's weight parallel to the plane.
- Since block is at rest  $N = mg \cos \theta$  and  $f = f_{s_{max}} = mg \sin \theta$ .
- Therefore  $\mu_s = \frac{f_{s_{max}}}{N} = \frac{mg \sin \theta}{mg \cos \theta} = \tan \theta$
- We can see that the coefficient of friction between the block and the inclined plane is equal to the tangent of the angle when the block begins to slide down.

