

**Lesson 08-Friction**

Friction is a force that occurs between two solid surfaces when they try to slide parallel to each other. Imagine sliding a book across the desk and you will have the idea. Friction-like forces also occur between solid bodies when they move through liquids, like a submarine through water, and when solid bodies move through gaseous fluids, like a skydiver falling through the atmosphere. We will limit our use of the term “friction” to just those instances where two solid bodies slide relative to each other.

Friction further divides itself into two categories: one when sliding fails to occur and one when sliding is accomplished. The first is called static friction and the second is called kinetic friction.

**The Normal Force**

Before we tackle friction, we need to quickly introduce a new term into this discussion. The normal force,  $F_N$ , is a force between two solid bodies that occurs at the surface where they touch each other. It is called “normal” because “normal” is a synonym for “perpendicular”. Anytime two surfaces touch there are actually two normal forces. They both have the same magnitude but they point in opposite directions. One normal force acts on each of the two bodies. The normal force acting on each body points in the direction that pushes it away from the other body along a line perpendicular to the surface between the bodies.

To illustrate, image a book sitting on a table. At the surface where they are in contact, a normal force acts on the book and points straight up. The normal force keeps the book from falling through the table. While we don’t often consider it, there is also another normal force acting on the table. It tries to push the table down and away from the book.

In physics, we usually look at the forces acting on only one object at a time. In a typical physics problem we would be seeking information about the behavior of the book. So, naturally, we will be interested in the normal force that acts on the book. For that reason we seldom need to discuss the normal force acting on the table. Just remember it is there.

On a horizontal table, it turns out that the normal force equals the weight of the book. The normal force and the weight are two different forces acting on the book, but if they are the only two forces acting on the book and the book is not accelerating, they must be equal and opposite forces, i.e. their vector sum must be zero.

**Static Friction**

Perhaps it is best to start by imagining what happens when there is no friction between two bodies. If a box sits on frictionless ice and we somehow manage to give it a small push, it will start to move. Furthermore, since it has momentum and there is no friction, it will continue sliding forever, or at least until it reaches the edge of the ice.

So what is different when friction is present?

The first thing to notice is that a small push will not move the box at all. Small forces cannot overpower the static friction between the box and the surface it sits on. The second thing to notice is that the friction force pushes against our applied force. For this reason we call it a reactive force. It reacts to outside forces. The third thing to notice, and this is a bit harder to imagine, is that the static friction force pushed back with exactly the same force as we applied with our push. It is both reactive and self-limiting. The static friction never gets larger than the applied force. The static friction force is never smaller than the applied force, either. Therefore, the static friction force is always exactly equal to the applied force.

The fourth thing to notice is that we can, with enough effort, overcome the static friction force. By pushing hard enough we can make the box move. That means the static friction force can only match our external force up to some maximum limit and then the external force overpowers it. At that point the static friction disappears. It is no longer present because the box has started moving and the situation is no longer static.

How do we describe this static friction force in mathematical terms? That turns out to be easier than you might have expected. Anytime the block is not moving, we know the static friction force opposes and has exactly the same magnitude as the applied force. If we know the magnitude and direction of the applied force,  $\mathbf{F}_A$ , then we automatically know that the static friction force equals the negative of the applied force,  $\mathbf{F}_S = -\mathbf{F}_A$ . In situations where no movement occurs we can only find the static friction force by first finding the applied force.

The other thing we need to calculate is the maximum value of the static friction force. In other words, how hard do we have to push to get the object to start moving? There is a simple relationship between the static friction force and the normal force acting on the object. It is

$$\mathbf{F}_S = \mu_S \cdot \mathbf{F}_N$$

Where  $\mu_S$  is a constant known as the coefficient of static friction. On a horizontal surface this reduces to

$$\mathbf{F}_S = \mu_S \cdot \mathbf{F}_N = \mu_S \cdot mg = \mu_S \cdot \text{weight}$$

On tilted surfaces the normal force and the weight are no longer equal. In those cases you must stick with the original equation. We will learn how to find the normal force when the surface is tilted in Lesson 27. Until then you may use the last equation because we will be working on horizontal surfaces until then.

That's all there is to static friction. The situation must be static for static friction to be present; the static friction is exactly equal in magnitude and opposite in direction to any applied force or forces; and the static force disappears if the applied gets larger than  $\mu_S \cdot \mathbf{F}_N$ .

## Kinetic Friction

Once an object starts under the influence of an external force, enter a new regime. The friction force is now called the kinetic friction force.

Unlike the static friction force, the kinetic friction force does not change its value. Neither the size of the external force nor the speed with which it slides will affect the kinetic friction force. It is still reactive, but only in the sense that the kinetic friction force points in the direction opposing the motion. In other words, it points in the direction opposite to the applied force that is moving the object.

A new constant, called  $\mu_K$ , and the normal force determine its magnitude. The equation for calculating the magnitude of the kinetic friction force looks like the equation used to calculate the maximum value of the static friction force. Remember, however, that numbers you get have two entirely different meanings.

To calculate the magnitude of the kinetic friction force use the following equation:

$$F_K = \mu_K \cdot F_N$$

As long as we are dealing with horizontal surfaces, the normal force is equal to the weight of the object and we have, as in the case of static friction, this equation,

$$F_S = \mu_S \cdot F_N = \mu_S \cdot mg = \mu_S \cdot \text{weight}$$

You may use this second equation until we get to Lesson 27 when we introduce tilted surfaces for the first time. After that, you must use the first equation unless you know that the surface is horizontal.

## Coefficients of Friction

What do we know about these coefficients of friction? The first thing to recognize is that the values of the static and kinetic coefficients are never equal. The coefficient of kinetic friction is always slightly smaller than the coefficient of static friction for the same two surfaces. The second thing to recognize is that the values of these coefficients are unique to each pair of surfaces. There are no tables where you can look up standard values. Anytime you must slide one object across another, it will be up to you to determine the values of the two coefficients.

On this last page is a graph of the friction force vs the applied force. It includes the transition region between the disappearance of the static force and the appearance of the kinetic force. To understand this graph, you need to imagine that the applied force starts small and increases slowly but steadily. At first the block does not move. Later it starts to move. Once it gets moving it will tend to go faster and faster as the applied force gets larger and larger. Note the behavior of the friction forces in these two regimes and in the transition region between them. We will not try to calculate the force in the transition.

