PHY 111: Principles of Physics I Summer 2023

LECTURE 11 — July 8, 2023

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1 Friction Force

Friction is a force that resists motion between two surfaces in contact with each other. When you try to slide a book across a table, you'll notice that it takes more force to get it moving than it does to keep it moving. This is due to the force of friction between the book and the table. Friction can be helpful in some cases, such as when you're trying to walk or drive a car, but it can also be a hindrance when trying to slide something across a surface.

We will be looking at the following three friction forces:

1. **Static friction** - this is the force that resists the initiation of motion between two surfaces in contact. For example, if you push a heavy box across the floor, the static friction force will make it difficult to move the box.
2. **Kinetic friction** - this is the force that resists the motion of two surfaces that are already in motion relative to each other. Once you've gotten the box moving, the kinetic friction force will make it harder to stop the box or change its direction.
3. **Rolling friction** - this is the force that resists an object that is rolling over a surface. When an object rolls over a surface, the deformation of the object and the surface it rolls over creates a resistance to motion. Rolling friction is usually less than sliding friction and is one of the reasons why rolling is often preferred over sliding motion.

1.1 Static Friction

The force of static friction is directly proportional to the force pushing the two surfaces together. It is proportional to the coefficient of static friction, which is a property of the two surfaces in contact.

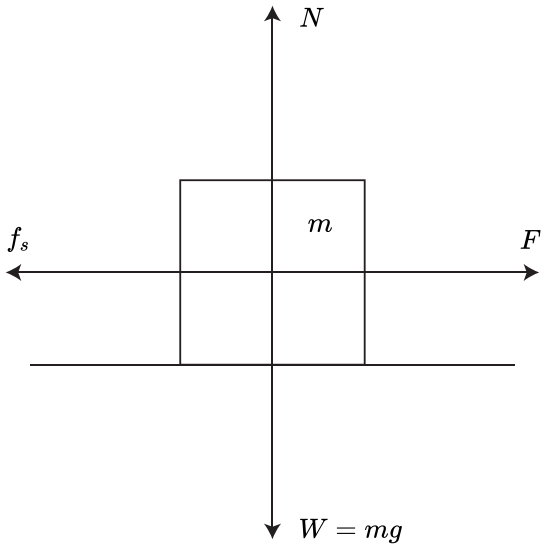

FIGURE 1: Static friction resists the applied force F until the object starts moving. This friction has a maximum limit $f_s^{\max}$, which must be met to move the object.

When an external force is applied to an object at rest, static friction will act to prevent the object from moving. The maximum amount of static friction that can be exerted is equal to the force that is pushing the two surfaces together, multiplied by the coefficient of static friction. The object will remain at rest if the external force is not large enough to overcome the maximum amount of static friction.

The coefficient of static friction can be determined experimentally by measuring the maximum external force that can be applied to an object at rest before it starts to move. This is often done using a device called a force gauge or a spring scale.

The equation for static friction is:

$$f_s \leq \mu_s N, \tag{1}$$

where f_s is the force of static friction, μ_s is the coefficient of static friction, and N is the normal force, which is the force perpendicular to the surface that the object is resting on. The equality holds only when $f_s = f_s^{\max}$.

The physical significance of each term in the equation is as follows:

1. f_s is the force of static friction, which is the force that opposes the tendency of an object to move when a force is applied to it.
2. μ_s is the coefficient of static friction, which is a property of the two surfaces in contact and represents the amount of friction that can be exerted before the object starts to move.
3. N is the normal force, which is the force perpendicular to the surface that the object is resting on and is equal to the weight of the object in most cases.

1.2 Kinetic Friction

When two surfaces are in contact, the irregularities in their surfaces cause them to interlock with each other. As a result, when an object is pushed or pulled across a surface, the interlocking points must break and re-form continuously. This breaking and re-forming of interlocking points require energy and create resistance or friction. This takes over the system once $f_s^{\max}$ is met and the object moves.

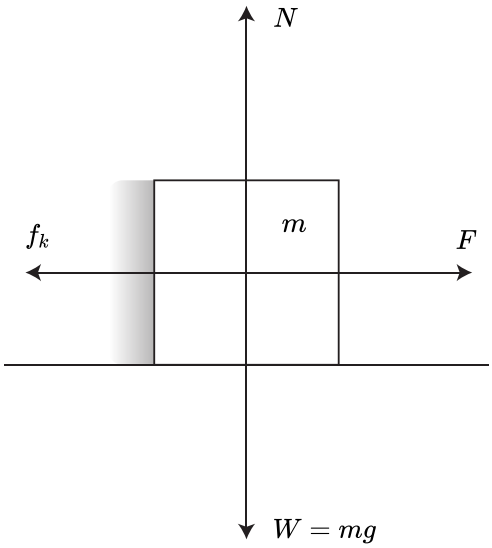

FIGURE 2: Kinetic friction resists the applied force F when the object is moving. This friction has no maximum or minimum limit. As long as the system moves with a constant velocity, f_k pretty much stays the same with a minuscule variation.

The magnitude of the kinetic frictional force is proportional to the normal force, which is the force exerted by the surface perpendicular to the object's motion. The direction of the kinetic friction force is opposite to the direction of the object's motion.

The coefficient of kinetic friction, denoted by μ_k, is a dimensionless quantity that represents the ratio of the kinetic frictional force to the normal force. It depends on the nature of the surfaces in contact and their smoothness. The value of μ_k ranges between 0 and 1, and it is always less than the coefficient of static friction for the same two surfaces.

The equation for kinetic friction is:

$$f_k = \mu_k N, \tag{2}$$

where f_k is the force of kinetic friction, μ_k is the coefficient of kinetic friction, and N is the normal force, which is the force perpendicular to the surface that the object is resting on.

The physical significance of each term in the equation is as follows:

1. f_k is the force acting on the object due to the sliding motion across the surface.
2. μ_k is a measure of the surface's roughness and determines the strength of the frictional force.
3. N is the force perpendicular to the surface exerted by the surface on the object. It determines the magnitude of the frictional force.

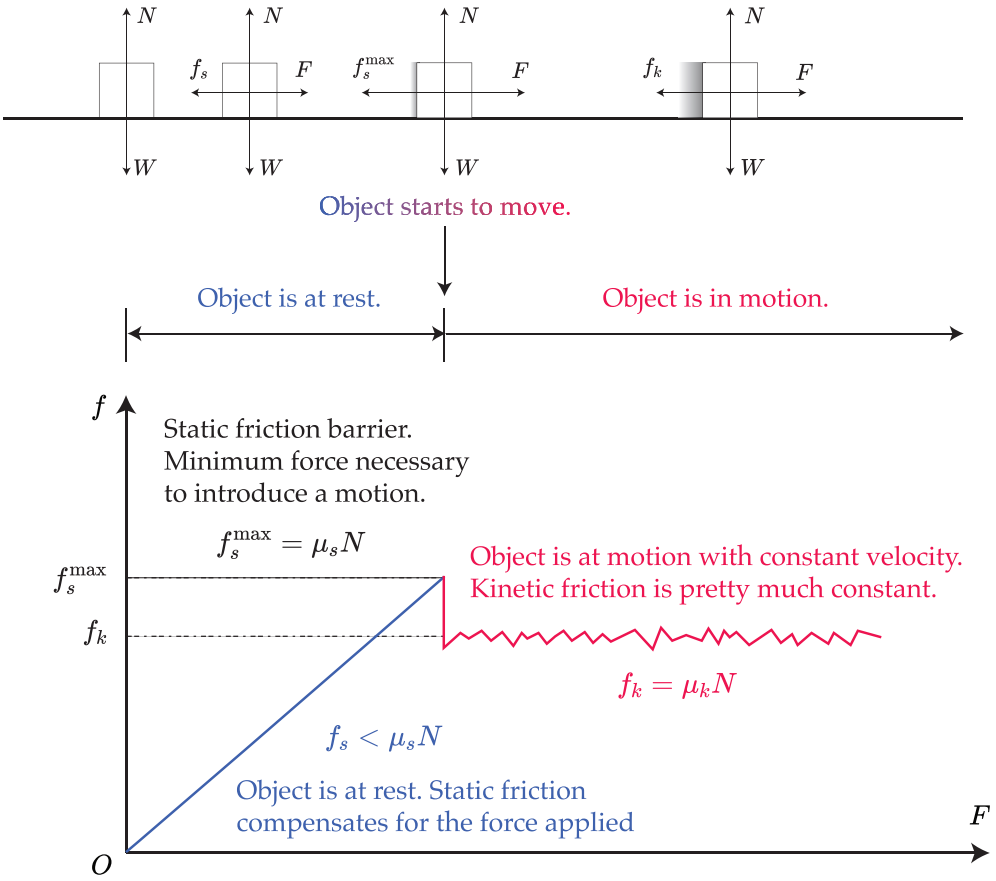

FIGURE 3: A graph representing the platform's friction force f response depending on the object's state of motion with increasing applied force F.

1.3 Rolling Friction

The magnitude of rolling friction depends on several factors, such as the materials of the object and the surface it rolls over, the object's shape, the surface area in contact with the surface, and the object's speed. In general, the rougher the surface or, the softer the material of the object, the greater the rolling friction. Rolling friction also depends on the normal force exerted on the object, which is the force exerted by the surface perpendicular to the object.

Rolling friction can be measured by placing an object on a flat surface and rolling it at a constant speed. The force required to maintain the constant speed is equal and opposite to the rolling friction. Alternatively, the coefficient of rolling friction can be measured by applying a known force to the object and measuring the resulting acceleration. The coefficient of rolling friction is the ratio of the force of rolling friction to the normal force exerted by the surface on the object. The equation for static friction is:

$$f_r = \mu_r N \tag{3}$$

where f_r is the force of rolling friction, μ_r is the coefficient of rolling friction, and N is the normal force exerted by the surface on the object.

The physical significance of each term in the equation is as follows:

1. f_r is the force that opposes the rolling motion of the object.
2. μ_r is a dimensionless quantity that measures the frictional properties of the materials in contact.
3. N is the force exerted perpendicular to the surface. This force is responsible for the deformation of the object and the surface it rolls over, which creates the resistance to motion known as rolling friction.