

Answer to Essential Question 5.1: When asked this question, most people are split over whether the friction force is kinetic or static. Think about what happens when you walk. When your shoe (or foot) is in contact with the ground, the shoe does not slip on the ground. Because there is no relative motion between the shoe and the ground, the friction force is static friction.

5-2 Static Friction

If there is no relative motion between objects in contact, then the friction force (if there is one) is the static force of friction (F_S). An example is a box that remains at rest on a ramp. The force of gravity acting down the ramp is opposed by a static force of friction acting up the ramp. A more challenging example is when the box is placed on the floor of a truck. When the truck accelerates and the box moves with the truck (remaining at rest relative to the truck), it is the force of static friction that acts on the box to keep it from sliding around in the truck.

Consider again the question about the friction force between the sole of your shoe and the floor, when you start to walk. In which direction is the force of static friction? Many people think this friction force is directed opposite to the way you are walking, but the force of static friction is actually directed the way you are going. To determine the direction of the force of static friction, think about the motion that would result if there were no friction. To start walking, you push back with your foot on the floor. Without friction, your foot would slide back, moving back relative to the floor, as shown in Figure 5.2. Static friction opposes this motion, the motion that would occur if there was no friction, and thus static friction is directed forward.

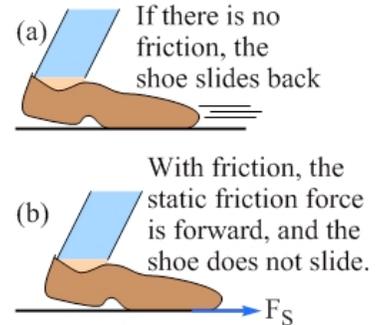


Figure 5.2: On a frictionless floor, your shoe slides backward over the floor when you try to walk forward (a). Static friction opposes this motion, so the static force of friction, applied by the ground on you, is directed forward (b).

The static force of friction opposes the relative motion that would occur if there were no friction. Another interesting feature is that **the static force of friction adjusts itself to whatever it needs to be to prevent relative motion between the surfaces in contact.** Within limits, that is. The static force of friction has a maximum value, $F_{S,max}$, and the coefficient of static friction is defined in terms of this maximum value:

$$\mu_S = \frac{F_{S,max}}{F_N} \quad \text{so} \quad F_S \leq \mu_S F_N. \quad (\text{Equation 5.2: Static friction})$$

Let's now explore a situation that involves the adjustable nature of the force of static friction.

EXPLORATION 5.2 – A box on the floor

A box with a weight of $mg = 40 \text{ N}$ is at rest on a floor. The coefficient of static friction between the box and the floor is $\mu_S = 0.50$, while the coefficient of kinetic friction between the box and the floor is $\mu_K = 0.40$.

Step 1 - What is the force of friction acting on the box if you exert no force on the box? Let's draw a free-body diagram of the box (see Figure 5.3b) as it sits at rest. Because the box remains at rest, its acceleration is zero and the forces must balance. Applying Newton's Second Law tells us that $F_N = mg = 40 \text{ N}$. There is no tendency for the box to move, so there is no force of friction.

Step 2 - What is the force of friction acting on the box if you push horizontally on the box with a force of 10 N, as in Figure 5.3a?

Nothing has changed vertically, so we still have $F_N = mg = 40 \text{ N}$. To determine whether or not the box moves, let's use equation 5.2 to determine the maximum possible force of static friction in this case. We get:

$$F_S \leq \mu_S F_N = 0.50 \times 40 \text{ N} = 20 \text{ N}.$$

The role of static friction is to keep the box at rest. If we exert a horizontal force of 10 N on the box, the force of static friction acting on the box must be 10 N in the opposite direction, to keep the box from moving. The free-body diagram of this situation is shown in Figure 5.3c. 10 N is below the 20 N maximum value, so the box will not move.

Step 3 - What is the force of friction acting on the box if you increase your force to 15 N? This situation is similar to step 2. Now, the force of static friction adjusts itself to 15 N in the opposite direction of your 15 N force. 15 N is still less than the maximum possible force of static friction (20 N), so the box does not move.

Step 4 - What is the force of friction acting on the box if you increase your force to 20 N? If your force is 20 N, the force of static friction matches you with 20 N in the opposite direction. We are now at the maximum possible value of the force of static friction. Pushing even a tiny bit harder would make the box move.

Step 5 - What is the force of friction acting on the box if you increase your force to 25 N? Increasing your force to 25 N, which is larger in magnitude than the maximum possible force of static friction, makes the box move. Because the box moves, the friction is the kinetic force of friction, which is in the direction opposite to your force with a magnitude of

$$F_K = \mu_K F_N = 0.40 \times 40 \text{ N} = 16 \text{ N}.$$

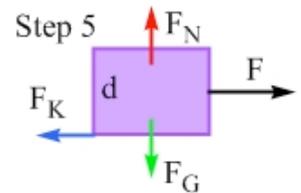
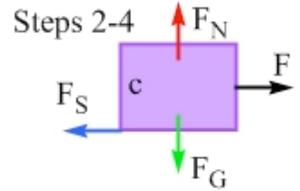
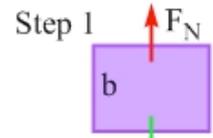


Figure 5.3: (a) The top diagram shows the box, and the force you exert on it. (b) The free-body diagram for step 1, in which you exert no force. (c) The free-body diagram that applies to steps 2 – 4, in which the force you exert is less than or equal to the maximum possible force of static friction. (d) The free-body diagram that applies to step 5, in which your force is large enough to cause the box to move.

Key ideas for static friction: The static force of friction is whatever is required to prevent relative motion between surfaces in contact. The static force of friction is adjustable only up to a point. If the required force exceeds the maximum value $F_{S,\max} = \mu_S F_N$, then relative motion will occur.

Related End-of-Chapter Exercises: 32, 34.

A microscopic model of friction

Figure 5.4 shows a magnified view of two surfaces in contact. Surface irregularities interfere with the motion of one surface left or right with respect to the other surface, giving rise to friction.

Essential Question 5.2: What is the magnitude of the net contact force exerted by the floor on the box in step 5 of Exploration 5.2?



Figure 5.4: A magnified view of two surfaces in contact. The irregularities in the objects prevent smooth motion of one surface over the other, giving rise to friction.