

What we have been discussing up to now is *kinetic friction*, when one object slides over another. There is also **static friction**, which refers to a force parallel to the two surfaces that can arise even when they are not sliding. Suppose an object such as a desk is resting on a horizontal floor. If no horizontal force is exerted on the desk, there also is no friction force. But now suppose you try to push the desk, and it doesn't move. You are exerting a horizontal force, but the desk isn't moving, so there must be another force on the desk keeping it from moving (the net force is zero on an object that doesn't move). This is the force of *static friction* exerted by the floor on the desk. If you push with a greater force without moving the desk, the force of static friction also has increased. If you push hard enough, the desk will eventually start to move, and kinetic friction takes over. At this point, you have exceeded the maximum force of static friction, which is given by $F_{fr}(\text{max}) = \mu_s F_N$, where μ_s is the *coefficient of static friction* (Table 4-2). Since the force of static friction can vary from zero to this maximum value, we write

$$F_{fr} \leq \mu_s F_N.$$

You may have noticed that it is often easier to keep a heavy object sliding than it is to start it sliding in the first place. This is consistent with μ_s generally being greater than μ_k (see Table 4-2).

EXAMPLE 4-16 Friction: static and kinetic. Our 10.0-kg mystery box rests on a horizontal floor. The coefficient of static friction is $\mu_s = 0.40$ and the coefficient of kinetic friction is $\mu_k = 0.30$. Determine the force of friction, F_{fr} , acting on the box if a horizontal external applied force F_A is exerted on it of magnitude: (a) 0, (b) 10 N, (c) 20 N, (d) 38 N, and (e) 40 N.

APPROACH We don't know, right off, if we are dealing with static friction or kinetic friction, nor if the box remains at rest or accelerates. We need to draw a free-body diagram, and then determine in each case whether or not the box will move, by using Newton's second law. The forces on the box are gravity $m\vec{g}$, the normal force exerted by the floor \vec{F}_N , the horizontal applied force \vec{F}_A , and the friction force \vec{F}_{fr} , as shown in Fig. 4-27.

SOLUTION The free-body diagram of the box is shown in Fig. 4-27. In the vertical direction there is no motion, so Newton's second law in the vertical direction gives $\Sigma F_y = ma_y = 0$, which tells us $F_N - mg = 0$. Hence the normal force is

$$F_N = mg = (10.0 \text{ kg})(9.8 \text{ m/s}^2) = 98 \text{ N}.$$

(a) Since no external force F_A is applied in this first case, the box doesn't move, and $F_{fr} = 0$.

(b) The force of static friction will oppose any applied force up to a maximum of

$$\mu_s F_N = (0.40)(98 \text{ N}) = 39 \text{ N}.$$

When the applied force is $F_A = 10 \text{ N}$, the box will not move. Since $\Sigma F_x = F_A - F_{fr} = 0$, then $F_{fr} = 10 \text{ N}$.

(c) An applied force of 20 N is also not sufficient to move the box. Thus $F_{fr} = 20 \text{ N}$ to balance the applied force.

(d) The applied force of 38 N is still not quite large enough to move the box; so the friction force has now increased to 38 N to keep the box at rest.

(e) A force of 40 N will start the box moving since it exceeds the maximum force of static friction, $\mu_s F_N = (0.40)(98 \text{ N}) = 39 \text{ N}$. Instead of static friction, we now have kinetic friction, and its magnitude is

$$F_{fr} = \mu_k F_N = (0.30)(98 \text{ N}) = 29 \text{ N}.$$

There is now a net (horizontal) force on the box of magnitude $F = 40 \text{ N} - 29 \text{ N} = 11 \text{ N}$, so the box will accelerate at a rate

$$a_x = \frac{\Sigma F}{m} = \frac{11 \text{ N}}{10 \text{ kg}} = 1.1 \text{ m/s}^2$$

as long as the applied force is 40 N. Figure 4-28 shows a graph that summarizes this Example.

Static friction

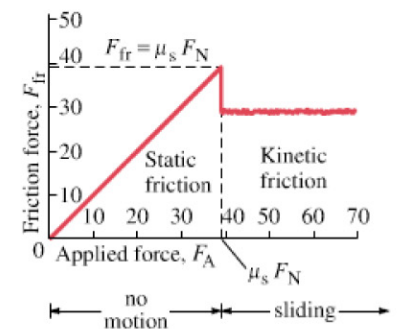


FIGURE 4-28 Example 4-16. Magnitude of the force of friction as a function of the external force applied to an object initially at rest. As the applied force is increased in magnitude, the force of static friction increases linearly to just match it, until the applied force equals $\mu_s F_N$. If the applied force increases further, the object will begin to move, and the friction force drops to a roughly constant value characteristic of kinetic friction.