5. Chapter Five: Friction

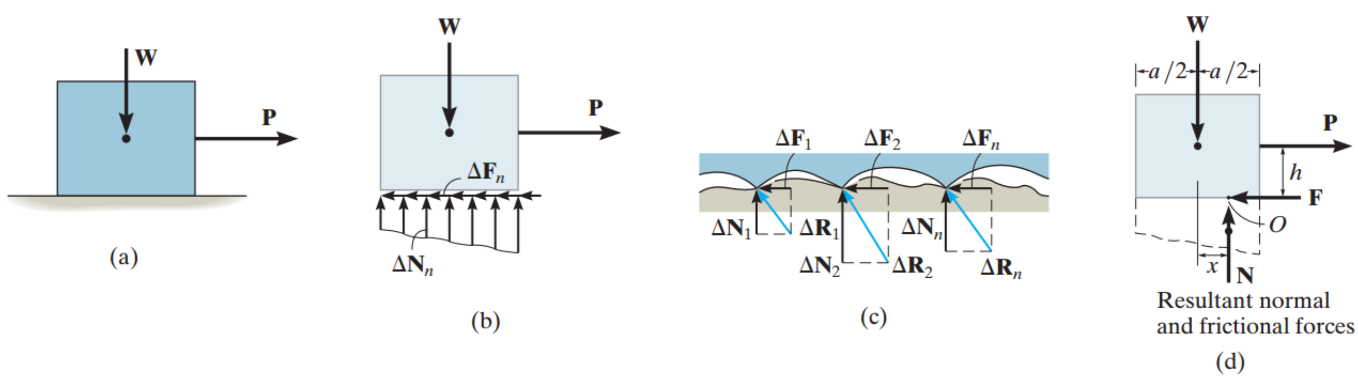
Friction is a force that resists the movement of two contacting surfaces that slide relative to one another. This force always acts tangent to the surface at the points of contact and is directed so as to oppose the possible or existing motion between the surfaces.

Dry friction occurs between the contacting surfaces of bodies when there is no lubricating fluid. Another type of friction, called ***fluid friction***, is studied in fluid mechanics.

In this chapter, we will study the effects of dry friction, which is sometimes called ***Coulomb friction*** since its characteristics were studied extensively by the French physicist Charles-Augustin de Coulomb in 1781.

5.1. Theory of Dry Friction

✓ **Equilibrium:**



The effect of the distributed normal and frictional loadings is indicated by their resultants **N** and **F** on the free-body diagram, Fig. d. Notice that **N** acts a distance **x** to the right of the line of action of **W**, Fig. d. This location, which coincides with the centroid or geometric center of the normal force distribution in Fig. b, is necessary in order to balance the "tipping effect" caused by **P**. For example, if **P** is applied at a height h from the surface, Fig. d, then moment equilibrium about point ***O*** is satisfied if **Wx = Ph or x = Ph /W**.

- ✓ **Impending Motion:** In cases where the surfaces of contact are rather "slippery," the frictional force F may not be great enough to balance P, and consequently the block will tend to slip.

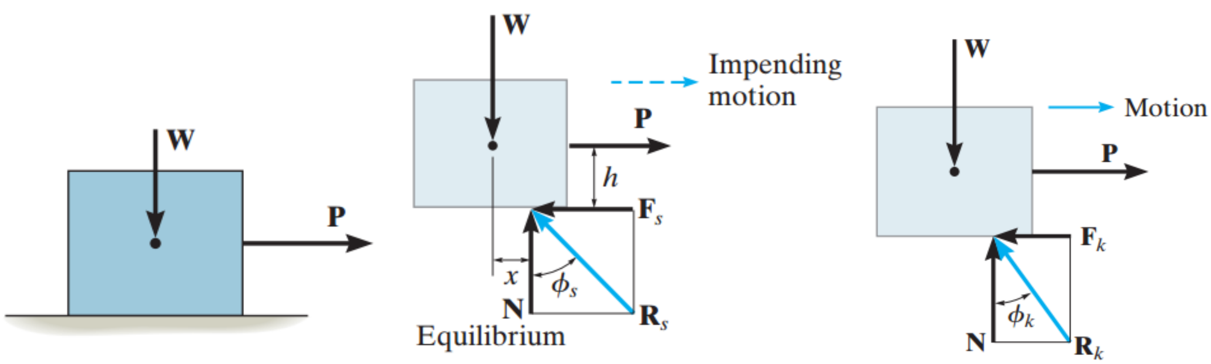
$$F_s = \mu_s N$$

Where:

F_s, called the limiting static frictional force, **μ_s** (mu "sub" s), is called the coefficient of static friction, and **N** the normal force.

The angle ϕ_s (phi "sub" s) that **R***s* makes with **N** is called the ***angle of static friction***.
From the figure below:

$$\phi_s = \tan^{-1}\left(\frac{F_s}{N}\right) = \tan^{-1}\left(\frac{\mu_s N}{N}\right) = \tan^{-1}\mu_s$$



(a) (b) (c)

- ✓ **Motion:** If the magnitude of **P** acting on the block is increased so that it becomes slightly greater than **F_s**, the frictional force at the contacting surface will drop to a smaller value **F_k**, called the ***kinetic frictional force***.

$$F_k = \mu_k N$$

Here the constant of proportionality, μ_k, is called the ***coefficient of kinetic friction***.

In this case, the resultant force at the surface of contact, $\mathbf{R_k}$, has a line of action defined by ϕ_k. This angle is referred to as the ***angle of kinetic friction***, where:

$$\phi_k = \tan^{-1}\left(\frac{F_k}{N}\right) = \tan^{-1}\left(\frac{\mu_k N}{N}\right) = \tan^{-1}\mu_k$$

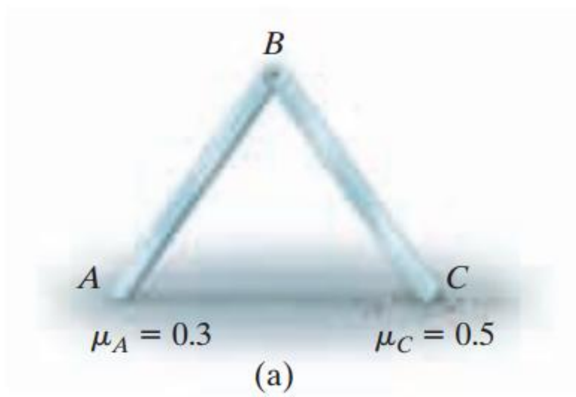
Characteristics of Dry Friction:

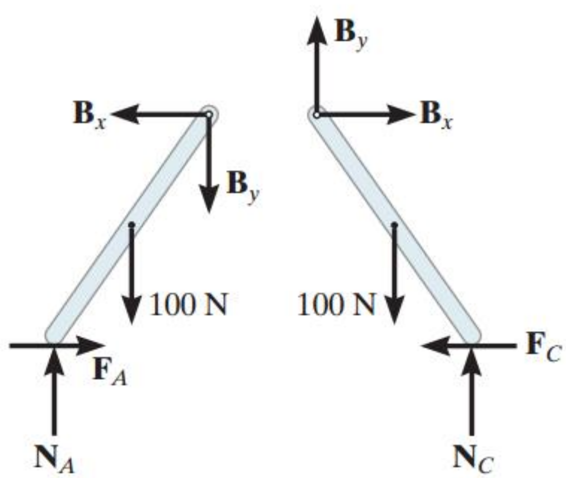
- The frictional force acts *tangent* to the contacting surfaces in a direction *opposed* to the *motion* or tendency for motion of one surface relative to another.
- The maximum static frictional force F_s that can be developed is independent of the area of contact, provided the normal pressure is not very low nor great enough to severely deform or crush the contacting surfaces of the bodies.
- The maximum static frictional force is generally greater than the kinetic frictional force for any two surfaces of contact. However, if one of the bodies is moving with a *very low velocity* over the surface of another, F_k becomes approximately equal to F_s, i.e., $\mu_s \approx \mu_k$.
- When *slipping* at the surface of contact is *about to occur*, the maximum static frictional force is proportional to the normal force, such that $F_s = \mu_s N$.
- When *slipping* at the surface of contact is *occurring*, the kinetic frictional force is proportional to the normal force, such that $F_k = \mu_k N$.

5.2. Types of Friction Problems

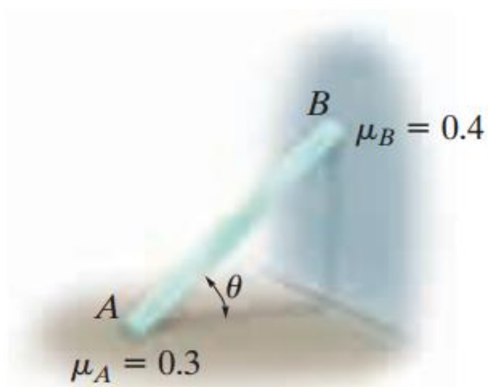
In general, there are three types of static problems involving dry friction. They can easily be classified once free-body diagrams are drawn and the total number of unknowns are identified and compared with the total number of available equilibrium equations.

No Apparent Impending Motion. Problems in this category are strictly equilibrium problems, which require the number of unknowns to be ***equal*** to the number of available equilibrium equations. Once the frictional forces are determined from the solution, however, their numerical values must be checked to be sure they satisfy the inequality $F \leq \mu_s N$; otherwise, slipping will occur and the body will not remain in equilibrium.

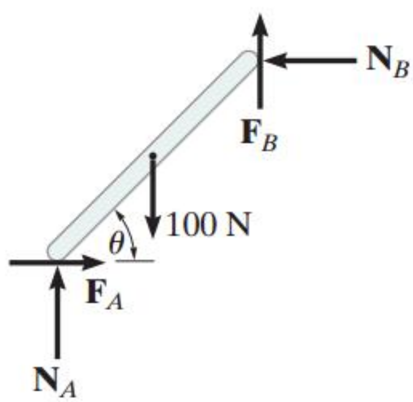




Impending Motion at All Points of Contact. In this case the total number of unknowns will ***equal*** the total number of available equilibrium equations ***plus*** the total number of available frictional equations, $F = \mu N$. When motion is impending at the points of contact, then $F_s = \mu_s N$; whereas if the body is slipping, then $F_k = \mu_k N$.

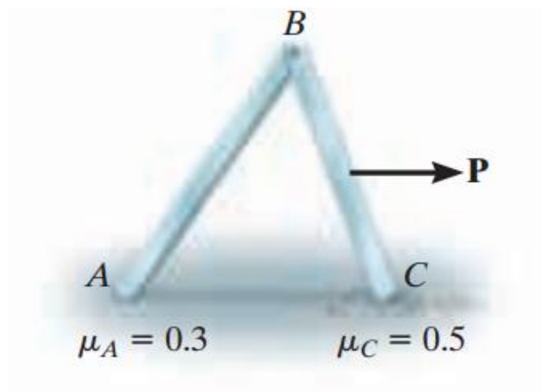


(a)



(b)

Impending Motion at Some Points of Contact. Here the number of unknowns will be ***less*** than the number of available equilibrium equations plus the number of available frictional equations or conditional equations for tipping. As a result, several possibilities for motion or impending motion will exist and the problem will involve a determination of the kind of motion which actually occurs.



(a)