22.3: Friction

In this section we consider the quantitative forms of non-conservative forces on the macroscopic level. We first examine the frictional force between two solid bodies and then consider viscosity in liquids.

Frictional Force Between Solids

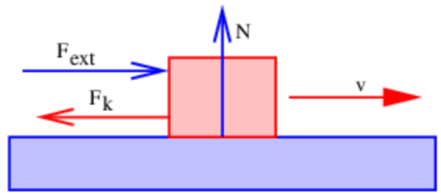

Figure 22.3.5:: The kinetic frictional force F_k is exerted on the upper body by the stationary lower body. The upper body is moving with velocity v and is pressed together with the lower body by a normal force N. It may also be acted upon by an additional external force F_{ext}.

The frictional force F_k between two solid objects in contact obeys an empirical law. If the two objects are sliding over each other, the frictional force on each object acts so as to oppose the relative motion of the two objects. (See Figure 22.3.5.) The frictional force is proportional to the normal force N pressing the objects together:

$$F_k = \mu_k N \quad (\text{ kinetic friction }) \tag{22.3.1}$$

The dimensionless quantity μ_k is called the coefficient of kinetic friction. This quantity is different for different pairs of materials rubbing together. It is typically of order one, but may be much less for particularly slippery materials.

Equation (22.3.1) is only valid if the two objects are moving relative to each other. If they are not in relative motion, but if some other force is being exerted on one of them, a static frictional force F_S will precisely counteract this force so as to result in zero net force on the object. However, the static frictional force will keep the bodies from slipping only up to some limit defined by

$$|F_s| \leq \mu_s N \quad (\text{static friction}) \tag{22.3.2}$$

where μ_S is the coefficient of static friction. Generally we find that $\mu_s > \mu_k$, so gradually increasing the external force on an object in static frictional contact with another object will cause it to suddenly break loose and accelerate when the maximum sustainable static frictional force is exceeded. Once the object is in motion, a lesser external force is needed to keep it moving at a constant velocity.

Viscosity

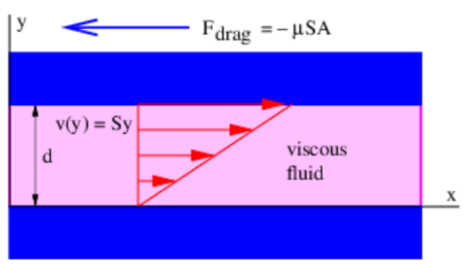

Figure 22.3.6:: Two solid plates separated by a distance d, the gap being filled by a viscous fluid. The lower plate is stationary and the upper plate is moving to the right at speed $v_p = v(d) = \mathrm{Sd}.$. The fluid is sheared, moving according to $v(y) = Sy$. The fluid velocity matches that of the plates where the fluid touches the plates. The upper plate experiences a drag force $F_{drag} = -\mu SA$ where μ is the viscosity of the fluid and A is the area of the plate.

If two objects are not in physical contact but are separated by a thin layer of fluid (i. e., a liquid or a gas), there is still a frictional or viscous drag force between the two objects, but its behavior is different. Figure 22.3.6 tells the story: The viscous drag force in this case is

$$F_{\text{drag}} = -\mu SA \tag{22.3.3}$$

where $S = v_p/d$ is the shear in the fluid, A is the area of the plates, and μ is the viscosity of the fluid. (Don't confuse this parameter with the static and dynamic coefficients of friction!) The parameter v_p is the velocity of the top plate with respect to the bottom plate and d is the separation between the plates.

Viscosity has the dimensions mass per length per time. The most common unit of viscosity is the Poise: 1 Poise = 1 g cm^{-1} s^{-1}. The viscosity of water varies from 0.0179 Poise at 0° C to 0.0100 Poise at 20° C to 0.0028 Poise at 100° C. The viscosity of water thus decreases with increasing temperature, which is typical of liquids. In contrast, the viscosity of a gas is independent of the density of the gas and is proportional to the square root of its absolute temperature. The viscosity of a gas thus increases with temperature, in contrast to the viscosity of a liquid. For air at 20° C, the viscosity is 1.81×10^{-4} Poise.

Thin layers of oil between moving parts are commonly used in machinery to reduce friction, since the resulting viscous drag is generally much less than the corresponding kinetic friction that would occur if the parts were in direct contact. The ways in which the layer of oil is maintained between moving parts are fascinating, but beyond the scope of this course.
