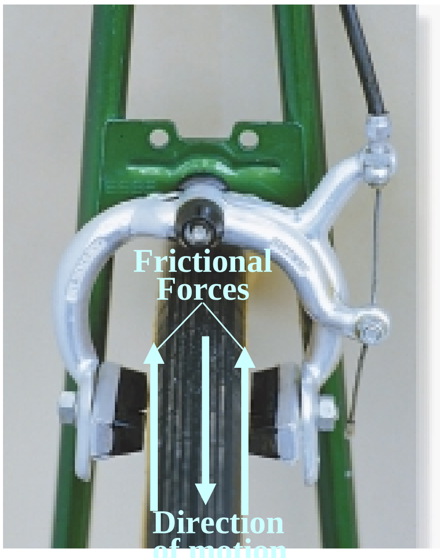
Friction- Part 1:

Definitions:

When two surfaces come into contact, forces are applied by each surface on the other. The part which is tangent to the contacting surfaces is called the frictional force. Friction is a resisting force that acts on a body to prevent or retard its motion. Friction force always acts tangent to the surface at points of contact. Friction force acts opposite to the direction of motion.



There are 2 types of friction:

Static friction: If the two surfaces in contact do not move relative to each other, one has static friction.

Kinetic friction: If the two contacting surfaces are moving relative to each other, then one has kinetic (dynamic or slipping) friction.

For each case we also have:

Fluid friction: it exists when the contacting surfaces are separated by a film of fluid (gas or liquid).

Dry friction (Coulomb friction): it occurs between the contacting surfaces of bodies in the absence of a lubricating fluid.

The frictional force F that can result between two surfaces without having the surfaces slide relative to each other (Static Friction) is bounded by the equation:

$$|F| \leq \mu_s N$$

where N is the normal force to the surface, and μ_s is the static coefficient of friction.

The frictional force F that results when two surfaces are sliding on each other (Kinetic Friction)is proportional to the normal force applied on the surfaces and is directed opposite to the relative motion of the surfaces. The factor of proportionality is the coefficient of kinetic friction, μ_k, and the equation for F is

$$F = \mu_k N$$

In general the coefficient of kinetic friction is smaller than the coefficient of static friction $\mu_k < \mu_s$, which explains the initial difficulty of getting an object to slide.

Impending motion: Impending motion refers to the state just before surfaces start to slip. In this case the static frictional force has reached its upper limit and is given by the equation:

$$F = \mu_s N$$

The direction of the frictional force is opposite to the pending relative motion of the surfaces.
If the force (P) increases, friction force (F) will also increase, until F≤Fs (limiting static frictional force).

If F = Fs, then the block is in unstable equilibrium and block will move.

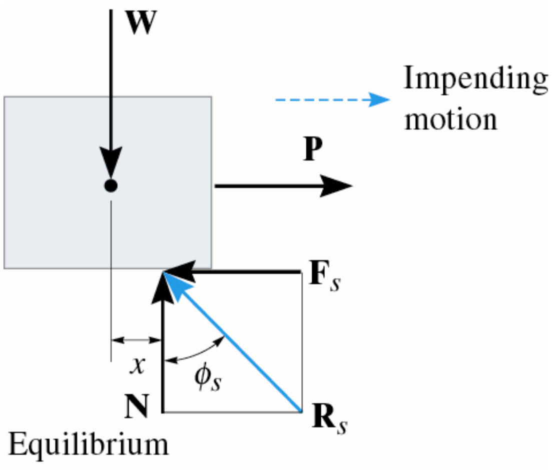
The general methods to be followed are,

1. Examine the problem to determine impending motion for each individual object, and the overall system. There may be one or more possible cases, each will require a separate solution.
2. Based upon the assumed motion at the points of contact, draw on friction forces that oppose the motion. Also draw on normal forces.
3. Solve the problem using equilibrium equations (but avoid using sums of moments for friction forces when they don't act on a clear point).
4. Examine the solution (and compare to others) for anomalies such as normal forces that separate friction surfaces. This will help determine problems, and to eliminate unreasonable solutions.

$$F_s = \mu_s N$$

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

Where:
μ_s: coefficient of static friction
ϕ_s: angle of static friction



If P > F_s and F = F_k (kinetic frictional force)
If P > F_k, then the block will slide with increasing speed.

$$F_k = \mu_k N$$

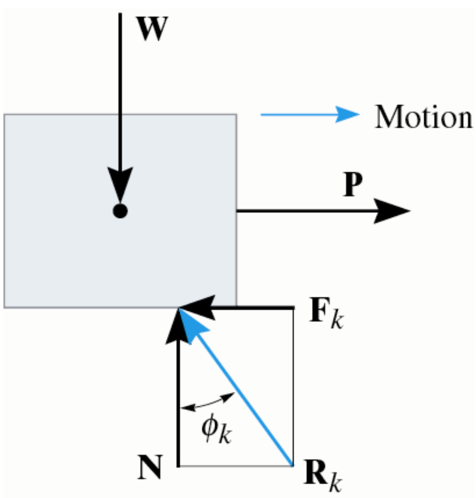
$$\phi_k = \tan^{-1}\left(\frac{F_k}{N}\right) = \tan^{-1}\left(\frac{\mu_k N}{N}\right) = \tan^{-1}\mu_k$$

Where:
μ_k: coefficient of kinetic friction
ϕ_k: angle of kinetic friction

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

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

$$F_s \geq F_k \Rightarrow \phi_s \geq \phi_k$$



Tipping: When an object starts to tip, it starts to pivot around a point. As a result the contact forces (frictional and normal) must be applied at the pivot point. If the object tips before it slips, then one can find the frictional force from the equations of equilibrium.

For Equilibrium:
F acts opposite to P and tangent to the contact surface
N acts upward to balance W
N acts at a distance x to the right of the centroid in order to balance the tipping effect caused by P

$$+\uparrow \sum F_y = 0$$

$$N - W = 0$$

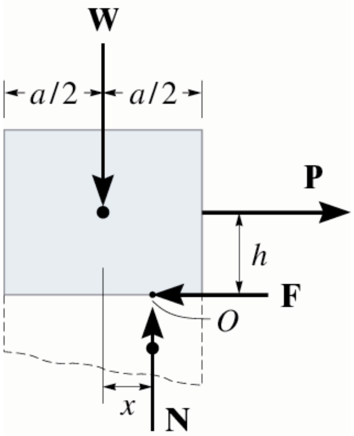
$$\Rightarrow N = W$$

$$\circlearrowleft + \sum M_O = 0$$

$$\Rightarrow Wx - Ph = 0$$

$$\Rightarrow x = \frac{Ph}{W}$$

Thus the block will be on the verge of tipping if N acts at the right corner of the block at
$x = a/2$



Resultant Normal and Frictional Forces