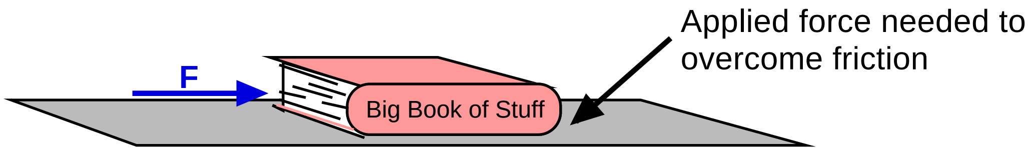
Demonstrations:
•blocks on planes, scales, to find coefficients of static and kinetic friction
Text: Fishbane 5-1, 5-2
Problems: 18, 21, 28, 30, 34 from Ch. 5

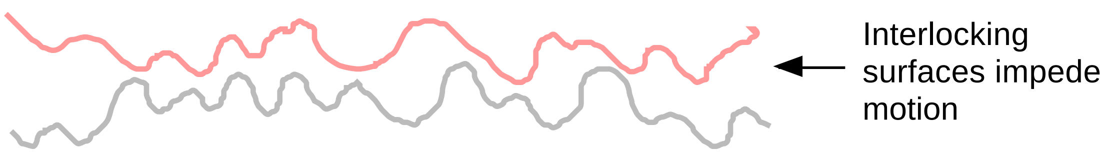
What's important:
•frictional forces
•coefficients of static and kinetic friction

Friction

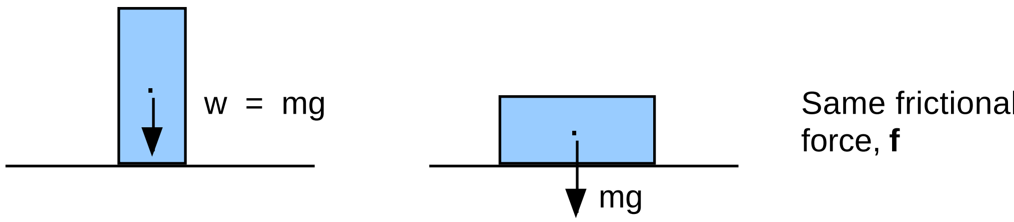
Where objects move in contact with other objects, we know that it may take a constant force to maintain a constant velocity. *E.g.*, motion of a book on a table



Friction arises on a microscopic scale because of the roughness of the surfaces.

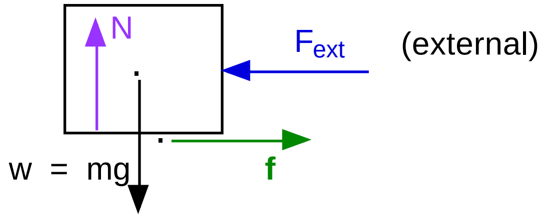


All other things being equal, the frictional force does not depend on the contact area between surfaces:

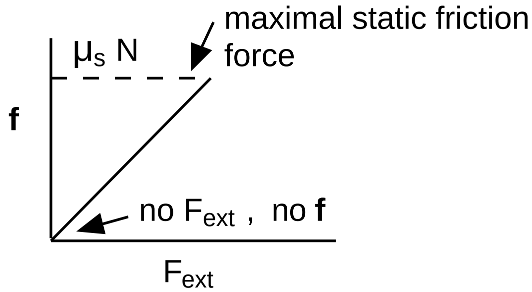


It depends only on the magnitude of the force **N** normal to the surface. **N** reacts against the weight of the object, and any other force that may be applied to it normal to the surface.

It is only present when a force attempts to move an object along the surface.



As can be seen in the demo, the force from static friction looks like:



f only opposes F_{ext}

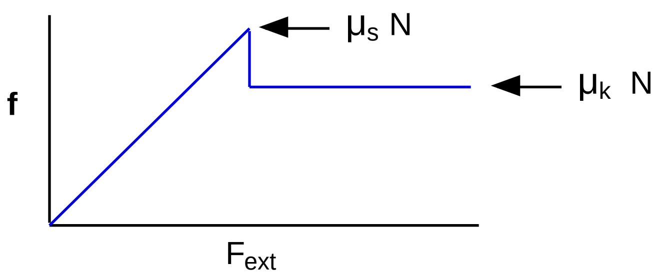
$\vec{\mathbf{f}}$ is in opposite direction to $\vec{F}_{ext}$

The maximum force of static friction, $\mathbf{f}_{max}$, is

$$\mathbf{f}_{max} = \boldsymbol{\mu}_S \mathbf{N},$$

where $\boldsymbol{\mu}_S$ is the **coefficient of static friction**. The friction force cannot exceed the applied force, or else the object would move!

What happens when $F_{ext} > \mu_s N$? Then the object begins to move and the frictional force drops:



μ_k = coefficient of kinetic friction

In the class demo, the coefficients of friction are found for aluminum on wet wood:

$\mu_s \sim 0.6$
$\mu_k \sim 0.5$

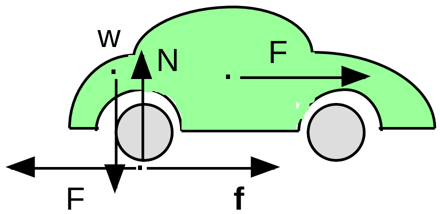
Some typical values for various material combinations:

smooth surfaces	μ_{static}	$\mu_{kinetic}$
steel on steel	0.7	0.6
glass on glass	0.9	0.4
teflon on steel	0.04	0.04
rubber on concrete (dry)	1.0	0.80
rubber on concrete (wet)	0.30	0.25
waxed ski on snow	0.1	0.05

Note the substantial coefficient of static friction for steel on steel, even though the surfaces are smooth. Railways couldn't work without it.

Example

The coefficient of static friction between a car's tires and a concrete road is 1.0. If 40 % of the car's weight is over the drive wheels, what is the maximum acceleration of the car?



$F \leq \mathbf{f}_{s\,,\,max}$ for no slipping

$= \mu N$

$= \mu (0.4 \bullet mg)$

But $F = ma$

$ma = 0.4\, \mu\, mg$

or $a = 0.4\, \mu\, g$

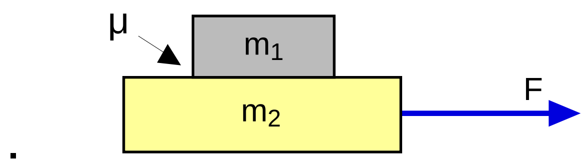
$= 0.4 \bullet 1 \bullet 9.8$

$= 3.9 \;\; m/s^2$

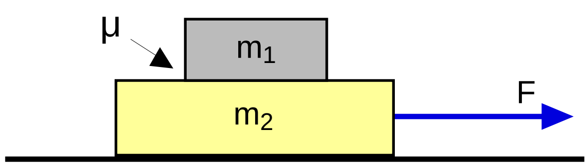
How long would it take for this car to go from 0 to 100 km/hr = 28 m/s? From **v** = **at**, then **t** = 28 / 3.9 = 7 seconds. Theoretically, if all of the weight were over the drive wheels, then **a** = 9.8 m/s^2 and the time for 0 to 100 km/hr would decrease to 28 / 9.8 = 3 seconds.

Example

A block of mass m_1 sits on another block of mass m_2 , which in turn sits on a frictionless table. What is the maximum force that can be applied to m_2 such that m_1 will not slide with respect to m_2?



Solution:

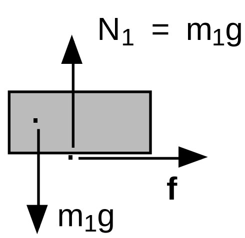


F results in an acceleration **a** of both blocks for **f** $<$ $\mu\, m_1\, g$

$$F = (m_1 + m_2)\,\mathbf{a}$$

Considering the top block only

m_1 :

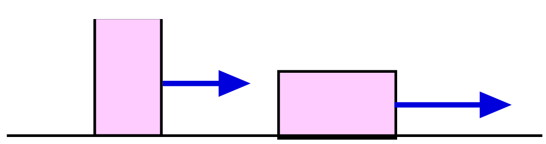


$$\mathbf{f} = m_1\,\mathbf{a} \quad \text{and} \quad \mathbf{f} \leq \mu\, m_1\, g$$

$$\mathbf{a} \leq \mu\, g$$

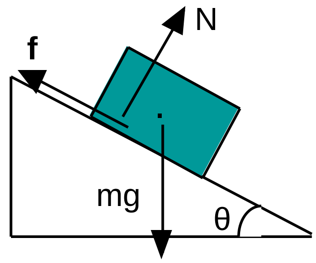
$$F \leq (m_1 + m_2)\,\mu\, g$$

Demonstrations:



- pull block with different orientations
-weigh block to get N
-find μ_s ~ 0.6, μ_k ~ 0.5 for aluminum on wet wood

Consider a block on a plane, the active forces being f, N and mg. The condition that the block not slide is that $f = mg\sin\theta$. The maximum force of static friction is:



$\mathbf{f} = \mu N$

$\mathbf{f} = mg \sin\theta$

$N = mg \cos\theta$

$\mu\, mg \cos\theta = mg \sin\theta$

$\mu = \tan\theta$

measure θ at slip point, find μ

In the demo, if $\mu = 0.6$, then $\theta = 31^o$.